2019-2198, -2201, -2202, -2204

UNITED STATES COURT OF APPEALS
FOR THE FEDERAL CIRCUIT

REALTIME DATA LLC, dba IXO,
Plaintiff-Appellant,

v.

REDUXIO SYSTEMS, INC., ARYAKA NETWORKS, INC., PANZURA, INC., FORTINET, INC.,
Defendants-Appellees.

Appeals from the United States District Court for the District of Delaware in Case Nos. 1:17-cv-01635-CFC, 1:17-cv-01676-CFC, 1:18-cv-01200-CFC, and 1:18-cv-02062-CFC, Judge Colm F. Connolly

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APPELLANT'S OPENING BRIEF

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CERTIFICATE OF INTEREST

Pursuant to Federal Circuit Rule 47.4(a)(1) and Federal Rule of Appellate Procedure 26.1, counsel for Plaintiff-Appellant Realtime Data LLC certifies the following:

1. The full name of the party represented by us is:

   - Realtime Data LLC d/b/a IXO.

2. The name of the real parties in interest represented by us:

   - Not applicable. Realtime Data LLC d/b/a IXO is a real party in interest.

3. All parent corporations and publicly held companies that own 10 percent or more of the stock of the party represented by us are as follows:

   - Not Applicable.

4. The names of all law firms and the partners or associates that appeared for Realtime Data LLC in the trial court, or are expected to appear in this Court are:

   - Marc A. Fenster, Reza Mirzaie, Brian D. Ledahl, Paul A. Kroeger, C. Jay Chung, and Stanley H. Thompson of Russ August & Kabat
   - Stephen B. Brauerman and Sara E. Bussiere of Bayard, P.A.

5. The title and number of any case known to counsel to be pending in this or any other court or agency that will directly affect or be directly affected by this court's decision in the pending appeal are:

The following cases are pending in the U.S. District Court for the District of Delaware:

- *Realtime Data LLC v. Fortinet, Inc.*, Case No. 1:17-cv-01635-CFC
- *Realtime Data LLC v. Panzura, Inc.*, Case No. 1:18-cv-01200-CFC
- *Realtime Data LLC v. MongoDB Inc.*, Case No. 1:19-cv-00492-CFC
- *Realtime Data LLC v. Open Text, Inc.*, Case No. 1:19-cv-00394-CFC
- *Realtime Data LLC v. Kaminario, Inc.*, Case No. 1:19-cv-00350-CFC
- *Realtime Data LLC v. Nimbus Data, Inc.*, Case No. 1:19-cv-00279-CFC
- *Realtime Data LLC v. CTERA Networks, LTD.*, Case No. 1:18-cv-02017-CFC
- *Realtime Data LLC v. SolarWinds Worldwide, LLC*, Case No. 1:18-cv-01995-CFC
- *Realtime Data LLC v. Quest Software, Inc.*, Case No. 1:18-cv-01964-CFC
- *Realtime Data LLC v. Spectra Logic Corporation*, Case No. 1:17-cv-00925-CFC
- *Realtime Data LLC v. Array Networks Inc.*, Case No. 1:17-cv-00800-CFC

The following cases are pending in the U.S. District Court for the District of Massachusetts:

- *Realtime Data LLC v. Sungard Availability Services, LP*, Case No. 1:18-cv-12227-IT
- *Realtime Data LLC v. Carbonite, Inc.*, Case No. 1:17-cv-12499-IT
- *Realtime Data LLC v. Acronis, Inc. Ltd*, Case No. 1:17-cv-11279-IT

The following cases are pending in the U.S. District Court for the Northern District of California:

- *Realtime Data LLC v. Veritas Technologies LLC*, Case No. 3:18-cv-06029-SI
- *Realtime Data LLC v. Fujitsu America, Inc.*, Case No. 3:17-cv-02109-SK

Dated: December 4, 2019

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STATEMENT OF RELATED CASES

No other appeal in or from the same civil action in the lower court was previously before this or any other appellate court.

The following cases pending in the U.S. District Court for the District of Delaware may be directly affected by this Court's decision:

- *Realtime Data LLC v. Fortinet, Inc.*, Case No. 1:17-cv-01635-CFC
- *Realtime Data LLC v. Panzura, Inc.*, Case No. 1:18-cv-01200-CFC
- *Realtime Data LLC v. MongoDB Inc.*, Case No. 1:19-cv-00492-CFC
- *Realtime Data LLC v. Open Text, Inc.*, Case No. 1:19-cv-00394-CFC
- *Realtime Data LLC v. Kaminario, Inc.*, Case No. 1:19-cv-00350-CFC
- *Realtime Data LLC v. Nimbus Data, Inc.*, Case No. 1:19-cv-00279-CFC
- *Realtime Data LLC v. CTERA Networks, LTD.*, Case No. 1:18-cv-02017-CFC
- *Realtime Data LLC v. SolarWinds Worldwide, LLC*, Case No. 1:18-cv-01995-CFC
- *Realtime Data LLC v. Quest Software, Inc.*, Case No. 1:18-cv-01964-CFC
- *Realtime Data LLC v. Spectra Logic Corporation*, Case No. 1:17-cv-00925-CFC
- *Realtime Data LLC v. Array Networks Inc.*, Case No. 1:17-cv-00800-CFC

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- *Realtime Data LLC v. Acronis, Inc. Ltd*, Case No. 1:17-cv-11279-IT

The following cases pending in the U.S. District Court for the Northern District of California may be directly affected by this Court's decision:

- *Realtime Data LLC v. Veritas Technologies LLC*, Case No. 3:18-cv-06029-SI
- *Realtime Data LLC v. Fujitsu America, Inc.*, Case No. 3:17-cv-02109-SK

I. INTRODUCTION

The District Court erred in concluding, at the pleading stage and without a written ruling, that 159 patent claims across five asserted patents and three distinct patent families, each of which are directed to methods and systems for digital data compression, are invalid under 35 U.S.C. § 101. Despite multiple judges in four separate rulings from two different districts having held that the *very same* patents asserted here, and related patents, are § 101 eligible, the District Court improperly focused on only *one claim* of one of the five asserted patents, parsed that claim into individual components to analyze whether each of those components, individually, involves an abstract idea, stripped out critical claim limitations, and ignored the advances and improvements to digital data compression technology expressly claimed in the patents. Similarly, in concluding that the patents lack inventive concept, the District Court improperly focused on whether individual claim elements are conventional, failed to consider the claims as an ordered combination, conflated issues of novelty, obviousness, and inventive concept, and improperly resolved questions of fact based solely on its erroneous conclusions, unsupported by any evidence, regarding the purported "common sense" of the inventions.

Contrary to the District Court's ruling, it is clear from the faces of the patents themselves, which, at the pleading stage, are to be accepted as true and construed in the light most favorable to the patentee, that the claims are directed to specific

improvements in computer functionality and thus are not abstract. More specifically, the patents provide improved, particularized methods of digital data compression that require specific, unconventional combinations of specially configured computer components. The patent claims thus fall squarely within the categories of claims that this Court has repeatedly held to be eligible under § 101.

The District Court's erroneous ruling disregards this Court's binding precedents and the prior district court rulings, and seemingly invents its own standard for evaluating § 101 patentability to invalidate all five asserted patents, without even so much as a written order. The District Court's failure to apply the correct legal standards, and its erroneous conclusions that the patents are directed to an abstract idea and lack inventive concept, contrary to fact and law, constitutes reversible error.

The District Court also abused its discretion in denying, without explanation, Plaintiff-Appellant Realtime Data LLC's ("Realtime") request for leave to amend. The District Court failed to provide any legitimate basis for its decision, simply stating that its practice is "to ignore [requests for leave to amend] and just to grant a motion to dismiss." This also constitutes reversible error.

The District Court's order of dismissal under Rule 12(b)(6) and subsequent judgment of invalidity should be reversed, and each of the asserted patents should be found eligible under § 101.

II. JURISDICTIONAL STATEMENT

Realtime began the proceedings below by filing patent infringement complaints against the Defendants-Appellees. The District Court has jurisdiction of the cases pursuant to 28 U.S.C. §§ 1331 and 1338. Realtime timely appeals from the final judgments entered by the District Court, wherein the District Court found all asserted patents invalid as directed to patent ineligible subject matter under 35 U.S.C. § 101, and from all underlying decisions, orders, and rulings intertwined with or that produced the judgments. This Court has jurisdiction under 28 U.S.C. §§ 1291 and 1295.

III. STATEMENT OF ISSUES FOR REVIEW

This appeal presents the following issues for review by this Court:

1. Did the District Court err in concluding, at the pleading stage and without any written ruling, that all five asserted patents in three distinct patent families comprising 159 total claims, each of which discloses methods and systems for digital data compression aimed at solving known problems in conventional data compression systems, are directed to an abstract idea?

2. Did the District Court err in concluding, at the pleading stage and without any written ruling, and without considering the claim elements as an ordered combination, that all 159 patent claims lack inventive concept, merely because some of the individual claim limitations utilize generic computer components and because,

as concluded by the District Court without any evidentiary support, certain aspects of the claimed inventions are "common sense"?

3. Did the District Court err in disregarding the patents' claimed advances and resolving disputed issues of fact based on the Court's unsupported conclusion regarding inventive concept, namely, whether certain aspects of the claimed inventions are "common sense"?

4. Did the District Court abuse its discretion in denying, without explanation, Realtime's request for leave to amend based solely on the District Court's stated practice of ignoring requests for leave to amend and just granting motions to dismiss?

IV. STATEMENT OF THE CASE

A. The Asserted Patents Claim Inventions Related to Digital Data Compression and Are Aimed Toward Solving Problems Unique to Digital Computer Data

This appeal concerns five United States patents from three distinct patent families. Patent Nos. 9,054,728 ("'728 patent") and 8,717,203 ("'203 patent") are in one family, Nos. 9,116,908 ("'908 patent") and 7,415,530 ("'530 patent") are in a second, distinct patent family, and No. 9,667,751 ("'751 patent") is in a third patent family, unrelated to the other two patent families. *See* Appx64–381.

At a high level, these patent families have some commonality in that they teach various improved, particularized digital data compression systems and

methods to address problems specific to digital data. Indeed, the patents themselves expressly state that they deal specifically with limitations and problems arising in the realm of compressing "[d]iffuse digital data," which is "a representation of data that . . . is typically *not easily recognizable to humans* in its native form." Appx88 at 1:15–36 (emphasis added); Appx308 at 1:15–37; Appx244 at 1:34–54; Appx165 at 1:31–51; *see also* Appx368–369 at 1:25–36, 3:21–4:6 (discussing various methods of encryption and digital data compression used in the transmission of digital data). But while the patents are all generally directed to specific methods and systems for digital data compression, each patent represents a distinct invention, and each patent family is directed to different systems and methods of digital data compression, as set forth below.

1. The '728 and '203 Patents

The '728 patent and '203 patent, entitled "Data Compression Systems and Methods," are directed to systems and methods for data compression using a combination of content-independent and content-dependent data compression and decompression. *See* Appx180 at Abstract; Appx244 at 1:34–37; Appx245 at 3:59–62; Appx246 at 6:24–27; Appx102 at Abstract; Appx165 at 1:31–34; Appx166 at 3:55–58; Appx167 at 6:18–21. The '728 and '203 patents address problems relating to lossless data compression techniques, including the "fundamental problem" of their "content sensitive behavior," i.e., "data dependency," which means that "the

compression ratio achieved is highly contingent upon the content of the data being compressed." Appx244 at 2:29–35; Appx165 at 2:26–31. These patents also discuss various other problems with lossless data compression, including that "there are significant variations in the compression ratio obtained when using a single lossless data compression technique for data streams having different data content and data size," i.e., "natural variation." Appx244 at 2:41–45; Appx165 at 2:38–42. "A further problem is that negative compression may occur when certain data compression techniques act upon many types of highly compressed data," and "many data compression techniques will substantially expand, not compress this type of data." Appx244 at 2:46–50; Appx165 at 2:43–47; *see also* Appx244 at 2:51–67; Appx165 at 2:48–64 (identifying additional problems in lossless data compression).

The '728 and '203 patents explain that while "conventional content dependent techniques," which typically rely on file type descriptors appended to file names such as ".doc," ".txt," etc., may be utilized to combat some of these problems, those content dependent techniques had "[f]undamental limitations" including:

> (1) the extremely large number of application programs, some of which do not possess published or documented file formats, data structures, or data type descriptors;
>
> (2) the ability for any data compression supplier or consortium to acquire, store, and access the vast amounts of data required to identify known file descriptors and associated data types, data structures, and formats; and
>
> (3) the rate at which new application programs are developed and the need to update file format data descriptions accordingly.

Appx244 at 2:65–3:19; Appx165 at 2:64–3:15.

The patents solved these and other problems with compression technology by providing a novel technological solution utilizing a combination of content-dependent and content-independent encoders to compress data blocks based on an analysis of the specific content or type of data being encoded, without relying solely on a descriptor such as a file extension. For example, when one or more digital-data parameters are identified in the content of a digital data block, the invention utilizes a content-dependent compression encoder. And if no such digital-data parameter is identified, the invention utilizes a content-independent encoder. The analysis of the digital data is not based solely a descriptor, thereby eliminating the problems associated with conventional content-dependent compression techniques. *See, e.g.*, Appx251 at 15:60–20:47; Appx172 at 15:53–20:38. Figure 13A, reproduced below, is illustrative of one preferred embodiment depicting a system utilizing a combination of content-dependent and content-independent encoders.

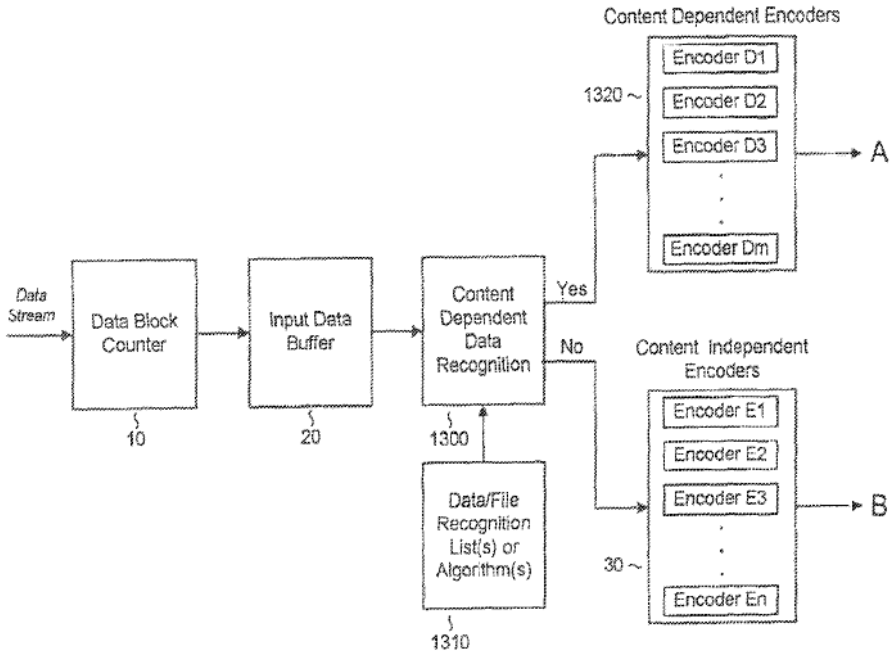


FIGURE 13A

Appx147; Appx226.

There are 25 total claims in the ’728 patent, and 30 claims in the ’203 patent. Asserted claim 1 of the ’728 patent discloses:

A system for compressing data comprising:

a processor;

one or more content dependent data compression encoders; and

a single data compression encoder;

wherein the processor is configured:

to analyze data within a data block to identify one or more parameters or attributes of the data wherein the analyzing of the data within the data block to identify the one or more parameters or attributes of the data excludes analyzing based solely on a descriptor

that is indicative of the one or more parameters or attributes of the data within the data block;

to perform content dependent data compression with the one or more content dependent data compression encoders if the one or more parameters or attributes of the data are identified; and

to perform data compression with the single data compression encoder, if the one or more parameters or attributes of the data are not identified.

Appx256.

Asserted claim 14 of the ’203 patent discloses:

A system for decompressing, one or more compressed data blocks included in one or more data packets using a data decompression engine, the one or more data packets being transmitted in sequence from a source that is internal or external to the data decompression engine, wherein a data packet from among the one or more data packets comprises a header containing control information followed by one or more compressed data blocks of the data packet the system comprising:

a data decompression processor configured to analyze the data packet to identify one or more recognizable data tokens associated with the data packet, the one or more recognizable data identifying a selected encoder used to compress one or more data blocks to provide the one or more compressed data blocks, the encoder being selected based on content of the one or more data blocks on which a compression algorithm was applied;

one or more decompression decoders configured to decompress a compressed data block from among the one or more compressed data blocks associated with the data packet based on the one or more recognizable data tokens; wherein:

the one or more decompression decoders are further configured to decompress the compressed data block utilizing content dependent data decompression to provide a first decompressed data block when

> the one or more recognizable data tokens indicate that the data block was encoded utilizing content dependent data compression; and
>
> the one or more decompression decoders are further configured to decompress the compressed data block utilizing content independent data decompression to provide a second decompressed data block when the one or more recognizable data tokens indicate that the data block was encoded utilizing content independent data compression; and
>
> an output interface, coupled to the data decompression engine, configured to output a decompressed data packet including the first or the second decompressed data block.

Appx178.

2. The ’908 and ’530 Patents

The ’908 patent and ’530 patent, entitled “System and Methods for Accelerated Data Storage and Retrieval,” are directed to systems and methods for accelerated data storage and retrieval utilizing lossless data compression and decompression. *See* Appx258 at Abstract; Appx308 at 1:15–18, 2:58–60; Appx309 at 4:42–44; Appx64 at Abstract; Appx88 at 1:15–18, 2:58–60; Appx89 at 4:42–44. The ’530 and ’908 patents addressed problems in the current art relating to digital data compression, including that “high performance disk interface standards . . . offer only the promise of higher data transfer rates through intermediate data buffering in random access memory” and do not address the “fundamental problem” with physical media limitations. Appx308 at 2:34–42; Appx88 at 2:34–42. The patents further explain that “[f]aster disk access data rates are only achieved by the high cost

solution of simultaneously accessing multiple disk drives with a technique known within the art as data striping." Appx308 at 2:42–45; Appx88 at 2:42–45. "Additional problems with bandwidth limitations similarly occur within the art by all other forms of sequential, pseudorandom, and random access mass storage devices." Appx308 at 2:46–51; Appx88 at 2:46–51.

The '928 and '530 patents solved these and other problems with digital data compression by providing novel technological solutions utilizing a plurality of different encoders, and optionally a compression descriptor, for accelerated storage and retrieval of data blocks. The novel approaches taught by the patents include, among other things:

- using a digital compression type descriptor "for output so as to indicate the type of compression format of the encoded data block";
- "the data storage and retrieval accelerator method and system [being] employed in a disk storage adapter to reduce the time required to store and retrieve data from computer to a disk memory device"; and
- "the data storage and retrieval accelerator method and system [being] employed in conjunction with random access memory to reduce the time required to store and retrieve data from random access memory."

Appx309 at 3:25–33; Appx313–314 at 12:40–13:18; Appx89 at 3:25–33; Appx93 at 12:14–59.

Figure 8 illustrates one preferred embodiment of a compression system utilizing, *inter alia*, a plurality of encoders:

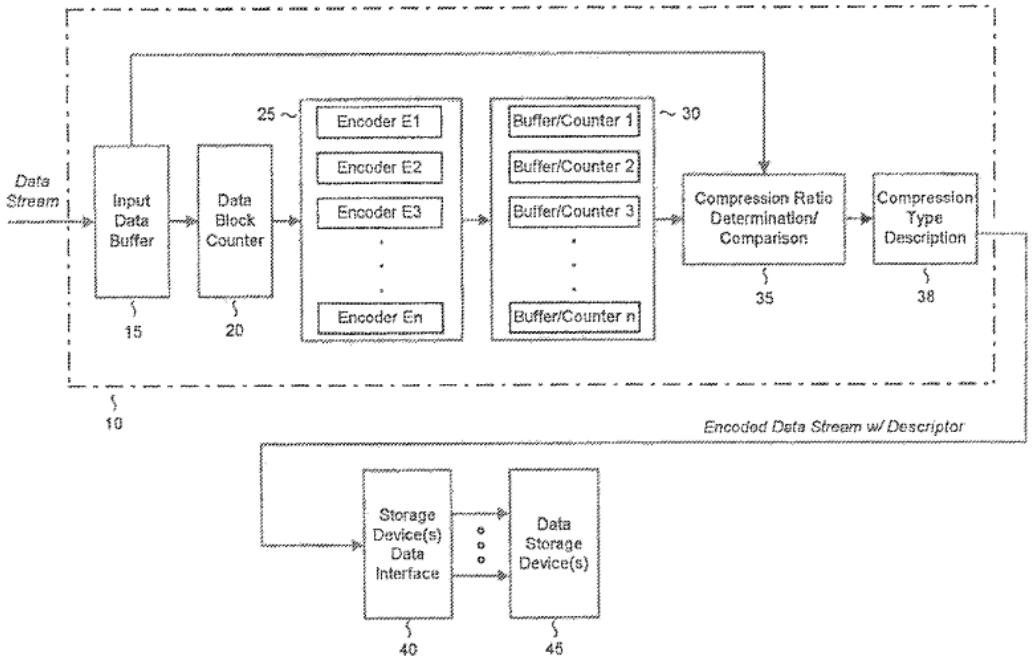


FIGURE 8

Appx79; Appx299.

As explained in the patents, in a preferred embodiment, "the encoding techniques are selected based upon their ability to effectively encode different types of input data." Appx313 at 12:5–7; Appx93 at 11:46–48. The encoder module comprising the multiple encoders "allows the user to tailor the operation of the data compression system for specific applications." Appx313 at 12:11–21; Appx93 at 11:52–62. Further, the encoders may operate either in parallel "(i.e., simultaneously processing a given input data block by utilizing task multiplexing on a single central processor, via dedicated hardware, by executing on a plurality of processor or dedicated hardware systems, or any combination thereof)" to "enhance encoding speed," or they "may operate sequentially on a given unbuffered or buffered input

data block." Appx313 at 12:21–30, 35–39; Appx93 at 11:62–12:4, 12:9–4. This process "eliminate[s] the complexity and additional processing overhead associated with multiplexing concurrent encoding techniques on a single central processor and/or dedicated hardware, set of central processors and/or dedicated hardware, or any achievable combination." Appx313 at 12:30–35; Appx93 at 12:4–9. A "compression type descriptor" is appended to the encoded data block output "so as to indicate the type of compression format of the encoded data block." Appx313 at 12:40–67; Appx93 at 12:14–41.

There are 30 claims in the '908 patent, and 26 claims in the '530 patent. Asserted claim 1 of the '908 patent discloses:

> A system comprising:
>
> > a memory device; and
> >
> > a data accelerator configured to compress: (i) a first data block with a first compression technique to provide a first compressed data block; and (ii) a second data block with a second compression technique, different from the first compression technique, to provide a second compressed data block;
> >
> > wherein the compressed first and second data blocks are stored on the memory device, and the compression and storage occurs faster than the first and second data blocks are able to be stored on the memory device in uncompressed form.

Appx316.

Asserted claim 1 of the '530 patent discloses:

> A system comprising:

a memory device; and

a data accelerator, wherein said data accelerator is coupled to said memory device, a data stream is received by said data accelerator in received form, said data stream includes a first data block and a second data block, said data stream is compressed by said data accelerator to provide a compressed data stream by compressing said first data block with a first compression technique and said second data block with a second compression technique, said first and second compression techniques are different, said compressed data stream is stored on said memory device, said compression and storage occurs faster than said data stream is able to be stored on said memory device in said received form, a first data descriptor is stored on said memory device indicative of said first compression technique, and said first descriptor is utilized to decompress the portion of said compressed data stream associated with said first data block.

Appx96.

3. The ’751 Patent

The ’751 patent, entitled “Data Feed Acceleration,” is directed to systems and methods for providing accelerated transmission of digital data over a communication channel using data compression and decompression to effectively increase the bandwidth of the communication channel and/or reduce the latency of data transmission. Appx319 at Abstract; Appx368 at 1:25–36; Appx370 at 5:33–43, 6:13–19. The ’751 patent addressed specific problems with conventional data transmission systems, explaining that “current methods of encryption and compression take as much or substantially more time than the actual time to transmit the uncompressed, unencrypted data.” Appx369 at 3:31–33. Thus, a “problem within the current art is the latency induced by the act of encryption, compression,

decryption, and decompression." *Id.* at 3:34–36. The patent discusses additional problems and limitations in conventional data compression systems, including "high latency and poor compression due to the use of generic data compression algorithms," "substantial latency caused by aggregating data packets due to poor data compression efficiency and packet overhead," "the need for data redundancy," which "add[s] cost and complexity, while also increasing latency and inherent data error rates," capacity limitations of data transmission using existing T1 lines and associated costs, and "[t]he limitation of highly significant bandwidth and/or long delays with co-location processing and long latency times." Appx368–370 at 1:40–5:22.

The '751 patent solved these and other technological problems and limitations in the prior art by providing novel technological solutions in digital data transmission, allowing for, among other things, "secure transmission and transparent multiplication of communication bandwidth," and a reduction in the "latency associated with data transmission of conventional systems." Appx370 at 5:28–29, 6:13–19. "The effective increase in bandwidth and reduction of latency of the communication channel is achieved by virtue of the faster than real-time, real-time, near real-time, compression of a received data stream prior to transmission." *Id.* at 6:36–40. The claimed invention achieves this by, for example, recognizing a characteristic, attribute, or parameter of the data to select a compression encoder,

and using a state machine to provide compressed data. *See, e.g.*, Appx380 at claim 25.

Advantages of the claimed invention include "a consistent reduction in latency" where "[t]he data compression ratio is substantial and repeatable on each data packet," and "no packet-to-packet data dependency," i.e., "packet independence." Appx371 at 7:52–8:3.

Figure 5 of the '751 patent is illustrative of one preferred embodiment depicting a content-independent data compression system:

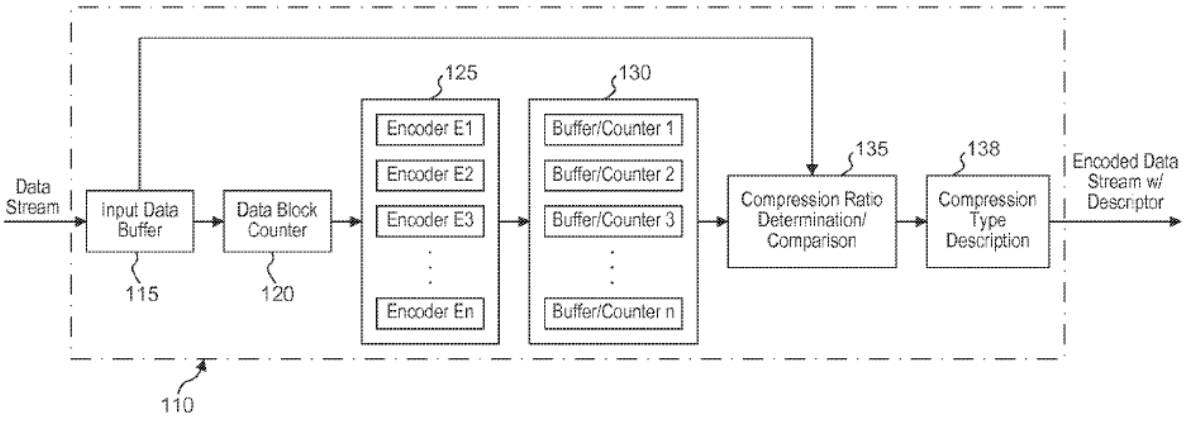


FIG. 5

Appx366; *see also* Appx375 at 15:1–16:67.

There are 48 claims in the '751 patent. Asserted claim 25 discloses:

A system for compressing data comprising:

a data server implemented on one or more processors and one or more memory systems and configured to:

analyze content of a data block to identify a parameter, attribute, or value of the data block that excludes analysis based solely on reading a descriptor;

select an encoder associated with the identified parameter, attribute, or value;

compress data in the data block with the selected encoder to produce a compressed data block, wherein the compression utilizes a state machine; and

store the compressed data block;

wherein the time of the compressing the data block and the storing the compressed data block is less than the time of storing the data block in uncompressed form.

Appx380.

B. Prior § 101 Rulings Upholding the Patentability of Realtime's Patents

1. The *Carbonite* Ruling

On February 27, 2017, Realtime filed a complaint against Carbonite, Inc. and EVault, Inc. in the Eastern District of Texas, Case No. 6:17-cv-00121-RWS-JDL ("*Carbonite*"), alleging infringement of the '728, '530, and '908 patents, in addition to U.S. Patent No. 8,717,204 ("'204 patent"), which is in the same family as the '751 patent. The Carbonite defendants filed a Rule 12(b)(6) motion to dismiss arguing that all of the asserted patents are invalid under § 101.

On September 20, 2017, Magistrate Judge John Love issued a detailed, 22-page report and recommendation finding that all of the asserted patents are *not* abstract and thus are patent-eligible under § 101. More specifically, Judge Love found that "[t]he '728 Patent is directed to patent eligible subject matter because it discloses a specific improvement in computer capabilities: a system for an improved data compression technique." Appx782. Judge Love's report and recommendation further notes that the '728 patent improves known issues in lossless data compression techniques by "applying a plurality of compression techniques on an input data stream so as to achieve maximum compression in accordance with the real-time or pseudo real-time data rate constraints." Appx783. Judge Love expressly rejected the defendants' reliance on *RecogniCorp, LLC v. Nintendo Co., Ltd.*, 855 F.3d 1322 (Fed. Cir. 2017), finding that "claim 1 of the '728 Patent is not simply encoding and decoding. Rather, it improves typical data compression by compressing the data stream through content dependent and independent data recognition, as well as a plethora of encoders to achieve its maximum compression. '728 Patent at 5:03–07. This results in real-time or pseudo-real-time compression." Appx785.

Still further, Judge Love found that "[e]ven if claim 1 of the '728 Patent is directed to an abstract idea, the claim, read as a whole, covers an "inventive concept"

because "it utilizes a system and its structural elements in a way that is a solution to a computing problem." Appx785, Appx786.

Regarding the '908 and '530 patents, Judge Love found that the claims are not abstract because "they utilize a system that improves computerized data compression through data storage and retrieval and bandwidth 'utilizing lossless data compression and decompression.'" Appx788–789. Judge Love further found that, "[s]imilar to the '728 Patent, these claims as a whole show a non-abstract idea despite disclosing generic, conventional computing elements." Appx790. "The claims pair a data accelerator with a memory device, and then places a data stream with a proper technique that compresses the data stream and puts the stream into storage more efficiently." *Id.* As noted by Judge Love, "this goes beyond the abstract patents in [*RecogniCorp*]," as Realtime's patents "improve a technological process by pairing data blocks with specific techniques to achieve "an effective increase of [] data storage and retrieval bandwidth of a memory storage device." *Id.*

As with the '728 patent, Judge Love further found that "[e]ven if the ['530 and '908 patent] claims were abstract, they produce an inventive concept," explaining: "Despite some of the well-known elements and techniques, the '530 and '908 Patents create an unconventional solution that results in faster disk access and bandwidth limitations by using a memory device and a data accelerator to compresses the data stream using different compression techniques utilizing lossless

data compression and decompression. . . . The claims create a specific combination of compressing a data stream that results in an inventive concept for data compression." Appx792.

Regarding the '204 patent, which is in the same family as the '751 patent, Judge Love found that the invention is "aimed at providing accelerated transmission of data in a communication channel using data compression and decompression to provide data feeds, transfers, and communications and effectively increase the bandwidth of the communication channel and/or reduce the latency of data transmission." Appx793. Judge Love further found that the '204 patent "offers more than a generic use of data transmission; it provides specific steps of analyzing information and compressing data using specific encoders related to recognized parameters within the data," and therefore is "not abstract." Appx795. And, similar to the other asserted patents, the '204 patent provides inventive concept because it "uses a specific method with various steps to provide faster transmission of data." Appx796. In rejecting the defendants' arguments that the claims rely on generic computer components, Judge Love found that "[a]lthough the claim may use some known technology, the system as a whole creates an unconventional solution because it utilizes 'data compression and decompression to provide data transfer. . . [and] reduce the latency of data transmission." *Id.*

Before the District Judge had a chance to rule on the Carbonite defendants' objections to the report and recommendation, the case was transferred to the District of Massachusetts. On March 7, 2018, Massachusetts District Court entered an order adopting Judge Love's report and recommendation in full "[a]fter careful consideration." Appx817. The motion to dismiss was denied. *Id.*

2. The *Actian* Ruling

The eligibility of Realtime's patents under § 101 came under scrutiny once again in another case in the Eastern District of Texas, No. 6:15-cv-00463-RWS-JDL ("*Actian*"), and were again confirmed to be patent eligible and not abstract. On May 1, 2018, Magistrate Judge Love issued a report and recommendation recommending denial of the defendants' Rule 12(b)(6) motion to dismiss regarding the '908 and '530 patents, as well as U.S. Patent Nos. 7,378,992 ("'992 patent"), 8,643,513 ("'513 patent"), and 6,597,812 ("'812 patent"). Appx799. The '992 and '513 patents are in the same family as, and share a specification with, the '728 and '203 patents.

In the report and recommendation, Judge Love found that "an assessment of the claims at issue—by a careful reading of the claims themselves—does not clearly reveal that the patents are abstract," thereby precluding dismissal at the pleading stage. Appx809.

District Judge Robert Schroeder adopted the Magistrate's report and recommendation in full, acknowledging that the patents themselves state that they

are directed to problems unique to the realm of digital data, a form of data not easily "recognizable to humans." Appx813. The District Judge further found that under Realtime's proposed constructions, the patents "provide technological solutions to problems arising specifically in the realm of computer technology," and therefore "Defendants' argument that the patents are directed to an abstract idea would fail." *Id.* In particular, the District Judge found that if the claim construction proceedings confirmed that the claimed inventions are directed to methods and systems for the compression of digital data—which they unquestionably are—then the claims would indeed be patent-eligible. *Id.*

C. The Delaware District Court's Erroneous § 101 Ruling

On November 10, 2017, Realtime filed a patent infringement complaint in the District of Delaware against Defendant-Appellee Fortinet, Inc. ("Fortinet") regarding the '728, '203, '908, and '751 patents. Appx1538. On February 20, 2018, Fortinet filed a Rule 12(b)(6) motion to dismiss for failure to state a claim, arguing that the asserted patents are invalid under § 101. Appx1794.

On November 20, 2017, Realtime filed a patent infringement complaint in the District of Delaware against Defendant-Appellee Reduxio Systems, Inc. ("Reduxio") regarding the '728, '203, '908 and '751 patents. Appx418. On March 27, 2018, Reduxio filed a Rule 12(b)(6) motion dismiss for failure to state a claim, arguing that the asserted patents are invalid under § 101. Appx729.

On August 7, 2018, Realtime filed a patent infringement complaint in the District of Delaware against Defendant-Appellee Panzura, Inc. ("Panzura") regarding the '728, '908, '530, and '751 patents. Appx1240. On February 15, 2019, Fortinet filed a Rule 12(b)(6) motion to dismiss for failure to state a claim, arguing that the asserted patents are invalid under § 101. Appx1511.

On December 28, 2018, Realtime filed a patent infringement complaint against Defendant-Appellee Aryaka Networks, Inc. ("Aryaka") regarding the '728, '908, '530, and '751 patents, which was amended on April 22, 2019. Appx891, Appx394. On May 6, 2019, Aryaka filed a Rule 12(b)(6) motion to dismiss likewise asserting that the patents are invalid under § 101. Appx1167.

On July 19, 2019, the District Court held a joint hearing on the foregoing Defendants-Appellees' motions to dismiss. Appx388, Appx390. Multiple times throughout the hearing, while Realtime's counsel was discussing the patents and the claimed data compression systems, the court inquired as to whether each individual component of the referenced system was "generic" and/or novel.

For example, while discussing the data compression system of claim 25 of the '751 patent (*see* Appx29–32 at 21:23–24:12), the District Court sought confirmation that each individual component in the claimed system, including the server, processors, and state machine, are "generic" and not novel:

[Realtime's counsel] MR. LEDAHL: So the claim is, the claim is to a system for compressing data.

THE COURT: Okay.

MR. LEDAHL: You've got a server.

THE COURT: I have a server. You agree that's a generic computer component. Right?

MR. LEDAHL: Yes, Your Honor, I would agree the server is a generic computer component and I'm going to anticipate a little bit. As we know from a lot of Federal Circuit cases, the combination of components in a new way is an invention whether they're generic components or not. Basically, that's every invention. It's very rare that people invent new elements, new . . . components altogether.

THE COURT: Let's keep going. We start with a data server.

MR. LEDAHL: That server is implemented on processors.

THE COURT: Which are generic computer parts. Right? Agreed?

MR. LEDAHL: Processors are generic computer components, that's correct.

THE COURT: You are not going to tell me it's novel to have a data server implemented on one or more processors, are you?

MR. LEDAHL: Well, Your Honor, what I'm going to say is that it's not an appropriate analysis to question the novelty of a claim based on a single element. And so –

THE COURT: I will give you your chance, but I've got to work through it slowly. . . . **So far we've got a data server, which you agree is a generic computer component, and it's implemented on one or more processors, which you agree are generic computer components, and you agree that the implementation of a data server on one or more processors is not novel**. All right. Now, keep going.

. . .

> THE COURT: So what's the new technology? Are we not in generic compression anymore?
>
> MR. LEDAHL: So part of this is as the claim goes on, we see that analyzing the data itself, not the descriptor of the data, but the data itself to make decisions about how to compress it was not something that was used in the art. It was –
>
> **THE COURT: You are saying nobody ever looked beyond the three-letter tag, the descriptor, and nobody ever looked at the data itself to compress it. Really?**
>
> . . .
>
> MR. LEDAHL: So we've talked a little bit, or perhaps a lot about analyzing the content of the data block. And the next element really goes to what I was mentioning, which is selecting an encoder, a mechanism for the compression based on that analysis, based on the parameter identified, and then obviously, use that to compress the data with that encoder and, in addition, here you're using what is called a state machine as part of that technique. So, in addition—
>
> **THE COURT: You agree that's a generic computer component?**

Appx32–34 at 24:11–26:6; Appx36 at 28:6–15; Appx39 at 31:2–18 (emphases added).

The District Court likewise attempted to parse the claimed system into individual components and functions, and inquired as to whether each of these individual components are directed to an abstract idea. Indeed, the District Court even asked Realtime's counsel to point to specific "words" and elements of the claims that are not abstract and/or inventive and/or novel:

> MR. LEDAHL: And this overall system is configured to analyze the content of a data block to identify a parameter or attribute or value of that block, and that excludes analysis based solely on reading a descriptor.

THE COURT: All right. Let's just stop there. So far is there anything non-abstract about what we just read?

MR. LEDAHL: Yes.

THE COURT: Where? Tell me. . . . And look at the words that we've just read and show me where it's not abstract.

MR. LEDAHL: So you're analyzing that data block in a specific fashion, and by that what I mean is, you are looking at the content of the data block itself, not at a descriptor. So there were lots of prior art systems.

. . .

THE COURT: Okay. So you're analyzing the content of data. Now, you agree, that's an abstract idea, analyzing the content of data. Right?

MR. LEDAHL: If that were all we were looking at by itself, yes.

THE COURT: Okay. All right.

. . .

MR. LEDAHL: . . . You then, having performed the compression as the claim requires, store the compressed data block, and the claim further recites that you do this using a decisional tree that basically causes you to compress and store the data faster than you could have stored it by – in its uncompressed form. And –

THE COURT: Now, that is an abstract idea. Right? You'll agree on that?

MR. LEDAHL: I do not agree that that is an abstract idea. . . .

THE COURT: Comparing, comparing how fast it takes just to do the compression with how fast it would take to make a comparison to other potentially faster compressions and adding up the time is not abstract?

MR. LEDAHL: I'm not sure I agree with the way you've characterized it. So the distinction that the claims draw is, can I do both? Can I compress it and store it faster than I could have just stored it if I didn't bother trying to compress it?

THE COURT: Okay. That's actually an understandable summary. All right. **You're telling me that comparison is not abstract?**

MR. LEDAHL: No, Your Honor, because it's part of the decisional logic that the system has to use in choosing these compression algorithms.

THE COURT: So would you agree decisional logic is abstract?

. . .

THE COURT: So I'm waiting for you to tell me something that is inventive or is not abstract and I have not heard one thing so far.

. . .

THE COURT: Now, what you've just said, I still have not heard one non-abstract idea or inventive concept. **So now just take what you have just described, break it down and identify for me within that summary an example of a non-abstract or inventive concept.**

. . .

THE COURT: Wait. Let's do this. **Let's make a list. So you keep going back to the summary of the overall system. Give me a list of the technical components.** I will write them down. Go ahead.

MR. LEDAHL: So, well, Your Honor, you have an encoder.

THE COURT: All right.

MR. LEDAHL: Some of the claims refer to a data accelerator. Some refer to a series of encoders.

THE COURT: I can't write that fast. I've got number one, technical component or technical solution, an encoder. All right. What's number two?

MR. LEDAHL: The encoder is integrated into the system in such a with a way that it analyzes before compression takes place to determine which compression to use so that it can accelerate the storage of data faster than either using compression alone without that process, or simply storing without using compression at all.

THE COURT: Okay. That is an abstract idea.

Appx34–35 at 26:17–27:16; Appx39–45 at 31:23–37:15 (emphases added).

The District Court also attempted to establish that the patent claims either are abstract or are not inventive based on its conclusion that the technical solutions provided by the patents (e.g., improving the speed of data compression systems) were "obvious" and "common sense":

> MR. LEDAHL: Your Honor, using compression in these ways, it improves the functioning of a computer. That is both required and it is the result of performing these steps. That if you do it this way, the computer works faster. The system works faster. That's essentially what these are about.
>
> THE COURT: I don't think anybody disputes that by looking at the underlying data as opposed to limiting yourself to the descriptor, you could use, make the computer work faster. . . . **I just think it's such an obvious – it's just stating the obvious**.
>
> [Defendants' counsel] MR. MASUR: Particularly to one who had practiced in the art in the prior art period. Yes, Your Honor.
>
> MR. LEDAHL: Well, Your Honor, now what we're talking about is a different question, which is this allegation of obviousness.
>
> THE COURT: I don't mean obviousness in the patent sense. I mean it is obvious like it's common sense.
>
> MR. LEDAHL: It's actually not, Your Honor. Respectfully, that, and I would submit, that's actually a fact question that you can't resolve in summary judgment.
>
> **THE COURT:** So, wait. **Just to be really clear, when I said common sense, what I mean is that it's obvious that it could be the case.** Maybe that's the best way to articulate it. **And so to look at the content of the data as opposed to limiting yourself to the descriptor, that idea that you would look at both is what I think is a common sense notion.**

Appx47–49 at 39:16–41:1 (emphases added).

The District Court did not identify any evidence or authority supporting its conclusion that the claimed inventions are "common sense." The District Court also never heard argument, nor asked questions, about any patent claims other than claim 25 of the '751 patent. Nor did the District Court make any findings as to whether claim 25 of the '751 patent is representative of all of the asserted claims in the five asserted patents.

At the conclusion of oral argument, the District Court announced that it would "not be issuing written opinions," and that the "[t]he [hearing] transcript will serve as my ruling." Appx52 at 44:13–16. The court read its ruling from the bench, declaring that all five asserted patents are invalid under § 101, and granting Defendants' Rule 12(b)(6) motions to dismiss. Appx57 at 49:1–21.

The District Court ruled that all five patents "generally claim systems and methods for digitally storing and transmitting data," and that "the claims lack a specific means or method that improves the relevant technology and instead merely invoke generic processes and machinery to achieve a desired result, that being the more efficient storage and transmission of digital data." Appx53 at 45:5–16. More specifically, the District Court found:

> With respect to the '728 patent, I think a fair description of what it is is choosing a compression method based on the data type.

> With respect to the '203 patent, a fair description of it is choosing a decompression method using a data type.
>
> With respect to the '908 patent, a fair description of it is using two or more compression techniques to compress and store data faster.
>
> And with respect to the '530 patent, it's using two or more compression techniques to compress and store data faster and using a descriptor – plus rather using a descriptor.
>
> For the '751 patent, it's choosing a compression method based on data type and using two or more compression techniques to compress and store data faster.
>
> These are abstract ideas, and none of the patents, getting to the Step 2 inquiry, provide an inventive concept. None of them point to a technical solution to compress or transmit data more efficiently. At bottom the patents claim a desired result and they do not present or recite a technical solution to achieve that result, and therefore they're not patent eligible.

Appx56 at 48:3–25.

The District Court identified *McRO, Inc. v. Bandai Namco Games Am. Inc.*, 837 F.3d 1299, 1314 (Fed. Cir. 2016), *Digitech Image Techs., LLC v. Elecs. for Imaging, Inc.*, 758 F.3d 1344 (Fed. Cir. 2014), *In re TLI Commc'ns LLC Patent Litig.*, 823 F.3d 607 (Fed. Cir. 2016), and *RecogniCorp, LLC v. Nintendo Co.*, 855 F.3d 1322 (Fed. Cir. 2017) as the decisions supporting its ruling. Appx53–54 at 45:16–46:13. The District Court did not explain, however, how or why any of these cases are applicable. *See id.*

D. The District Court's Denial of Leave to Amend

In response to Realtime's request for leave to amend, made in its opposition briefing as well as at the hearing, the District Court stated that "***my practice has been to ignore [requests for leaving to amend] and just to grant a motion to dismiss***." Appx50 at 52:4–7 (emphasis added).

The District Court then proceeded to deny, without explanation, Realtime's request for leave to amend on the basis that Realtime could appeal the § 101 ruling to the Federal Circuit:

> THE COURT: All right. Okay. I'm going to deny it. I'm not going to give leave to amend. I am going to grant the motion to dismiss and I think you can take your issues up with the Federal Circuit, and if I'm wrong, I'm wrong.

Appx63 at 55:9–13.

Final judgment in favor of Defendants-Appellees Fortinet, Reduxio, Panzura, and Aryaka was entered on July 29, 2019. Appx1–8. Realtime timely filed notices of appeal on the same day. Appx890, Appx1239, Appx1537, Appx1879.

V. SUMMARY OF ARGUMENT

The District Court erred in finding, at the pleading stage and without any written ruling, that all 159 claims of the five asserted patents, across three distinct families, are invalid under § 101.

All five patents are directed to methods and systems for digital data compression and are aimed at solving known problems in conventional data

compression systems. For example, the faces of the ’728 and ’530 patents make clear that they are directed to systems and methods for data compression using a combination of content-independent and content-dependent encoders, and are aimed at solving problems in the prior art relating to, *inter alia*, data dependency. The faces of the ’908 and ’530 patents make clear that they are directed to systems and methods for accelerated data storage and retrieval utilizing lossless data compression and decompression, and are aimed at solving problems in the prior art relating to, *inter alia*, bandwidth limitations. And the face of the ’751 patent makes clear that it is directed to systems and methods for providing accelerated transmission of digital data over a communication channel using data compression and decompression to effectively increase the bandwidth of the communication channel and/or reduce the latency of data transmission. The ’751 patent is aimed at solving problems in the prior art relating to, *inter alia*, latency, data redundancy, increased error rates, and bandwidth limitations.

The claims are directed to specific improvements in computer functionality and thus are not abstract. And even assuming, *arguendo*, that they are abstract, they are nonetheless patent eligible because they require specific, unconventional combinations of specially configured computer elements, including, for example, a plurality of content-dependent and content-independent encoders, a data accelerator, and a state machine configured to perform specific functions.

The District Court's conclusion that the patents are abstract and do not provide inventive concepts is contrary to fact and law. In reaching this conclusion, the District Court applied the wrong analysis in direct contravention of this Court's and Supreme Court precedent. The District Court considered only one claim from one asserted patent, and parsed that claim into individual components to determine whether each component, individually, involves an abstract concept and/or is a "generic computer component." The District Court improperly failed to consider each of the asserted claims as a whole, failed to consider the claims in light of their respective specifications and claimed advances, and, in assessing inventive concept, failed to consider the elements of each claim as an ordered combination.

The District Court also improperly conflated § 101, § 102, and § 103 issues, and improperly resolved disputed issues of fact based on the District Court's factual conclusion, unsupported by any evidence, that certain aspects of the claimed inventions are "obvious," but not "obviousness in the "patent sense"—obviousness "like it's common sense." Appx47–49 at 39:22–41:1.

The District Court also abused its discretion in denying, without explanation, Realtime's request for leave to amend. The District Court failed to provide any legitimate reason for its denial, stating that its "practice has been to ignore [requests for leave to amend] and just to grant a motion to dismiss." Appx60 at 52:4–7.

The District Court's judgment that the asserted patents are invalid under § 101 should be reversed.

VI. STANDARD OF REVIEW

A district court's dismissal for failure to state a claim is reviewed under the law of the regional circuit, which, in this case, is the Third Circuit. *Content Extraction & Transmission LLC v. Wells Fargo Bank, Nat. Ass'n*, 776 F.3d 1343, 1346 (Fed. Cir. 2014) (applying Third Circuit law). The Third Circuit reviews dismissals for failure to state a claim under Rule 12(b)(6) *de novo*, and thus this Court should review the District Court's determination of patent eligibility under § 101 *de novo*. *See id.* (citing *Sands v. McCormick*, 502 F.3d 263, 267 (3d Cir. 2007)). Denial of leave to amend is reviewed for abuse of discretion. *Spuck v. Clearfield Cty., Pa.*, 540 F. App'x 73, 74 (3d Cir. 2013).

On a Rule 12(b)(6) motion to dismiss, the allegations in the complaint must be accepted as true and construed in the light most favorable to Realtime. *Alston v. Countrywide Fin. Corp.*, 585 F.3d 753, 758 (3d Cir. 2009). Further, in determining whether the complaint states a claim for relief, "[t]he issue is not whether a plaintiff will ultimately prevail but whether he or she is entitled to offer evidence to support the claims." *Ballentine v. United States*, 486 F.3d 806, 810 (3d Cir. 2007).

While patent eligibility can be determined at the Rule 12(b)(6) stage, "[t]his is true only when there are no factual allegations that, taken as true, prevent resolving

the eligibility question as a matter of law." *Aatrix Software, Inc. v. Green Shades Software, Inc.*, 882 F.3d 1121, 1125 (Fed. Cir. 2018). "[P]lausible factual allegations may preclude dismissing a case under § 101 where, for example, 'nothing on th[e] record . . . refutes those allegations as a matter of law or justifies dismissal under Rule 12(b)(6).'" *Id.*

VII. ARGUMENT

A. The Legal Standard for Determining Patent Eligibility Under § 101

Section 101 defines patent-eligible subject matter as "any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof." 35 U.S.C. § 101. To determine patent eligibility under § 101, courts conduct a two-step analysis as articulated by the Supreme Court in *Alice Corp. Pty. v. CLS Bank Int'l*, 573 U.S. 208, 216 (2014). First, the court must determine "(1) whether the claim, as a whole, is 'directed to' patent-ineligible matter—here, an abstract idea—and (2) if so, whether the elements of the claim, considered individually or as an ordered combination 'transform the nature of the claim' into a patent-eligible application." *Ancora Techs., Inc. v. HTC Am., Inc.*, 908 F.3d 1343, 1347 (Fed. Cir. 2018).

This Court has emphasized the importance of the first step of the § 101 analysis, explaining that *Alice* "plainly contemplates that the first step of the inquiry is a meaningful one." *Enfish, LLC v. Microsoft Corp.*, 822 F.3d 1327, 1334 (Fed.

Cir. 2016). "The 'directed to' inquiry, therefore, cannot simply ask whether the claims involve a patent-ineligible concept, because essentially every routinely patent-eligible claim involving physical products and actions involves a law of nature and/or natural phenomenon." *Id.* at 1335. Rather, the "directed to" inquiry requires consideration of the claims "in light of the specification" to determine whether "their character as a whole is directed to excluded subject matter." *Id.*

In determining whether patent claims are directed to an abstract idea, courts must examine the patent's "claimed advance." *Ancora*, 908 F.3d at 1347. "In cases involving software innovations, this inquiry often turns on whether the claims focus on 'the specific asserted improvement in computer capabilities . . . or, instead, on a process that qualifies as an 'abstract idea' for which computers are invoked merely as a tool.'" *Id.* (citing *Enfish*, 822 F.3d at 1335–36). This Court has repeatedly held claims focused on improvements in computer technology to "pass muster under *Alice* step one," explaining that both hardware and software can make such non-abstract improvements. *Id.*

For example, in *Enfish*, this Court reversed an ineligibility ruling on a database patent, which the district court described as being directed to "storing, organizing, and retrieving memory in a logical table." *Enfish*, 822 F.3d at 1337. This Court held that "describing the claims at such a high level of abstraction and untethered from the language of the claims all but ensures that the exceptions to § 101 swallow the

rule." *Id.* It further criticized the district court's analysis for "downplay[ing] the invention's benefits" disclosed in the specification. *Id.* at 1337–38. Because the claims were "designed to improve the way a computer stores and retrieves data in memory," they were "directed to a specific implementation of a solution to a problem in the software arts" and thus were "not directed to an abstract idea." *Id.* at 1339.

More recently in *Visual Memory LLC v. NVIDIA Corp.*, this Court drew a similar conclusion about claims focused on a specific improvement in computer memory. 867 F.3d 1253, 1262 (Fed. Cir. 2017). The district court had determined that the claims were directed to the abstract concept of categorical data storage. *Id.* at 1257. This Court, however, determined that this was error because the patent was specifically "directed to an improved computer memory system, not to the abstract idea of categorical data storage." *Id.* at 1259. More specifically, as summarized in *Ancora*, the claims in *Visual Memory* were directed to "an 'improved memory system' that configured operational characteristics of a computer's cache memory based on the type of processor connected to the memory system," allowing "the claimed invention to accommodate different types of processors without compromising performance." *Ancora*, 908 F.3d at 1348. This was an improvement in computer functionality and therefore not abstract. *Visual Memory*, 867 F.3d at 1260; *see also Finjan, Inc. v. Blue Coat Sys., Inc.*, 879 F.3d 1299, 1303–06 (Fed.

Cir. 2018) (claims to a "behavior-based virus scan" were directed to an improvement in computer security and thus not directed to an abstract idea); *Core Wireless Licensing v. LG Elecs., Inc.*, 880 F.3d 1356, 1362–63 (Fed. Cir. 2018) (claims to a method for making websites easier to navigate on a small-screen device not directed to an abstract idea); *Data Engine Techs. LLC v. Google LLC*, 906 F.3d 999, 1007–11 (Fed. Cir. 2018) (claims to "a specific method for navigating through three-dimensional electronic spreadsheets" not directed to an abstract idea).

If the claims are not directed to an abstract idea, then the inquiry ends and the claims are patent eligible under § 101. *Ancora*, 908 F.3d at 1349. But if the claims are directed to an abstract idea, the second step of the *Alice* analysis calls for the court to "consider the elements of each claim both individually and 'as an ordered combination' to determine whether [the claims contain] an element or combination of elements that is 'sufficient to ensure that the patent in practice amounts to significantly more than a patent upon the [abstract idea] itself.'" *Alice*, 134 S. Ct. at 2355.

Inventions that "improve[] an existing technological process" or "solve[] a technological problem in 'conventional industry practice'" are patent eligible. *Id*. at 2358. Furthermore, a defendant *cannot* prevail on this step simply by showing that each individual claim element was "known in the art" or conventional. *BASCOM Glob. Internet Servs., Inc. v. AT&T Mobility LLC*, 827 F.3d 1341, 1349 (Fed. Cir.

2016). Even where individual elements are conventional technologies, the specific arrangement of conventional technologies can also form the inventive concept. *Id.* at 1350. Indeed, "[t]he genius of invention is often a combination of known elements which in hindsight seems preordained." *McGinley v. Franklin Sports, Inc.*, 262 F.3d 1339, 1351 (Fed. Cir. 2001).

For example, in *BASCOM*, this Court held that claims to a method and system of filtering Internet content using an Internet Service Provider (ISP) server were a "technical improvement over the prior art ways of filtering such content." 827 F.3d at 1341, 1350, 1352. In holding the claimed invention eligible under *Alice* step two, the Court reasoned that although "[f]iltering content on the Internet was already a known concept, . . . the patent describes how its particular arrangement of elements is a technical improvement over the prior art ways of filtering such content." *Id.* at 1349–50.

B. The District Court Erred in Holding that All Five Asserted Patents Across Three Distinct Patent Families Are Directed to An Abstract Idea Under *Alice* Step One

1. The District Court improperly parsed the claims into individual components to determine whether those components are abstract and failed to consider the claims as a whole

In one fell swoop, at the pleading stage and without any written ruling, the District Court invalidated five patents across three distinct patent families, comprising 159 patent claims, because they are purportedly directed to an abstract

idea. In so doing, the District Court applied the wrong legal standard, improperly parsing the claims into individual components and stripping out critical claim limitations.

This Court has repeatedly cautioned that district courts "'must be careful to avoid oversimplifying the claims' by looking at them generally and failing to account for the specific requirements of the claims." *McRO, Inc. v. Bandai Namco Games Am. Inc.*, 837 F.3d 1299, 1313 (Fed. Cir. 2016). As set forth above, the "directed to" inquiry under *Alice* step one requires courts to consider the claims "as a whole" and "in light of the specification." *Enfish*, 822 F.3d at 1334–35. Courts "cannot simply ask whether the claims involve a patent-ineligible concept," *id.*—but that is precisely what the District Court did here.

Several times throughout the hearing on Defendants-Appellees' motions to dismiss, the District Court interrupted counsel's discussion of the claimed system to obtain admissions that each individual component of the claim is abstract. *See, e.g.*, Appx34–35 at 26:17–27:16; Appx39–45 at 31:23–37:15. Indeed, the District Court admonished Realtime's counsel for talking about the "overall system," and expressly requested that counsel "break [] down" the claims and provide a "list" of components that are not abstract. Appx43 at 35:6–22; Appx44 at 36:22–25. This is the complete opposite of the correct analysis under step one, which inquires whether the claims *as a whole* are directed to an abstract idea—not merely whether the individual

elements involve abstract ideas. "[T]he [Supreme] Court has made clear that it is inappropriate to determine the patent-eligibility of a claim as a whole based on whether selected limitations constitute patent-eligible subject matter." *In re Bilski*, 545 F.3d 943, 958 (Fed. Cir. 2008). The District Court's erroneous analysis requires reversal.

And regardless, as set forth below, the District Court's conclusions as to what the patents are directed to are wrong. *See* Appx56 at 48:3–18. The District Court improperly stripped out critical claim limitations and oversimplified the claims, and failed to acknowledge, much less consider, the patents' claimed advances.

2. It is clear from the faces of the asserted patents that they are directed to improved, particularized methods of digital data compression, and thus the District Court erred in concluding that they are directed an abstract idea

Under a proper analysis of the asserted patent claims (i.e., considered as a whole and in light of their respective specifications), it is clear that they are directed to specific improvements in computer functionality and thus are not abstract. More specifically, the patents provide improved, particularized methods of digital data compression, which this Court has expressly recognized as precisely the type of claim that is patent eligible under § 101. *See DDR Holdings, LLC v. Hotels.com, L.P.*, 773 F.3d 1245, 1259 (Fed. Cir. 2014) (recognizing that an improved method of "digital data compression" is not abstract).

For example, the faces of the ’728 and ’203 patents themselves make clear that they are directed to systems and methods for data compression using a combination of content-independent and content-dependent data compression and decompression. *See, e.g.*, Appx180 at Abstract; Appx244 at 1:34–37; Appx245 at 3:59–62; Appx246 at 6:24–27; Appx102 at Abstract; Appx165 at 1:31–34; Appx166 at 3:55–58; Appx167 at 6:18–21. The ’728 and ’203 patents discuss certain “[f]undamental limitations” associated with conventional data compression techniques, including, *inter alia*, their “content sensitive behavior,” i.e., “data dependency,” and the “extremely large number of application programs, some of which do not possess published or documented file formats, data structures, or data type descriptors.” *See, e.g.*, Appx244–245 at 2:29–3:19; Appx165–166 at 2:26–3:15.

The ’728 and ’203 patents solved these problems found in conventional compression technology by providing systems utilizing two digital-data compression techniques (e.g., content-dependent and content-independent) to compress and decompress data blocks based on analysis of the specific content of the data. The patents overcame the issues associated with relying solely on a descriptor (e.g., file extensions such as “.doc,” “.txt,” etc.) by requiring a direct examination of the digital-data payload rather than examining just the descriptor. *See, e.g.*, Appx251–253 at 15:60–20:47; Appx256 at claim 1; Appx172–174 at 15:53–20:38; Appx178 at claim 14.

Likewise, the faces of the ’908 and ’530 patents make clear that they are directed to systems and methods for accelerated data storage and retrieval utilizing lossless data compression and decompression, and thus are not directed to abstract ideas. *See* Appx258 at Abstract; Appx308 at 1:15–18; 2:58–60; Appx 309 at 4:42–44; Appx64 at Abstract; Appx88 at 1:15–18, 2:58–60; Appx89 at 4:42–44. The ’530 and ’908 patents addressed problems in the current art relating to digital data compression, including, *inter alia*, problems relating to bandwidth limitations. *See, e.g.*, Appx308 at 2:34–51; Appx88 at 2:34–51. The ’908 and ’530 patents solved these problems found in conventional digital data compression by providing novel technological solutions utilizing a plurality of encoders, and optionally a compression descriptor, for accelerated storage and retrieval of data blocks. Appx309 at 3:25–33; Appx313–314 at 12:40–13:18; Appx316 at claim 1; Appx89 at 3:25–33; Appx93 at 12:14–59; Appx96 at claim 1.

And finally, it is clear from the face of the ’751 patent that it is directed to systems and methods for providing accelerated transmission of digital data over a communication channel using data compression and decompression to effectively increase the bandwidth of the communication channel and/or reduce the latency of data transmission. Appx319 at Abstract; Appx368 at 1:25–36; Appx370 at 5:33–43; 6:13–19. The ’751 patent addressed specific problems found in conventional data transmission systems, including those relating to latency, increased error rates, and

bandwidth limitations. Appx368–370 at 1:40–5:22. The '751 patent solved these and other technological problems and limitations in conventional digital data compression by utilizing a state machine to compress data blocks based on an analysis of the specific content of the data being encoded. *See, e.g.*, Appx370 at 5:28–6:40; Appx371 at 7:52–8:3; Appx380 at claim 25.

The claims thus present precisely the type of invention that this Court recognizes as unquestionably patent eligible—particularized systems and methods of digital data compression. *See DDR Holdings*, 773 F.3d at 1259. Contrary to the District Court's oversimplification of the claims, each of the claims at issue are directed to improvements in the functionality of computer systems, which this Court has repeatedly held to be not abstract. This Court's analysis and holding in *Visual Memory* is particularly salient here. In that case, this Court rejected the district court's conclusion that the claims were directed to abstract concept of categorical data storage, and found that they were instead "directed to an improved computer memory system," which is not abstract. *Visual Memory*, 867 F.3d at 1259. Indeed, directly analogous to Realtime's patent claims, the claims in *Visual Memory*, which recited "memory" and a "processor" with "operational characteristics" which "determines a type of data," were directed to "an 'improved memory system' that configured operational characteristics of a computer's cache memory *based on the type of processor* connected to the memory system," allowing "the claimed invention

to accommodate different types of processors without compromising performance." *Ancora*, 908 F.3d at 1348 (summarizing *Visual Memory*, emphasis added). This Court correctly concluded that this type of improvement in computer functionality is not abstract. *Visual Memory*, 867 F.3d at 1260

Notably, multiple judges in four separate rulings from two different districts, after *properly* applying Supreme Court and Federal Circuit precedents, have held that the very same patents asserted here, and related patents, are § 101 eligible. For instance, Magistrate Judge Love in the Eastern District of Texas found that the '728, '530, '908 patents, in addition to the '204 patent, which is in the same family as and shares a specification with the '751 patent, are directed to improvements in digital data compression systems and thus are not abstract. Appx776–797. The case was subsequently transferred, and Judge Love's findings were adopted in full "after careful consideration" by the District of Massachusetts. Appx817.

In another decision involving the '908 and '530 patents, as well as patents in the same family and with the same specifications as the '728 and '203 patents, the court found that the patents are not facially abstract. Appx799–815. The court further found that under Realtime's proposed constructions, the patents "provide technological solutions to problems arising specifically in the realm of computer technology," and any argument that they are "directed to an abstract idea would fail."

Appx813. Thus, dismissal at the pleading stage, before claim construction, was inappropriate. Appx815.

Here, however, the Delaware District Court did not even acknowledge, much less distinguish, these prior rulings. Indeed, the District Court did not issue a written ruling at all. The District Court also had previously requested letter briefs from the parties identifying the Supreme Court or Federal Circuit case "most similar to the challenged claim(s)," but did not even address in its ruling the *Visual Memory* case identified by Realtime. *See* Appx1535. Instead, the District Court proceeded to apply the wrong analysis, without any discussion or acknowledgement of the expressly disclosed problems in the prior art and the patents' claimed advances, and summarily ruled that the patents are directed to abstract ideas. And while the District Court appeared to acknowledge that the patents are directed to methods and systems for data compression, the District Court nonetheless found that they are abstract. *See* Appx56 at 48:3–18. The District Court's ruling is contrary to fact and law and should be reversed.

C. The District Court Erred in Holding that the Five Asserted Patents Do Not Provide Inventive Concepts Under *Alice* Step Two

1. The District Court improperly failed to consider the claims as an ordered combination, conflated the issues of novelty, obviousness, and inventive concept, and improperly resolved questions of fact based on its erroneous and unsupported factual conclusion regarding purported obviousness

Similar to its erroneous step one analysis, at every turn the District Court—again focusing on only one claim from one asserted patent (claim 25 of the '751 patent)—sought to parse the claim into individual components and obtain admissions that each component, individually, is a "generic computer component." *See, e.g.*, Appx32–34 at 24:11–26:6; Appx39 at 31:2–18 (seeking admissions that servers, processors, and state machines are each generic computer components). The District Court's analysis flies in the face of longstanding Supreme Court and Federal Circuit precedent mandating that the elements of the claim must be considered "both individually *and 'as an ordered combination.'" Alice*, 134 S. Ct. at 2355 (emphasis added); *see also Ancora*, 908 F.3d at 1347. Indeed, this Court has expressly held that defendants *cannot* prevail on this step simply by showing that each individual claim element was "known in the art" or conventional—which is exactly what the District Court did here. *See BASCOM*, 827 F.3d at 1349.

The District Court also improperly conflated the issues of novelty and obviousness with its analysis of whether the claims provide inventive concept. *See, e.g.*, Appx33 at 25:10–12 ("THE COURT: You are not going to tell me it's novel to

have a data server implemented on one or more processors, are you?"); Appx34 at 26:1–5, 11–13 ("[Y]ou agree that the implementation of a data server on one or more processors is not novel."). But as held by the Supreme Court, "[t]he 'novelty' of any element or steps in a process, or even of the process itself, is of ***no relevance*** in determining whether the subject matter of a claim falls within the § 101 categories of possibly patentable subject matter." *Diamond v. Diehr*, 450 U.S. 175, 188–89 (1981) (emphasis added). While "it may later be determined that the [claimed] process is not deserving of patent protection because it fails to satisfy the statutory conditions of novelty under § 102 or nonobviousness under § 103[,] [a] rejection on either of these grounds does not affect the determination that [the] claims recited subject matter which was eligible for patent protection under § 101." *Id.* at 191; *see also Synopsys, Inc. v. Mentor Graphics Corp.*, 839 F.3d 1138, 1151 (Fed. Cir. 2016) ("The search for a § 101 inventive concept is thus distinct from demonstrating § 102 novelty.").

Even worse, the District Court compounded its error by injecting its own opinions, with no supporting evidence, that certain aspects of the claimed invention are "obvious" and "common sense." *See, e.g.*, Appx47–49 at 39:16–41:1 (characterizing the inventions as "stating the obvious"). The District Court's attempt to distinguish between "obviousness in the patent sense," and "obvious[ness] like it's common sense" (Appx48–49 at 40:7–41:1) only further obfuscated the issues,

and demonstrates the District Court's failure to apply this Court's standard for determining eligibility under § 101. Whether a particular element of a claim is obvious, in the "patent sense" or as a "common sense notion," is irrelevant to the § 101 analysis. *Diehr*, 450 U.S. at 188–89, 191. Indeed, "[t]he genius of invention is often a combination of known elements which in hindsight seems preordained." *McGinley*, 262 F.3d at 1351.

Further, even ignoring that the District Court's opinions regarding obviousness—in either sense of the word—are wrong, the District Court's reliance on such incorrect and improper factual determinations constitutes legal error. As recently confirmed by this Court, "[t]he question of whether a claim element or combination of elements is well-understood, routine and conventional to a skilled artisan in the relevant field is a question of fact." *Berkheimer v. HP Inc.*, 881 F.3d 1360, 1368–69 (Fed. Cir. 2018). This Court further explained that "[w]hether a particular technology is well-understood, routine, and conventional goes beyond what was simply known in the prior art," and "[t]he mere fact that something is disclosed in a piece of prior art . . . does not mean it was well-understood, routine, and conventional." *Id.* at 1369 (holding that the improvements cited in the specification created a "factual dispute" precluding summary judgment); *see also Aatrix Software*, 882 F.3d at 1125–26 (holding that plaintiff's allegations "at a minimum raised factual disputes underlying the § 101 analysis, such as whether the

claim term 'data file' constitutes an inventive concept, alone or in combination with other elements," and reversing Rule 12(b)(6) dismissal).

In sum, the District Court's failure to consider the elements of each asserted claim as an ordered combination, erroneous conflation of § 101, § 102 and § 103 issues, and improper injection of its irrelevant and unsupported factual determinations to resolve a disputed issue of fact at the pleading stage, requires reversal.

And regardless, as discussed further below, the District Court's conclusion that the patents lack inventive concept is wrong. It is clear from the faces of the patents that they provide unconventional technological solutions to technological problems in the field of digital data compression, which are patent eligible.

2. Contrary to the District Court's ruling, the asserted patents provide unconventional solutions to known problems in digital data compression and therefore provide inventive concept

As expressly set forth in the patents themselves, the disclosed inventions provide improvements in digital data compression systems that addressed known problems in conventional prior art systems. The '728 and '203 patents addressed problems relating to, *inter alia*, "data dependency," "significant variations in the compression ratio obtained when using a single lossless data compression technique for data streams having different data content and data size," and the "extremely

large number of application programs, some of which do not possess published or documented file formats, data structures, or data type descriptors." Appx244–245 at 2:7–3:55; Appx165–166 at 2:4–3:51. To solve these technological issues, the '728 and '203 patent claims require specific, unconventional combinations of specially configured computer elements. For example, claim 1 of the '728 patent requires (a) "content dependent data compression encoders"; (b) a different "single data compression encoder"; and (c) and a processor configured to (i) "analyze data within a data block to identify one or more parameters or attributes of the data," where the "analyzing . . . excludes analyzing based solely on a descriptor"; (ii) "perform content dependent data compression . . . if the one or more parameters or attributes of the data are identified," and (iii) otherwise "perform data compression with the single data compression encoder." Appx256. The '203 patent likewise claims an unconventional combination of computer elements in context of decompressing digital data. *See, e.g.*, Appx178 at claim 14.

The '908 and '530 patents addressed problems in conventional digital data compression systems, including that "high performance disk interface standards . . . offer only the promise of higher data transfer rates through intermediate data buffering in random access memory," "[f]aster disk access data rates are only achieved by the high cost solution of simultaneously accessing multiple disk drives with a technique known within the art as data striping," and "problems with

bandwidth limitations . . . by all other forms of sequential, pseudorandom, and random access mass storage devices." Appx308 at 2:20–54; Appx88 at 2:19–53. To solve these technological issues, '908 and '530 claims require specific, unconventional combinations of specially configured computer elements. For example, claim 1 of the '908 patent requires (a) "a memory device"; and (b) "a data accelerator" configured to utilize two different data compression techniques to provide a first and second compressed data block, which data blocks are stored on the memory device, and where the "compression and storage occurs faster than the first and second data blocks are able to be stored on the memory device in uncompressed form." Appx316. The claimed data accelerator is unconventional, as it requires two different compression techniques and the structural capability of compressing and storing digital data faster than the digital data can be stored in uncompressed form. *Id.* Claim 1 of the '530 patent additionally requires that "a first data descriptor is stored on said memory device indicative of said first compression technique, and said first descriptor is utilized to decompress the portion of said compressed data stream associated with said first data block." Appx96.

And finally, the '751 patent addressed specific problems in the prior art data compression systems, including "latency induced by the act of encryption, compression, decryption, and decompression," "substantial latency caused by aggregating data packets due to poor data compression efficiency and packet

overhead," capacity limitations of data transmission using existing T1 lines and associated costs, and "[t]he limitation of highly significant bandwidth and/or long delays with co-location processing and long latency times." Appx368–370 at 1:40–5:22. The '751 patent solved these technological problems by providing an unconventional compression system allowing for a multiplication of bandwidth and a reduction in transmission latency. Appx370 at 5:28–29. For example, claim 25 of the '751 patent discloses a "system for compressing data" requiring a specific and unconventional combination of specially configured computer elements, including "a data server implemented on one or more processors and one or more memory systems and configured to" (a) "analyze content of a data block to identify a parameter, attribute, or value of the data block that excludes analysis based solely on reading a descriptor," (b) "select an encoder associated with the identified parameter, attribute, or value," (c) "compress data in the data block with the selected encoder to produce a compressed data block, wherein the compression utilizes a state machine," and (d) "store the compressed data block." Appx380. Claim 25 further requires that "the time of the compressing the data block and the storing the compressed data block is less than the time of storing the data block in uncompressed form." *Id.*

Thus, even assuming that the patents are directed to an abstract idea—which they clearly are not—it is clear that each patent claim "amounts to significantly more

than a patent upon the [abstract idea] itself." *Alice*, 134 S. Ct. at 2355. The disclosed inventions solve technological problems in conventional data compression systems, and thus are patent eligible. *Id*. at 2358. While it may be true that data compression, generally, was already a known concept, the patents describe how their "particular arrangement of elements is a technical improvement over the prior art." *BASCOM*, 827 F.3d at 1350.

Contrary to the District Court's ruling, the mere fact that the claims utilize generic computer components does not render them ineligible. This Court has repeatedly rejected the notion that the disclosure of conventional computing elements "dooms the claims." *Enfish*, 822 F.3d at 1338; *see also Visual Memory*, 867 F.3d at 1262 (a "patent's use of conventional computer components" not "fatal to patent eligibility"). Where, as here, the claims do not simply "add general-purpose computer components to a fundamental economic practice or mathematical equation," but rather are directed to specific improvement in computer functionality, they are not abstract. *Enfish*, 822 F.3d at 1338–39.

Properly analyzing the claims as a whole, in light of the statements made in the specification—which must be accepted as true and construed in favor of Realtime—and considering the recited components as an ordered combination, it is clear that the claims recite specific, discrete implementations of digital data compression, and the recited claim elements "operate in an unconventional manner

to achieve an improvement in computer functionality." *See Amdocs (Israel) Ltd. v. Openet Telecom, Inc.*, 841 F.3d 1288, 1300–01 (Fed. Cir. 2016). And in any event, the claimed components are not generic. For example, the processor recited in claim 1 of the '728 patent must be specially configured to perform the recited, non-conventional functions, including analyzing the data to identify one or more parameters or attributes and performing compression with a plurality of different encoders based on that analysis.

To the extent that the District Court's ruling was based on a finding that the claims merely describe desired results, this finding is wrong for the same reasons. The only way to reach such a conclusion would be to ignore the specific requirements of the claims, which is improper. *See McRO, Inc. v. Bandai Namco Games Am. Inc.*, 837 F.3d 1299, 1313 (Fed. Cir. 2016) ("Courts 'must be careful to avoid oversimplifying the claims' by looking at them generally and failing to account for the specific requirements of the claim."); *Visual Memory*, 867 F.3d at 1257, 1260–61 (upholding patentability of comparable claim and rejecting defendant's argument that the patent does not "describe how to implement the 'programmable operational characteristic' and requires someone else to supply the innovative programming effort"); *Finjan*, 879 F.3d at 1305 (holding claims recited more than a mere result where they recited "specific steps—generating a security profile that identifies suspicious code and linking it to a downloadable—that

accomplish the desired result").

Indeed, multiple judges from different districts have expressly *rejected* similar arguments that the patents require only conventional computer technology and claim desired results. *See, e.g.*, Appx776–797, Appx817 (ruling that the '728, '530, '908, and '204 (related to the '751) patents are "inventive" and "directed to patent eligible subject matter" because they disclose "specific improvement[s] in computer capabilities" and "specify direct ways to fix issues in data transmission."). As correctly noted by one court, "the patents set out specified rules to lead to [faster compression] and move them past an over-simplified result-oriented patent." Appx791. At the very least, these contrary rulings created factual issues precluding dismissal at the pleading stage.

D. The Cases Referenced by the District Court Are Distinguishable and Do Not Support a Finding of Unpatentability Under § 101

The cases referenced by the District Court at the hearing (*see* Appx53–54 at 45:16–46:13) do not support its decision. First, the District Court referenced *McRO, Inc. v. Bandai Namco Games Am. Inc.*, 837 F.3d 1299, 1314 (Fed. Cir. 2016), which actually supports Realtime's position that the claims are eligible under § 101. In that case, this Court *upheld* the patentability of claims related to automating part of a preexisting 3–D animation method. *McRO*, 837 F.3d at 1303. The Court expressly cautioned against "oversimplifying the claims," and reiterated that district courts

"must look to the claims as an ordered combination, without ignoring the requirements of the individual steps." *Id.* at 1313. This Court further explained that the proper analysis looks at whether the patent claims "focus on a specific means or method that improves the relevant technology or are instead directed to a result or effect that itself is the abstract idea and merely invoke generic processes and machinery." *Id.* at 1314. Because the claim at issue "focused on a specific asserted improvement in computer animation, i.e., the automatic use of rules of a particular type," it was held to be *not abstract*. *Id.* Likewise, Realtime's claims at issue here are limited to specific methods and systems for digital data compression, which are "specifically designed to achieve an improved technological result in conventional industry practice," and thus are not abstract. *Id.* at 1316.

The other cases cited by the District Court are distinguishable. The patents at issue in *Digitech Image Techs., LLC v. Elecs. for Imaging, Inc.*, 758 F.3d 1344 (Fed. Cir. 2014)—which decision predates *Alice*—related to digital image processing. The "device profile" claims merely claimed "collections of information," and the method claims merely claimed a "process of organizing information . . . not tied to a specific structure or machine." *Id.* at 1350–51. Similarly, the patents *In re TLI Commc'ns LLC Patent Litig.*, 823 F.3d 607 (Fed. Cir. 2016) were related to digital image processing, and per the face of the patent and the patentee's own admission, the claim at issue was merely directed to a method for classifying and storing images.

Id. at 612. The claim was "not directed to a specific improvement to computer functionality," but rather was "directed to the use of conventional or generic technology in a nascent but well-known environment, without any claim that the invention reflects an inventive solution to any problem." *Id.* These decisions are clearly inapposite, as Realtime's patents go far beyond simply collecting and organizing information—they involve digital data compression using specific, nonconventional methods (e.g., analysis of the data not based solely on a descriptor), and require specific combinations of computer machinery specially configured to perform specific functions (e.g., encoders, data accelerators, state machines). The patents specifically identify known problems in conventional data compression systems and expressly claim solutions to those problems.

Finally, the claims at issue in *RecogniCorp, LLC v. Nintendo Co.*, 855 F.3d 1322 (Fed. Cir. 2017)—the case mostly heavily relied on by the Defendants-Appellees (Appx1526, Appx1865)—also were not directed to improvements in computer functionality, but rather recited methods for creating a composite image using standard encoding and decoding techniques. More specifically, the claimed invention was limited to taking an image on a display, assigning an image code, and reproducing the image based on the codes, which, as the court noted, "does not even require a computer." *Id.* at 1326, 1328. Here, by contrast, the asserted patents are not simply directed to encoding and decoding. Nor do they merely use conventional

computing techniques to achieve an abstract result. Rather, the patents disclose specific improvements to data compression by, for example, using multiple encoders to compress data blocks based on an analysis of the specific content or type of data being encoded, without relying solely on a descriptor such as a file extension. *See, e.g.*, Appx256 at claim 1.

Indeed, in its ruling upholding the patentability of the '728, '530, '908, and '204 patents, the *Carbonite* court expressly rejected the defendants' reliance on *RecogniCorp* to argue that the patents claim "nothing more than unpatentable encoding and decoding," explaining:

> In this case, claim 1 of the '728 Patent is not simply encoding and decoding. It improves typical data compression by compressing the data stream through content dependent and independent data recognition, as well as a plethora of encoders to achieve its maximum compression. '728 Patent at 5:03–07. This results in real-time or pseudo-real-time compression.

Appx785 (internal case citations omitted); *see also* Appx817.

Though the District Court in this case failed to provide a written ruling and it is thus impossible to discern the court's reasoning in applying the foregoing cases, it is clear that these cases are inapposite and do not support its ruling.

E. The District Court Abused Its Discretion in Denying Realtime's Request for Leave to Amend

The District Court erred in concluding that all five asserted patents are ineligible under § 101. And even assuming its ruling was correct, it independently erred in denying, without explanation, Realtime's request for leave to amend. Had

Realtime been granted leave to amend, it would have added factual allegations to its complaint regarding, for example, the patents' claimed advances and inventive concept. This Court has expressly held that allowing a patentee to file an "amended complaint, which alleges facts directed to the inventive concepts in its claimed invention, would not be futile," and that denying leave to amend under such circumstances constitutes an "abuse of discretion." *Aatrix Software*, 882 F.3d at 1127 (vacating Rule 12(b)(6) dismissal and reversing denial of plaintiff's motion for leave to file a second amended complaint).

Here, the District Court denied Realtime's request for leave to amend not for any legitimate legal reason, but because its "practice has been to ignore [requests for leave to amend] and just to grant a motion to dismiss." Appx60 at 52:4–7. This was an abuse of discretion and requires reversal.

VIII. CONCLUSION

For the foregoing reasons, the District Court's entry of judgment should be reversed, and the asserted patents should be found patent eligible under § 101. In the alternative, this Court should reverse the District Court's denial of Realtime's request for leave to amend and direct the District Court to allow Realtime to file an amended complaint.

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ADDENDUM

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

REALTIME DATA LLC d/b/a IXO,	)	
	)	
Plaintiff,	)	
v.	)	C.A. No. 17-1676-CFC
	)	
REDUXIO SYSTEMS, INC.,	)	
	)	
Defendant.	)	

~~[PROPOSED]~~ ORDER FOR DISMISSAL AND ENTRY OF JUDGMENT

Based on the files, records, and proceedings in the above-captioned case, and for the reasons discussed during the July 19, 2019 hearing and resulting Order (D.I. 46),

IT IS ORDERED THAT:

1. Judgment is entered in favor of Defendant Reduxio Systems, Inc. and against Plaintiff Realtime Data LLC d/b/a IXO that U.S. Patent No. 8,717,203; U.S. Patent No. 9,054,728; U.S. Patent No. 9,116,908; and U.S. Patent No. 9,667,751 are invalid as directed to patent ineligible subject matter under 35 U.S.C. § 101; and

2. In view of the invalidity finding, judgment is entered in favor of Reduxio Systems, Inc. with respect to Plaintiff's claims for infringement (Counts I-IV (D.I. 1));

LET JUDGMENT BE ENTERED ACCORDINGLY.

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Attorneys for Reduxio Systems, Inc.

SO ORDERED this 29th day of July, 2019.

United States District Judge

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

REALTIME DATA, LLC., d/b/a IXO Plaintiff, v. ARYAKA NETWORKS, INC., Defendant.	C.A. No. 18-2062 (CFC)

~~[PROPOSED]~~ **ORDER FOR DISMISSAL AND ENTRY OF JUDGMENT**

Based on the files, records, and proceedings in the above-captioned case, and for the reasons discussed during the July 19, 2019 hearing and resulting Order (D.I. 23),

IT IS ORDERED THAT:

1. Judgment is entered in favor of Defendant Aryaka Networks, Inc. and against Plaintiff Realtime Data LLC d/b/a IXO that U.S. Patent No. 7,415,530; U.S. Patent No. 9,054,728; U.S. Patent No. 9,116,908; and U.S. Patent No. 9,667,751 are invalid as directed to patent ineligible subject matter under 35 U.S.C. § 101; and

2. In view of the invalidity finding, judgment is entered in favor of Aryaka Networks, Inc. with respect to Plaintiff's claims for infringement (Counts I-IV (D.I. 13)).

LET JUDGMENT BE ENTERED ACCORDINGLY.

11074732/1

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July 26, 2019

SO ORDERED this 29th day of July, 2019.

United States District Judge

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

REALTIME DATA, LLC., d/b/a IXO Plaintiff, v. PANZURA, INC., Defendant.	C.A. No. 18-1200 (CFC)

~~[PROPOSED]~~ ORDER FOR DISMISSAL AND ENTRY OF JUDGMENT

Based on the files, records, and proceedings in the above-captioned case, and for the reasons discussed during the July 19, 2019 hearing and resulting Order (D.I. 42),

IT IS ORDERED THAT:

1. Judgment is entered in favor of Defendant Panzura, Inc. and against Plaintiff Realtime Data LLC d/b/a IXO that U.S. Patent No. 7,415,530; U.S. Patent No. 9,054,728; U.S. Patent No. 9,116,908; and U.S. Patent No. 9,667,751 are invalid as directed to patent ineligible subject matter under 35 U.S.C. § 101; and

2. In view of the invalidity finding, judgment is entered in favor of Panzura, Inc. with respect to Plaintiff's claims for infringement (Counts I-IV (D.I. 1)).

LET JUDGMENT BE ENTERED ACCORDINGLY.

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July 26, 2019

SO ORDERED this 29th day of July, 2019.

United States District Judge

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

REALTIME DATA, LLC., d/b/a IXO Plaintiff, v. FORTINET, INC., Defendant.	C.A. No. 17-1635 (CFC)

~~[PROPOSED]~~ **ORDER FOR DISMISSAL AND ENTRY OF JUDGMENT**

Based on the files, records, and proceedings in the above-captioned case, and for the reasons discussed during the July 19, 2019 hearing and resulting Order (D.I. 59),

IT IS ORDERED THAT:

1. Judgment is entered in favor of Defendant Fortinet, Inc. and against Plaintiff Realtime Data LLC d/b/a IXO that U.S. Patent No. 8,717,203; U.S. Patent No. 9,054,728; U.S. Patent No. 9,116,908; and U.S. Patent No. 9,667,751 are invalid as directed to patent ineligible subject matter under 35 U.S.C. § 101; and

2. In view of the invalidity finding, judgment is entered in favor of Fortinet, Inc. with respect to Plaintiff's claims for infringement (Counts I-IV (D.I. 1)).

LET JUDGMENT BE ENTERED ACCORDINGLY.

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July 26, 2019

SO ORDERED this 29th day of July, 2019.

United States District Judge

US007415530B2

(12) **United States Patent**
Fallon

(10) **Patent No.: US 7,415,530 B2**
(45) **Date of Patent: Aug. 19, 2008**

(54) **SYSTEM AND METHODS FOR ACCELERATED DATA STORAGE AND RETRIEVAL**

(75) Inventor: **James J Fallon**, Armonk, NY (US)

(73) Assignee: **Realtime Data LLC**, New York, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/553,426**

(22) Filed: **Oct. 26, 2006**

(65) **Prior Publication Data**

US 2007/0067483 A1 Mar. 22, 2007

Related U.S. Application Data

(63) Continuation of application No. 10/628,795, filed on Jul. 28, 2003, now Pat. No. 7,130,913, which is a continuation of application No. 09/266,394, filed on Mar. 11, 1999, now Pat. No. 6,601,104.

(51) **Int. Cl.**
G06F 13/00 (2006.01)

(52) **U.S. Cl.** **709/231**

(58) **Field of Classification Search** 709/231, 709/233

See application file for complete search history.

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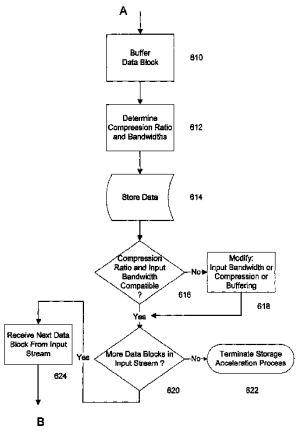
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(57) **ABSTRACT**

Systems and methods for providing accelerated data storage and retrieval utilizing lossless data compression and decompression. A data storage accelerator includes one or a plurality of high speed data compression encoders that are configured to simultaneously or sequentially losslessly compress data at a rate equivalent to or faster than the transmission rate of an input data stream. The compressed data is subsequently stored in a target memory or other storage device whose input data storage bandwidth is lower than the original input data stream bandwidth. Similarly, a data retrieval accelerator includes one or a plurality of high speed data decompression decoders that are configured to simultaneously or sequentially losslessly decompress data at a rate equivalent to or faster than the input data stream from the target memory or storage device. The decompressed data is then output at rate data that is greater than the output rate from the target memory or data storage device. The data storage and retrieval accelerator method and system may employed: in a disk storage adapter to reduce the time required to store and retrieve data from computer to disk; in conjunction with random access memory to reduce the time required to store and retrieve data from random access memory; in a display controller to reduce the time required to send display data to the display controller or processor; and/or in an input/output controller to reduce the time required to store, retrieve, or transmit data.

23 Claims, 20 Drawing Sheets



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2006/0181442	A1	8/2006	Fallon	
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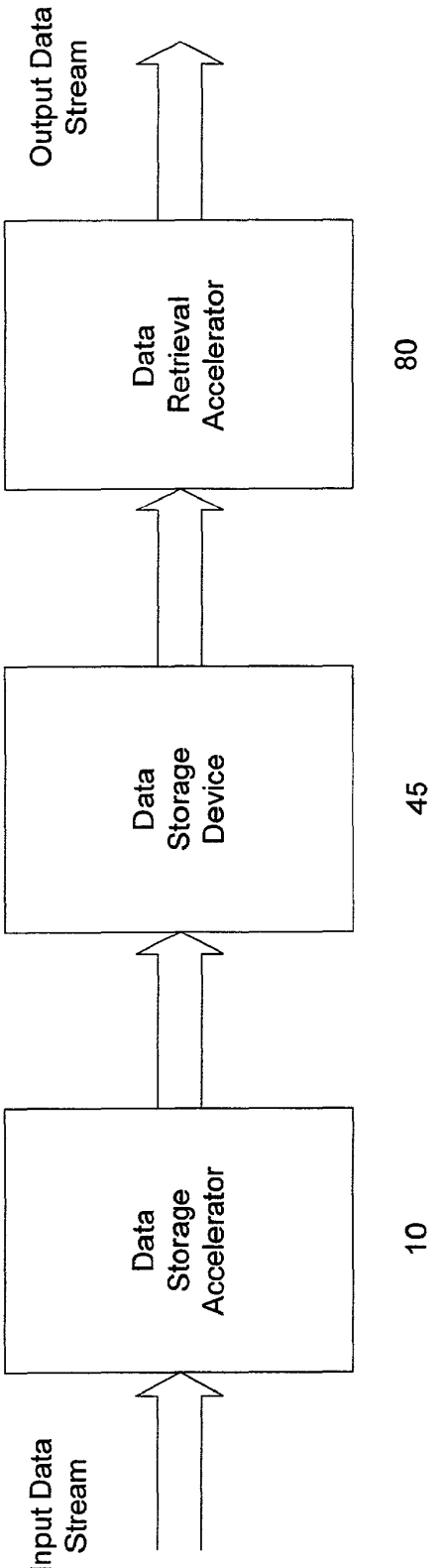

Output Data Stream
Data Retrieval Accelerator
80
Data Storage Device
45
Data Storage Accelerator
10
Input Data Stream

FIGURE 1

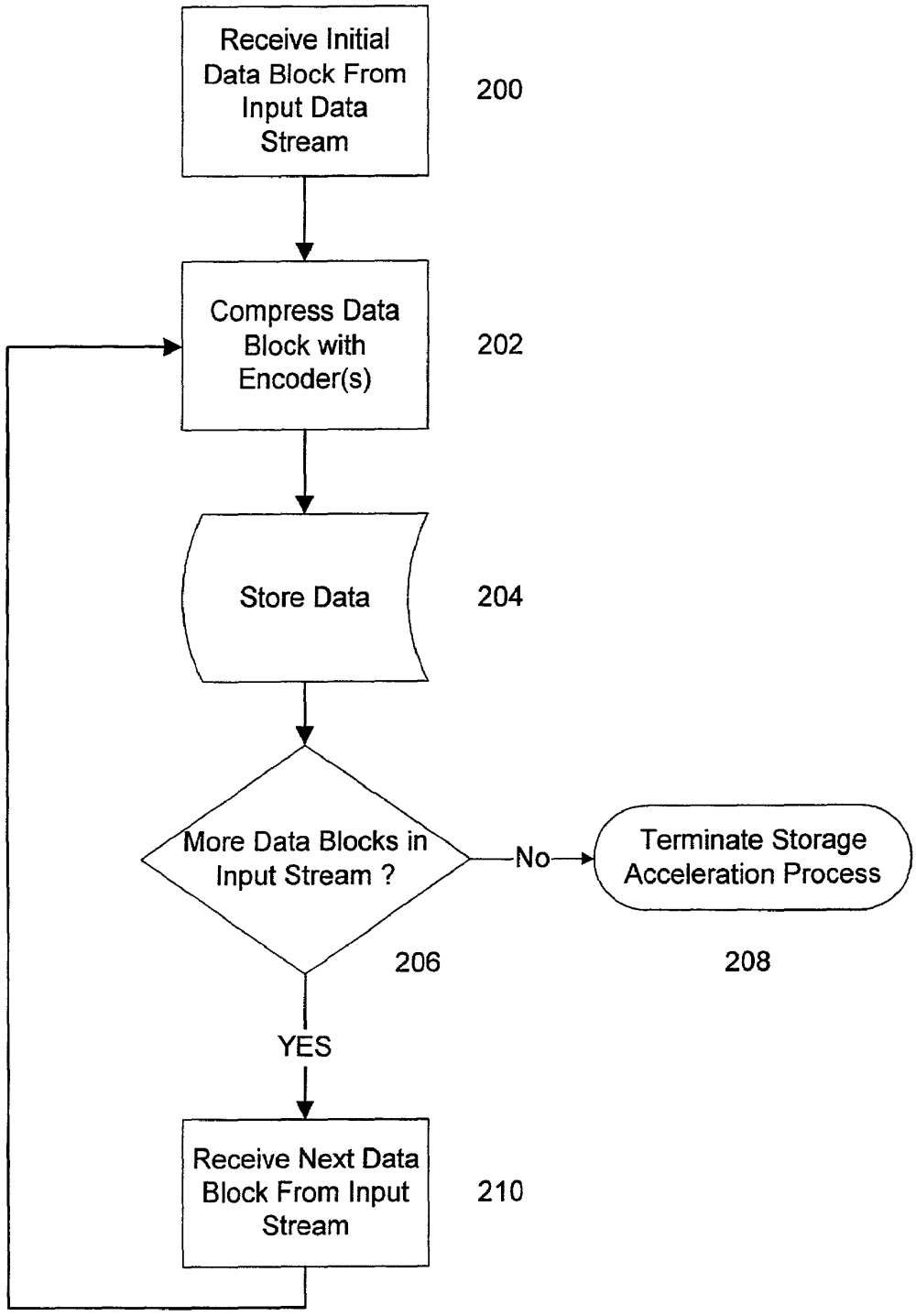

Receive Initial Data Block From Input Data Stream
200
Compress Data Block with Encoder(s)
202
Store Data
204
More Data Blocks in Input Stream ?
No
Terminate Storage Acceleration Process
206
208
YES
Receive Next Data Block From Input Stream
210

FIGURE 2

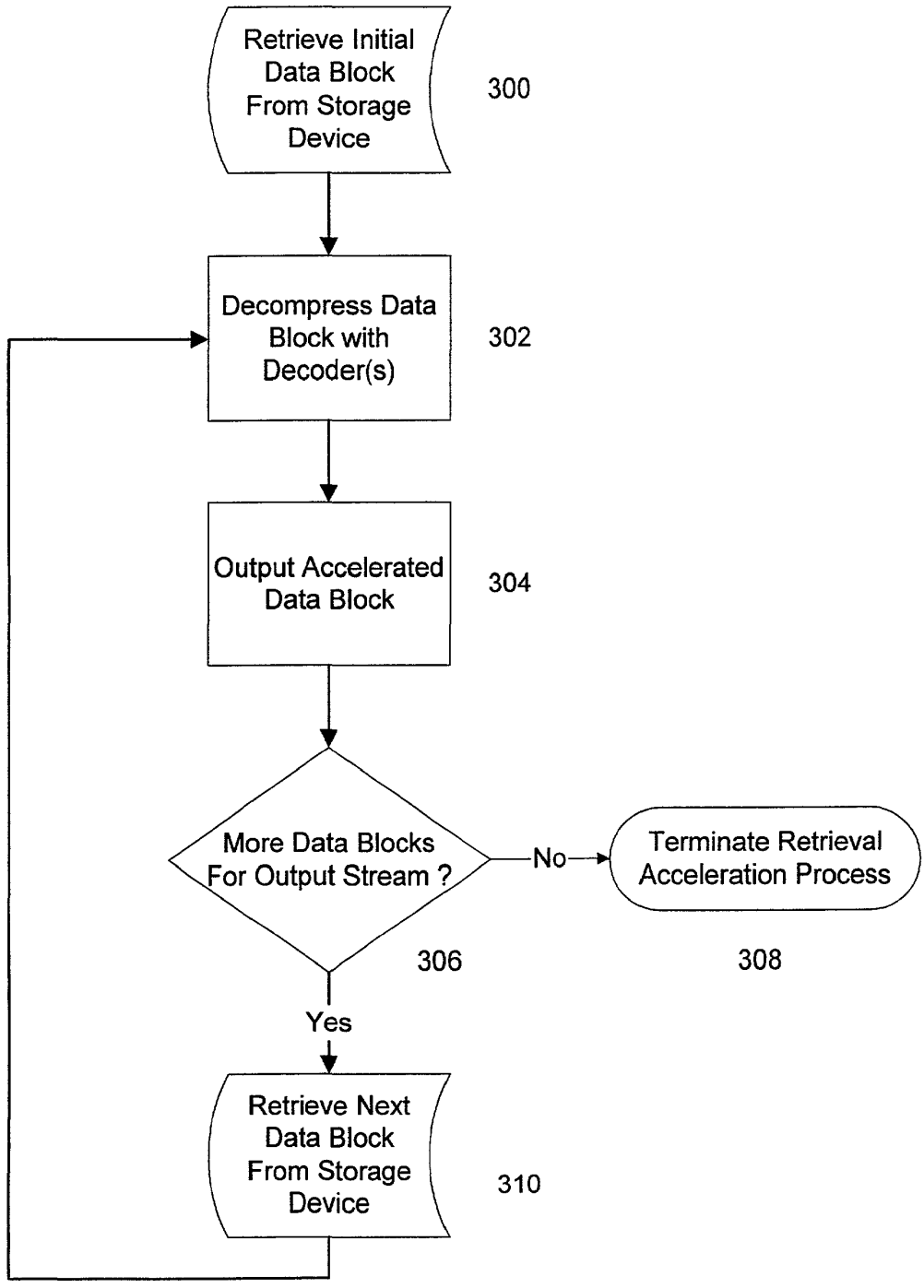

Retrieve Initial Data Block From Storage Device
300
Decompress Data Block with Decoder(s)
302
Output Accelerated Data Block
304
More Data Blocks For Output Stream ?
306
No
Terminate Retrieval Acceleration Process
308
Yes
Retrieve Next Data Block From Storage Device
310

FIGURE 3

Time Interval	T1	T2	T3	T4	Ti
Receive Data Block	Recieve Data Block 1	Receive Data Block 2	Receive Data Block 3	Receive Data Block 4	Receive Data Block i
METHOD 1					
Compress Data Block	Compress Data Block 1	Compress Data Block 2	Compress Data Block 3	Compress Data Block 4	Compress Data Block i
Store Encoded Data Block	Store Encoded Data Block 1	Store Encoded Data Block 2	Store Encoded Data Block 3	Store Encoded Data Block 4	Store Encoded Data Block i
METHOD 2					
Compress Data Block		Compress Data Block 1	Compress Data Block 2	Compress Data Block 3	Compress Data Block (i-1)
Store Encoded Data Block			Store Encoded Data Block 1	Store Encoded Data Block 2	Store Encoded Data Block (i-2)

FIGURE 4a

Time Interval	T(i+1)	T(i+2)	Tn	T(n+1)	T(n+2)
Receive Data Block	Recieve Data Block (i+1)	Receive Data Block (i+2)	Receive Data Block n		
METHOD 1					
Compress Data Block	Compress Data Block (i+1)	Compress Data Block (i+2)	Compress Data Block n		
Store Encoded Data Block	Store Encoded Data Block (i+1)	Store Encoded Data Block (i+2)	Store Encoded Data Block n		
METHOD 2					
Compress Data Block	Compress Data Block i	Compress Data Block (i+1)	Compress Data Block (n-1)	Compress Data Block n	
Store Encoded Data Block	Store Encoded Data Block (i-1)	Store Encoded Data Block i	Store Encoded Data Block (n-2)	Store Encoded Data Block (n-1)	Store Encoded Data Block n

FIGURE 4b

Time Interval	T1	T2	T3	T4	Ti
Retrieve Data Block	Retrieve Data Block 1	Retrieve Data Block 2	Retrieve Data Block 3	Retrieve Data Block 4	Retrieve Data Block i
METHOD 1					
Decompress Data Block	Decompress Data Block 1	Decompress Data Block 2	Decompress Data Block 3	Decompress Data Block 4	Decompress Data Block i
Output Decoded Data Block	Output Decoded Data Block 1	Output Decoded Data Block 2	Output Decoded Data Block 3	Output Decoded Data Block 4	Output Decoded Data Block i
METHOD 2					
Decompress Data Block		Decompress Data Block 1	Decompress Data Block 2	Decompress Data Block 3	Decompress Data Block (i-1)
Output Decoded Data Block			Output Decoded Data Block 1	Output Decoded Data Block 2	Output Decoded Data Block (i-2)

FIGURE 5a

Time Interval	T(i+1)	T(i+2)	Tn	T(n+1)	T(n+2)
Retrieve Data Block	Retrieve Data Block (i+1)	Retrieve Data Block (i+2)	Retrieve Data Block n		
METHOD 1					
Decompress Data Block	Decompress Data Block (i+1)	Decompress Data Block (i+2)	Decompress Data Block n		
Output Decoded Data Block	Output Decoded Data Block (i+1)	Output Decoded Data Block (i+2)	Output Decoded Data Block n		
METHOD 2					
Decompress Data Block	Decompress Data Block i	Decompress Data Block (i+1)	Decompress Data Block (n-1)	Decompress Data Block n	
Output Decoded Data Block	Output Decoded Data Block (i-1)	Output Decoded Data Block i	Output Decoded Data Block (n-2)	Output Decoded Data Block (n-1)	Output Decoded Data Block n

FIGURE 5b

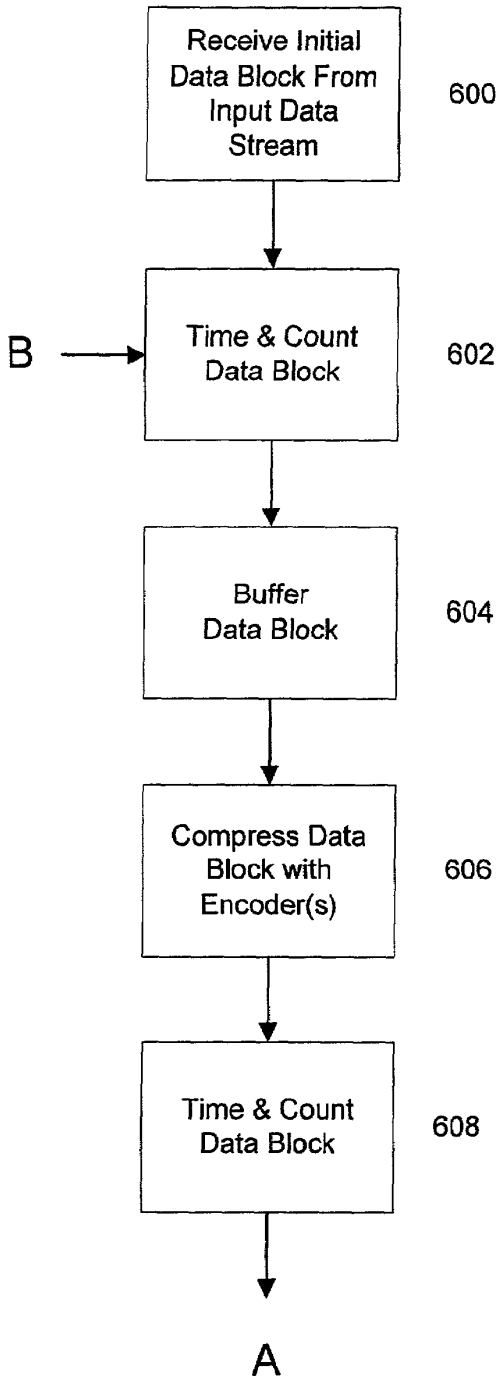

Receive Initial Data Block From Input Data Stream
600
B
Time & Count Data Block
602
Buffer Data Block
604
Compress Data Block with Encoder(s)
606
Time & Count Data Block
608
A

FIGURE 6a

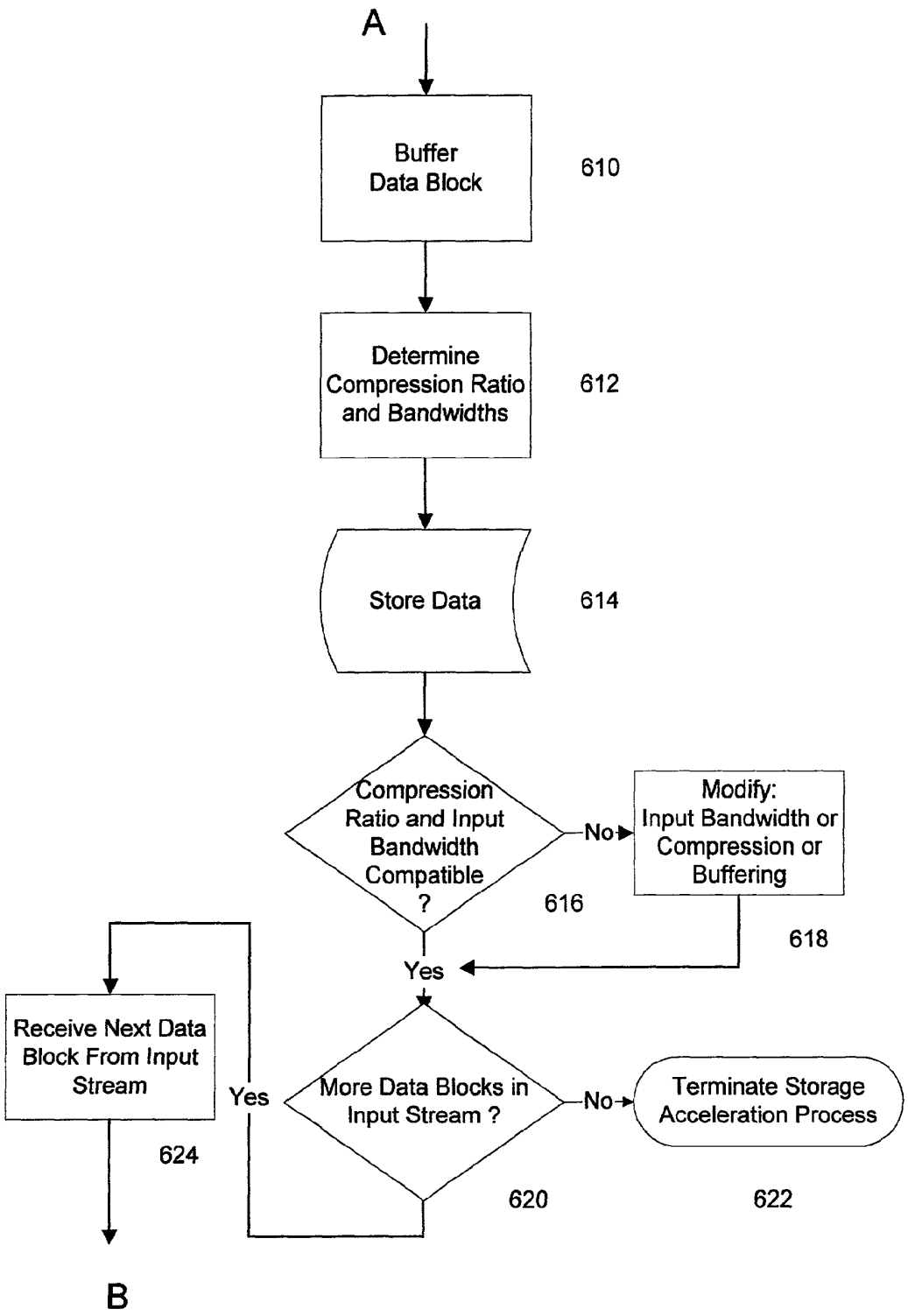

A
Buffer Data Block
610
Determine Compression Ratio and Bandwidths
612
Store Data
614
Compression Ratio and Input Bandwidth Compatible ?
No
Modify: Input Bandwidth or Compression or Buffering
616
618
Yes
Receive Next Data Block From Input Stream
Yes
More Data Blocks in Input Stream ?
No
Terminate Storage Acceleration Process
624
620
622
B

FIGURE 6b

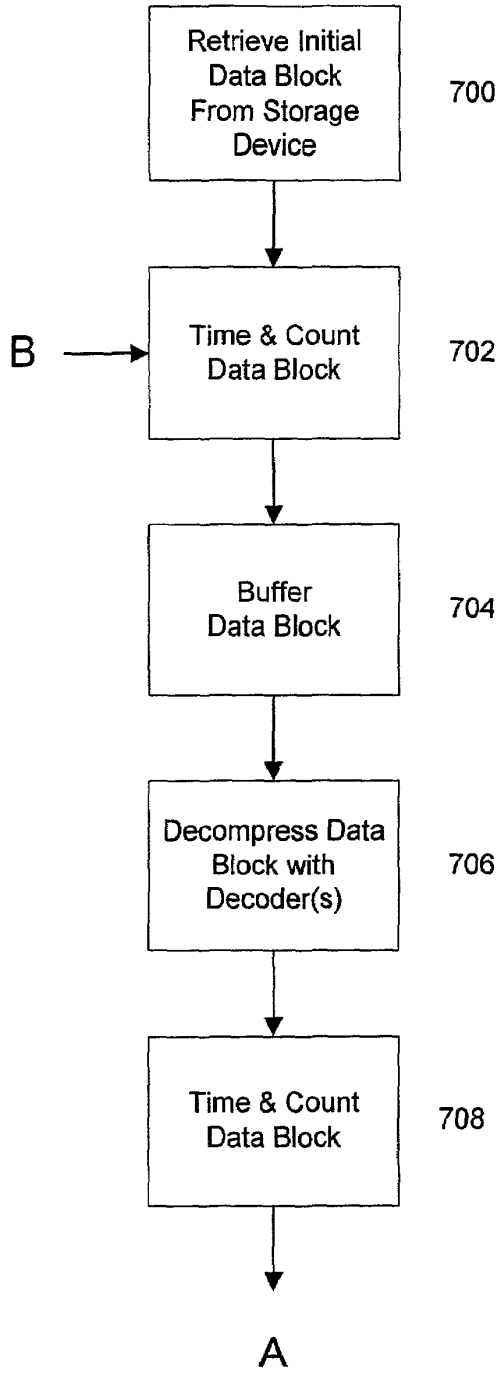

Retrieve Initial Data Block From Storage Device
700
B
Time & Count Data Block
702
Buffer Data Block
704
Decompress Data Block with Decoder(s)
706
Time & Count Data Block
708
A

FIGURE 7a

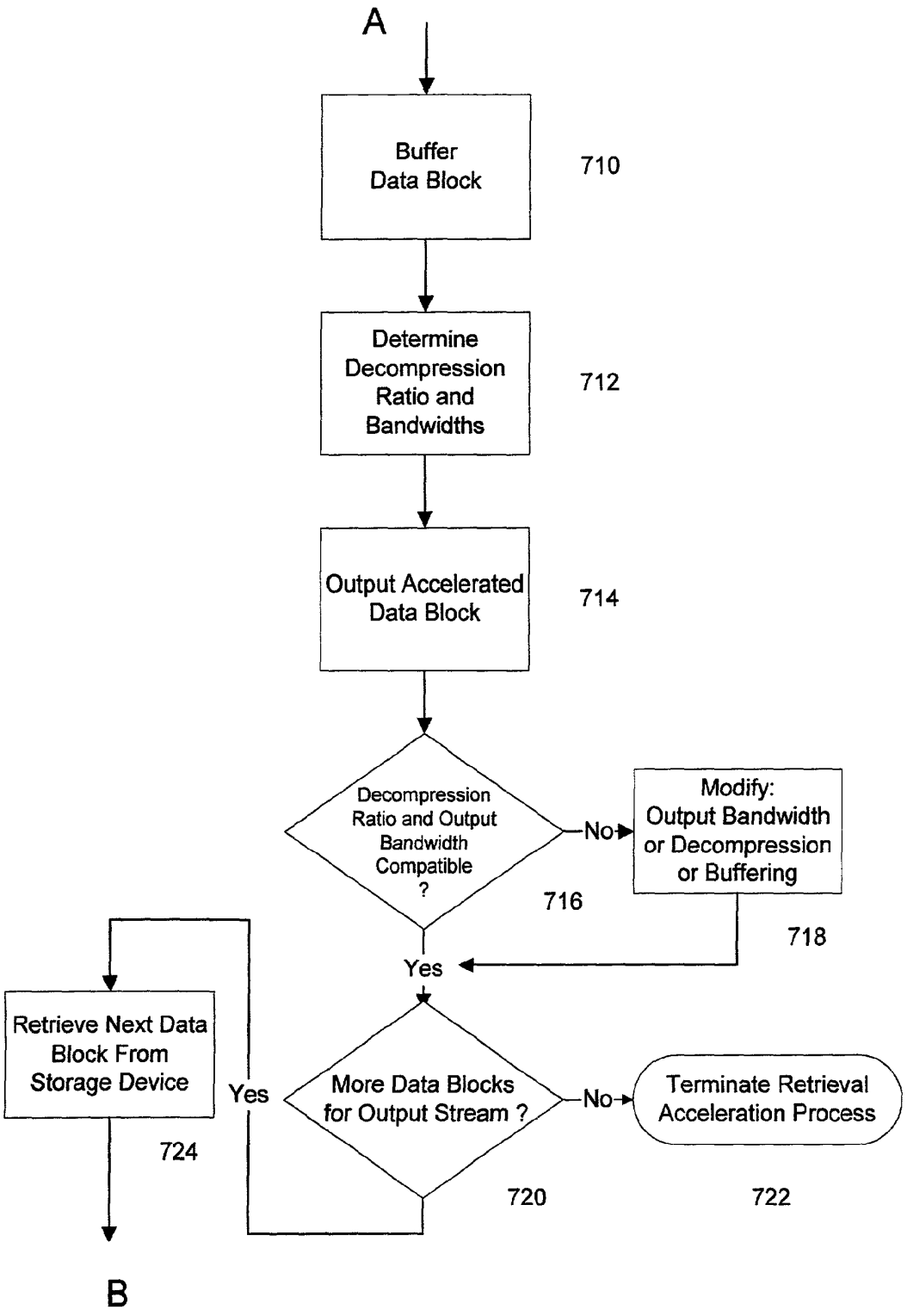

A
Buffer Data Block
710
Determine Decompression Ratio and Bandwidths
712
Output Accelerated Data Block
714
Decompression Ratio and Output Bandwidth Compatible ?
No
Modify: Output Bandwidth or Decompression or Buffering
716
718
Yes
Retrieve Next Data Block From Storage Device
Yes
More Data Blocks for Output Stream ?
No
Terminate Retrieval Acceleration Process
724
720
722
B

FIGURE 7b

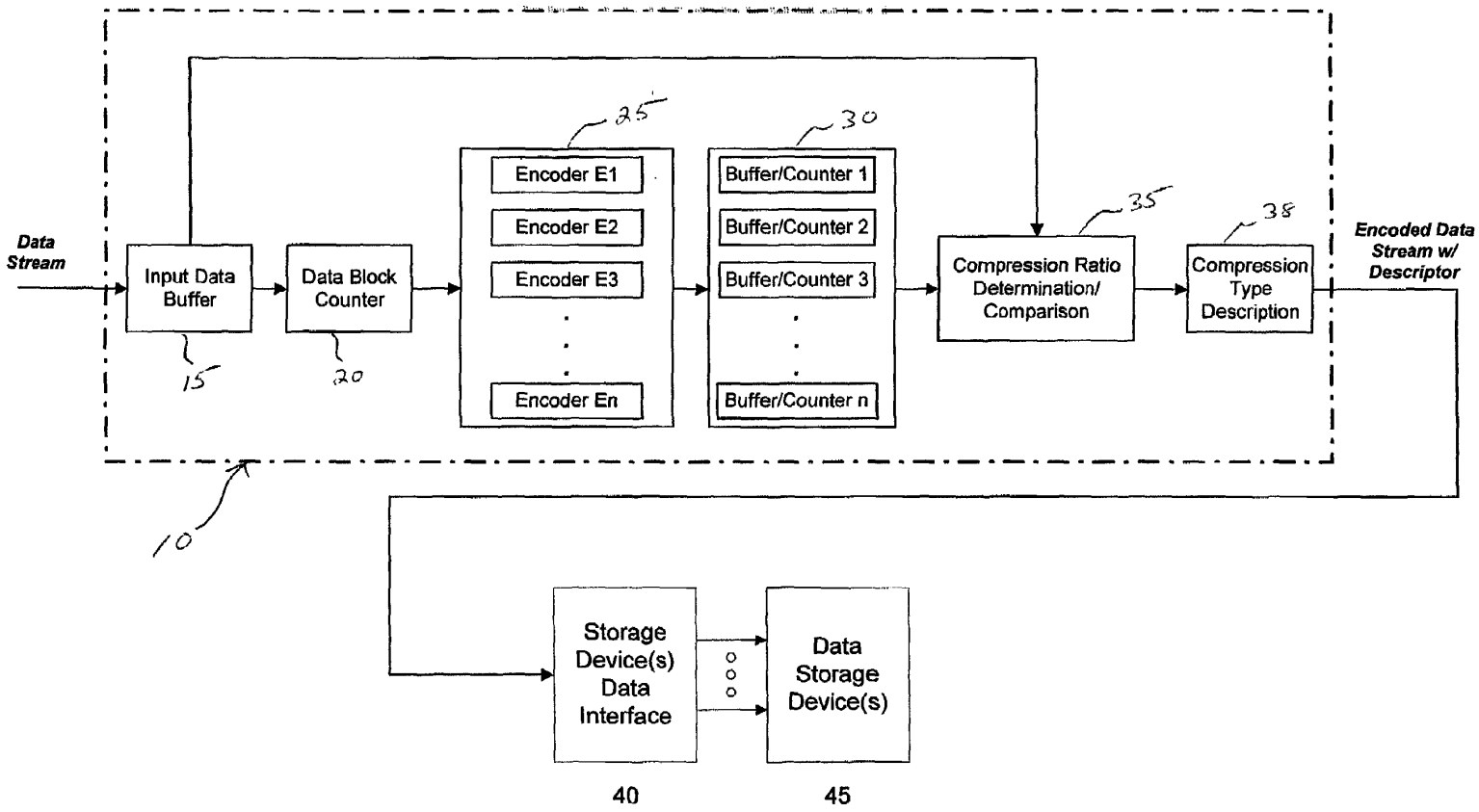

Data Stream
Input Data Buffer
15
Data Block Counter
20
25
Encoder E1
Encoder E2
Encoder E3
Encoder En
30
Buffer/Counter 1
Buffer/Counter 2
Buffer/Counter 3
Buffer/Counter n
35
Compression Ratio Determination/ Comparison
38
Compression Type Description
Encoded Data Stream w/ Descriptor
10
Storage Device(s) Data Interface
40
Data Storage Device(s)
45

FIGURE 8

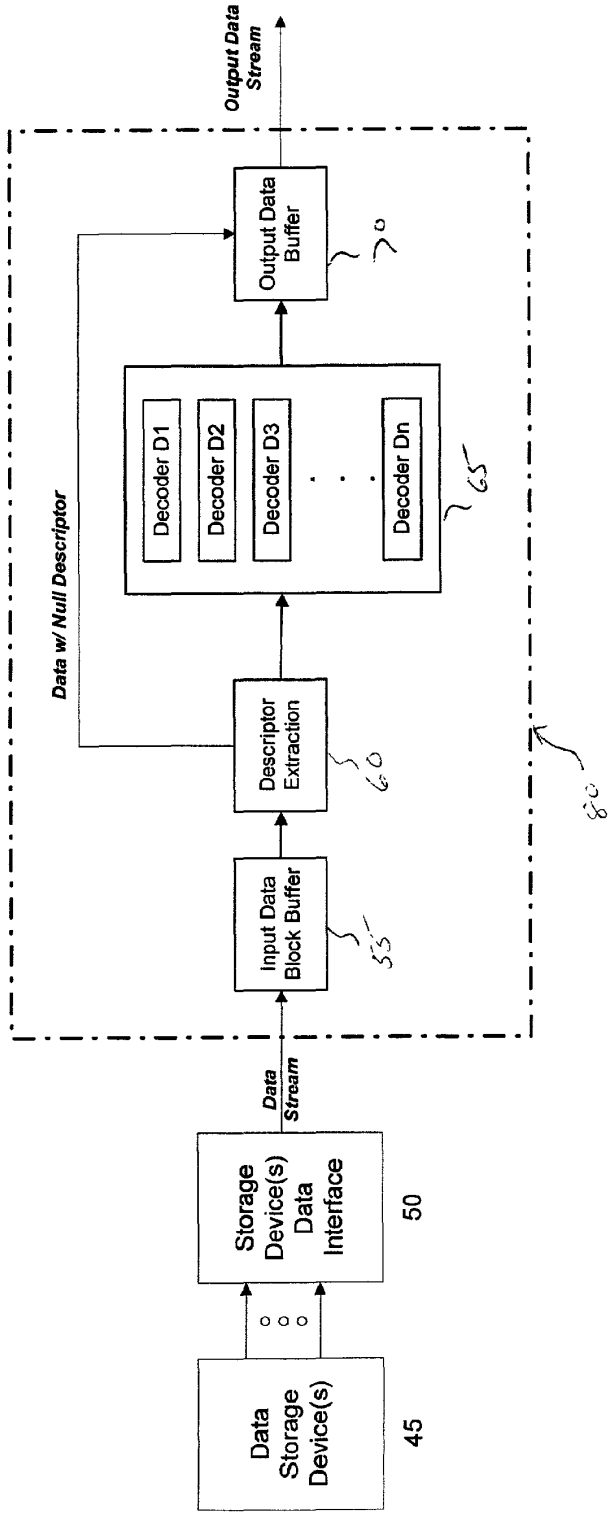

Data Storage Device(s)
45
Storage Device(s) Data Interface
50
Data Stream
Input Data Block Buffer
55
Descriptor Extraction
60
Data w/ Null Descriptor
Decoder D1
Decoder D2
Decoder D3
Decoder Dn
65
Output Data Buffer
70
Output Data Stream
80

FIG. 9

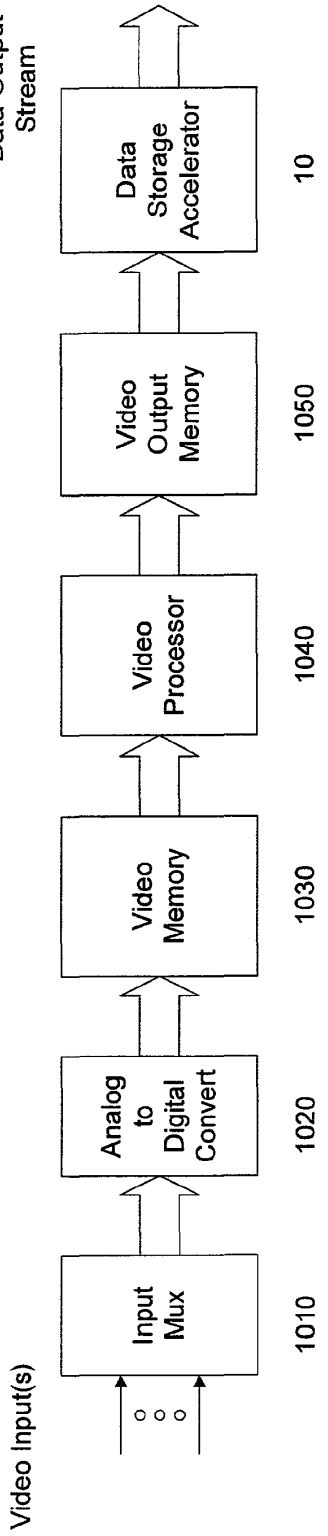

Video Input(s)
Input Mux
1010
Analog to Digital Convert
1020
Video Memory
1030
Video Processor
1040
Video Output Memory
1050
Data Storage Accelerator
10
Data Output Stream

FIGURE 10

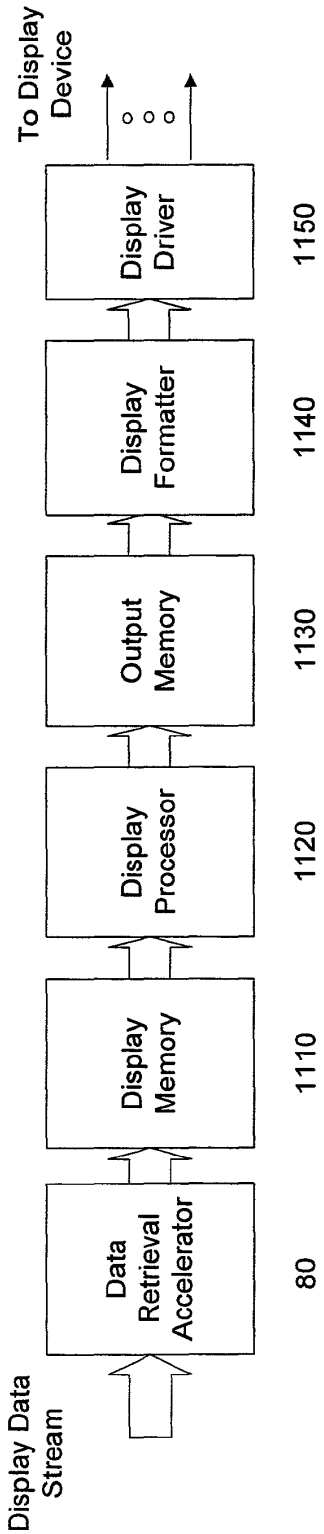

Display Data Stream
Data Retrieval Accelerator
80
Display Memory
1110
Display Processor
1120
Output Memory
1130
Display Formatter
1140
Display Driver
1150
To Display Device

FIGURE 11

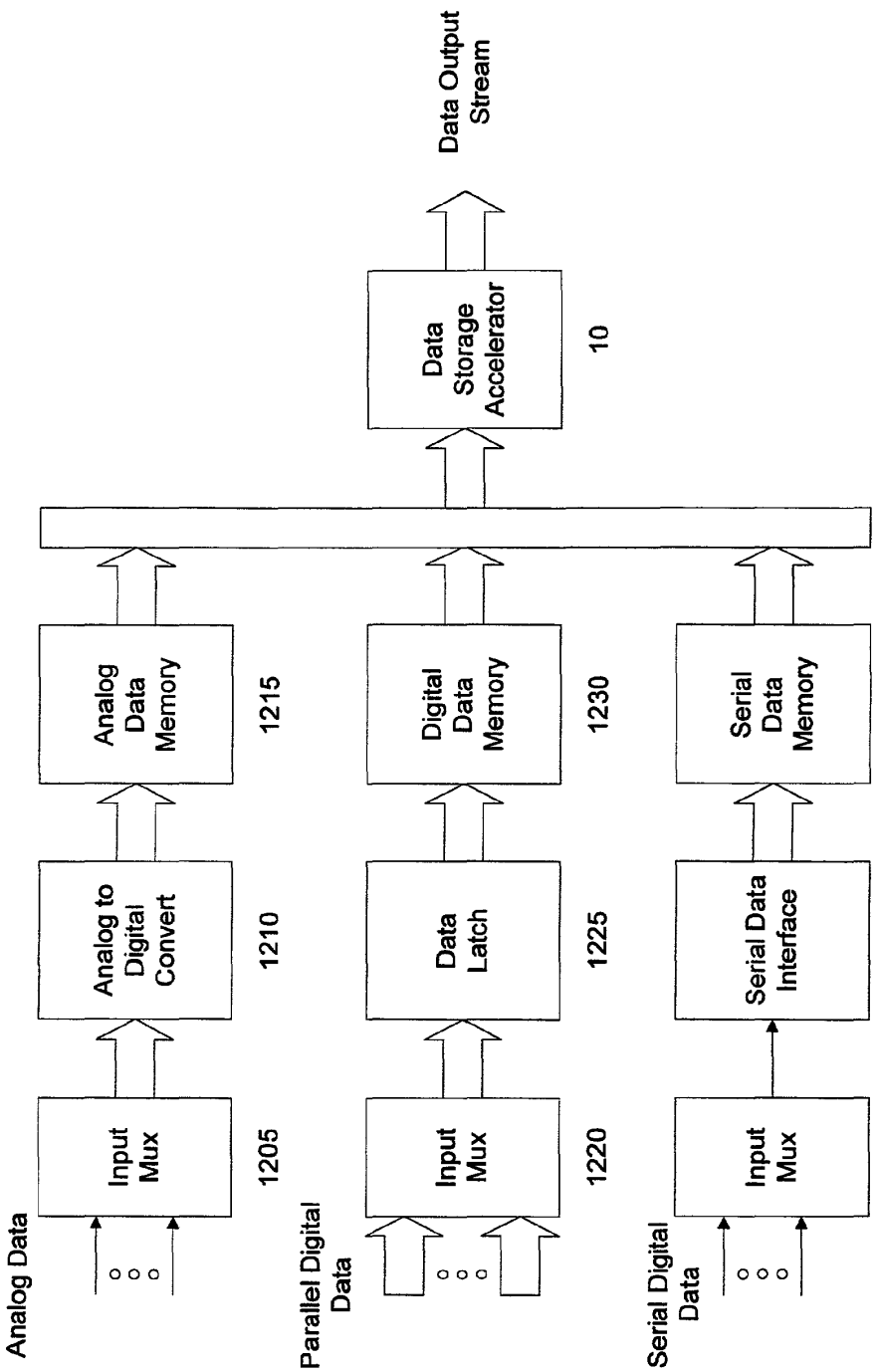

Analog Data
Parallel Digital Data
Serial Digital Data
Input Mux
1205
1220
1235
Analog to Digital Convert
1210
Data Latch
1225
Serial Data Interface
1240
Analog Data Memory
1215
Digital Data Memory
1230
Serial Data Memory
1245
Data Storage Accelerator
10
Data Output Stream

FIGURE 12

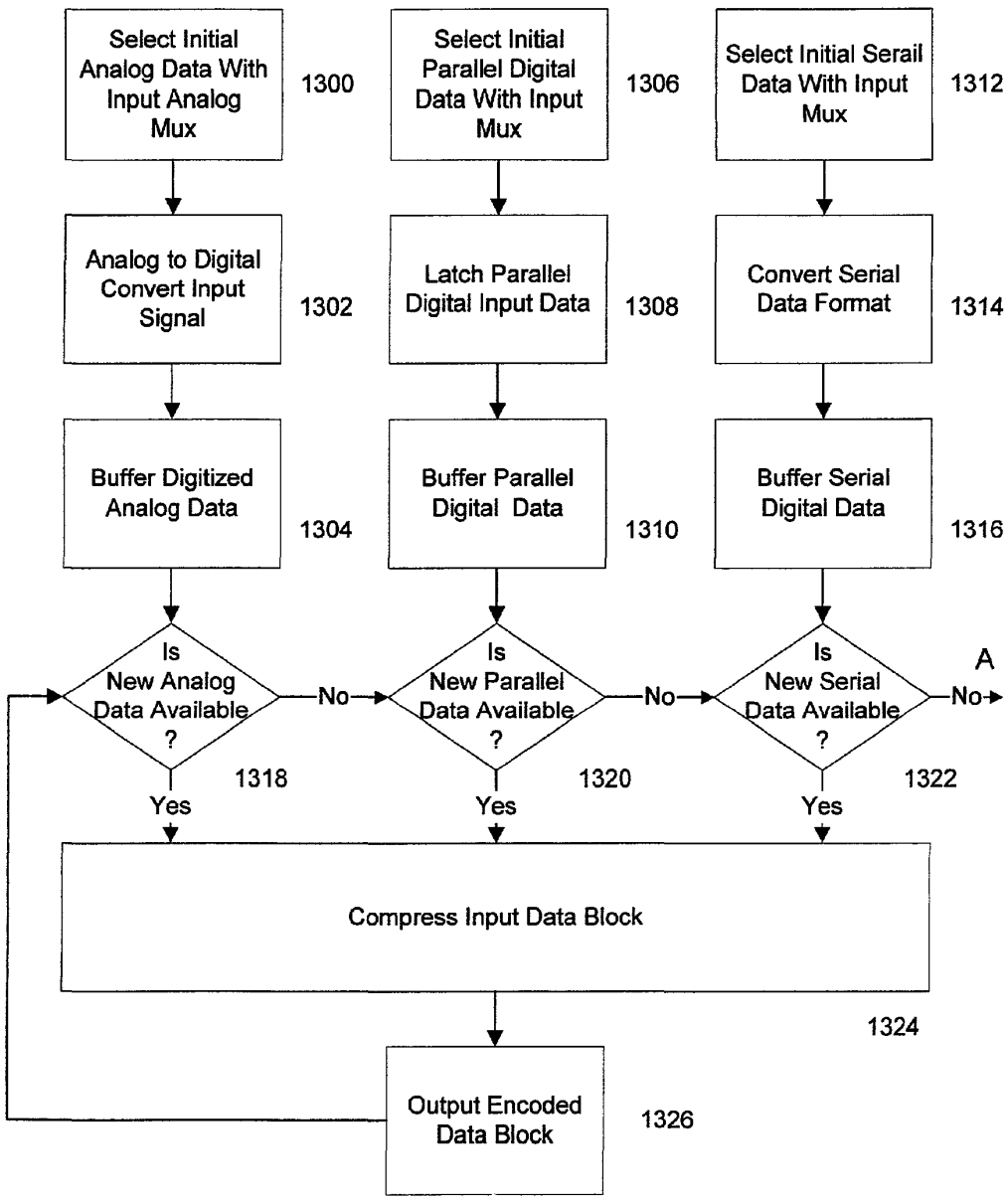

Select Initial Analog Data With Input Analog Mux
1300
Select Initial Parallel Digital Data With Input Mux
1306
Select Initial Serail Data With Input Mux
1312
Analog to Digital Convert Input Signal
1302
Latch Parallel Digital Input Data
1308
Convert Serial Data Format
1314
Buffer Digitized Analog Data
1304
Buffer Parallel Digital Data
1310
Buffer Serial Digital Data
1316
Is New Analog Data Available ?
1318
No
Is New Parallel Data Available ?
1320
No
Is New Serial Data Available ?
1322
No
A
Yes
Yes
Yes
Compress Input Data Block
1324
Output Encoded Data Block
1326

FIGURE 13

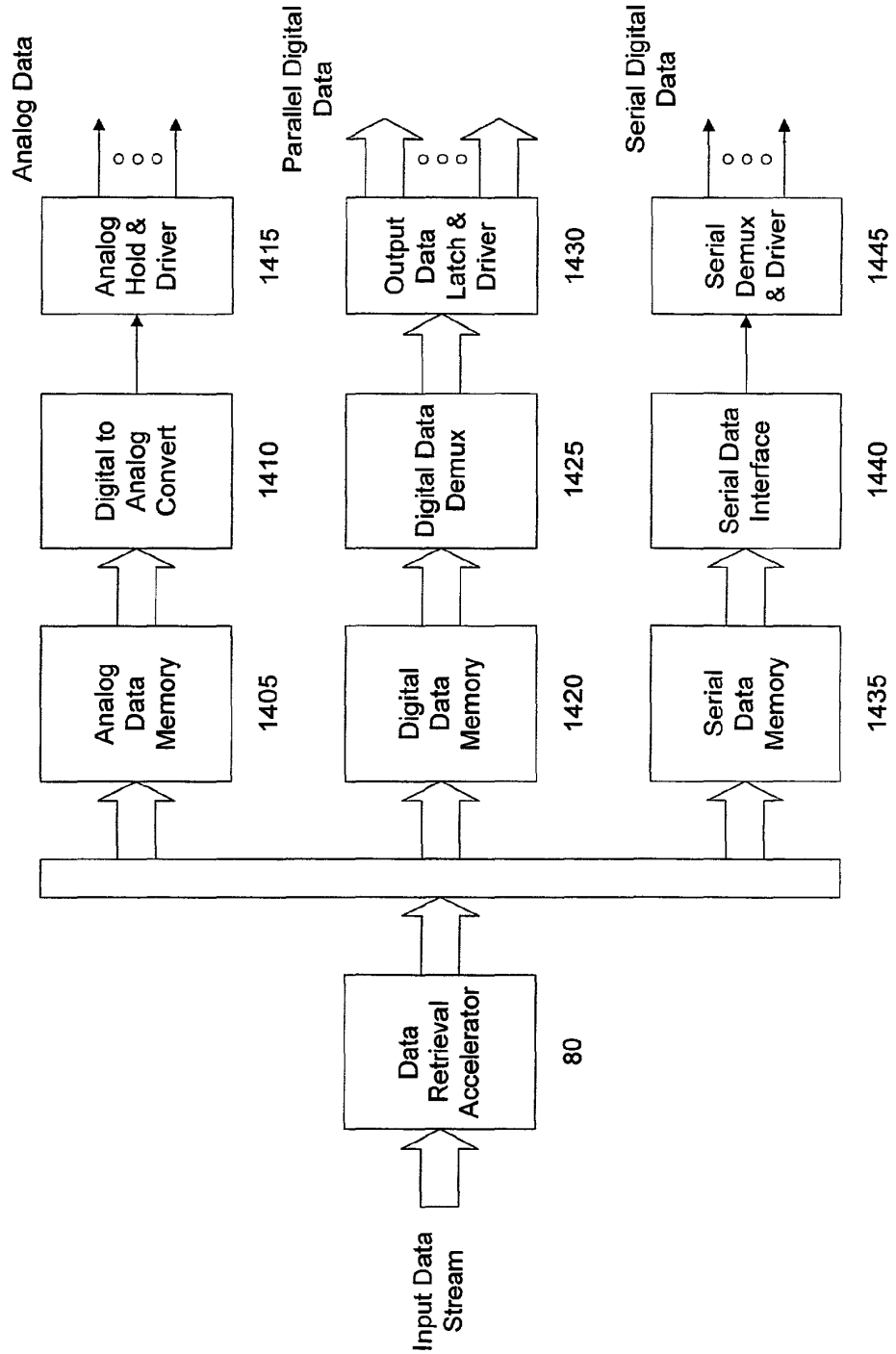

Analog Data
Parallel Digital Data
Serial Digital Data
Analog Hold & Driver
1415
Output Data Latch & Driver
1430
Serial Demux & Driver
1445
Digital to Analog Convert
1410
Digital Data Demux
1425
Serial Data Interface
1440
Analog Data Memory
1405
Digital Data Memory
1420
Serial Data Memory
1435
Data Retrieval Accelerator
80
Input Data Stream

FIGURE 14

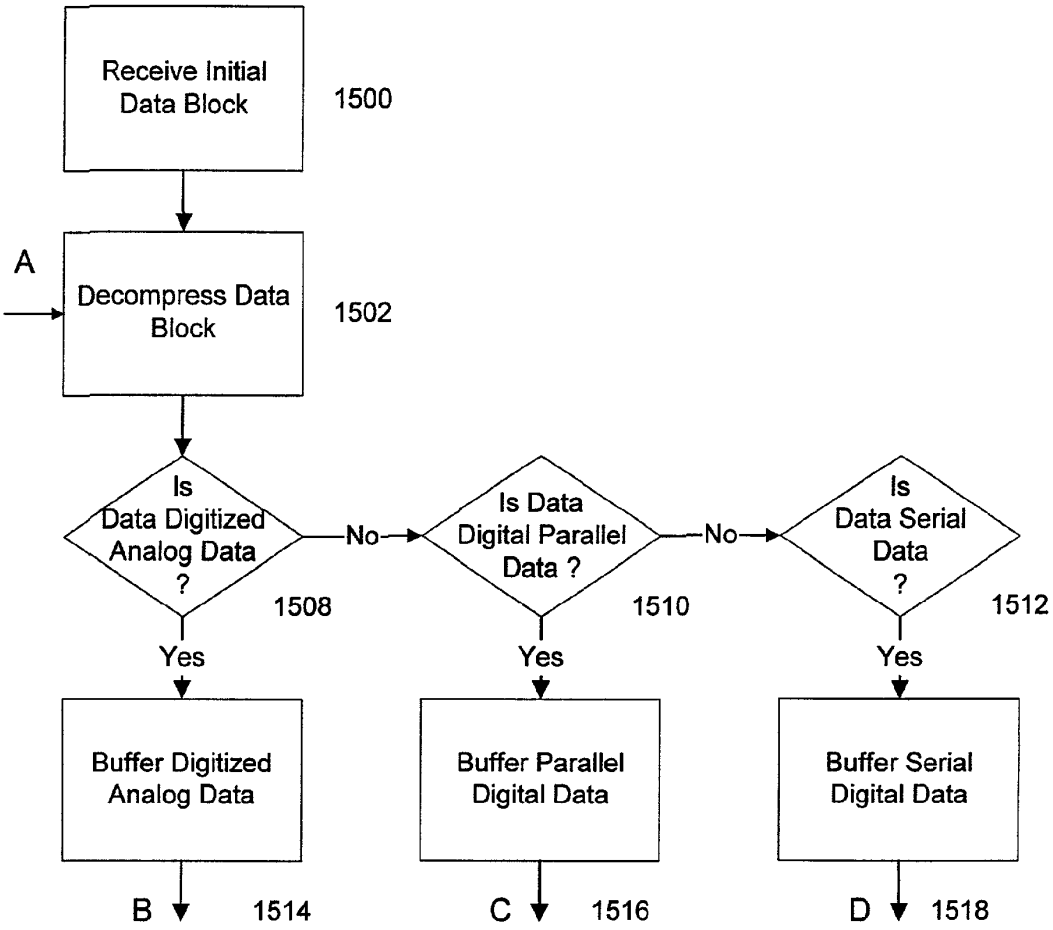

Receive Initial Data Block
1500
A
Decompress Data Block
1502
Is Data Digitized Analog Data ?
1508
No
Is Data Digital Parallel Data ?
1510
No
Is Data Serial Data ?
1512
Yes
Yes
Yes
Buffer Digitized Analog Data
Buffer Parallel Digital Data
Buffer Serial Digital Data
B
1514
C
1516
D
1518

FIGURE 15a

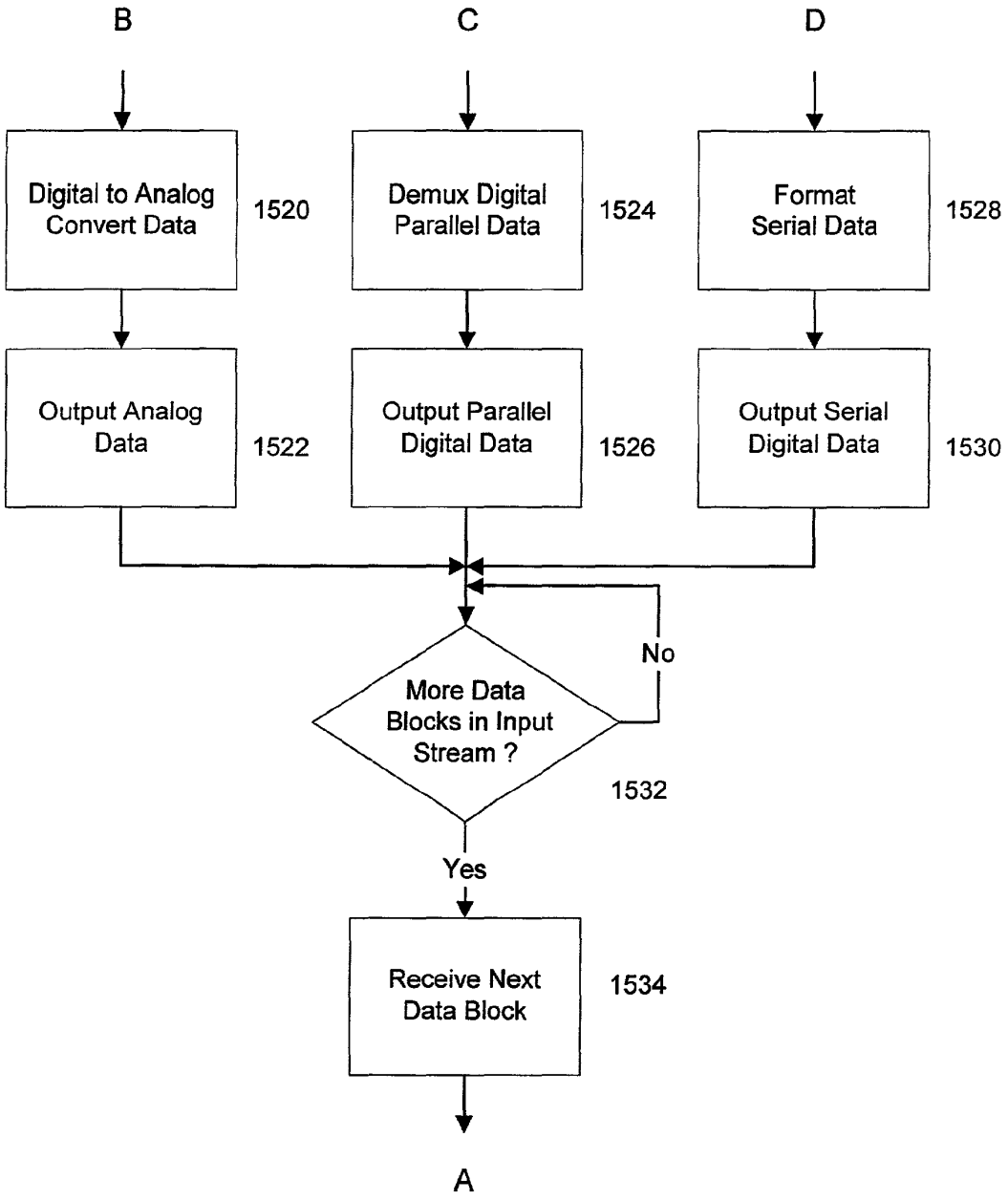

B
C
D
Digital to Analog Convert Data
1520
Demux Digital Parallel Data
1524
Format Serial Data
1528
Output Analog Data
1522
Output Parallel Digital Data
1526
Output Serial Digital Data
1530
No
More Data Blocks in Input Stream ?
1532
Yes
Receive Next Data Block
1534
A

FIGURE 15b

SYSTEM AND METHODS FOR ACCELERATED DATA STORAGE AND RETRIEVAL

This application is a continuation of U.S. patent application Ser. No. 10/628,795, filed on Jul. 28, 2003, now U.S. Pat. No. 7,130,913, which is a continuation of U.S. patent application Ser. No. 09/266,394 filed on Mar 11, 1999, now U.S. Pat. No. 6,601,104, both of which are hereby incorporated by reference herein in their entirety.

BACKGROUND

1. Technical Field

The present invention relates generally to data storage and retrieval and, more particularly to systems and methods for improving data storage and retrieval bandwidth utilizing lossless data compression and decompression.

2. Description of the Related Art

Information may be represented in a variety of manners. Discrete information such as text and numbers are easily represented in digital data. This type of data representation is known as symbolic digital data. Symbolic digital data is thus an absolute representation of data such as a letter, figure, character, mark, machine code, or drawing.

Continuous information such as speech, music, audio, images and video frequently exists in the natural world as analog information. As is well-known to those skilled in the art, recent advances in very large scale integration (VLSI) digital computer technology have enabled both discrete and analog information to be represented with digital data. Continuous information represented as digital data is often referred to as diffuse data. Diffuse digital data is thus a representation of data that is of low information density and is typically not easily recognizable to humans in its native form.

There are many advantages associated with digital data representation. For instance, digital data is more readily processed, stored, and transmitted due to its inherently high noise immunity. In addition, the inclusion of redundancy in digital data representation enables error detection and/or correction. Error detection and/or correction capabilities are dependent upon the amount and type of data redundancy, available error detection and correction processing, and extent of data corruption.

One outcome of digital data representation is the continuing need for increased capacity in data processing, storage, and transmittal. This is especially true for diffuse data where increases in fidelity and resolution create exponentially greater quantities of data. Data compression is widely used to reduce the amount of data required to process, transmit, or store a given quantity of information. In general, there are two types of data compression techniques that may be utilized either separately or jointly to encode/decode data: lossy and lossless data compression.

Lossy data compression techniques provide for an inexact representation of the original uncompressed data such that the decoded (or reconstructed) data differs from the original unencoded/uncompressed data. Lossy data compression is also known as irreversible or noisy compression. Negentropy is defined as the quantity of information in a given set of data. Thus, one obvious advantage of lossy data compression is that the compression ratios can be larger than that dictated by the negentropy limit, all at the expense of information content. Many lossy data compression techniques seek to exploit various traits within the human senses to eliminate otherwise imperceptible data. For example, lossy data compression of

visual imagery might seek to delete information content in excess of the display resolution or contrast ratio of the target display device.

On the other hand, lossless data compression techniques provide an exact representation of the original uncompressed data. Simply stated, the decoded (or reconstructed) data is identical to the original unencoded/uncompressed data. Lossless data compression is also known as reversible or noiseless compression. Thus, lossless data compression has, as its current limit, a minimum representation defined by the negentropy of a given data set.

It is well known within the current art that data compression provides several unique benefits. First, data compression can reduce the time to transmit data by more efficiently utilizing low bandwidth data links. Second, data compression economizes on data storage and allows more information to be stored for a fixed memory size by representing information more efficiently.

One problem with the current art is that existing memory storage devices severely limit the performance of consumer, entertainment, office, workstation, servers, and mainframe computers for all disk and memory intensive operations. For example, magnetic disk mass storage devices currently employed in a variety of home, business, and scientific computing applications suffer from significant seek-time access delays along with profound read/write data rate limitations. Currently the fastest available (10,000) rpm disk drives support only a 17.1 Megabyte per second data rate (MB/sec). This is in stark contrast to the modern Personal Computer's Peripheral Component Interconnect (PCI) Bus's input/output capability of 264 MB/sec and internal local bus capability of 800 MB/sec.

Another problem within the current art is that emergent high performance disk interface standards such as the Small Computer Systems Interface (SCSI-3) and Fibre Channel offer only the promise of higher data transfer rates through intermediate data buffering in random access memory. These interconnect strategies do not address the fundamental problem that all modern magnetic disk storage devices for the personal computer marketplace are still limited by the same physical media restriction of 17.1 MB/sec. Faster disk access data rates are only achieved by the high cost solution of simultaneously accessing multiple disk drives with a technique known within the art as data striping.

Additional problems with bandwidth limitations similarly occur within the art by all other forms of sequential, pseudo-random, and random access mass storage devices. Typically mass storage devices include magnetic and optical tape, magnetic and optical disks, and various solid-state mass storage devices. It should be noted that the present invention applies to all forms and manners of memory devices including storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof.

SUMMARY OF THE INVENTION

The present invention is directed to systems and methods for providing accelerated data storage and retrieval by utilizing lossless data compression and decompression. The present invention provides an effective increase of the data storage and retrieval bandwidth of a memory storage device. In one aspect of the present invention, a method for providing accelerated data storage and retrieval comprises the steps of:

receiving a data stream at an input data transmission rate which is greater than a data storage rate of a target storage device;

compressing the data stream at a compression ratio which provides a data compression rate that is greater than the data storage rate;

storing the compressed data stream in the target storage device;

retrieving the compressed data stream from the target storage device at a rate equal to a data access rate of the target storage device; and

decompressing the compressed data at a decompression ratio to provide an output data stream having an output transmission rate which is greater than the data access rate of the target storage device.

In another aspect of the present invention, the method for providing accelerated data storage and retrieval utilizes a compression ratio that is at least equal to the ratio of the input data transmission rate to the data storage rate so as to provide continuous storage of the input data stream at the input data transmission rate.

In another aspect of the present invention, the method for providing accelerated data storage and retrieval utilizes a decompression ratio which is equal to or greater than the ratio of the data access rate to a maximum accepted output data transmission rate so as to provide a continuous and optimal data output transmission rate.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in a disk storage adapter to reduce the time required to store and retrieve data from computer to a disk memory device.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in conjunction with random access memory to reduce the time required to store and retrieve data from random access memory.

In another aspect of the present invention a data storage and retrieval accelerator method and system is employed in a video data storage system to reduce the time required to store digital video data.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in a display controller to reduce the time required to send display data to the display controller or processor.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in an input/output controller to reduce the time required to store, retrieve, or transmit data various forms of data.

The present invention is realized due to recent improvements in processing speed, inclusive of dedicated analog and digital hardware circuits, central processing units, digital signal processors, dedicated finite state machines (and any hybrid combinations thereof), that, coupled with advanced data compression and decompression algorithms, are enabling of ultra high bandwidth data compression and decompression methods that enable improved data storage and retrieval bandwidth.

These and other aspects, features and advantages, of the present invention will become apparent from the following detailed description of preferred embodiments, that is to be read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a system for accelerated data storage and retrieval according to one embodiment of the present invention;

FIG. **2** is a flow diagram of a method for accelerated data storage in accordance with one aspect of the present invention;

FIG. **3** is a flow diagram of a method for accelerated data retrieval in accordance with one aspect of the present invention;

FIGS. **4***a* and **4***b* are timing diagrams of methods for accelerated data storage according to the present invention;

FIGS. **5***a* and **5***b* are timing diagrams of methods for accelerated data retrieval according to the present invention;

FIGS. **6***a* and **6***b* comprise a flow diagram of a method for accelerated data storage in accordance with a further aspect of the present invention;

FIGS. **7***a* and **7***b* comprise a flow diagram of a method for accelerated data retrieval in accordance with a further aspect of the present invention;

FIG. **8** is a detailed block diagram of a system for accelerated data storage according to a preferred embodiment of the present invention;

FIG. **9** is a detailed block diagram of a system for accelerated data retrieval according to a preferred embodiment of the present invention;

FIG. **10** is a block diagram of a system for accelerated video storage according to one embodiment of the present invention;

FIG. **11** is a block diagram of a system for accelerated retrieval of video data according to one embodiment of the present invention;

FIG. **12** is a block diagram of an input/output controller system for accelerated storage of analog, digital, and serial data according to one embodiment of the present invention;

FIG. **13** is a flow diagram of a method for accelerated storage of analog, digital, and serial data according to one aspect of the present invention;

FIG. **14** is a block diagram of an input/output system for accelerated retrieval of analog, digital, and serial data according to one embodiment of the present invention; and

FIGS. **15***a* and **15***b* comprise a flow diagram of method for accelerated retrieval of analog, digital, and serial data according to one aspect of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention is directed to systems and methods for providing improved data storage and retrieval bandwidth utilizing lossless data compression and decompression. In the following description, it is to be understood that system elements having equivalent or similar functionality are designated with the same reference numerals in the Figures. It is to be further understood that the present invention may be implemented in various forms of hardware, software, firmware, or a combination thereof. Preferably, the present invention is implemented on a computer platform including hardware such as one or more central processing units (CPU) or digital signal processors (DSP), a random access memory (RAM), and input/output (I/O) interface(s). The computer platform may also include an operating system, microinstruction code, and dedicated processing hardware utilizing combinatorial logic or finite state machines. The various processes and functions described herein may be either part of the hardware, microinstruction code or application programs that are executed via the operating system, or any combination thereof.

It is to be further understood that, because some of the constituent system components described herein are preferably implemented as software modules, the actual system connections shown in the Figures may differ depending upon the manner in that the systems are programmed. It is to be appreciated that special purpose microprocessors, digital sig-

nal processors, dedicated hardware, or and combination thereof may be employed to implement the present invention. Given the teachings herein, one of ordinary skill in the related art will be able to contemplate these and similar implementations or configurations of the present invention.

Referring now to FIG. **1**, a block diagram illustrates a system for accelerated data storage and retrieval in accordance with an embodiment of the present invention. The system includes a data storage accelerator **10**, operatively coupled to a data storage device **45**. The data storage accelerator operates to increase the effective data storage rate of the data storage device **45**. It is to be appreciated that the data storage device **45** may be any form of memory device including all forms of sequential, pseudo-random, and random access storage devices. The memory storage device **45** may be volatile or non-volatile in nature, or any combination thereof. Storage devices as known within the current art include all forms of random access memory, magnetic and optical tape, magnetic and optical disks, along with various other forms of solid-state mass storage devices. Thus it should be noted that the current invention applies to all forms and manners of memory devices including, but not limited to, storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof.

The data storage accelerator **10** receives and processes data blocks from an input data stream. The data blocks may range in size from individual bits through complete files or collections of multiple files, and the data block size may be fixed or variable. In order to achieve continuous data storage acceleration, the data storage accelerator **10** must be configured to compress a given input data block at a rate that is equal to or faster than receipt of the input data. Thus, to achieve optimum throughput, the rate that data blocks from the input data stream may be accepted by the data storage accelerator **10** is a function of the size of each input data block, the compression ratio achieved, and the bandwidth of the target storage device. For example, if the data storage device **45** (e.g., a typical target mass storage device) is capable of storing 20 megabytes per second and the data storage accelerator **10** is capable of providing an average compression ratio of 3:1, then 60 megabytes per second may be accepted as input and the data storage acceleration is precisely 3:1, equivalent to the average compression ratio.

It should be noted that it is not a requirement of the present invention to configure the storage accelerator **10** to compress a given input data block at a rate that is equal to or faster than receipt of the input data. Indeed, if the storage accelerator **10** compresses data at a rate that is less than the input data rate, buffering may be applied to accept data from the input data stream for subsequent compression.

Additionally, it is not a requirement that the data storage accelerator **10** utilize data compression with a ratio that is at least the ratio of the input data stream to the data storage access rate of the data storage device **45**. Indeed, if the compression ratio is less than this ratio, the input data stream may be periodically halted to effectively reduce the rate of the input data stream. Alternatively, the input data stream or the output of the data accelerator **10** may be buffered to temporarily accommodate the mismatch in data bandwidth. An additional alternative is to reduce the input data rate to rate that is equal to or slower than the ratio of the input data rate to the data storage device access rate by signaling the data input source and requesting a slower data input rate, if possible.

Referring again to FIG. **1**, a data retrieval accelerator **80** is operatively connected to and receives data from the data storage device **45**. The data retrieval accelerator **80** receives and processes compressed data from data storage device **45** in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. The data retrieval accelerator **80** is configured to decompress each compressed data block which is received from the data storage device **45**. In order to achieve continuous accelerated data retrieval, the data retrieval accelerator must decompress a given input data block at a rate that is equal to or faster than receipt of the input data.

In a manner analogous to the data storage accelerator **10**, achieving optimum throughput with the data retrieval accelerator **80** is a function of the rate that compressed data blocks are retrieved from the data storage device **45**, the size of each data block, the decompression ratio achieved, and the limitation on the bandwidth of the output data stream, if any. For example, if the data storage device **45** is capable of continuously supplying 20 megabytes per second and the data retrieval accelerator **80** is capable of providing an average decompression ratio of 1:3, then a 60 megabytes per second output data stream is achieved, and the corresponding data retrieval acceleration is precisely 1:3, equivalent to the average decompression ratio.

It is to be understood that it is not required that the data retrieval accelerator **80** utilize data decompression with a ratio that is at most equal to the ratio of the retrieval rate of the data storage device **45** to the maximum rate data output stream. Indeed, if the decompression ratio is greater than this ratio, retrieving data from the data storage device may be periodically halted to effectively reduce the rate of the output data stream to be at or below its maximum. Alternatively, the compressed data retrieved from the data storage device **45** or the output of the data decompressor may be buffered to temporarily accommodate the mismatch in data bandwidth. An additional alternative is to increase the output data rate by signaling or otherwise requesting the data output device(s) receiving the output data stream to accept a higher bandwidth, if possible.

Referring now to FIG. **2**, a flow diagram of a method for accelerated data storage according to one aspect of the present invention illustrates the operation of the data storage acceleration shown in FIG. **1**. As previously stated above, data compression is performed on a per data block basis. Accordingly, the initial input data block in the input data stream (step **200**) is input into and compressed by the data storage accelerator **10** (step **202**). Upon completion of the encoding of the input data block, the encoded data block is then stored in the data storage device **45** (step **204**). A check or other form of test is performed to see if there are additional data blocks available in the input stream (step **206**). If no more data blocks are available, the storage acceleration process is terminated (step **208**). If more data blocks are available in the input data stream, the next data block is received (step **210**) and the process repeats beginning with data compression (step **202**).

Referring now to FIG. **3**, a flow diagram of a method for accelerated data retrieval according to one aspect of the present invention illustrates the operation of the data retrieval accelerator **80** shown in FIG. **1**. Data decompression is also performed on a per data block basis. The initial compressed data block is retrieved from the storage device **45** (step **300**) and is decompressed by the data retrieval accelerator **80** (step **302**). Upon completion of the decoding of the initial data block, the decoded data block is then output for subsequent processing, storage, or transmittal (step **304**). A check or other form of test is performed to see if additional data blocks available from the data storage device (step **306**). If no more data blocks are available, the data retrieval acceleration process is terminated (step **308**). If more data blocks are available

from the data storage device, the next data block is retrieved (step **310**) and the process repeats beginning with data decompression (step **302**).

Referring now to FIGS. **4***a* and **4***b*, a timing diagram illustrates methods for accelerated data storage utilizing data compression in accordance with the present invention. Successive time intervals of equal duration are represented as T**1** through T(n+2). Data block **1** is received from an input stream of one or more data blocks. Similarly, data block **2** through data block n are received during time intervals T**2** through Tn, respectively. For the purposes of discussion, FIGS. **4***a* and **4***b* demonstrate one embodiment of the data storage utilizing a stream of n data blocks. As previously stated, the input data stream is comprised of one or more data blocks data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable.

In accordance with Method **1**, compression of data block **1** and subsequent storage of the encoded data block **1** occurs within time interval T**1**. Similarly, the compression and storage of each successive data block occurs within the time interval the data block is received. Specifically, data blocks **2** . . . n are compressed in time intervals T**2** . . . Tn, respectively, and the corresponding encoded data blocks **2** . . . n are stored during the time intervals T**2** . . . Tn, respectively. It is to be understood that Method **1** relies on data compression and encoding techniques that process data as a contiguous stream, i.e., are not block oriented. It is well known within the current art that certain data compression techniques including, but not limited to, dictionary compression, run length encoding, null suppression and arithmetic compression are capable of encoding data when received. Method **1** possesses the advantage of introducing a minimum delay in the time from receipt of input to storage of encoded data blocks.

Referring again to FIGS. **4***a* and **4***b*, Method **2** illustrates compressing and storing data utilizing pipelined data processing. For Method **2**, successive time intervals of equal duration are represented as T**1** through T(n+2). Data block **1** is received from an input stream of one or more data blocks during time interval T**1**. Similarly, data block **2** through data block n are received during time intervals T**2** through Tn, respectively. Compression of data block **1** occurs during time interval T**2** and the storage of encoded data block **1** occurs during time interval T**3**. As shown by Method **2**, compression of each successive data block occurs within the next time interval after the data block is received and data storage of the corresponding encoded data block occur in the next time interval after completion of data compression.

The pipelining of Method **2**, as shown, utilizes successive single time interval delays for data compression and data storage. Within the current invention, it is permissible to have increased pipelining to facilitate additional data processing or storage delays. For example, data compression processing for a single input data block may utilize more than one time interval. Accommodating more than one time interval for data compression requires additional data compressors to process successive data blocks, e.g., data compression processing of a single data block through three successive time intervals requires three data compressors, each processing a successive input data block. Due to the principle of causality, encoded data blocks are output only after compression encoding.

Method **2** provides for block oriented processing of the input data blocks. Within the current art, block oriented data compression techniques provide the opportunity for increased data compression ratios. The disadvantage of Method **2** is increased delay from receipt of input data block to storage of encoded data. Depending on factors such as the size of input data blocks, the rate that they are received, the time required for data compression processing, the data compression ratio achieved, the bandwidth of the data storage device, and the intended application, the delay may or may not be significant. For example, in a modern database system, recording data for archival purposes, the opportunity for increased data compression may far outweigh the need for minimum delay. Conversely, in systems such as a military real-time video targeting system, minimizing delay is often of the essence. It should be noted that Method **1** and Method **2** are not mutually exclusive, and may be utilized in any combination.

Referring now to FIGS. **5***a* and **5***b*, a timing diagram illustrates methods for accelerated data retrieval utilizing data decompression in accordance the present invention shown. Successive time intervals of equal duration are represented as T**1** through T(n+2). Data block **1** is retrieved or otherwise accepted as input from one or more compressed data blocks retrieved from a data storage device. As shown, data block **2** through data block n are retrieved during time intervals T**2** through Tn, respectively. For the purposes of discussion, FIGS. **5***a* and **5***b* demonstrate one embodiment of the data retrieval accelerator utilizing a stream of n data blocks. Once again, the retrieved data stream is comprised of one or more data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the retrieved data block size may be fixed or variable.

In accordance with Method **1**, decompression of data block **1** and subsequent outputting of the decoded data block **1** occurs within time interval T**1**. Similarly, decompression and outputting of each successive data block occurs within the time intervals they are retrieved. In particular, data block **2** through data block n are decompressed and decoded data block **2** through decoded data block n are output during time intervals T**2** . . . Tn, respectively. It is to be understood that Method **1** relies on data decompression and decoding techniques that process compressed data as a contiguous stream, i.e., are not block oriented. It is well known within the current art that certain data decompression techniques including, but not limited to, dictionary compression, run length encoding, null suppression and arithmetic compression are capable of decoding data when received. Method **1** possesses the advantage of introducing a minimum delay in the time from retrieval of compressed data to output of decoded data blocks.

Referring again to FIGS. **5***a* and **5***b*, Method **2** involves decompressing and outputting data utilizing pipelined data processing. For Method **2**, successive time intervals of equal duration are represented as T**1** through T(n+2). Data block **1** through data block n are retrieved or otherwise accepted as input from a data storage device during time intervals T**1** through Tn, respectively. Decompression of data block **1** occurs during time interval T**2** and the decoded data block **1** is output during time interval T**3**. Similarly, decompression of each successive data block occurs within the next time interval after the data block is retrieved and the outputting of the decoded data block occurs during the next time interval after completion of data decompression.

The pipelining of Method **2**, utilizes successive single time interval delays for data decompression and data output. Within the current invention, it is permissible to have increased pipelining to facilitate additional data retrieval or data decompression processing delays. For example, data decompression processing for a single input data block may utilize more than one time interval. Accommodating more than one time interval for data compression requires additional data decompressors to process successive compressed data blocks, e.g., data decompression processing of a single

data block through three successive time intervals requires three data decompressors, each processing a successive input data block. Due to the principle of causality, decoded data blocks are only output after decompression decoding.

As before, Method **2** provides for block oriented processing of the retrieved data blocks. Within the current art, block oriented data decompression techniques provide the opportunity to utilize data compression encoders that increase data compression ratios. The disadvantage of method **2** is increased delay from retrieval of compressed data block to output of decompressed data. As previously discussed for data storage acceleration, depending on the size of retrieved data blocks, the rate that they are retrieved, the time required for data decompression processing, the data decompression ratio achieved, the bandwidth of the data output, and the intended application, the delay may or may not be significant.

Referring now to FIGS. **6***a* and **6***b*, a flow diagram illustrates a method for accelerated data storage according to a further aspect of the present invention. With this method, the data compression rate of the storage accelerator **10** is not required to be equal to or greater than the ratio of the input data rate to the data storage access rate. As previously stated above, data compression is performed on a per data block basis. Accordingly, the initial input data block in the input data stream is received (step **600**) and then timed and counted (step **602**). Timing and counting enables determination of the bandwidth of the input data stream. The input data block is then buffered (step **604**) and compressed by the data storage accelerator **10** (step **606**). During and after the encoding of the input data block, the encoded data block is then timed and counted (step **608**), thus enabling determination of the compression ratio and compression bandwidth. The compressed, timed and counted data block is then buffered (step **610**). The compression ratio and bandwidths of the input data stream and the encoder are then determined (step **612**). The compressed data block is then stored in the data storage device **45** (step **614**). Checks or other forms of testing are applied to ensure that the data bandwidths of the input data stream, data compressor, and data storage device are compatible (step **616**). If the bandwidths are not compatible, then one or more system parameters may be modified to make the bandwidths compatible (step **618**). For instance, the input bandwidth may be adjusted by either not accepting input data requests, lowering the duty cycle of input data requests, or by signaling one or more of the data sources that transmit the input data stream to request or mandate a lower data rate. In addition, the data compression ratio of the data storage accelerator **10** may be adjusted by applying a different type of encoding process such as employing a single encoder, multiple parallel or sequential encoders, or any combination thereof. Furthermore, additional temporary buffering of either the input data stream or the compressed data stream (or both) may be utilized.

By way of example, assuming the input data rate is 90 MB/sec and the data storage accelerator **10** provides a compression ration of 3:1, then the output of the data storage accelerator **10** would be 30 MB/sec. If the maximum data storage rate of the data storage device **45** is 20 MB/sec (which is less than the data rate output from the data storage accelerator **10**), data congestion and backup would occur at the output of the data storage accelerator **10**. This problem may be solved by adjusting any one of the system parameters as discussed above, e.g., by adjusting the compression ratio to provide a data output rate from the data storage accelerator **10** to be equal to the data storage rate of the data storage device **45**.

On the other hand, if the bandwidths are compatible (or made compatible by adjusting one or more of the system parameters), then a check or other form of test is performed to determine if there are additional data blocks available in the input stream (step **620**). If no more data blocks are available, the storage acceleration process is terminated (step **622**). If more data blocks are available in the input data stream, the next data block is received (step **624**) and the process repeats beginning with timing and counting of the input data block (step **602**).

Referring now to FIGS. **7***a* and **7***b*, a flow diagram illustrates a method for accelerated data retrieval according to one aspect of the present invention. With this method, the data decompression ratio is not required to be less than or equal to the ratio of the data retrieval access rate to the maximum output data rate. As previously stated above, data decompression is performed on a per data block basis. Accordingly, the initial input data block is retrieved from the storage device (step **700**) and is timed and counted (step **702**). Timing and counting enables determination of the bandwidth of data retrieval. The retrieved data block is then buffered (step **704**) and decompressed by the data retrieval accelerator **80** (step **706**). During and after the decoding of the input data block, the decoded data block is then timed and counted (step **708**), thus enabling determination of the decompression ratio and decompression bandwidth. The decompressed, timed and counted data block is then buffered (step **710**). The decompression ratio and bandwidths of the retrieved data and the decoder are then determined (step **712**). The decompressed data block is then output (step **714**). Checks or other forms of testing are applied to ensure that the data bandwidths of the retrieved data, data decompressor, and data output are compatible (step **716**). If the bandwidths are not compatible, then one or more system parameters may be modified to make the bandwidths compatible (step **718**). For instance, the data retrieval bandwidth may be adjusted either not accepting (continuously) data blocks retrieved from the data storage device or lowering the duty cycle of data blocks retrieved from the data storage device. In addition, one or more of the output data devices that receive the output data stream may be signaled or otherwise requested to accept a higher data rate. Moreover, a different type of decoding process may be applied to adjust the data decompression rate by applying, for example, a single decoder, multiple parallel or sequential decoders, or any combination thereof. Also, additional temporary buffering of either the retrieved or output data or both may be utilized.

By way of example, assuming the data storage device **45** has a data retrieval rate of 20 MB/sec and the data retrieval accelerator **80** provides a 1:4 decompression ratio, then the output of the data retrieval accelerator **80** would be 80 MB/sec. If the maximum output data transmission rate that can be accepted from the data retrieval accelerator **80** is 60 MB/sec (which is lower than the data output data rate of 80 MB/sec of the data retrieval accelerator **80**), data congestion and backup would occur at the output of the data retrieval accelerator **80**. This problem may be solved by adjusting any one of the system parameters as discussed above, e.g., by adjusting the decompression ratio to provide a data output rate from the data storage accelerator **80** to be equal to the maximum accepted output data transmission rate.

On the other hand, if the bandwidths are compatible (or made compatible by adjusting one or more system parameters), then a check or other form of test is performed to see if there are additional data blocks available from the data storage device (step **720**). If no more data blocks are available for output, the retrieval acceleration process is terminated (step

722). If more data blocks are available to be retrieved from the data storage device, the next data block is retrieved (step **724**) and the process repeats beginning with timing and counting of the retrieved data block (return to step **702**).

It is to be understood that any conventional compression/decompression system and method (which comply with the above mentioned constraints) may be employed in the data storage accelerator **10** and data retrieval accelerator **80** for providing accelerated data storage and retrieval in accordance with the present invention. Preferably, the present invention employs the data compression/decompression techniques disclosed in U.S. Ser. No. 09/210,491 entitled "Content Independent Data Compression Method and System," filed on Dec. 11, 1998, which is commonly assigned and which is fully incorporated herein by reference. It is to be appreciated that the compression and decompression systems and methods disclosed in U.S. Ser. No. 09/210,491 are suitable for compressing and decompressing data at rates which provide accelerated data storage and retrieval.

Referring now to FIG. **8**, a detailed block diagram illustrates a preferred system for accelerated data storage which employs a compression system as disclosed in the above-incorporated U.S. Ser. No. 09/210,491. In this embodiment, the data storage accelerator **10** accepts data blocks from an input data stream and stores the input data block in an input buffer or cache **15**. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. A counter **20** counts or otherwise enumerates the size of input data block in any convenient units including bits, bytes, words, double words. It should be noted that the input buffer **15** and counter **20** are not required elements of the present invention. The input data buffer **15** may be provided for buffering the input data stream in order to output an uncompressed data stream in the event that, as discussed in further detail below, every encoder fails to achieve a level of compression that exceeds an a priori specified minimum compression ratio threshold.

Data compression is performed by an encoder module **25** which may comprise a set of encoders E**1**, E**2**, E**3** . . . En. The encoder set E**1**, E**2**, E**3** . . . En may include any number "n" (where n may=1) of those lossless encoding techniques currently well known within the art such as run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. It is to be understood that the encoding techniques are selected based upon their ability to effectively encode different types of input data. It is to be appreciated that a full complement of encoders are preferably selected to provide a broad coverage of existing and future data types.

The encoder module **25** successively receives as input each of the buffered input data blocks (or unbuffered input data blocks from the counter module **20**). Data compression is performed by the encoder module **25** wherein each of the encoders E**1** . . . En processes a given input data block and outputs a corresponding set of encoded data blocks. It is to be appreciated that the system affords a user the option to enable/disable any one or more of the encoders E**1** . . . En prior to operation. As is understood by those skilled in the art, such feature allows the user to tailor the operation of the data compression system for specific applications. It is to be further appreciated that the encoding process may be performed either in parallel or sequentially. In particular, the encoders E**1** through En of encoder module **25** may operate in parallel (i.e., simultaneously processing a given input data block by utilizing task multiplexing on a single central processor, via dedicated hardware, by executing on a plurality of processor or dedicated hardware systems, or any combination thereof). In addition, encoders E**1** through En may operate sequentially on a given unbuffered or buffered input data block. This process is intended to eliminate the complexity and additional processing overhead associated with multiplexing concurrent encoding techniques on a single central processor and/or dedicated hardware, set of central processors and/or dedicated hardware, or any achievable combination. It is to be further appreciated that encoders of the identical type may be applied in parallel to enhance encoding speed. For instance, encoder E**1** may comprise two parallel Huffman encoders for parallel processing of an input data block.

A buffer/counter module **30** is operatively connected to the encoder module **25** for buffering and counting the size of each of the encoded data blocks output from encoder module **25**. Specifically, the buffer/counter **30** comprises a plurality of buffer/counters BC**1**, BC**2**, BC**3** . . . BCn, each operatively associated with a corresponding one of the encoders E**1** . . . En. A compression ratio module **35**, operatively connected to the output buffer/counter **30**, determines the compression ratio obtained for each of the enabled encoders E**1** . . . En by taking the ratio of the size of the input data block to the size of the output data block stored in the corresponding buffer/counters BC**1** . . . BCn. In addition, the compression ratio module **35** compares each compression ratio with an a priori-specified compression ratio threshold limit to determine if at least one of the encoded data blocks output from the enabled encoders E**1** . . . En achieves a compression that exceeds an a priori-specified threshold. As is understood by those skilled in the art, the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. A description module **38**, operatively coupled to the compression ratio module **35**, appends a corresponding compression type descriptor to each encoded data block which is selected for output so as to indicate the type of compression format of the encoded data block. A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal. If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit, then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto. A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal.

The data storage acceleration device **10** is connected to a data storage device interface **40**. The function of the data storage interface **40** is to facilitate the formatting and transfer of data to one or more data storage devices **45**. The data storage interface may be any of the data interfaces known to those skilled in the art such as SCSI (Small Computer Systems Interface), Fibre Channel, "Firewire", IEEE P1394, SSA (Serial Storage Architecture), IDE (Integrated Disk

Electronics), and ATA/ATAPI interfaces. It should be noted that the storage device data interface **40** is not required for implementing the present invention. As before, the data storage device **45** may be any form of memory device including all forms of sequential, pseudo-random, and random access storage devices. The data storage device **45** may be volatile or non-volatile in nature, or any combination thereof. Storage devices as known within the current art include all forms of random access memory (RAM), magnetic and optical tape, magnetic and optical disks, along with various other forms of solid-state mass storage devices (e.g., ATA/ATAPI IDE disk). Thus it should be noted that the current invention applies to all forms and manners of memory devices including, but not limited to, storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof.

Again, it is to be understood that the embodiment of the data storage accelerator **10** of FIG. **8** is exemplary of a preferred compression system which may be implemented in the present invention, and that other compression systems and methods known to those skilled in the art may be employed for providing accelerated data storage in accordance with the teachings herein. Indeed, in another embodiment of the compression system disclosed in the above-incorporated U.S. Ser. No. 09/210,491, a timer is included to measure the time elapsed during the encoding process against an a priori-specified time limit. When the time limit expires, only the data output from those encoders (in the encoder module **25**) that have completed the present encoding cycle are compared to determine the encoded data with the highest compression ratio. The time limit ensures that the real-time or pseudo real-time nature of the data encoding is preserved. In addition, the results from each encoder in the encoder module **25** may be buffered to allow additional encoders to be sequentially applied to the output of the previous encoder, yielding a more optimal lossless data compression ratio. Such techniques are discussed in greater detail in the above-incorporated U.S. Ser. No. 09/210,491.

Referring now to FIG. **9**, a detailed block diagram illustrates a preferred system for accelerated data retrieval employing a decompression system as disclosed in the above-incorporated U.S. Ser. No. 09/210,491. In this embodiment, the data retrieval accelerator **80** retrieves or otherwise accepts data blocks from one or more data storage devices **45** and inputs the data via a data storage interface **50**. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. As stated above, the memory storage device **45** may be volatile or non-volatile in nature, or any combination thereof. Storage devices as known within the current art include all forms of random access memory, magnetic and optical tape, magnetic and optical disks, along with various other forms of solid-state mass storage devices. Thus it should be noted that the current invention applies to all forms and manners of memory devices including storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof. The data storage device interface **50** converts the input data from the storage device format to a format useful for data decompression.

The storage device data interface **50** is operatively connected to the data retrieval accelerator **80** which is utilized for decoding the stored (compressed) data, thus providing accelerated retrieval of stored data. In this embodiment, the data retrieval accelerator **80** comprises an input buffer **55** which receives as input an uncompressed or compressed data stream comprising one or more data blocks. The data blocks may range in size from individual bits through complete files or collections of multiple files. Additionally, the data block size may be fixed or variable. The input data buffer **55** is preferably included (not required) to provide storage of input data for various hardware implementations. A descriptor extraction module **60** receives the buffered (or unbuffered) input data block and then parses, lexically, syntactically, or otherwise analyzes the input data block using methods known by those skilled in the art to extract the data compression type descriptor associated with the data block. The data compression type descriptor may possess values corresponding to null (no encoding applied), a single applied encoding technique, or multiple encoding techniques applied in a specific or random order (in accordance with the data compression system embodiments and methods discussed above).

A decoder module **65** includes one or more decoders D**1** . . . Dn for decoding the input data block using a decoder, set of decoders, or a sequential set of decoders corresponding to the extracted compression type descriptor. The decoders D**1** . . . Dn may include those lossless encoding techniques currently well known within the art, including: run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. Decoding techniques are selected based upon their ability to effectively decode the various different types of encoded input data generated by the data compression systems described above or originating from any other desired source.

As with the data compression systems discussed in U.S. application Ser. No. 09/210,491, the decoder module **65** may include multiple decoders of the same type applied in parallel so as to reduce the data decoding time. The data retrieval accelerator **80** also includes an output data buffer or cache **70** for buffering the decoded data block output from the decoder module **65**. The output buffer **70** then provides data to the output data stream. It is to be appreciated by those skilled in the art that the data retrieval accelerator **80** may also include an input data counter and output data counter operatively coupled to the input and output, respectively, of the decoder module **65**. In this manner, the compressed and corresponding decompressed data block may be counted to ensure that sufficient decompression is obtained for the input data block.

Again, it is to be understood that the embodiment of the data retrieval accelerator **80** of FIG. **9** is exemplary of a preferred decompression system and method which may be implemented in the present invention, and that other data decompression systems and methods known to those skilled in the art may be employed for providing accelerated data retrieval in accordance with the teachings herein.

In accordance with another aspect of the present invention, the data storage and retrieval accelerator system and method may be employed in for increasing the storage rate of video data. In particular, referring now to FIG. **10**, a block diagram illustrates a system for providing accelerated video data storage in accordance with one embodiment of the present invention. The video data storage acceleration system accepts as input one or more video data streams that are analog, digital, or any combination thereof in nature. The input multiplexer **1010** selects the initial video data stream for data compression and acceleration. The input multiplexer **1010** is operatively connected to an analog to digital converter **1020** which converts analog video inputs to digital format of desired resolution. The analog to digital converter **1020** may also include functions to strip video data synchronization to perform other data formatting functions. It should be noted that the analog to digital conversion process is not required for digital video inputs. The analog to digital converter **1020** is operatively connected a video memory **1030** that is, in turn, operatively

connected to a video processor **1040**. The video processor **1040** performs manipulation of the digital video data in accordance with any user desired processing functions. The video processor **1040** is operatively coupled to a video output memory **1050**, that is operatively connected to a data storage accelerator **10** which compresses the video data to provide accelerated video data to the output data stream for subsequent data processing, storage, or transmittal of the video data. This video data acceleration process is repeated for all data blocks in the input data stream. If more video data blocks are available in the input data stream, the video multiplexer selects the next block of video for accelerated processing. Again, it is to be understood that the data storage accelerator **10** may employ any compression system which is capable of compressing data at a rate suitable for providing accelerated video data storage in accordance with the teachings herein.

In accordance with another aspect of the present invention, the accelerated data storage and retrieval system may be employed in a display controller to reduce the time required to send display data to a display controller or processor. In particular, referring now to FIG. **11**, a block diagram illustrates a display accelerator system in accordance with one embodiment of the present invention. The video display accelerator accepts as input one or more digital display data blocks from an input display data stream. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input video data block size may be fixed or variable. The input data blocks are processed by a data retrieval accelerator **80** which employs a data decompression system in accordance with the teachings herein. Upon completion of data decompression, the decompressed data block is then output to a display memory **1110** that provides data to a display processor **1120**. The display processor **1120** performs any user desired processing function. It is well known within the current art that display data is often provided in one or more symbolic formats such as Open Graphics Language (Open GL) or another display or image language. The display processor **1120** is operatively connected an output memory buffer **1130**. The output memory **1130** supplies data to a display formatter **1140** that converts the data to a format compatible with the output display device or devices. Data from the display formatter **1140** is provided to the display driver **1150** that outputs data in appropriate format and drive signal levels to one or more display devices. It should be noted that the display memory **1110**, display processor **1120**, output memory **1130**, display formatter **1140**, and display driver **1150** are not required elements of the present invention.

In accordance with yet another aspect of the present invention, the data storage and retrieval accelerator system and method may be employed in an I/O controller to reduce the time for storing, retrieving or transmitting parallel data streams. In particular, referring now to FIG. **12**, a block diagram illustrates a system for accelerated data storage of analog, digital, and serial data in accordance with one embodiment of the present invention. The data storage accelerator **10** is capable of accepting one or more simultaneous analog, parallel digital, and serial data inputs. An analog input multiplexer **1205** selects the initial analog data for data compression and acceleration. The analog input multiplexer **1205** is operatively connected to an analog to digital converter **1210** that converts the analog input signal to digital data of the desired resolution. The digitized data output of the analog to digital converter **1210** is stored in an analog data memory buffer **1215** for subsequent data storage acceleration. Similarly, a parallel digital data input multiplexer **1220** selects the initial parallel digital data for data compression and acceleration. The parallel digital data input multiplexer **1220** is operatively connected to an input data latch **1225** that holds the input parallel digital data. The parallel digital data is then stored in digital data memory buffer **1245** for subsequent data storage acceleration. In addition, a serial digital data input multiplexer **1235** selects the initial serial digital data for data compression and acceleration. The serial digital data input multiplexer **1235** is operatively connected to a serial data interface **1240** that converts the serial data stream to a format useful for data acceleration. The formatted serial digital data is then stored in serial data memory buffer **1245** for subsequent data acceleration. The analog data memory **1215**, parallel digital data memory **1230**, and serial data memory **1245** are operatively connected to the data storage accelerator device **10**. Data is selected from each data memory subsystem based upon a user defined algorithm or other selection criteria. It should be noted that the analog input multiplexer **1205**, analog to digital converter **1210**, analog data memory **1215**, parallel data input multiplexer **1220**, data latch **1225**, digital data memory **1230**, serial data input multiplexer **1235**, serial data interface **1240**, serial data memory **1245**, and counter **20** are not required elements of the present invention. As stated above, the data storage accelerator **10** employs any of the data compression methods disclosed in the above-incorporated U.S. Ser. No. 09/210,491, or any conventional data compression method suitable for compressing data at a rate necessary for obtaining accelerated data storage. The data storage accelerator supplies accelerated data to the output data stream for subsequent data processing, storage, or transmittal.

Referring now to FIG. **13**, a flow diagram illustrates a method for accelerated data storage of analog, digital, and serial data according to one aspect of the present invention. The analog input multiplexer selects the initial analog data for data compression and acceleration (step **1300**). The analog input multiplexer provides analog data to the analog to digital converter that converts the analog input signal to digital data of the desired resolution (step **1302**). The digitized data output of the analog to digital converter is then buffered in the analog data memory buffer (step **1304**) for subsequent data acceleration. Similarly, the parallel digital data multiplexer selects the initial parallel digital data for data compression and acceleration (step **1306**). The parallel digital data multiplexer provides data to the input data latch that then holds the input parallel digital data (step **1308**). The parallel digital data is then stored in digital data memory buffer for subsequent data acceleration (step **1310**). The serial digital data input multiplexer selects the initial serial digital data for data compression and acceleration (step **1312**). The serial digital data input multiplexer provides serial data to the serial data interface that converts the serial data stream to a format useful for data acceleration (step **1314**). The formatted serial digital data is then stored in the serial data memory buffer for subsequent data acceleration (step **1316**). A test or other check is performed to see if new analog data is available (step **1318**). If no new analog data is available a second check is performed to see if new parallel data is available (step **1320**). If no new parallel data is available, a third test is performed to see if new serial data is available (step **1322**). If no new serial data is available (step **1322**) the test sequence repeats with the test for new analog data (step **1318**). If new analog data block is available (step **1318**), or if new parallel data block is available (step **1320**), or if new serial data block is available (step **1322**), the input data block is compressed by the data storage accelerator (step **1324**) utilizing any compression method suitable for providing accelerated data storage in accordance with the teachings herein. After data compression is com-

plete, the compressed data block is then output subsequent accelerated data processing, storage, or transmittal (step **1326**). After outputting data the process repeats beginning with a test for new analog data (return to step **1318**).

Referring now to FIG. **14**, a block diagram illustrates a system for accelerated retrieval of analog, digital, and serial data in accordance with one embodiment of the present invention. A data retrieval accelerator **80** receives data from an input data stream. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. The data retrieval accelerator **80** decompresses the input data utilizing any of the decompression methods suitable for providing accelerated data retrieval in accordance with the teachings herein. The data retrieval accelerator **80** is operatively connected to analog data memory **1405**, digital data memory **1420**, and serial data memory **1435**. Dependent upon the type of input data block, the decoded data block is stored in the appropriate analog **1405**, digital **1420**, or serial **1435** data memory.

The analog data memory **1405** is operatively connected to a digital to analog converter **1410** that converts the decompressed digital data block into an analog signal. The digital to analog converter **1410** is further operatively connected to an analog hold and output driver **1415**. The analog hold and output driver **1415** demultiplexes the analog signal output from the digital to analog converter **1410**, samples and holds the analog data, and buffers the output analog data.

In a similar manner, the digital data memory **1420** is operatively connected to a digital data demultiplexer **1425** that routes the decompressed parallel digital data to the output data latch and driver **1430**. The output latch and driver **1430** holds the digital data and buffers the parallel digital output.

Likewise, the serial data memory **1435** is operatively connected to a serial data interface **1440** that converts the decompressed data block to an output serial data stream. The serial data interface **1440** is further operatively connected to the serial demultiplexer and driver **1445** that routes the serial digital data to the appropriate output and buffers the serial data output.

Referring now to FIGS. **15***a* and **15***b*, a flow diagram illustrates a method for accelerated retrieval of analog, digital, and serial data according to one aspect of the present invention. An initial data block is received (step **1500**) and then decompressed by the data storage retrieval accelerator (step **1502**). Upon completion of data decompression, a test or other check is performed to see if the data block is digitized analog data (step **1508**). If the data block is not digitized analog data, a second check is performed to see if the data block is parallel digital data (step **1510**). If the data block is not parallel digital data, a third test is performed to see if the data block serial data (step **1512**). The result of at least one of the three tests will be affirmative.

If the data block is comprised of digitized analog data, the decoded data block is buffered in an "analog" digital data memory (step **1514**). The decoded data block is then converted to an analog signal by a digital to analog converter (step **1520**). The analog signal is then output (step **1522**).

If the data block is comprised of parallel digital data, the decoded data block is buffered in a "parallel" digital data memory (step **1516**). The decoded data block is then demultiplexed (step **1524**) and routed to the appropriate the output data latch and driver. The output latch and driver then holds the digital data and buffers the parallel digital output (step **1526**).

If the data block is comprised of serial data, the decoded data block is buffered in "serial" digital data memory (step **1518**). The decoded data is then formatted to a serial data format (step **1528**). The serial data is then demultiplexed, routed to the appropriate output, and output to a buffer (step **1530**).

Upon output of analog data (step **1522**), parallel digital data (step **1526**), or serial digital data (step **1530**), a test or other form of check is performed for more data blocks in the input stream (step **1532**). If no more data blocks are available, the test repeats (return to step **1532**). If a data block is available, the next data block is received (step **1534**) and the process repeats beginning with step **1502**.

Although illustrative embodiments have been described herein with reference to the accompanying drawings, it is to be understood that the present invention is not limited to those precise embodiments, and that various other changes and modifications may be affected therein by one skilled in the art without departing from the scope or spirit of the invention. All such changes and modifications are intended to be included within the scope of the invention as defined by the appended claims.

What is claimed is:

1. A system comprising:

a memory device; and

a data accelerator, wherein said data accelerator is coupled to said memory device, a data stream is received by said data accelerator in received form, said data stream includes a first data block and a second data block, said data stream is compressed by said data accelerator to provide a compressed data stream by compressing said first data block with a first compression technique and said second data block with a second compression technique, said first and second compression techniques are different, said compressed data stream is stored on said memory device, said compression and storage occurs faster than said data stream is able to be stored on said memory device in said received form, a first data descriptor is stored on said memory device indicative of said first compression technique, and said first descriptor is utilized to decompress the portion of said compressed data stream associated with said first data block.

2. The system of claim **1**, wherein said data accelerator stores said first descriptor to said memory device.

3. The system of claim **1**, wherein said data accelerator retrieves said first descriptor and said compressed data stream from said memory device.

4. The system of claim **1**, wherein said data accelerator retrieves said compressed data stream from said memory device.

5. The system of claim **1**, wherein said data accelerator retrieves said compressed data stream from said memory device and said decompression of the portion of said compressed data stream associated with said first data block is performed by said data accelerator.

6. The system of claim **1**, wherein said data accelerator is coupled to said memory device via a small computer systems interface.

7. The system of claim **1**, wherein said data accelerator is coupled to said memory device via a fibre channel.

8. The system of claim **1**, wherein said data accelerator is coupled to said memory device via a serial storage architecture.

9. The system of claim **1**, wherein said memory device is a magnetic memory device.

10. The system of claim **1**, wherein said memory device is an optical memory device.

11. The system of claim 1, wherein said memory device is a random access memory.

12. The system of claim 1, wherein said memory device is a solid-state mass storage device.

13. The system of claim 1, wherein said first compression technique includes compressing with Huffman encoding.

14. The system of claim 1, wherein said first compression technique includes compressing with Lempel-Ziv encoding.

15. The system of claim 1, wherein said first compression technique includes compressing with a plurality of encoders in a serial configuration.

16. The system of claim 1, wherein said first compression technique includes compressing with a plurality of encoders in a parallel configuration.

17. The system of claim 1, wherein said first compression technique includes compressing with a plurality of encoders in a parallel configuration and each one of said plurality of encoders is an identical type of encoder.

18. The system of claim 1, wherein said first compression technique comprises compressing with a first encoder.

19. The system of claim 1, wherein said data stream comprises a collection of multiple files.

20. The system of claim 1, wherein said data stream includes a third data block and a fourth data block.

21. The system of claim 1, wherein said data stream includes a third data block and a fourth data block and said compressed data stream is provided by compressing said third data block with a third compression technique and compressing said fourth data block with a fourth compression technique.

22. The system of claim 1, wherein said data stream is an analog video data stream.

23. The system of claim 1, wherein said data stream is a digital video data stream.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,415,530 B2
APPLICATION NO. : 11/553426
DATED : August 19, 2008
INVENTOR(S) : James J. Fallon

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Cover page, item (57), --be-- should be inserted after "may".

Cover page, item (56), Other Publications, Smith, T.B., et al., "Vo.45" should be --Vol.45--.

In the Drawings
Figure 13, Box 1312, "Serail" should be --Serial--.

Column 3, line 45, first occurrence of "data" should be deleted.

Column 4, line 66, "that" should be --which--.

Column 5, line 1, "and" should be --any--.

Column 5, line 60, --a-- should be inserted before second occurrence of "rate".

Column 6, line 64, --are-- should be inserted after "blocks".

Column 7, line 14, second occurrence of "data blocks" should be deleted.

Column 7, line 47, "occur" should be --occurs--.

Column 8, line 15, --with-- should be inserted after "accordance".

Column 9, line 57, "ration" should be --ratio--.

Column 14, line 51, "for" should be deleted.

Column 14, line 67, --to-- should be inserted after "connected".

Column 15, line 40, --to-- should be inserted after "connected".

Column 17, line 1, --to-- should be inserted after "subsequent".

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,415,530 B2
APPLICATION NO. : 11/553426
DATED : August 19, 2008
INVENTOR(S) : James J. Fallon

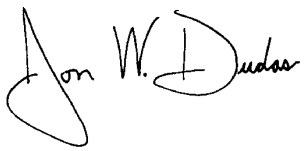
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 17, line 52, --is-- should be inserted after "block".

Column 17, line 64, "the" after "appropriate" should be deleted.

Signed and Sealed this

Second Day of December, 2008



JON W. DUDAS
Director of the United States Patent and Trademark Office

US007415530C1

(12) **INTER PARTES REEXAMINATION CERTIFICATE** (671st)

United States Patent
Fallon

(10) **Number: US 7,415,530 C1**
(45) **Certificate Issued: Aug. 16, 2013**

(54) **SYSTEM AND METHODS FOR ACCELERATED DATA STORAGE AND RETRIEVAL**

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(73) Assignee: **Realtime Data LLC**, New York, NY (US)

Reexamination Request:
No. 95/001,927, Mar. 2, 2012

Reexamination Certificate for:
Patent No.: **7,415,530**
Issued: **Aug. 19, 2008**
Appl. No.: **11/553,426**
Filed: **Oct. 26, 2006**

Certificate of Correction issued Dec. 2, 2008

Related U.S. Application Data

(63) Continuation of application No. 10/628,795, filed on Jul. 28, 2003, now Pat. No. 7,130,913, which is a continuation of application No. 09/266,394, filed on Mar. 11, 1999, now Pat. No. 6,601,104.

(51) **Int. Cl.**
G06F 15/16 (2006.01)

(52) **U.S. Cl.**
USPC **709/231**

(58) **Field of Classification Search**
None
See application file for complete search history.

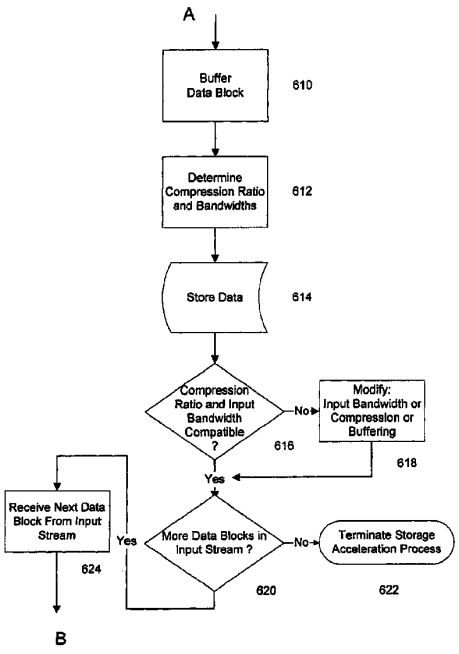
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To view the complete listing of prior art documents cited during the proceeding for Reexamination Control Number 95/001,927, please refer to the USPTO's public Patent Application Information Retrieval (PAIR) system under the Display References tab.

Primary Examiner — Mark Sager

(57) **ABSTRACT**

Systems and methods for providing accelerated data storage and retrieval utilizing lossless data compression and decompression. A data storage accelerator includes one or a plurality of high speed data compression encoders that are configured to simultaneously or sequentially losslessly compress data at a rate equivalent to or faster than the transmission rate of an input data stream. The compressed data is subsequently stored in a target memory or other storage device whose input data storage bandwidth is lower than the original input data stream bandwidth. Similarly, a data retrieval accelerator includes one or a plurality of high speed data decompression decoders that are configured to simultaneously or sequentially losslessly decompress data at a rate equivalent to or faster than the input data stream from the target memory or storage device. The decompressed data is then output at rate data that is greater than the output rate from the target memory or data storage device. The data storage and retrieval accelerator method and system may employed: in a disk storage adapter to reduce the time required to store and retrieve data from computer to disk; in conjunction with random access memory to reduce the time required to store and retrieve data from random access memory; in a display controller to reduce the time required to send display data to the display controller or processor; and/or in an input/output controller to reduce the time required to store, retrieve, or transmit data.



INTER PARTES REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 316

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **1**, **2**, **16-21** and **23** is confirmed.

New claims **24-26** are added and determined to be patentable.

Claims **3-15** and **22** were not reexamined.

24. A system comprising:

a memory device; and

a data accelerator, wherein said data accelerator is coupled to said memory device, a data stream is received by said data accelerator in received form, wherein a bandwidth of the received data stream is determined, said data stream includes a first data block and a second data block, said data stream is compressed by said data accelerator to provide a compressed data stream by compressing said first data block with a first compression technique and said second data block with a second compression technique, said first and second compression techniques are different, wherein a data rate of the compressed data stream is adjusted, by modifying a system parameter, to make a bandwidth of the compressed data stream compatible with a bandwidth of the memory device, said compressed data stream is stored on said memory device, said compression and storage occurs faster than said data stream is able to be stored on said memory device in said received form, a first data descriptor is stored on said memory device indicative of said first compression technique, and said first descriptor is utilized to decompress the portion of said compressed data stream associated with said first data block.

25. The system of claim 1, wherein the data accelerator is configured to append a type descriptor to the first and second compressed data blocks in the compressed data stream, and wherein the type descriptor includes values corresponding to a plurality of encoding techniques that were applied to the compressed data stream.

26. The system of claim 1, wherein the data accelerator is configured to adjust the data rate of the compressed data stream by adjusting a compression ratio of a lossless encoder.

* * * * *

US008717203B2

(12) **United States Patent**
Fallon

(10) **Patent No.: US 8,717,203 B2**
(45) **Date of Patent: May 6, 2014**

(54) **DATA COMPRESSION SYSTEMS AND METHODS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/035,561**

(22) Filed: **Sep. 24, 2013**

(65) **Prior Publication Data**

US 2014/0022098 A1 Jan. 23, 2014

Related U.S. Application Data

(63) Continuation of application No. 13/154,211, filed on Jun. 6, 2011, which is a continuation of application No. 12/703,042, filed on Feb. 9, 2010, now Pat. No. 8,502,707, which is a continuation of application No. 11/651,366, filed on Jan. 8, 2007, now abandoned, which is a continuation of application No. 11/651,365, filed on Jan. 8, 2007, now Pat. No. 7,714,747, said application No. 11/651,366 is a continuation of application No. 10/668,768, filed on Sep. 22, 2003, now Pat. No. 7,161,506, which is a continuation of application No. 10/016,355, filed on Oct. 29, 2001, now Pat. No. 6,624,761, which is a continuation of application No. 09/705,446, filed on Nov. 3, 2000, now Pat. No. 6,309,424, which is a continuation of application No. 09/210,491, filed on Dec. 11, 1998, now Pat. No. 6,195,024.

(51) **Int. Cl.**
H03M 7/34 (2006.01)

(52) **U.S. Cl.**
USPC **341/51**; 341/50; 341/65; 341/67; 341/87; 341/107

(58) **Field of Classification Search**
USPC 341/51, 65, 67, 79, 87, 106, 107
See application file for complete search history.

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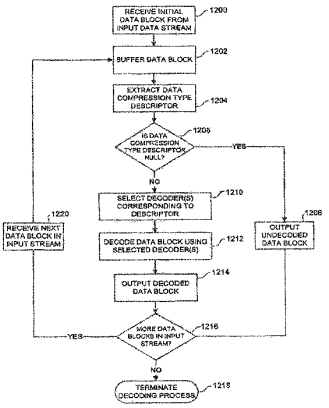
(Continued)

Primary Examiner — Linh Nguyen
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(57) **ABSTRACT**

Systems and methods for providing fast and efficient data compression using a combination of content independent data compression and content dependent data compression. In one aspect, a method for compressing data comprises the steps of: analyzing a data block of an input data stream to identify a data type of the data block, the input data stream comprising a plurality of disparate data types; performing content dependent data compression on the data block, if the data type of the data block is identified; performing content independent data compression on the data block, if the data type of the data block is not identified.

30 Claims, 34 Drawing Sheets



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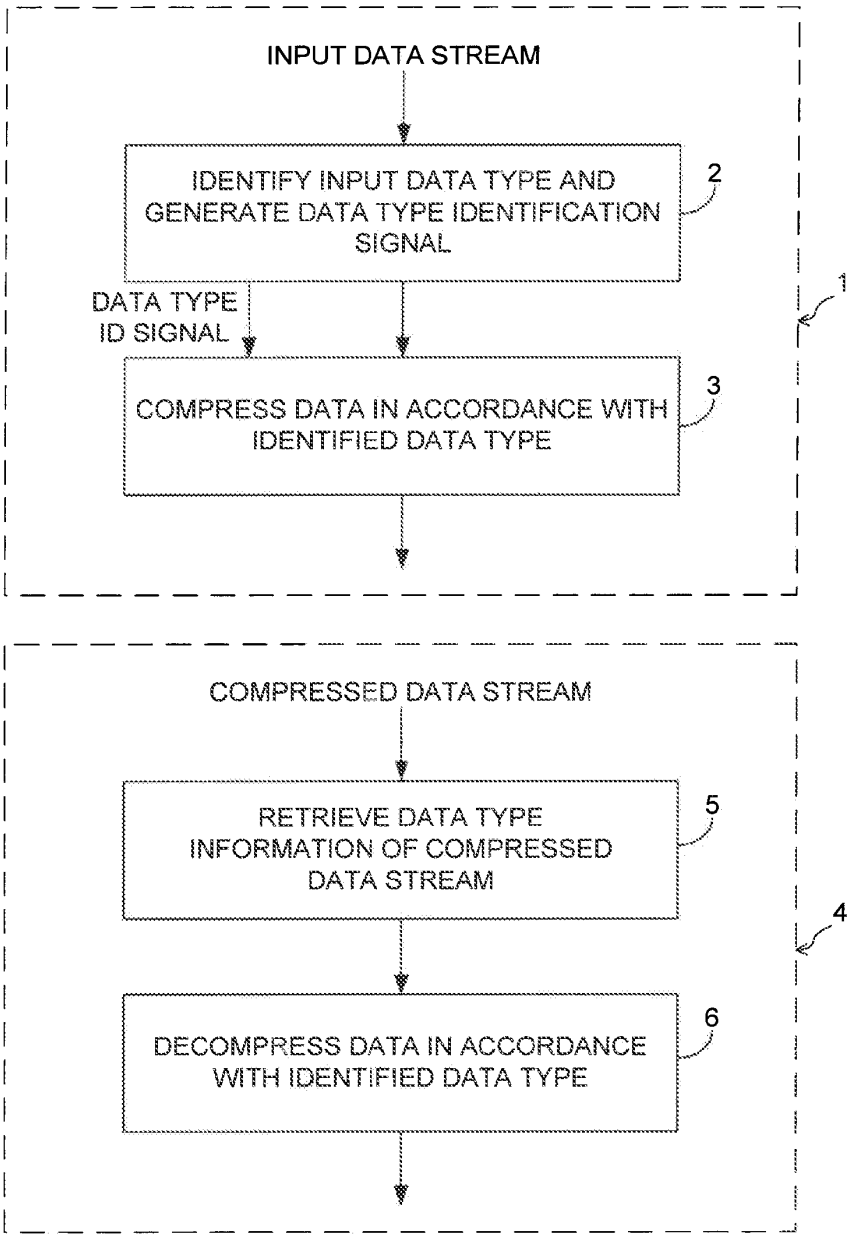


FIG. 1
PRIOR ART

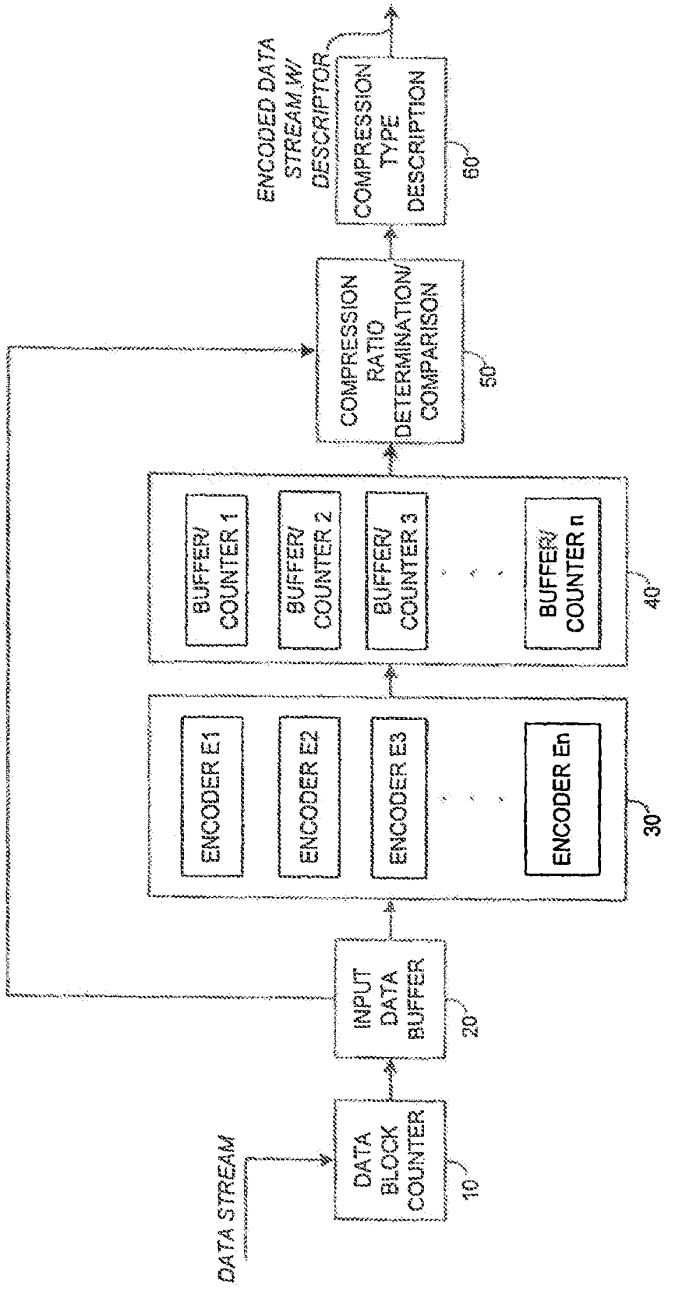

DATA STREAM
DATA BLOCK COUNTER
10
INPUT DATA BUFFER
20
ENCODER E1
ENCODER E2
ENCODER E3
ENCODER En
30
BUFFER/ COUNTER 1
BUFFER/ COUNTER 2
BUFFER/ COUNTER 3
BUFFER/ COUNTER n
40
COMPRESSION RATIO DETERMINATION/ COMPARISON
50
COMPRESSION TYPE DESCRIPTION
60
ENCODED DATA STREAM W/ DESCRIPTOR

FIG. 2

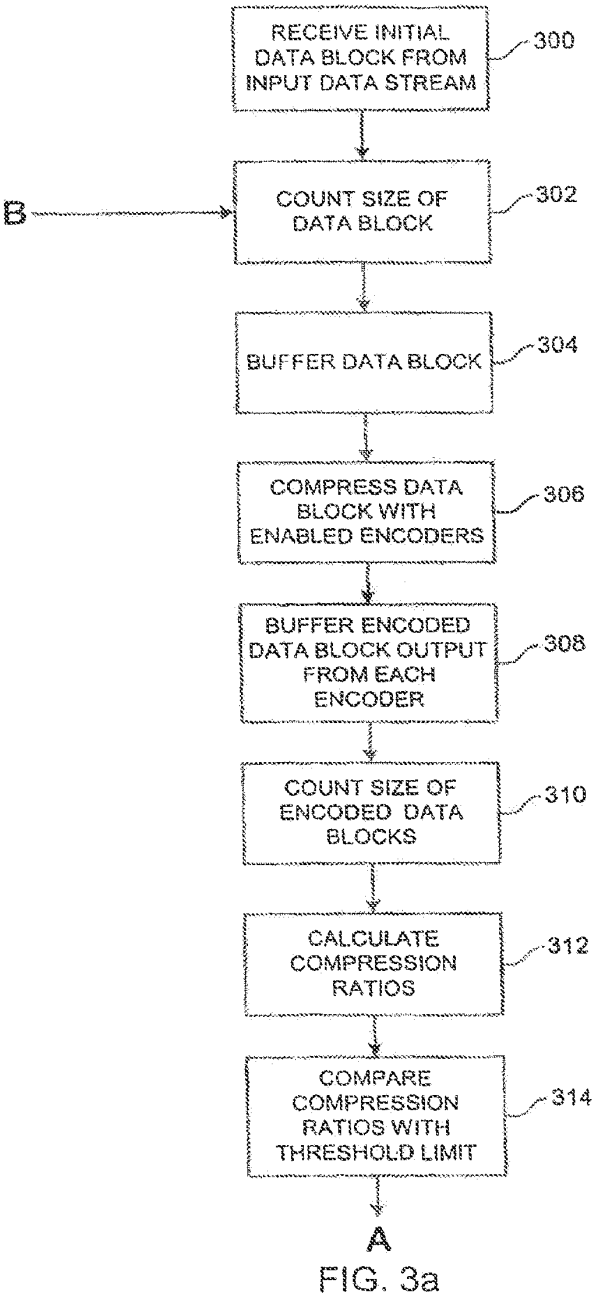

RECEIVE INITIAL DATA BLOCK FROM INPUT DATA STREAM
300
B
COUNT SIZE OF DATA BLOCK
302
BUFFER DATA BLOCK
304
COMPRESS DATA BLOCK WITH ENABLED ENCODERS
306
BUFFER ENCODED DATA BLOCK OUTPUT FROM EACH ENCODER
308
COUNT SIZE OF ENCODED DATA BLOCKS
310
CALCULATE COMPRESSION RATIOS
312
COMPARE COMPRESSION RATIOS WITH THRESHOLD LIMIT
314
A

FIG. 3a

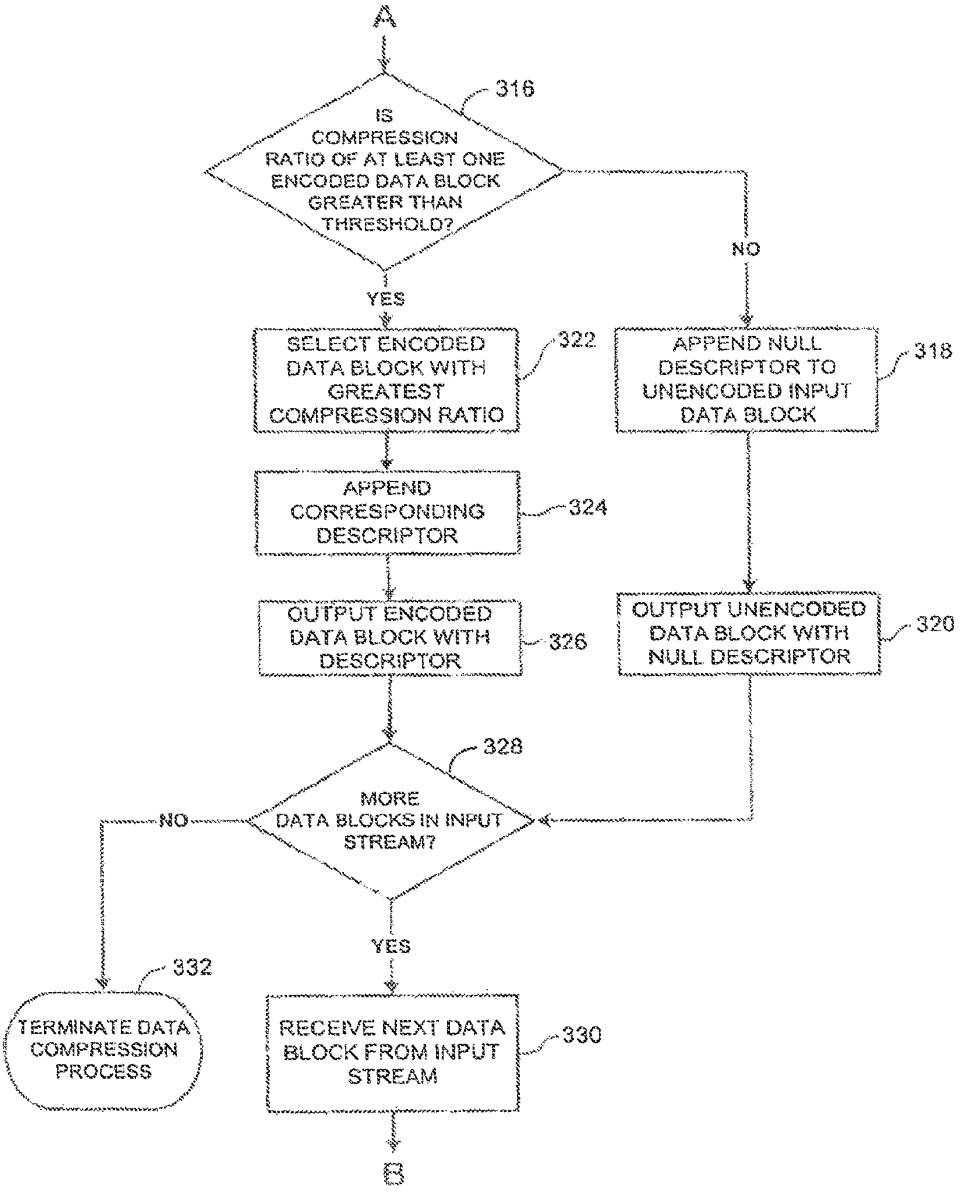

A
316
IS COMPRESSION RATIO OF AT LEAST ONE ENCODED DATA BLOCK GREATER THAN THRESHOLD?
NO
YES
322
SELECT ENCODED DATA BLOCK WITH GREATEST COMPRESSION RATIO
318
APPEND NULL DESCRIPTOR TO UNENCODED INPUT DATA BLOCK
APPEND CORRESPONDING DESCRIPTOR
324
OUTPUT ENCODED DATA BLOCK WITH DESCRIPTOR
326
OUTPUT UNENCODED DATA BLOCK WITH NULL DESCRIPTOR
320
328
MORE DATA BLOCKS IN INPUT STREAM?
NO
YES
332
TERMINATE DATA COMPRESSION PROCESS
RECEIVE NEXT DATA BLOCK FROM INPUT STREAM
330
B

FIG. 3b

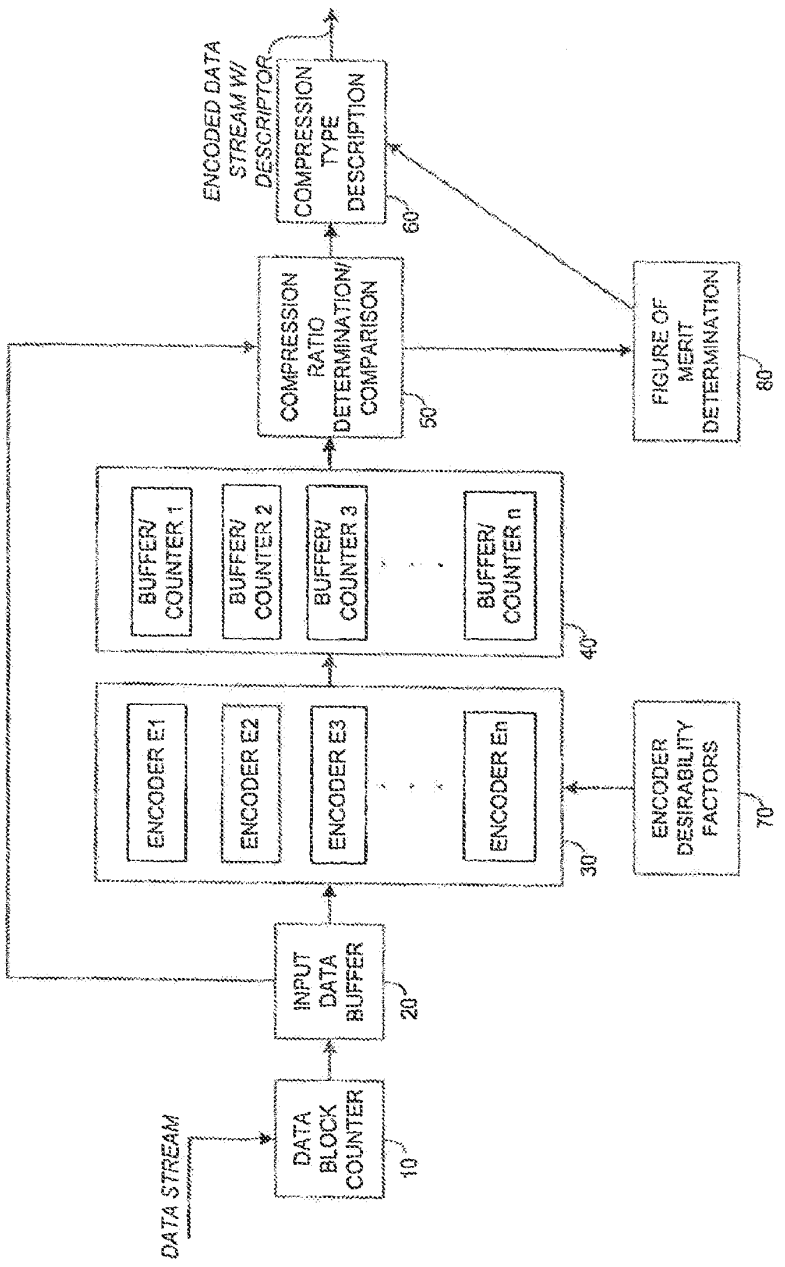

DATA STREAM
DATA BLOCK COUNTER
10
INPUT DATA BUFFER
20
ENCODER E1
ENCODER E2
ENCODER E3
ENCODER En
30
ENCODER DESIRABILITY FACTORS
70
BUFFER/ COUNTER 1
BUFFER/ COUNTER 2
BUFFER/ COUNTER 3
BUFFER/ COUNTER n
40
COMPRESSION RATIO DETERMINATION/ COMPARISON
50
FIGURE OF MERIT DETERMINATION
80
COMPRESSION TYPE DESCRIPTION
60
ENCODED DATA STREAM W/ DESCRIPTOR

FIG. 4

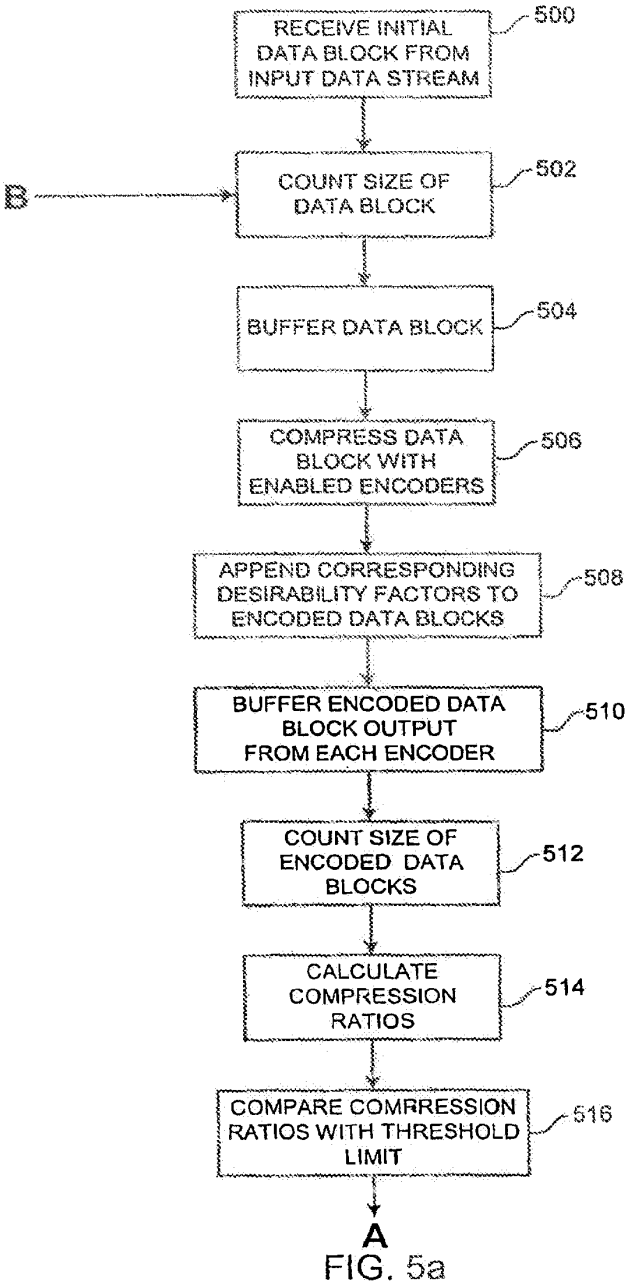

RECEIVE INITIAL DATA BLOCK FROM INPUT DATA STREAM
500
B
COUNT SIZE OF DATA BLOCK
502
BUFFER DATA BLOCK
504
COMPRESS DATA BLOCK WITH ENABLED ENCODERS
506
APPEND CORRESPONDING DESIRABILITY FACTORS TO ENCODED DATA BLOCKS
508
BUFFER ENCODED DATA BLOCK OUTPUT FROM EACH ENCODER
510
COUNT SIZE OF ENCODED DATA BLOCKS
512
CALCULATE COMPRESSION RATIOS
514
COMPARE COMRRESSION RATIOS WITH THRESHOLD LIMIT
516
A

FIG. 5a

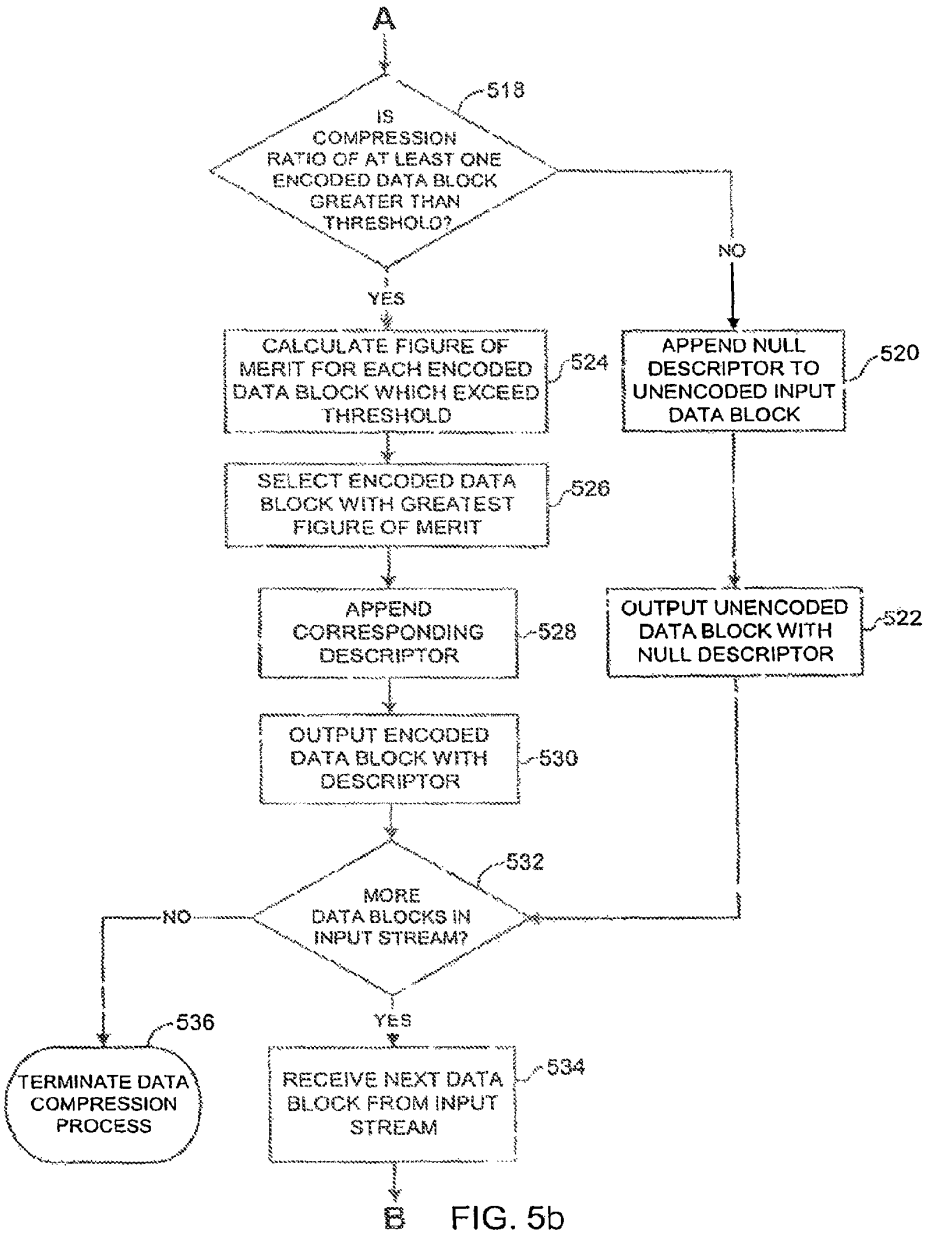

A
518
IS COMPRESSION RATIO OF AT LEAST ONE ENCODED DATA BLOCK GREATER THAN THRESHOLD?
NO
YES
CALCULATE FIGURE OF MERIT FOR EACH ENCODED DATA BLOCK WHICH EXCEED THRESHOLD
524
APPEND NULL DESCRIPTOR TO UNENCODED INPUT DATA BLOCK
520
SELECT ENCODED DATA BLOCK WITH GREATEST FIGURE OF MERIT
526
APPEND CORRESPONDING DESCRIPTOR
528
OUTPUT UNENCODED DATA BLOCK WITH NULL DESCRIPTOR
522
OUTPUT ENCODED DATA BLOCK WITH DESCRIPTOR
530
532
MORE DATA BLOCKS IN INPUT STREAM?
NO
YES
536
TERMINATE DATA COMPRESSION PROCESS
RECEIVE NEXT DATA BLOCK FROM INPUT STREAM
534
B

FIG. 5b

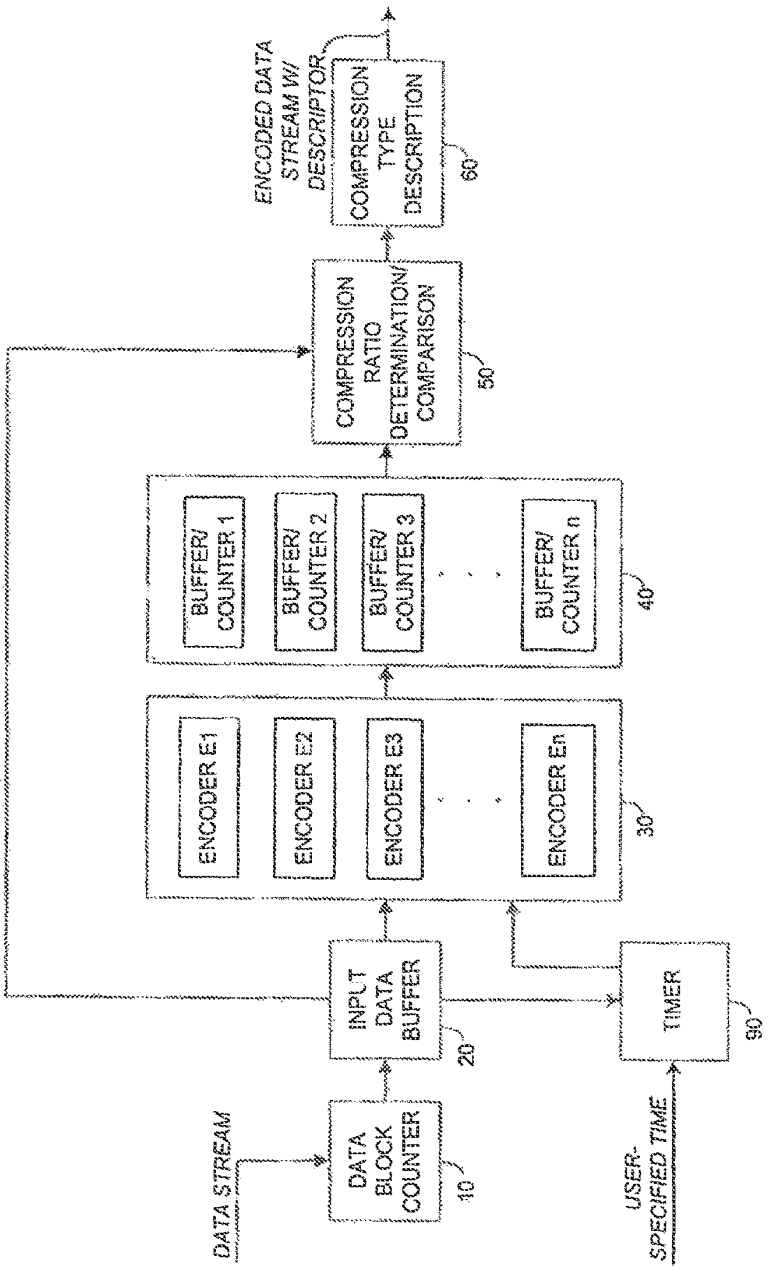

DATA STREAM
DATA BLOCK COUNTER
10
INPUT DATA BUFFER
20
ENCODER E1
ENCODER E2
ENCODER E3
ENCODER En
30
BUFFER/ COUNTER 1
BUFFER/ COUNTER 2
BUFFER/ COUNTER 3
BUFFER/ COUNTER n
40
COMPRESSION RATIO DETERMINATION/ COMPARISON
50
COMPRESSION TYPE DESCRIPTION
60
ENCODED DATA STREAM W/ DESCRIPTOR
TIMER
90
USER-SPECIFIED TIME

FIG. 6

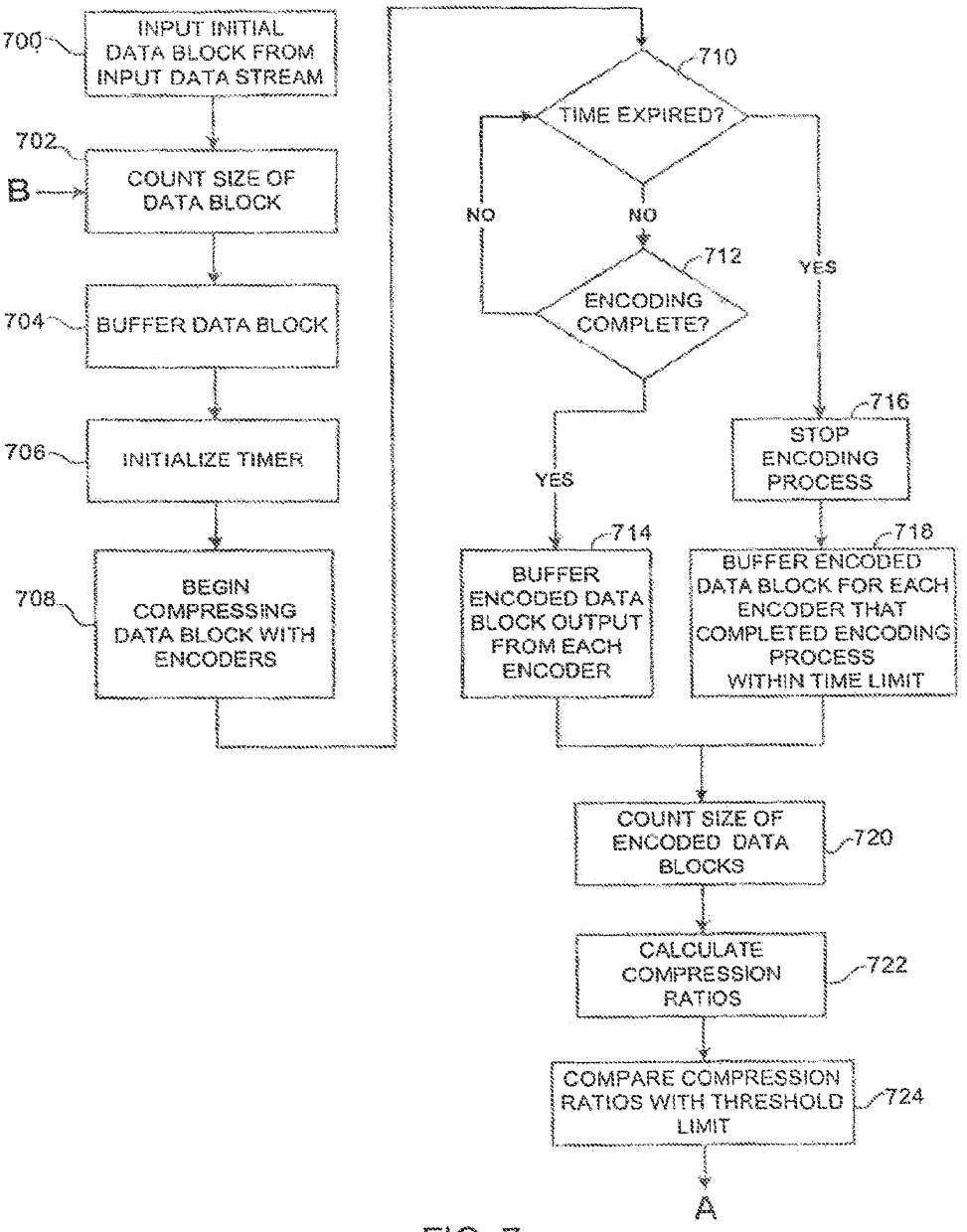

700
INPUT INITIAL DATA BLOCK FROM INPUT DATA STREAM
702
B
COUNT SIZE OF DATA BLOCK
704
BUFFER DATA BLOCK
706
INITIALIZE TIMER
708
BEGIN COMPRESSING DATA BLOCK WITH ENCODERS
710
TIME EXPIRED?
NO
NO
712
ENCODING COMPLETE?
YES
YES
714
BUFFER ENCODED DATA BLOCK OUTPUT FROM EACH ENCODER
716
STOP ENCODING PROCESS
718
BUFFER ENCODED DATA BLOCK FOR EACH ENCODER THAT COMPLETED ENCODING PROCESS WITHIN TIME LIMIT
720
COUNT SIZE OF ENCODED DATA BLOCKS
722
CALCULATE COMPRESSION RATIOS
724
COMPARE COMPRESSION RATIOS WITH THRESHOLD LIMIT
A

FIG. 7a

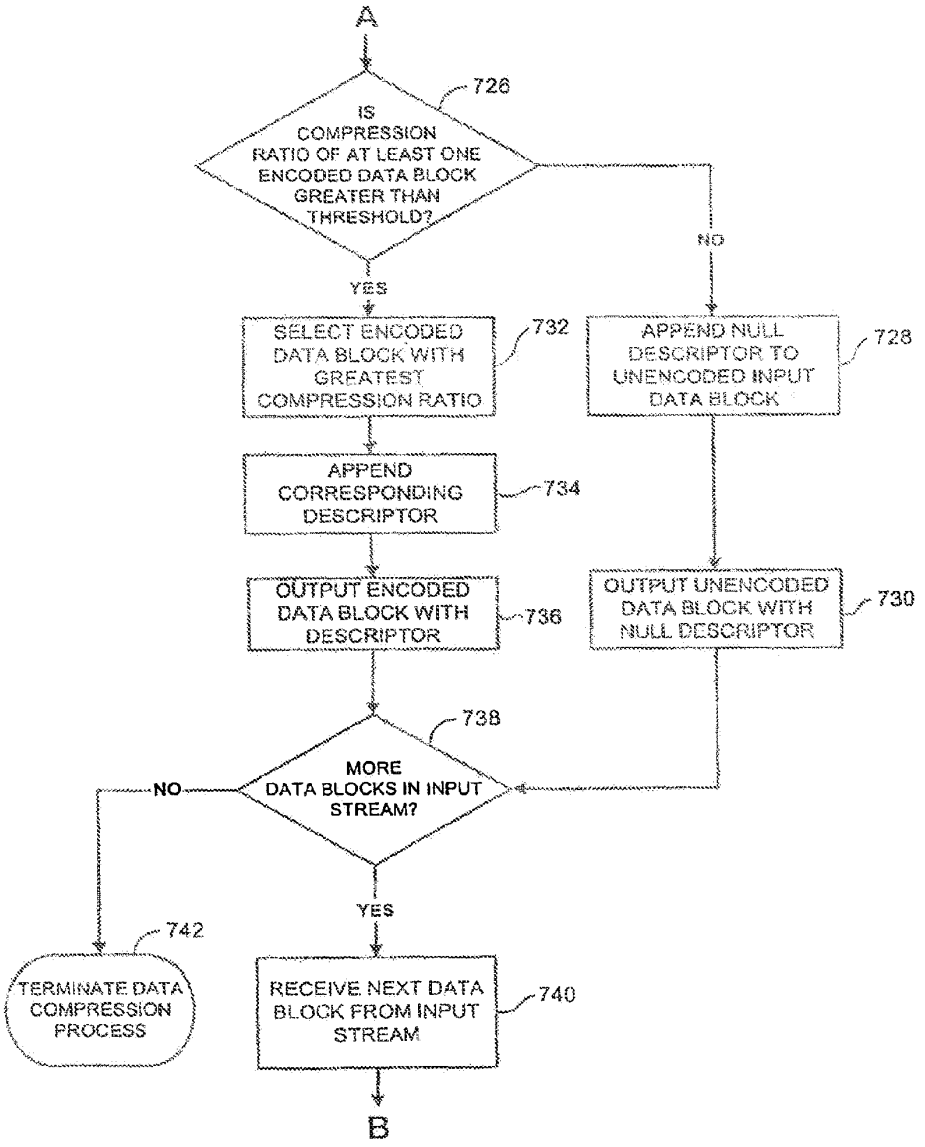

A
726
IS COMPRESSION RATIO OF AT LEAST ONE ENCODED DATA BLOCK GREATER THAN THRESHOLD?
NO
YES
SELECT ENCODED DATA BLOCK WITH GREATEST COMPRESSION RATIO
732
APPEND NULL DESCRIPTOR TO UNENCODED INPUT DATA BLOCK
728
APPEND CORRESPONDING DESCRIPTOR
734
OUTPUT ENCODED DATA BLOCK WITH DESCRIPTOR
736
OUTPUT UNENCODED DATA BLOCK WITH NULL DESCRIPTOR
730
738
MORE DATA BLOCKS IN INPUT STREAM?
NO
YES
742
TERMINATE DATA COMPRESSION PROCESS
RECEIVE NEXT DATA BLOCK FROM INPUT STREAM
740
B

FIG. 7b

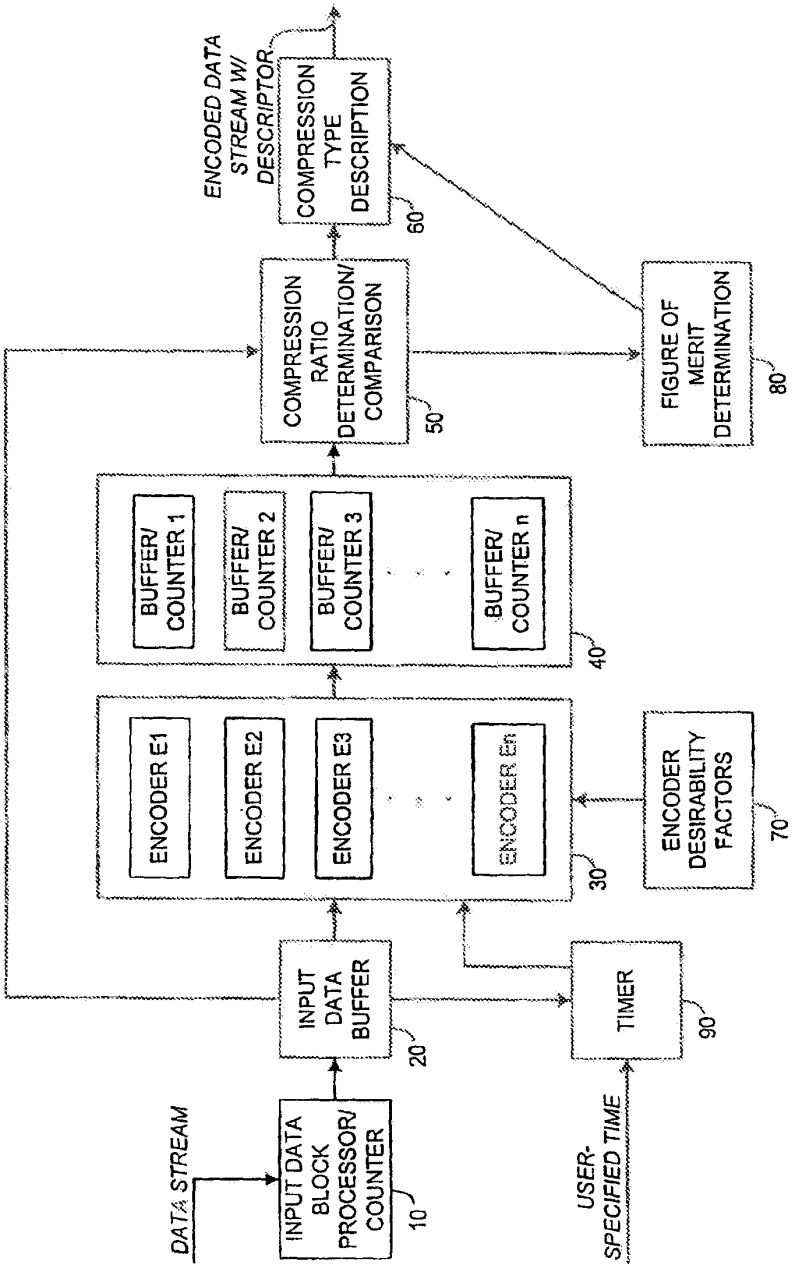

DATA STREAM
INPUT DATA BLOCK PROCESSOR/ COUNTER
10
INPUT DATA BUFFER
20
ENCODER E1
ENCODER E2
ENCODER E3
ENCODER En
30
BUFFER/ COUNTER 1
BUFFER/ COUNTER 2
BUFFER/ COUNTER 3
BUFFER/ COUNTER n
40
COMPRESSION RATIO DETERMINATION/ COMPARISON
50
COMPRESSION TYPE DESCRIPTION
60
ENCODED DATA STREAM W/ DESCRIPTOR
TIMER
90
USER-SPECIFIED TIME
ENCODER DESIRABILITY FACTORS
70
FIGURE OF MERIT DETERMINATION
80

FIG. 8

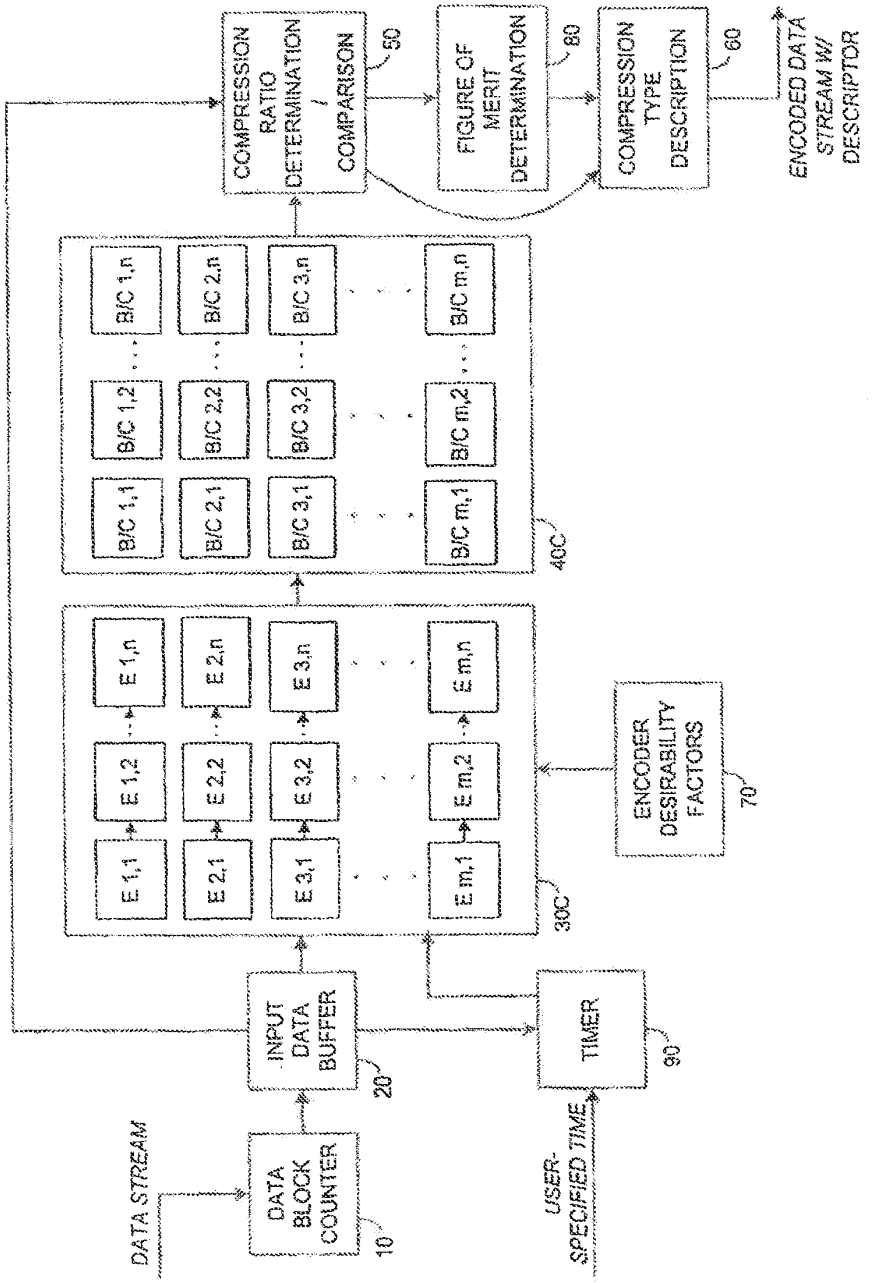

DATA STREAM
DATA BLOCK COUNTER
10
INPUT DATA BUFFER
20
E 1,1
E 1,2
E 1,n
E 2,1
E 2,2
E 2,n
E 3,1
E 3,2
E 3,n
E m,1
E m,2
E m,n
30C
B/C 1,1
B/C 1,2
B/C 1,n
B/C 2,1
B/C 2,2
B/C 2,n
B/C 3,1
B/C 3,2
B/C 3,n
B/C m,1
B/C m,2
B/C m,n
40C
COMPRESSION RATIO DETERMINATION / COMPARISON
50
FIGURE OF MERIT DETERMINATION
80
COMPRESSION TYPE DESCRIPTION
60
ENCODED DATA STREAM W/ DESCRIPTOR
ENCODER DESIRABILITY FACTORS
70
TIMER
90
USER-SPECIFIED TIME

FIG. 9

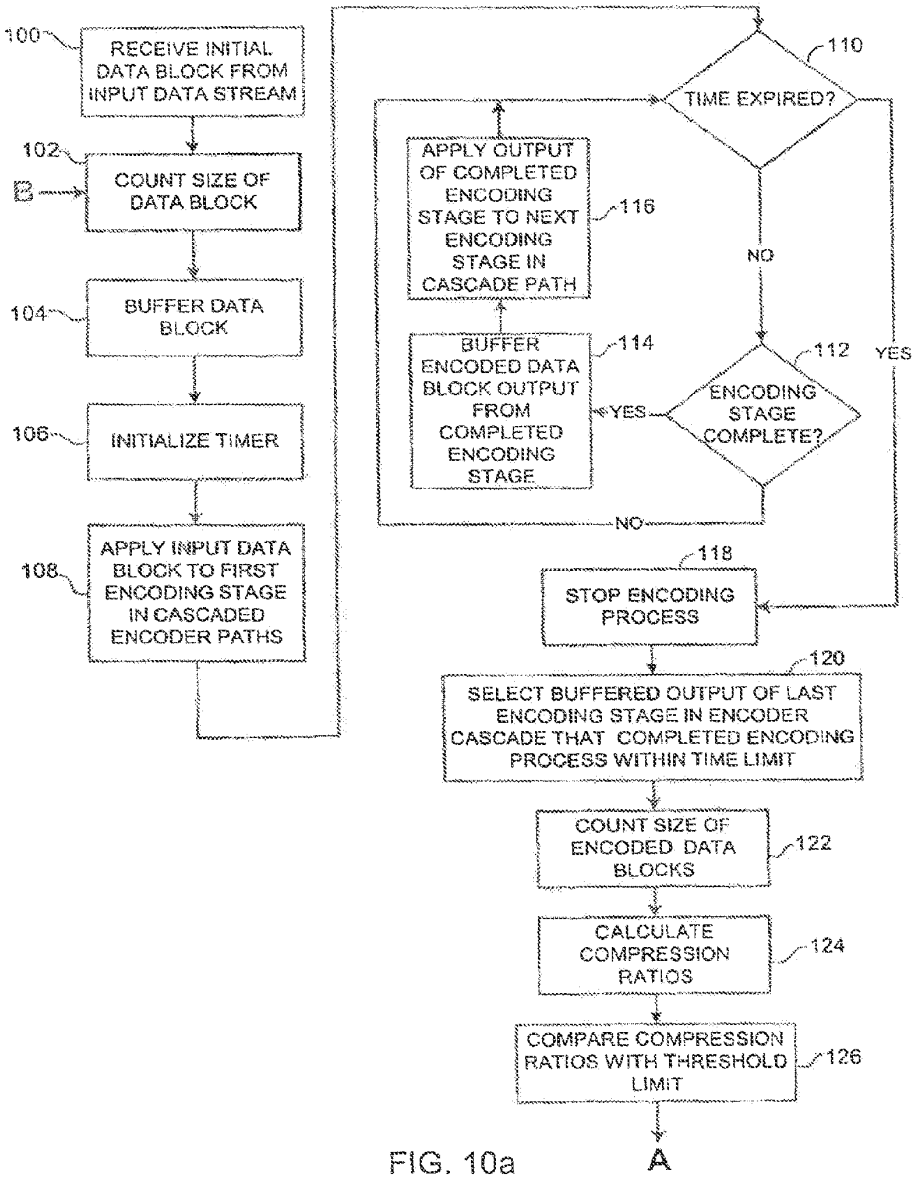

100
RECEIVE INITIAL DATA BLOCK FROM INPUT DATA STREAM
102
COUNT SIZE OF DATA BLOCK
B
104
BUFFER DATA BLOCK
106
INITIALIZE TIMER
108
APPLY INPUT DATA BLOCK TO FIRST ENCODING STAGE IN CASCADED ENCODER PATHS
110
TIME EXPIRED?
YES
NO
116
APPLY OUTPUT OF COMPLETED ENCODING STAGE TO NEXT ENCODING STAGE IN CASCADE PATH
114
BUFFER ENCODED DATA BLOCK OUTPUT FROM COMPLETED ENCODING STAGE
112
ENCODING STAGE COMPLETE?
YES
NO
118
STOP ENCODING PROCESS
120
SELECT BUFFERED OUTPUT OF LAST ENCODING STAGE IN ENCODER CASCADE THAT COMPLETED ENCODING PROCESS WITHIN TIME LIMIT
122
COUNT SIZE OF ENCODED DATA BLOCKS
124
CALCULATE COMPRESSION RATIOS
126
COMPARE COMPRESSION RATIOS WITH THRESHOLD LIMIT
A

FIG. 10a

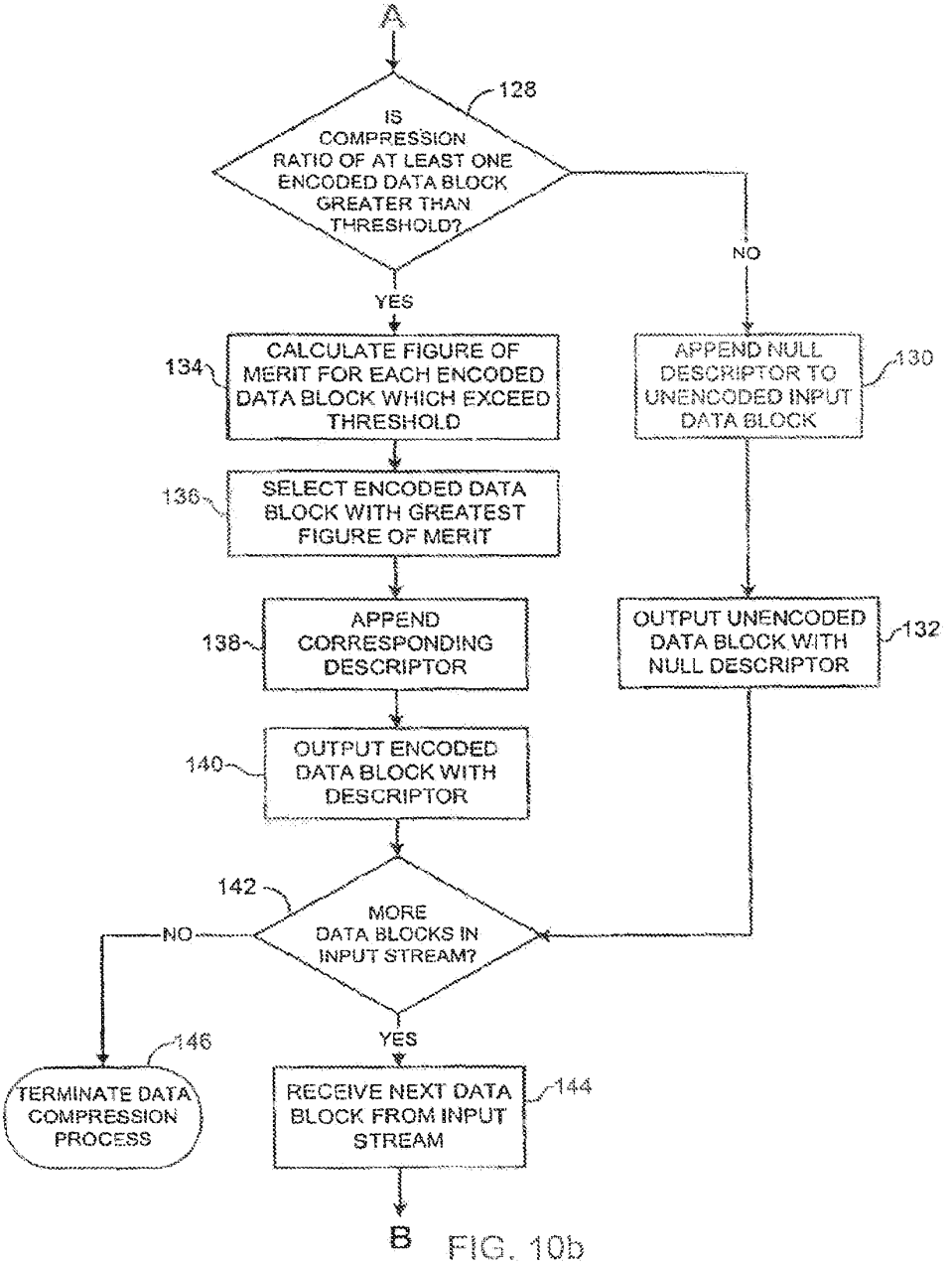

A
128
IS COMPRESSION RATIO OF AT LEAST ONE ENCODED DATA BLOCK GREATER THAN THRESHOLD?
NO
YES
134
CALCULATE FIGURE OF MERIT FOR EACH ENCODED DATA BLOCK WHICH EXCEED THRESHOLD
130
APPEND NULL DESCRIPTOR TO UNENCODED INPUT DATA BLOCK
136
SELECT ENCODED DATA BLOCK WITH GREATEST FIGURE OF MERIT
138
APPEND CORRESPONDING DESCRIPTOR
OUTPUT UNENCODED DATA BLOCK WITH NULL DESCRIPTOR
132
140
OUTPUT ENCODED DATA BLOCK WITH DESCRIPTOR
142
MORE DATA BLOCKS IN INPUT STREAM?
NO
YES
146
TERMINATE DATA COMPRESSION PROCESS
RECEIVE NEXT DATA BLOCK FROM INPUT STREAM
144
B

FIG. 10b

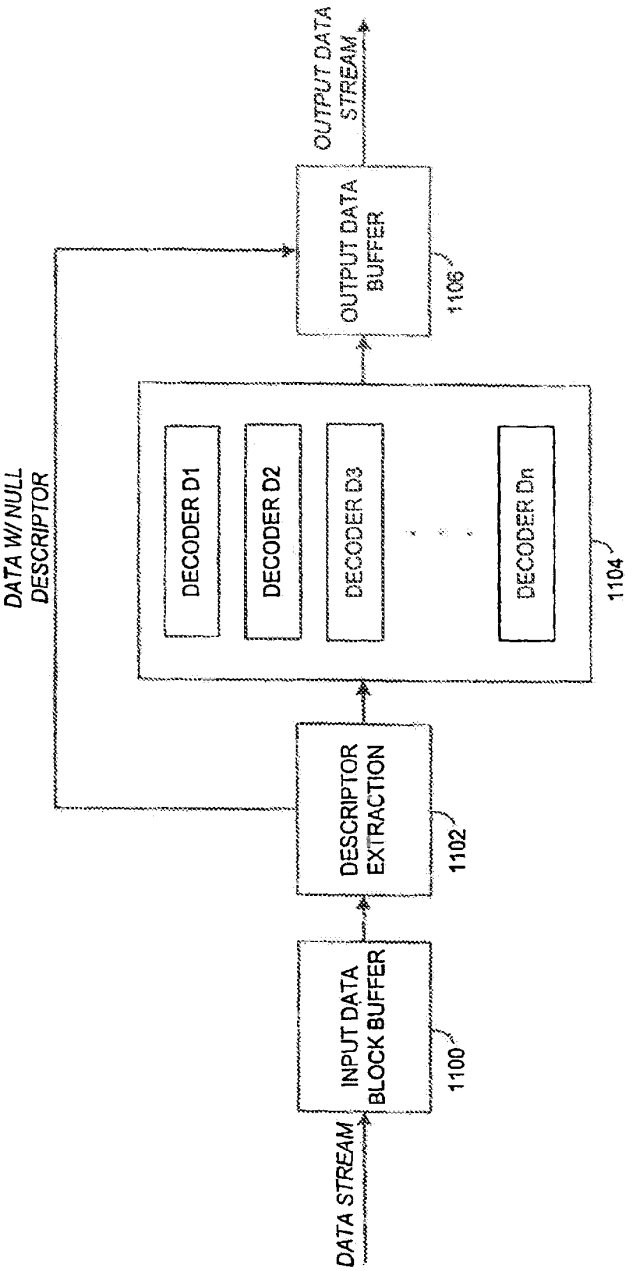

DATA STREAM
INPUT DATA BLOCK BUFFER
1100
DESCRIPTOR EXTRACTION
1102
DECODER D1
DECODER D2
DECODER D3
DECODER Dn
1104
OUTPUT DATA BUFFER
1106
OUTPUT DATA STREAM
DATA W/ NULL DESCRIPTOR

FIG. 11

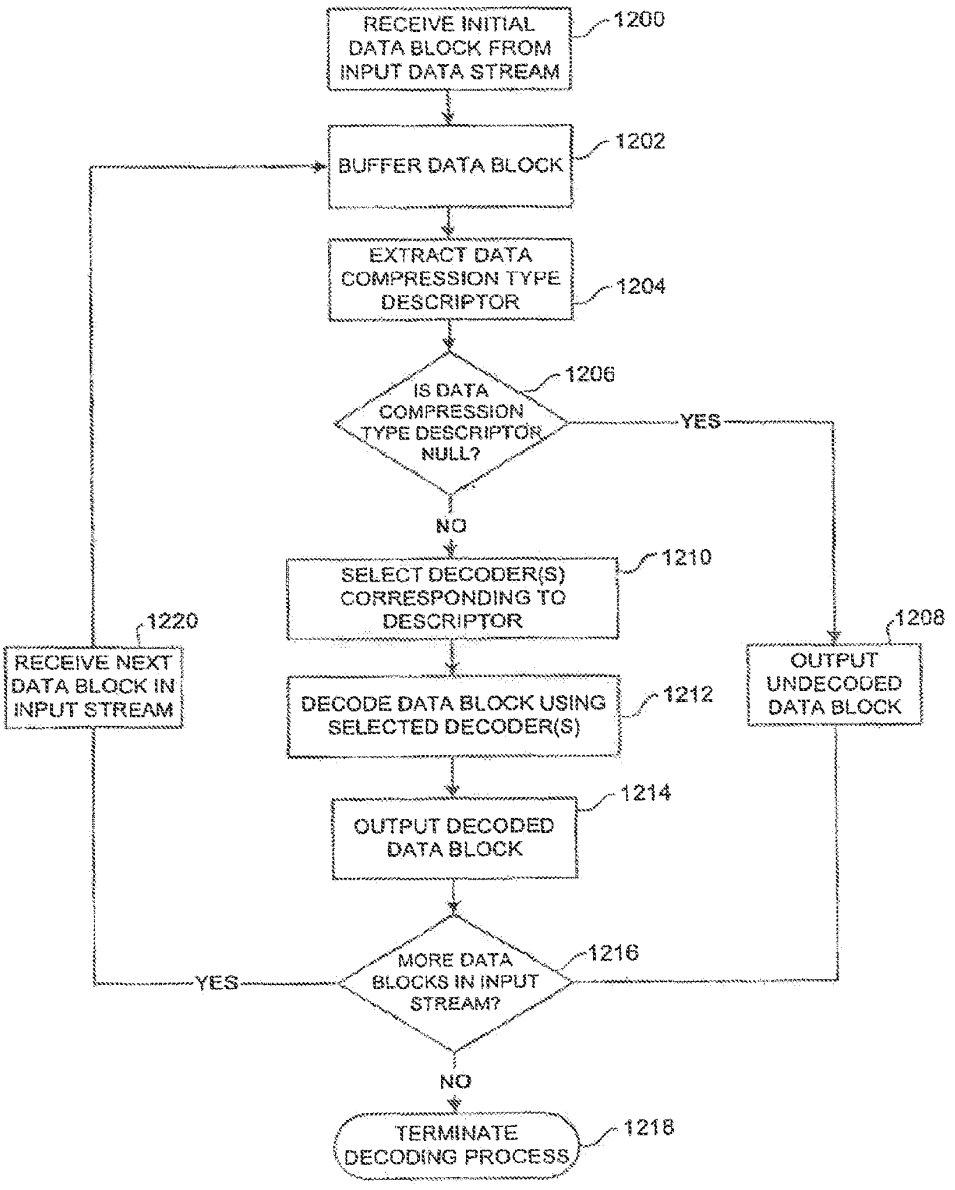

RECEIVE INITIAL DATA BLOCK FROM INPUT DATA STREAM
1200
BUFFER DATA BLOCK
1202
EXTRACT DATA COMPRESSION TYPE DESCRIPTOR
1204
IS DATA COMPRESSION TYPE DESCRIPTOR NULL?
1206
YES
NO
SELECT DECODER(S) CORRESPONDING TO DESCRIPTOR
1210
DECODE DATA BLOCK USING SELECTED DECODER(S)
1212
OUTPUT DECODED DATA BLOCK
1214
MORE DATA BLOCKS IN INPUT STREAM?
1216
YES
NO
TERMINATE DECODING PROCESS
1218
RECEIVE NEXT DATA BLOCK IN INPUT STREAM
1220
OUTPUT UNDECODED DATA BLOCK
1208

FIG. 12

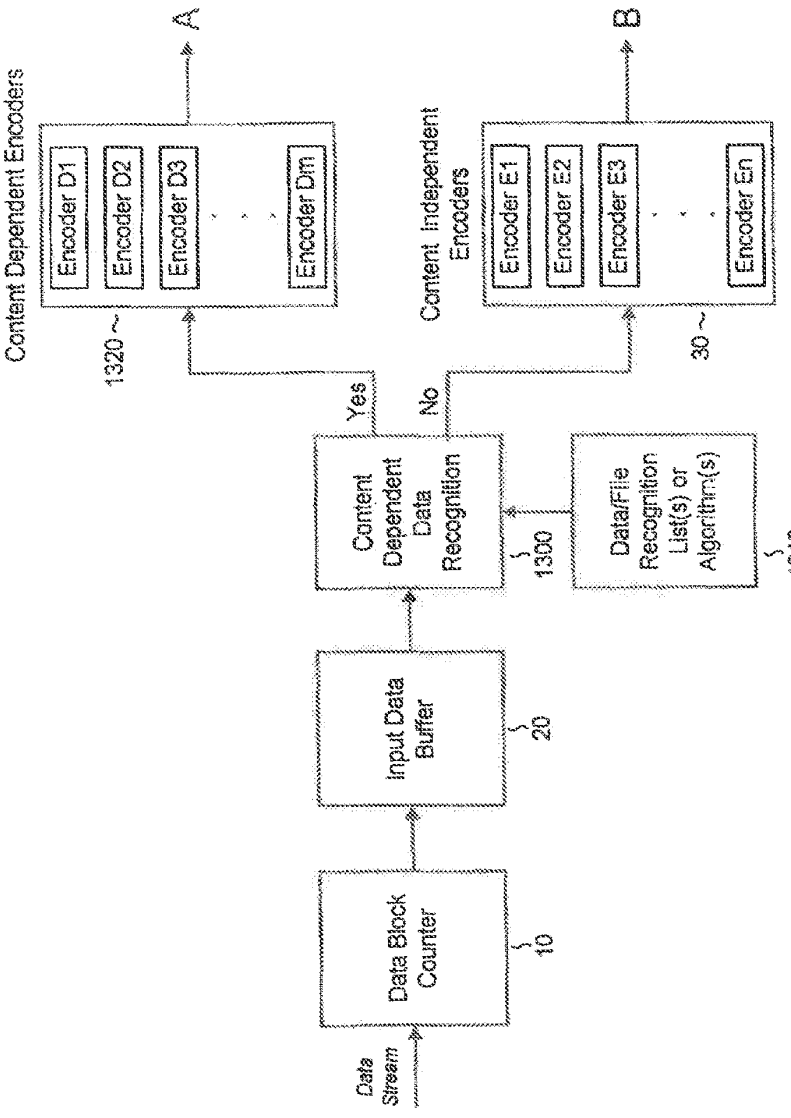

Data Stream
Data Block Counter
10
Input Data Buffer
20
Content Dependent Data Recognition
1300
Data/File Recognition List(s) or Algorithm(s)
1310
Yes
No
Content Dependent Encoders
Encoder D1
Encoder D2
Encoder D3
Encoder Dm
1320
A
Content Independent Encoders
Encoder E1
Encoder E2
Encoder E3
Encoder En
30
B

FIGURE 13A

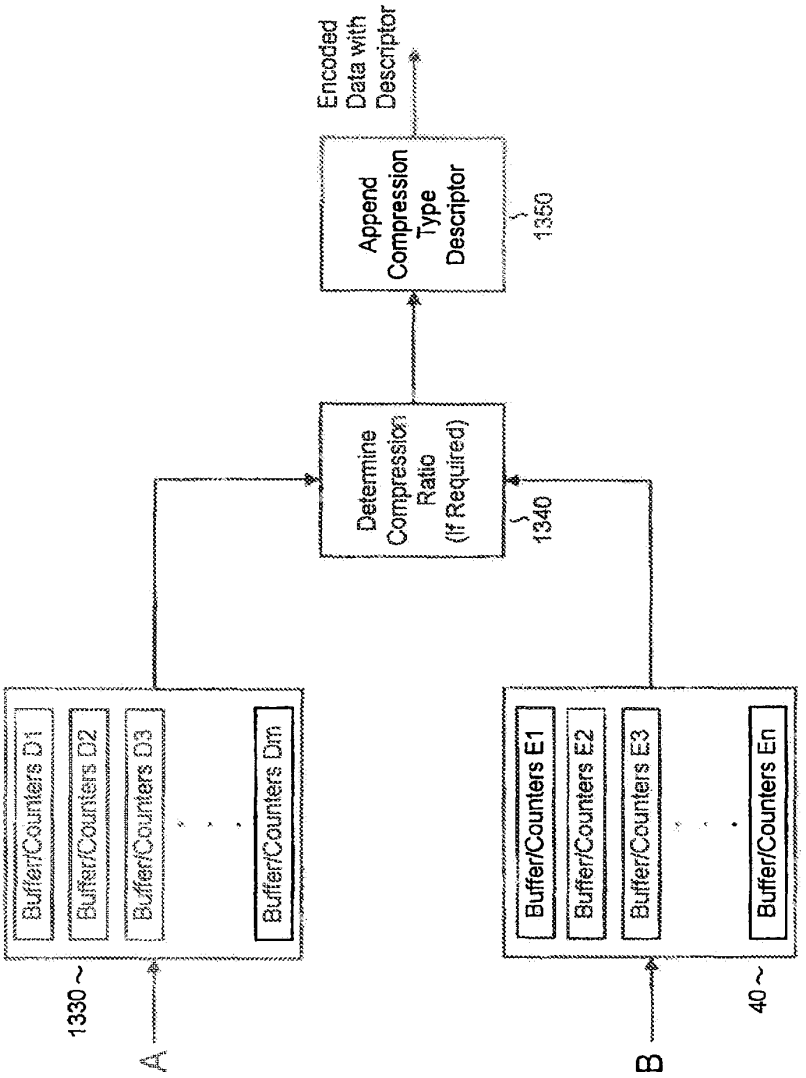

Encoded Data with Descriptor
Append Compression Type Descriptor
1350
Determine Compression Ratio (If Required)
1340
Buffer/Counters D1
Buffer/Counters D2
Buffer/Counters D3
Buffer/Counters Dm
1330
A
Buffer/Counters E1
Buffer/Counters E2
Buffer/Counters E3
Buffer/Counters En
40
B

FIGURE 13B

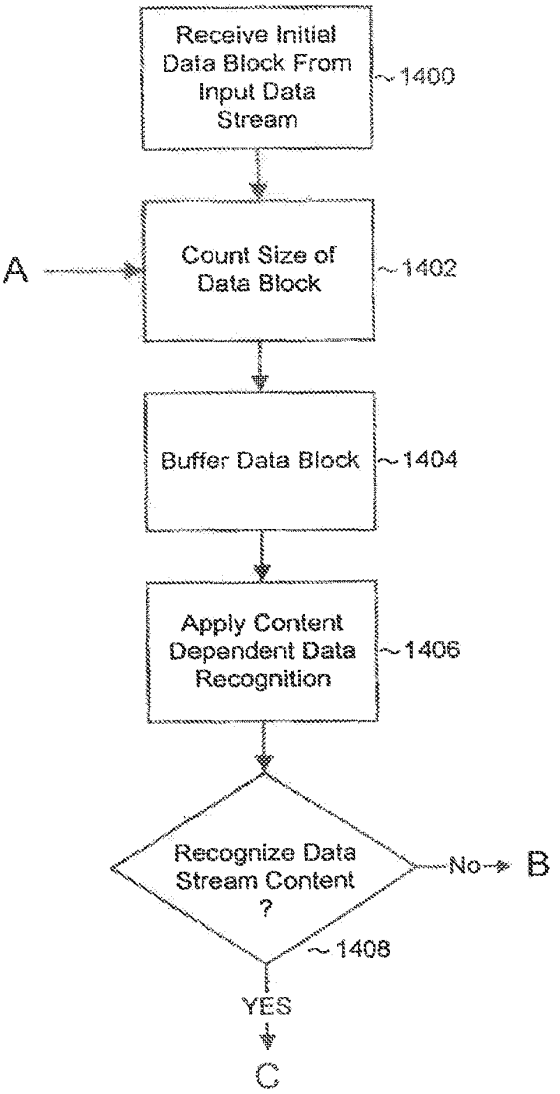

Receive Initial Data Block From Input Data Stream
1400
A
Count Size of Data Block
1402
Buffer Data Block
1404
Apply Content Dependent Data Recognition
1406
Recognize Data Stream Content ?
No
B
1408
YES
C

FIGURE 14A

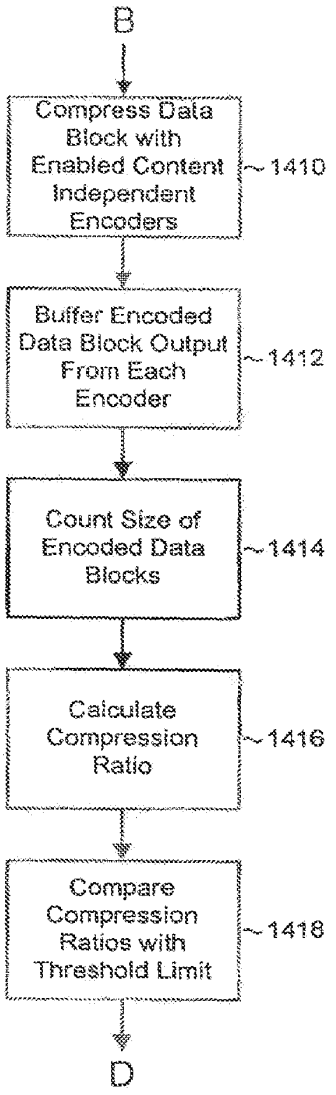

B
Compress Data Block with Enabled Content Independent Encoders
1410
Buffer Encoded Data Block Output From Each Encoder
1412
Count Size of Encoded Data Blocks
1414
Calculate Compression Ratio
1416
Compare Compression Ratios with Threshold Limit
1418
D

FIGURE 14B

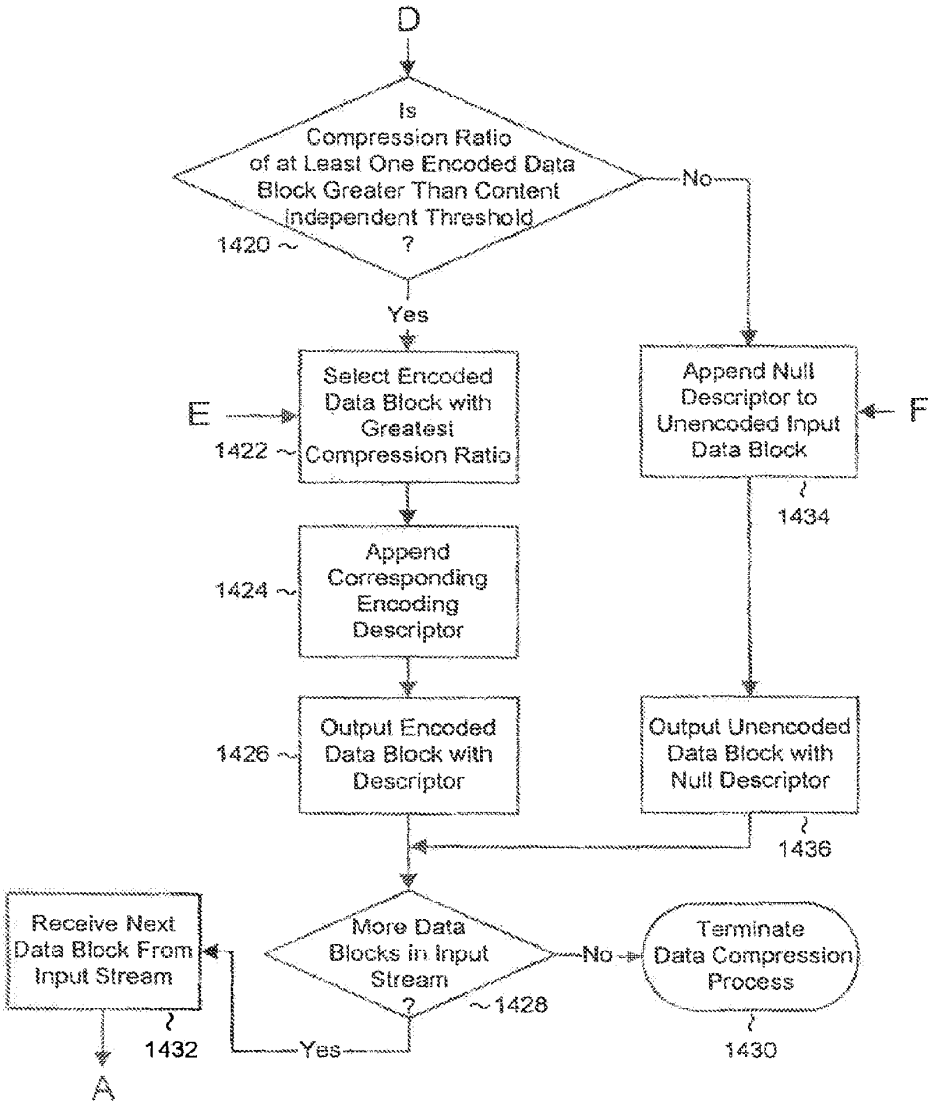

D
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Independent Threshold ?
1420
No
Yes
E
Select Encoded Data Block with Greatest Compression Ratio
1422
Append Null Descriptor to Unencoded Input Data Block
F
1434
Append Corresponding Encoding Descriptor
1424
Output Encoded Data Block with Descriptor
1426
Output Unencoded Data Block with Null Descriptor
1436
Receive Next Data Block From Input Stream
1432
More Data Blocks in Input Stream ?
1428
No
Yes
Terminate Data Compression Process
1430
A

FIGURE 14C

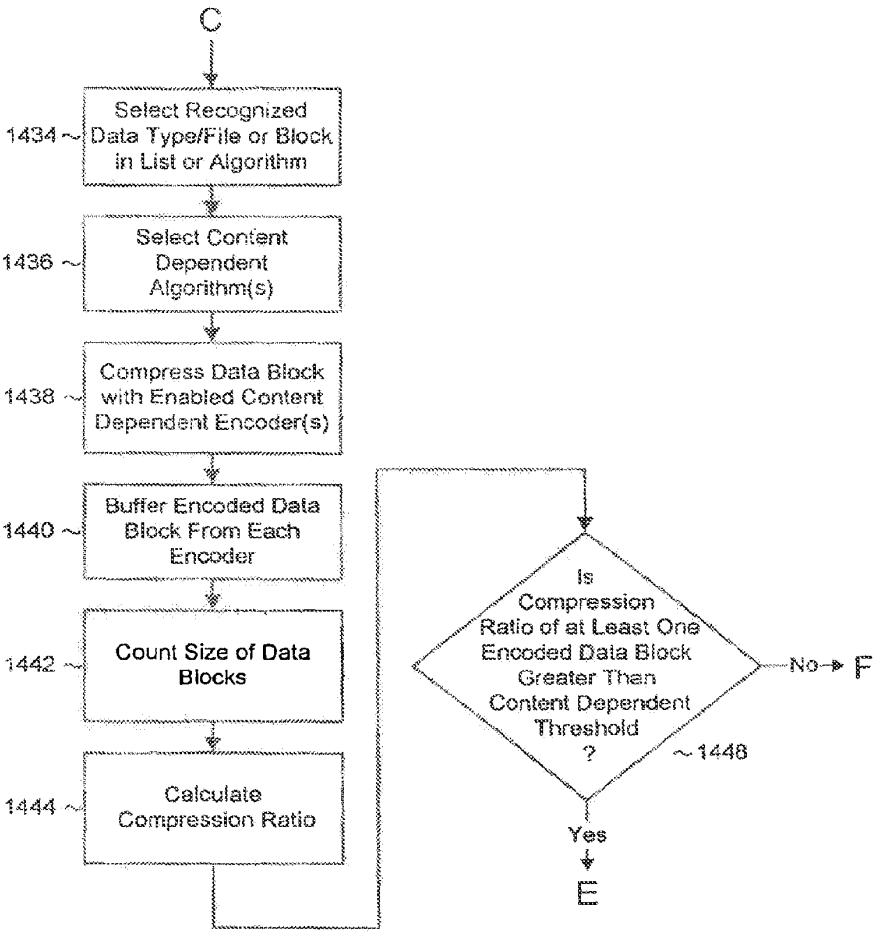

C
1434
Select Recognized Data Type/File or Block in List or Algorithm
1436
Select Content Dependent Algorithm(s)
1438
Compress Data Block with Enabled Content Dependent Encoder(s)
1440
Buffer Encoded Data Block From Each Encoder
1442
Count Size of Data Blocks
1444
Calculate Compression Ratio
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Dependent Threshold ?
1448
No
F
Yes
E

FIGURE 14D

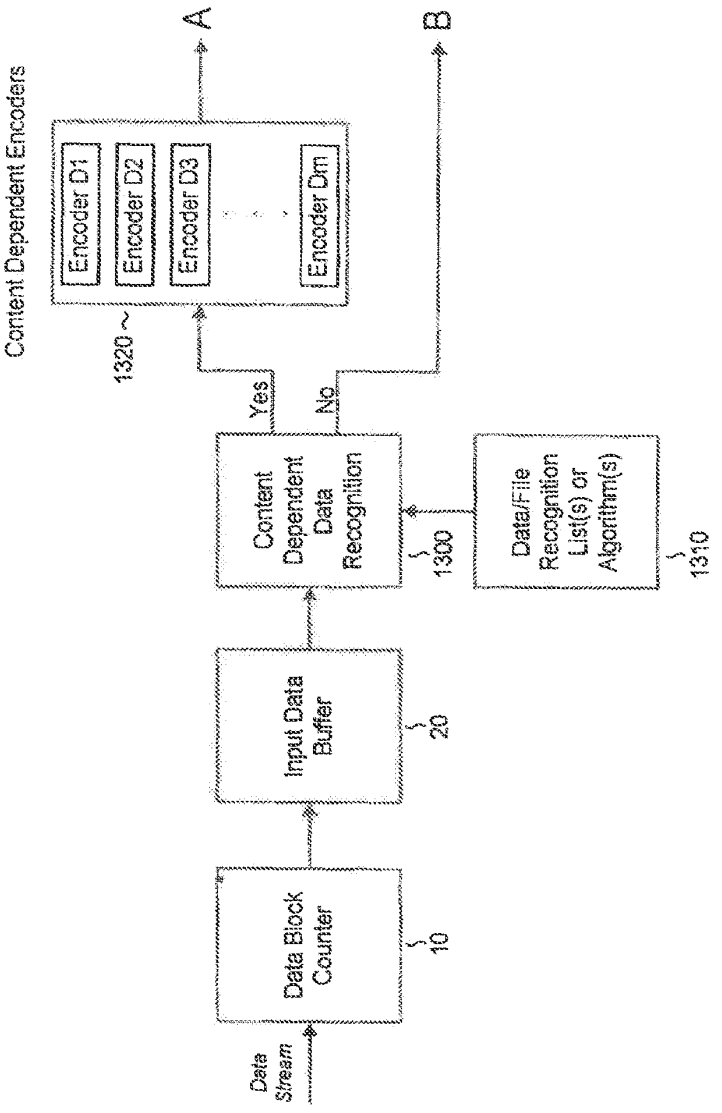

Data Stream
Data Block Counter
10
Input Data Buffer
20
Content Dependent Data Recognition
1300
Data/File Recognition List(s) or Algorithm(s)
1310
Yes
No
A
B
Content Dependent Encoders
1320
Encoder D1
Encoder D2
Encoder D3
Encoder Dm

FIGURE 15A

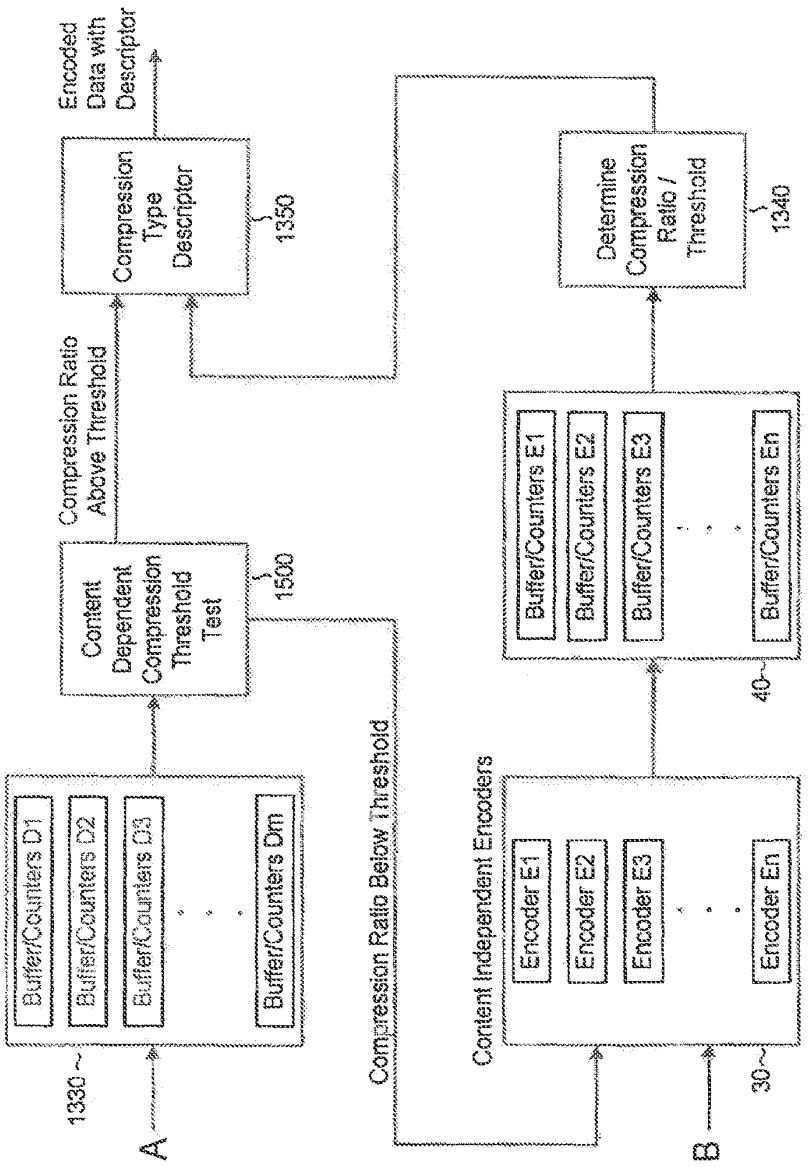

Encoded Data with Descriptor
Compression Type Descriptor
1350
Determine Compression Ratio / Threshold
1340
Compression Ratio Above Threshold
Content Dependent Compression Threshold Test
1500
Compression Ratio Below Threshold
Buffer/Counters D1
Buffer/Counters D2
Buffer/Counters D3
Buffer/Counters Dm
1330
A
Content Independent Encoders
Encoder E1
Encoder E2
Encoder E3
Encoder En
B
30
Buffer/Counters E1
Buffer/Counters E2
Buffer/Counters E3
Buffer/Counters En
40

FIGURE 15B

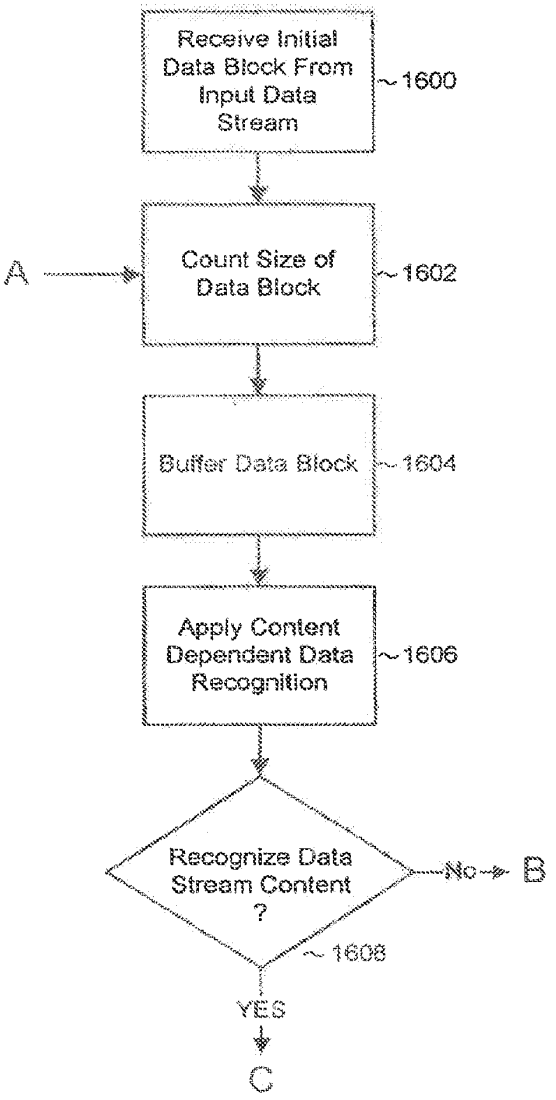

Receive Initial Data Block From Input Data Stream
1600
A
Count Size of Data Block
1602
Buffer Data Block
1604
Apply Content Dependent Data Recognition
1606
Recognize Data Stream Content ?
No
B
1608
YES
C

FIGURE 16A

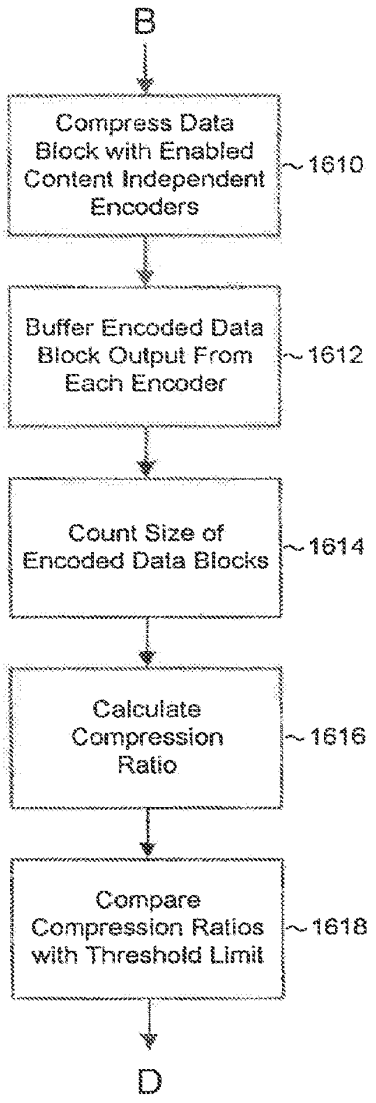

B
Compress Data Block with Enabled Content Independent Encoders
1610
Buffer Encoded Data Block Output From Each Encoder
1612
Count Size of Encoded Data Blocks
1614
Calculate Compression Ratio
1616
Compare Compression Ratios with Threshold Limit
1618
D

FIGURE 16B

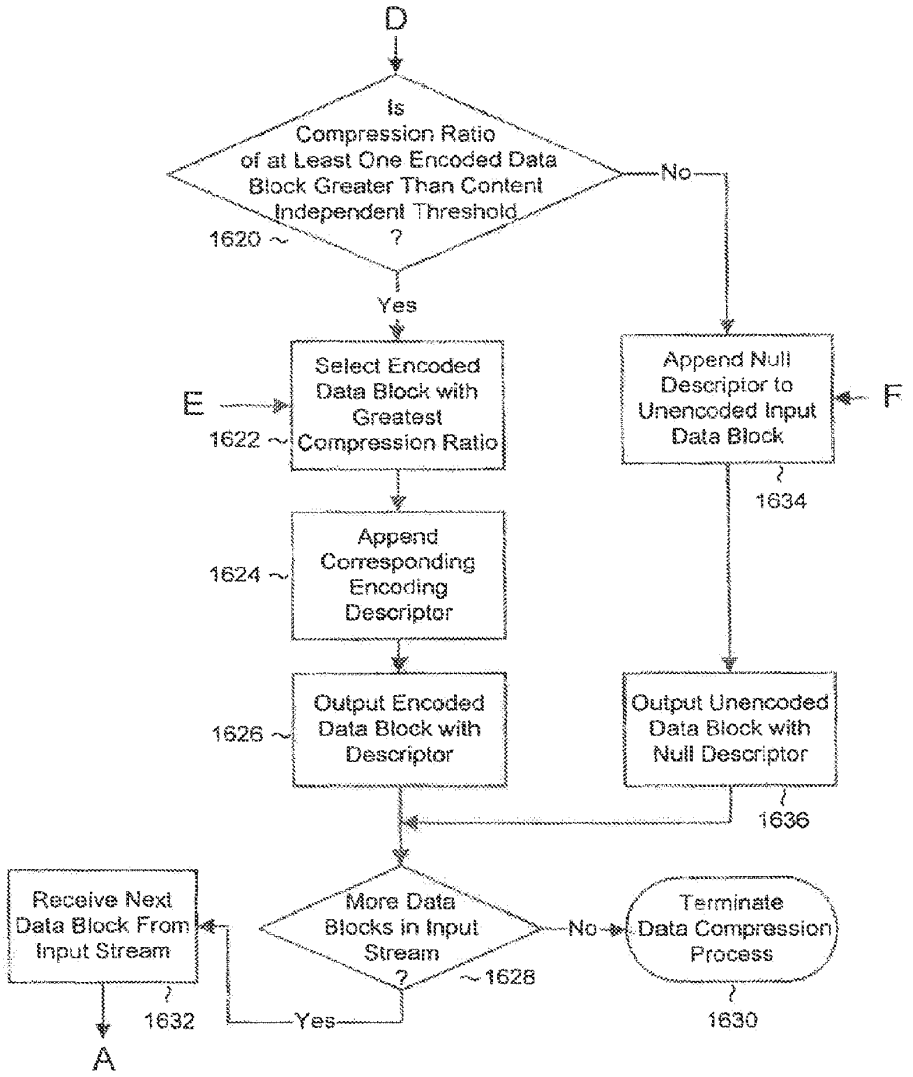

D
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Independent Threshold ?
1620
No
Yes
E
Select Encoded Data Block with Greatest Compression Ratio
1622
Append Corresponding Encoding Descriptor
1624
Output Encoded Data Block with Descriptor
1626
F
Append Null Descriptor to Unencoded Input Data Block
1634
Output Unencoded Data Block with Null Descriptor
1636
More Data Blocks in Input Stream ?
1628
No
Terminate Data Compression Process
1630
Yes
Receive Next Data Block From Input Stream
1632
A

FIGURE 16C

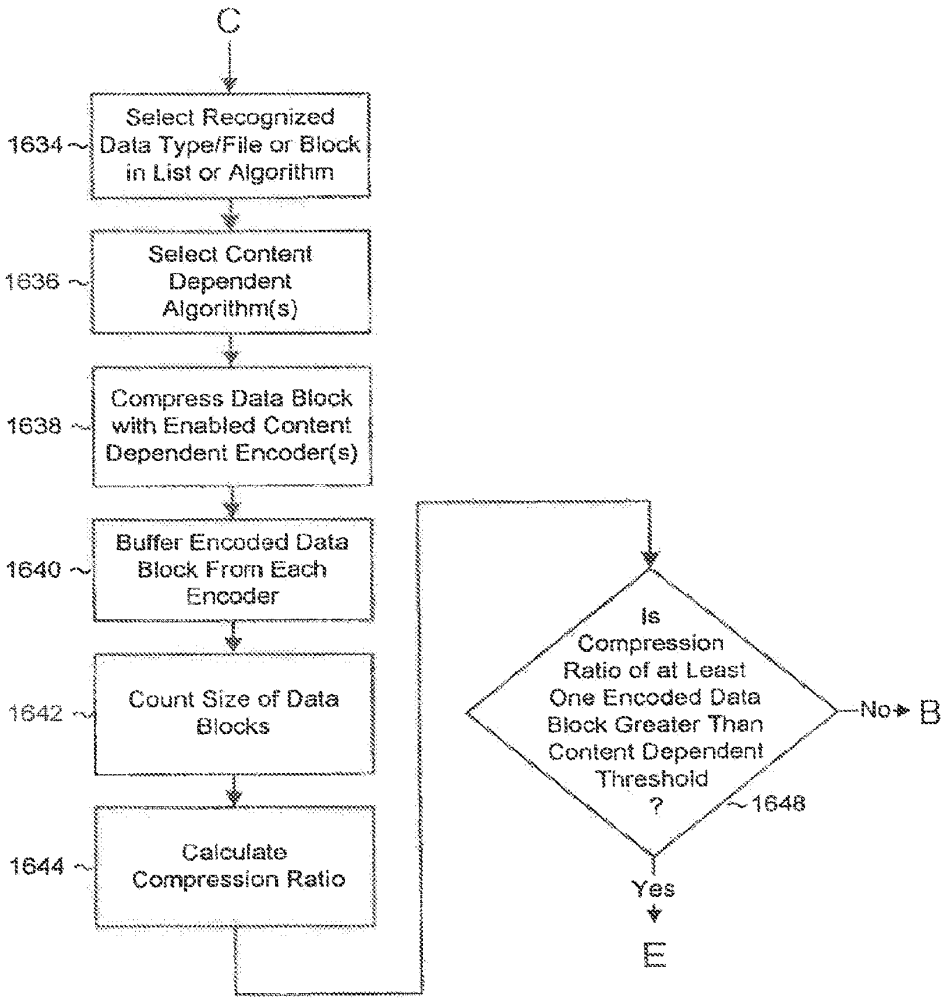

C
1634
Select Recognized Data Type/File or Block in List or Algorithm
1636
Select Content Dependent Algorithm(s)
1638
Compress Data Block with Enabled Content Dependent Encoder(s)
1640
Buffer Encoded Data Block From Each Encoder
1642
Count Size of Data Blocks
1644
Calculate Compression Ratio
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Dependent Threshold ?
1648
No
B
Yes
E

FIGURE 16D

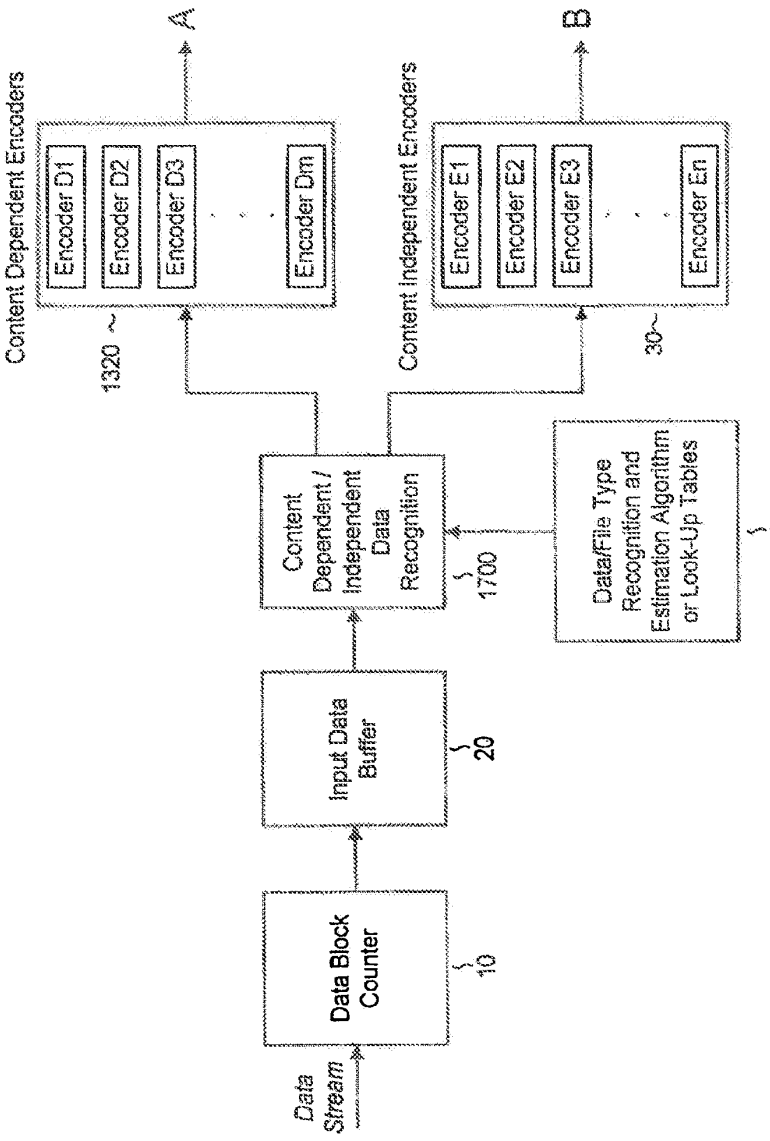

Data Stream
Data Block Counter
10
Input Data Buffer
20
Content Dependent / Independent Data Recognition
1700
Data/File Type Recognition and Estimation Algorithm or Look-Up Tables
1710
Content Dependent Encoders
Encoder D1
Encoder D2
Encoder D3
Encoder Dm
1320
A
Content Independent Encoders
Encoder E1
Encoder E2
Encoder E3
Encoder En
30
B

FIGURE 17A

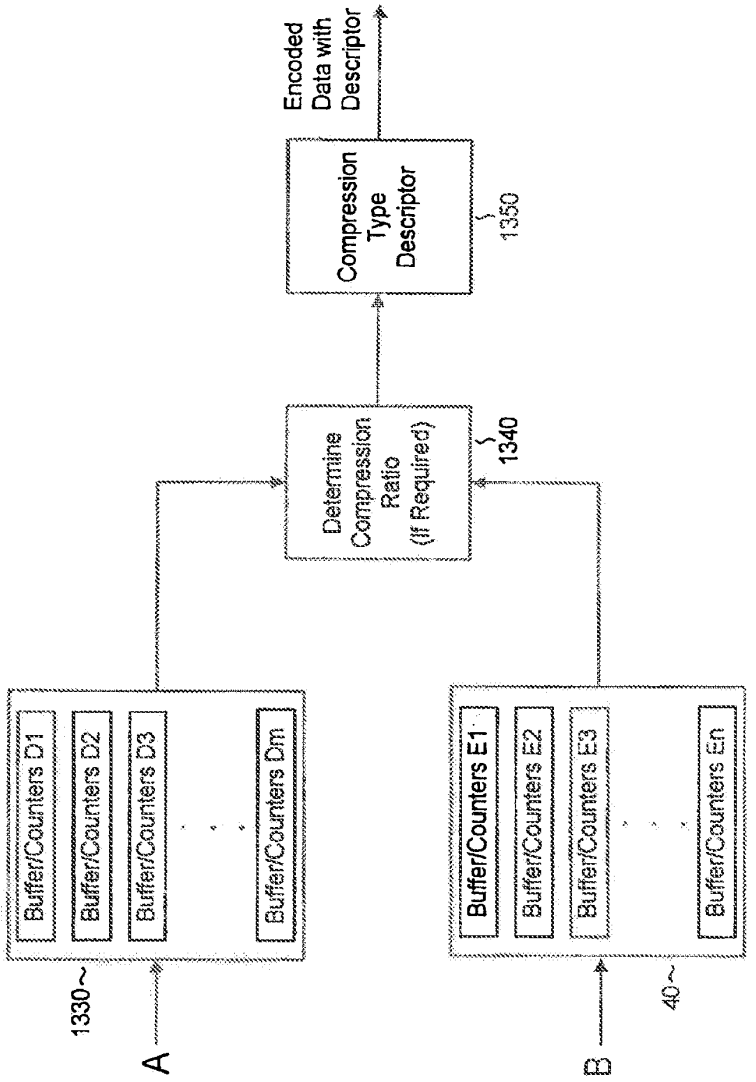

Encoded Data with Descriptor
Compression Type Descriptor
1350
Determine Compression Ratio (If Required)
1340
Buffer/Counters D1
Buffer/Counters D2
Buffer/Counters D3
Buffer/Counters Dm
1330
A
Buffer/Counters E1
Buffer/Counters E2
Buffer/Counters E3
Buffer/Counters En
40
B

FIGURE 17B

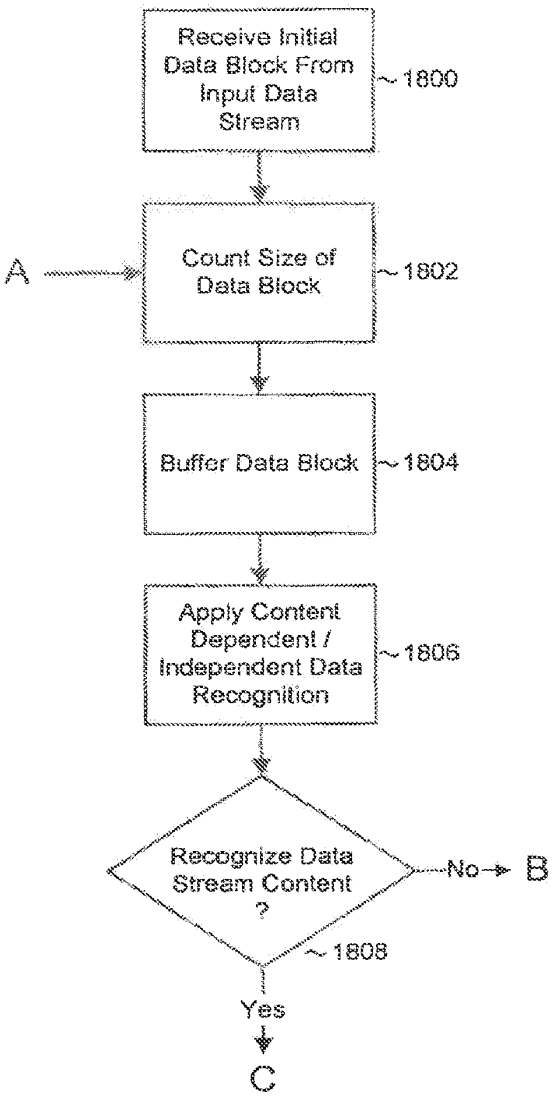

Receive Initial Data Block From Input Data Stream
1800
A
Count Size of Data Block
1802
Buffer Data Block
1804
Apply Content Dependent / Independent Data Recognition
1806
Recognize Data Stream Content ?
No
B
1808
Yes
C

FIGURE 18A

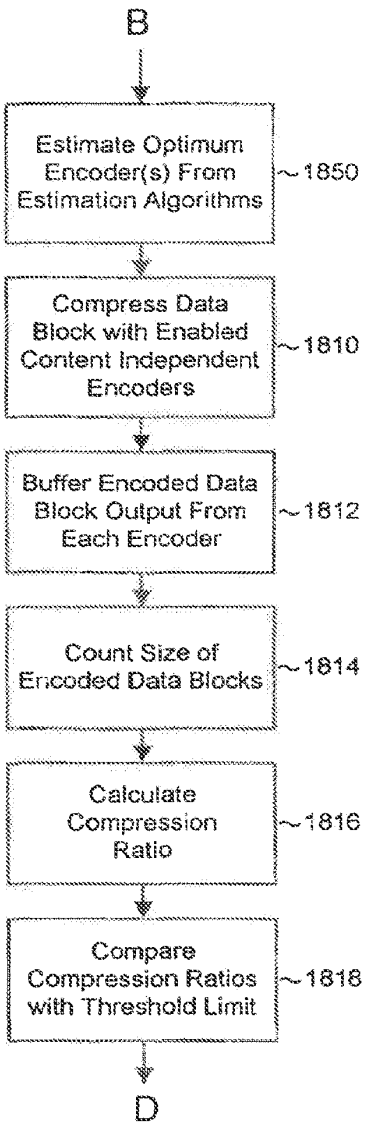

B
Estimate Optimum Encoder(s) From Estimation Algorithms
1850
Compress Data Block with Enabled Content Independent Encoders
1810
Buffer Encoded Data Block Output From Each Encoder
1812
Count Size of Encoded Data Blocks
1814
Calculate Compression Ratio
1816
Compare Compression Ratios with Threshold Limit
1818
D

FIGURE 18B

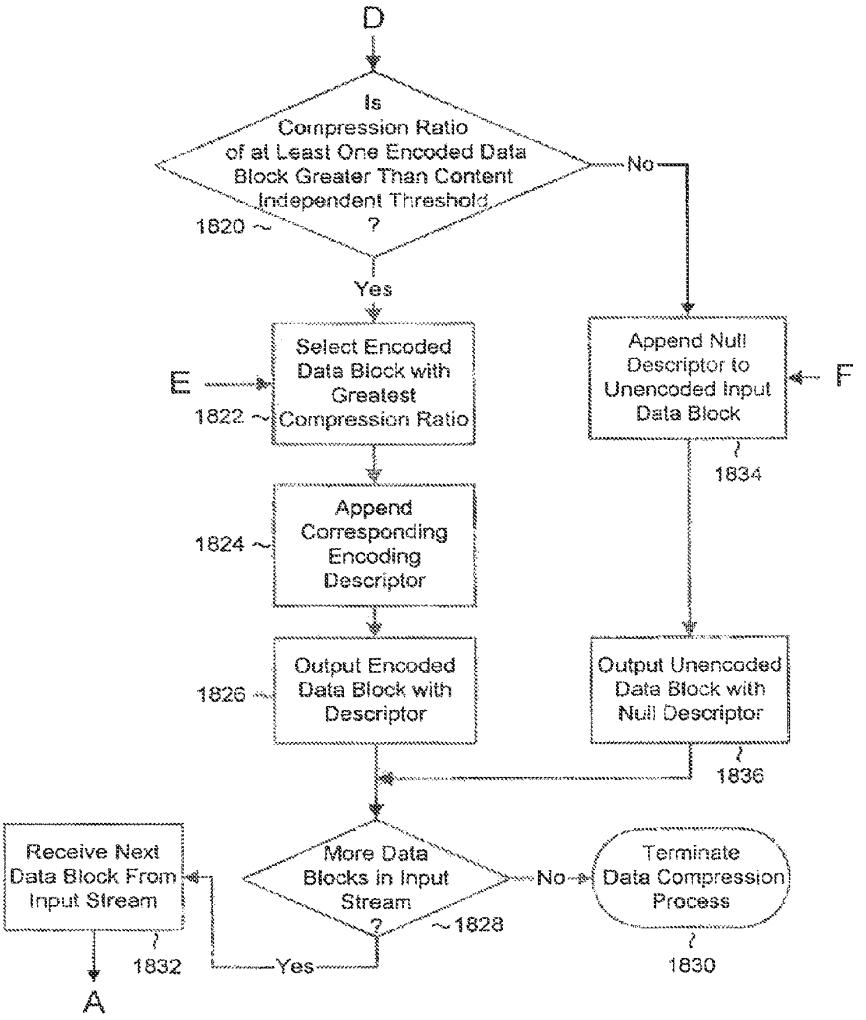

D
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Independent Threshold ?
1820
No
Yes
Select Encoded Data Block with Greatest Compression Ratio
E
1822
Append Null Descriptor to Unencoded Input Data Block
F
1834
Append Corresponding Encoding Descriptor
1824
Output Encoded Data Block with Descriptor
1826
Output Unencoded Data Block with Null Descriptor
1836
Receive Next Data Block From Input Stream
1832
A
More Data Blocks in Input Stream ?
1828
No
Yes
Terminate Data Compression Process
1830

FIGURE 18C

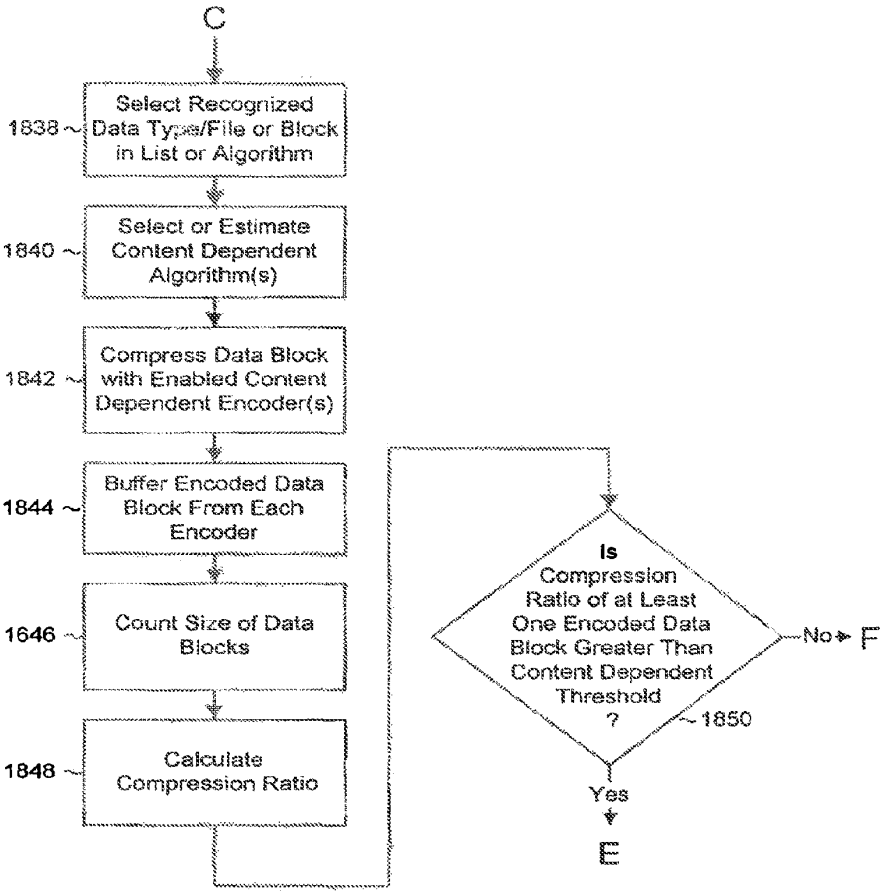

C
1838
Select Recognized Data Type/File or Block in List or Algorithm
1840
Select or Estimate Content Dependent Algorithm(s)
1842
Compress Data Block with Enabled Content Dependent Encoder(s)
1844
Buffer Encoded Data Block From Each Encoder
1646
Count Size of Data Blocks
1848
Calculate Compression Ratio
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Dependent Threshold ?
1850
No
F
Yes
E

FIGURE 18D

DATA COMPRESSION SYSTEMS AND METHODS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Continuation of U.S. patent application Ser. No. 13/154,211, filed Jun. 6, 2011, which is a Continuation of U.S. patent application Ser. No. 12/703,042, filed Feb. 9, 2010, now U.S. Pat. No. 8,502,707, which is a Continuation of both U.S. patent application Ser. No. 11/651,366, filed Jan. 8, 2007, now abandoned, and U.S. patent application Ser. No. 11/651,365, filed Jan. 8, 2007, now U.S. Pat. No. 7,714,747. Each of application Ser. No. 11/651,366 and application Ser. No. 11/651,365 is a Continuation of U.S. patent application Ser. No. 10/668,768, filed Sep. 22, 2003, now U.S. Pat. No. 7,161,506, which is a Continuation of U.S. patent application Ser. No. 10/016,355, filed Oct. 29, 2001, now U.S. Pat. No. 6,624,761, which is a Continuation-In-Part of U.S. patent application Ser. No. 09/705,446, filed Nov. 3, 2000, now U.S. Pat. No. 6,309,424, which is a Continuation of U.S. patent application Ser. No. 09/210,491, filed Dec. 11, 1998, which is now U.S. Pat. No. 6,195,024. Each of the listed applications are incorporated herein by reference in their entireties.

BACKGROUND

1. Technical Field

The present invention relates generally to a data compression and decompression and, more particularly, to systems and methods for data compression using content independent and content dependent data compression and decompression.

2. Description of Related Art

Information may be represented in a variety of manners. Discrete information such as text and numbers are easily represented in digital data. This type of data representation is known as symbolic digital data. Symbolic digital data is thus an absolute representation of data such as a letter, figure, character, mark, machine code, or drawing.

Continuous information such as speech, music, audio, images and video, frequently exists in the natural world as analog information. As is well known to those skilled in the art, recent advances in very large scale integration (VLSI) digital computer technology have enabled both discrete and analog information to be represented with digital data. Continuous information represented as digital data is often referred to as diffuse data. Diffuse digital data is thus a representation of data that is of low information density and is typically not easily recognizable to humans in its native form.

There are many advantages associated with digital data representation. For instance, digital data is more readily processed, stored, and transmitted due to its inherently high noise immunity. In addition, the inclusion of redundancy in digital data representation enables error detection and/or correction. Error detection and/or correction capabilities are dependent upon the amount and type of data redundancy, available error detection and correction processing, and extent of data corruption.

One outcome of digital data representation is the continuing need for increased capacity in data processing, storage, and transmittal. This is especially true for diffuse data where increases in fidelity and resolution create exponentially greater quantities of data. Data compression is widely used to reduce the amount of data required to process, transmit, or store a given quantity of information. In general, there are two

types of data compression techniques that may be utilized either separately or jointly to encode/decode data: lossless and lossy data compression.

Lossy data compression techniques provide for an inexact representation of the original uncompressed data such that the decoded (or reconstructed) data differs from the original unencoded/uncompressed data. Lossy data compression is also known as irreversible or noisy compression. Entropy is defined as the quantity of information in a given set of data. Thus, one obvious advantage of lossy data compression is that the compression ratios can be larger than the entropy limit, all at the expense of information content. Many lossy data compression techniques seek to exploit various traits within the human senses to eliminate otherwise imperceptible data. For example, lossy data compression of visual imagery might seek to delete information content in excess of the display resolution or contrast ratio.

On the other hand, lossless data compression techniques provide an exact representation of the original uncompressed data. Simply stated, the decoded (or reconstructed) data is identical to the original unencoded/uncompressed data. Lossless data compression is also known as reversible or noiseless compression. Thus, lossless data compression has, as its current limit, a minimum representation defined by the entropy of a given data set.

There are various problems associated with the use of lossless compression techniques. One fundamental problem encountered with most lossless data compression techniques are their content sensitive behavior. This is often referred to as data dependency. Data dependency implies that the compression ratio achieved is highly contingent upon the content of the data being compressed. For example, database files often have large unused fields and high data redundancies, offering the opportunity to losslessly compress data at ratios of 5 to 1 or more. In contrast, concise software programs have little to no data redundancy and, typically, will not losslessly compress better than 2 to 1.

Another problem with lossless compression is that there are significant variations in the compression ratio obtained when using a single lossless data compression technique for data streams having different data content and data size. This process is known as natural variation.

A further problem is that negative compression may occur when certain data compression techniques act upon many types of highly compressed data. Highly compressed data appears random and many data compression techniques will substantially expand, not compress this type of data.

For a given application, there are many factors that govern the applicability of various data compression techniques. These factors include compression ratio, encoding and decoding processing requirements, encoding and decoding time delays, compatibility with existing standards, and implementation complexity and cost, along with the is adaptability and robustness to variations in input data. A direct relationship exists in the current art between compression ratio and the amount and complexity of processing required. One of the limiting factors in most existing prior art lossless data compression techniques is the rate at which the encoding and decoding processes are performed. Hardware and software implementation tradeoffs are often dictated by encoder and decoder complexity along with cost.

Another problem associated with lossless compression methods is determining the optimal compression technique for a given set of input data and intended application. To combat this problem, there are many conventional content dependent techniques that may be utilized. For instance, file type descriptors are typically appended to file names to

describe the application programs that normally act upon the data contained within the file. In this manner data types, data structures, and formats within a given file may be ascertained. Fundamental limitations with this content dependent technique include:

(1) the extremely large number of application programs, some of which do not possess published or documented file formats, data structures, or data type descriptors;

(2) the ability for any data compression supplier or consortium to acquire, store, and access the vast amounts of data required to identify known file descriptors and associated data types, data structures, and formats; and

(3) the rate at which new application programs are developed and the need to update file format data descriptions accordingly.

An alternative technique that approaches the problem of selecting an appropriate lossless data compression technique is disclosed, for example, in U.S. Pat. No. 5,467,087 to Chu entitled "High Speed Lossless Data Compression System" ("Chu"). FIG. **1** illustrates an embodiment of this data compression and decompression technique. Data compression **1** comprises two phases, a data pre-compression phase **2** and a data compression phase **3**. Data decompression **4** of a compressed input data stream is also comprised of two phases, a data type retrieval phase **5** and a data decompression phase **6**. During the data compression process **1**, the data pre-compressor **2** accepts an uncompressed data stream, identifies the data type of the input stream, and generates a data type identification signal. The data compressor **3** selects a data compression method from a preselected set of methods to compress the input data stream, with the intention of producing the best available compression ratio for that particular data type.

There are several limitations associated with the Chu method. One such limitation is the need to unambiguously identify various data types. While these might include such common data types as ASCII, binary, or unicode, there, in fact, exists a broad universe of data types that fall outside the three most common data types. Examples of these alternate data types include: signed and unsigned integers of various lengths, differing types and precision of floating point numbers, pointers, other forms of character text, and a multitude of user defined data types. Additionally, data types may be interspersed or partially compressed, making data type recognition difficult and/or impractical. Another limitation is that given a known data type, or mix of data types within a specific set or subset of input data, it may be difficult and/or impractical to predict which data encoding technique yields the highest compression ratio.

Accordingly, there is a need for a data compression system and method that would address limitations in conventional data compression techniques as described above.

SUMMARY OF THE INVENTION

The present invention is directed to systems and methods for providing fast and efficient data compression using a combination of content independent data compression and content dependent data compression. In one aspect of the invention, a method for compressing data comprises the steps of:

analyzing a data block of an input data stream to identify a data type of the data block, the input data stream comprising a plurality of disparate data types;

performing content dependent data compression on the data block, if the data type of the data block is identified;

performing content independent data compression on the data block, if the data type of the data block is not identified.

In another aspect, the step of performing content independent data compression comprises: encoding the data block with a plurality of encoders to provide a plurality of encoded data blocks; determining a compression ratio obtained for each of the encoders; comparing each of the determined compression ratios with a first compression threshold; selecting for output the input data block and appending a null compression descriptor to the input data block, if all of the encoder compression ratios do not meet the first compression threshold; and selecting for output the encoded data block having the highest compression ratio and appending a corresponding compression type descriptor to the selected encoded data block, if at least one of the compression ratios meet the first compression threshold.

In another aspect, the step of performing content dependent compression comprises the steps of: selecting one or more encoders associated with the identified data type and encoding the data block with the selected encoders to provide a plurality of encoded data blocks; determining a compression ratio obtained for each of the selected encoders; comparing each of the determined compression ratios with a second compression threshold; selecting for output the input data block and appending a null compression descriptor to the input data block, if all of the encoder compression do not meet the second compression threshold; and selecting for output the encoded data block having the highest compression ratio and appending a corresponding compression type descriptor to the selected encoded data block, if at least one of the compression ratios meet the second compression threshold.

In yet another aspect, the step of performing content independent data compression on the data block, if the data type of the data block is not identified, comprises the steps of: estimating a desirability of using of one or more encoder types based one characteristics of the data block; and compressing the data block using one or more desirable encoders.

In another aspect, the step of performing content dependent data compression on the data block, if the data type of the data block is identified, comprises the steps of: estimating a desirability of using of one or more encoder types based on characteristics of the data block; and compressing the data block using one or more desirable encoders.

In another aspect, the step of analyzing the data block comprises analyzing the data block to recognize one of a data type, data structure, data block format, file substructure, and/or file types. A further step comprises maintaining an association between encoder types and data types, data structures, data block formats, file substructure, and/or file types.

In yet another aspect of the invention, a method for compressing data comprises the steps of:

analyzing a data block of an input data stream to identify a data type of the data block, the input data stream comprising a plurality of disparate data types;

performing content dependent data compression on the data block, if the data type of the data block is identified;

determining a compression ratio of the compressed data block obtained using the content dependent compression and comparing the compression ratio with a first compression threshold; and

performing content independent data compression on the data block, if the data type of the data block is not identified or if the compression ratio of the compressed data block obtained using the content dependent compression does not meet the first compression threshold.

Advantageously, the present invention employs a plurality of encoders applying a plurality of compression techniques on an input data stream so as to achieve maximum compression in accordance with the real-time or pseudo real-time data

rate constraint. Thus, the output bit rate is not fixed and the amount, if any, of permissible data quality degradation is user or data specified.

These and other aspects, features and advantages of the present invention will become apparent from the following detailed description of preferred embodiments, which is to be read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block/flow diagram of a content dependent high-speed lossless data compression and decompression system/method according to the prior art;

FIG. **2** is a block diagram of a content independent data compression system according to one embodiment of the present invention;

FIGS. **3***a* and **3***b* comprise a flow diagram of a data compression method according to one aspect of the present invention, which illustrates the operation of the data compression system of FIG. **2**;

FIG. **4** is a block diagram of a content independent data compression system according to another embodiment of the present invention having an enhanced metric for selecting an optimal encoding technique;

FIGS. **5***a* and **5***b* comprise a flow diagram of a data compression method according to another aspect of the present invention, which illustrates the operation of the data compression system of FIG. **4**;

FIG. **6** is a block diagram of a content independent data compression system according to another embodiment of the present invention having an a priori specified timer that provides real-time or pseudo real-time of output data;

FIGS. **7***a* and **7***b* comprise a flow diagram of a data compression method according to another aspect of the present invention, which illustrates the operation of the data compression system of FIG. **6**;

FIG. **8** is a block diagram of a content independent data compression system according to another embodiment having an a priori specified timer that provides real-time or pseudo real-time of output data and an enhanced metric for selecting an optimal encoding technique;

FIG. **9** is a block diagram of a content independent data compression system according to another embodiment of the present invention having an encoding architecture comprising a plurality of sets of serially cascaded encoders;

FIGS. **10***a* and **10***b* comprise a flow diagram of a data compression method according to another aspect of the present invention, which illustrates the operation of the data compression system of FIG. **9**;

FIG. **11** is block diagram of a content independent data decompression system according to one embodiment of the present invention;

FIG. **12** is a flow diagram of a data decompression method according to one aspect of the present invention, which illustrates the operation of the data compression system of FIG. **11**;

FIGS. **13***a* and **13***b* comprise a block diagram of a data compression system comprising content dependent and content independent data compression, according to an embodiment of the present invention;

FIGS. **14***a*-**14***d* comprise a flow diagram of a data compression method using both content dependent and content independent data compression, according to one aspect of the present invention;

FIGS. **15***a* and **15***b* comprise a block diagram of a data compression system comprising content dependent and content independent data compression, according to another embodiment of the present invention;

FIGS. **16***a*-**16***d* comprise a flow diagram of a data compression method using both content dependent and content independent data compression, according to another aspect of the present invention;

FIGS. **17***a* and **17***b* comprise a block diagram of a data compression system comprising content dependent and content independent data compression, according to another embodiment of the present invention; and

FIGS. **18***a*-**18***d* comprise a flow diagram of a data compression method using both content dependent and content independent data compression, according to another aspect of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to systems and methods for providing data compression and decompression using content independent and content dependent data compression and decompression. In the following description, it is to be understood that system elements having equivalent or similar functionality are designated with the same reference numerals in the Figures. It is to be further understood that the present invention may be implemented in various forms of hardware, software, firmware, or a combination thereof. In particular, the system modules described herein are preferably implemented in software as an application program that is executable by, e.g., a general purpose computer or any machine or device having any suitable and preferred microprocessor architecture. Preferably, the present invention is implemented on a computer platform including hardware such as one or more central processing units (CPU), a random access memory (RAM), and input/output (I/O) interface(s). The computer platform also includes an operating system and microinstruction code. The various processes and functions described herein may be either part of the microinstruction code or application programs which are executed via the operating system. In addition, various other peripheral devices may be connected to the computer platform such as an additional data storage device and a printing device.

It is to be further understood that, because some of the constituent system components described herein are preferably implemented as software modules, the actual system connections shown in the Figures may differ depending upon the manner in which the systems are programmed. It is to be appreciated that special purpose microprocessors may be employed to implement the present invention. Given the teachings herein, one of ordinary skill in the related art will be able to contemplate these and similar implementations or configurations of the present invention.

Referring now to FIG. **2** a block diagram illustrates a content independent data compression system according to one embodiment of the present invention. The data compression system includes a counter module **10** that receives as input an uncompressed or compressed data stream. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the data block size may be fixed or variable. The counter module **10** counts the size of each input data block (i.e., the data block size is counted in bits, bytes, words, any convenient data multiple or metric, or any combination thereof).

An input data buffer **20**, operatively connected to the counter module **10**, may be provided for buffering the input data stream in order to output an uncompressed data stream in the event that, as discussed in further detail below, every

encoder fails to achieve a level of compression that exceeds an a priori specified minimum compression ratio threshold. It is to be understood that the input data buffer **20** is not required for implementing the present invention.

An encoder module **30** is operatively connected to the buffer **20** and comprises a set of encoders E**1**, E**2**, E**3** . . . En. The encoder set E**1**, E**2**, . . . E**3** . . . En may include any number "n" of those lossless encoding techniques currently well known within the art such as run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. It is to be understood that the encoding techniques are selected based upon their ability to effectively encode different types of input data. It is to be appreciated that a full complement of encoders are preferably selected to provide a broad coverage of existing and future data types.

The encoder module **30** successively receives as input each of the buffered input data blocks (or unbuffered input, data blocks from the counter module **10**). Data compression is performed by the encoder module **30** wherein each of the encoders E**1** . . . En processes a given input data block and outputs a corresponding set of encoded data blocks, It is to be appreciated that the system affords a user the option to enable/disable any one or more of the encoders E**1** . . . En prior to operation. As is understood by those skilled in the art, such feature allows the user to tailor the operation of the data compression system for specific applications. It is to be further appreciated that the is encoding process may be performed either in parallel or sequentially. In particular, the encoders E**1** through En of encoder module **30** may operate in parallel (i.e., simultaneously processing a given input data block by utilizing task multiplexing on a single central processor, via dedicated hardware, by executing on a plurality of processor or dedicated hardware systems, or any combination thereof). In addition, encoders E**1** through En may operate sequentially on a given unbuffered or buffered input data block, This process is intended to eliminate the complexity and additional processing overhead associated with multiplexing concurrent encoding techniques on a single central processor and/or dedicated hardware, set of central processors and/or dedicated hardware, or any achievable combination. It is to be further appreciated that encoders of the identical type may be applied in parallel to enhance encoding speed. For instance, encoder E**1** may comprise two parallel Huffman encoders for parallel processing of an input data block.

A buffer/counter module **40** is operatively connected to the encoding module **30** for buffering and counting the size of each of the encoded data blocks output from encoder module **30**. Specifically, the buffer/counter **30** comprises a plurality of buffer/counters BC**1**, BC**2**, BC**3** . . . BCn, each operatively associated with a corresponding one of the encoders E**1** . . . En. A compression ratio module **50**, operatively connected to the output buffer/counter **40**, determines the compression ratio obtained for each of the enabled encoders E**1** . . . En by taking the ratio of the size of the input data block to the size of the output data block stored in the corresponding buffer/counters BC**1** . . . BCn. In addition, the compression ratio module **50** compares each compression ratio with an a priori-specified compression ratio threshold limit to determine if at least one of the encoded data blocks output from the enabled encoders E**1** . . . En achieves a compression that exceeds an a priori-specified threshold. As is understood by those skilled in the art, the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. A description module **60**, operatively coupled to the compression ratio module **50**, appends a corresponding compression type descriptor to each encoded data block which is selected for output so as to indicate the type of compression format of the encoded data block.

The operation of the data compression system of FIG. **2** will now be discussed in is further detail with reference to the flow diagram of FIGS. **3***a* and **3***b*. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the stream is received (step **300**). As stated above, data compression is performed on a per data block basis. Accordingly, the first input data block in the input data stream is input into the counter module **10** that counts the size of the data block (step **302**). The data block is then stored in the buffer **20** (step **304**). The data block is then sent to the encoder module **30** and compressed by each (enabled) encoder E**1** . . . En (step **306**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **308**), and the encoded data block size is counted (step **310**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10**) to the size of each encoded data block output from the enabled encoders (step **312**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **314**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art.

After the compression ratios are compared with the threshold, a determination is s made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **316**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **316**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **318**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **320**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **316**), then the encoded data block having the greatest compression ratio is selected (step **322**). An appropriate data compression type descriptor is then appended (step **324**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data

compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **326**).

After the encoded data block or the unencoded data input data block is output (steps **326** and **320**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **328**). If the input data stream includes additional data blocks (affirmative result in step **328**), the next successive data block is received (step **330**), its block size is counted (return to step **302**) and the data compression process in repeated. This process is iterated for each data block in the input data stream. Once the final input data block is processed (negative result in step **328**), data compression of the input data stream is finished (step **322**).

Since a multitude of data types may be present within a given input data block, it is often difficult and/or impractical to predict the level of compression that will be achieved by a specific encoder. Consequently, by processing the input data blocks with a plurality of encoding techniques and comparing the compression results, content free data compression is advantageously achieved. It is to be appreciated that this approach is scalable through future generations of processors, dedicated hardware, and software. As processing capacity increases and costs reduce, the benefits provided by the present invention will continue to increase. It should again be noted that the present invention may employ any lossless data encoding technique.

Referring now to FIG. **4**, a block diagram illustrates a content independent data compression system according to another embodiment of the present invention. The data compression system depicted in FIG. **4** is similar to the data compression system of FIG. **2** except that the embodiment of FIG. **4** includes an enhanced metric functionality for selecting an optimal encoding technique. In particular, each of the encoders E**1** . . . En in the encoder module **30** is tagged with a corresponding one of user-selected encoder desirability factors **70**. Encoder desirability is defined as an a priori user specified factor that takes into account any number of user considerations including, but not limited to, compatibility of the encoded data with existing standards, data error robustness, or any other aggregation of factors that the user wishes to consider for a particular application. Each encoded data block output from the encoder module **30** has a corresponding desirability factor appended thereto. A figure of merit module **80**, operatively coupled to the compression ratio module **50** and the descriptor module **60**, is provided for calculating a figure of merit for each of the encoded data blocks which possess a compression ratio greater than the compression ratio threshold limit. The figure of merit for each encoded data block is comprised of a weighted average of the a priori user specified threshold and the corresponding encoder desirability factor. As discussed below in further detail with reference to FIGS. **5***a* and **5***b*, the figure of merit substitutes the a priori user compression threshold limit for selecting and outputting encoded data blocks.

The operation of the data compression system of FIG. **4** will now be discussed in further detail with reference to the flow diagram of FIGS. **5***a* and **5***b*. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the stream is received (step **500**). The size of the first data block is then determined by the counter module **10** (step **502**). The data block is then stored in the buffer **20** (step **504**). The data block is then sent to the encoder module **30** and compressed by each (enabled) encoder in the encoder set E**1** . . . En (step **506**). Each encoded data block processed in the encoder module **30** is tagged with an encoder desirability factor that corresponds the particular encoding technique applied to the encoded data block (step **508**). Upon completion of the encoding of the input data block, an encoded data block with its corresponding desirability factor is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **510**), and the encoded data block size is counted (step **512**).

Next, a compression ratio obtained by each enabled encoder is calculated by taking the ratio of the size of the input data block (as determined by the input counter **10**) to the size of the encoded data block output from each enabled encoder (step **514**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **516**). A determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **518**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **518**), then the original unencoded input data block is selected for output and a null data compression type descriptor (as discussed above) is appended thereto (step **520**). Accordingly, the original unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **522**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **518**), then a figure of merit is calculated for each encoded data block having a compression ratio which exceeds the compression ratio threshold limit (step **524**). Again, the figure of merit for a given encoded data block is comprised of a weighted average of the a priori user specified threshold and the corresponding encoder desirability factor associated with the encoded data block. Next, the encoded data block having the greatest figure of merit is selected for output (step **526**). An appropriate data compression type descriptor is then appended (step **528**) to indicate the data encoding technique applied to the encoded data block. The encoded data block (which has the greatest figure of merit) along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **530**).

After the encoded data block or the unencoded input data block is output (steps **530** and **522**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **532**). If the input data stream includes additional data blocks (affirmative result in step **532**), then the next successive data block is received (step **534**), its block size is counted (return to step **502**) and the data compression process is iterated for each successive data block in the input data stream. Once the final input data block is processed (negative result in step **532**), data compression of the input data stream is finished (step **536**).

Referring now to FIG. **6**, a block diagram illustrates a data compression system according to another embodiment of the present invention. The data compression system depicted in FIG. **6** is similar to the data compression system discussed in detail above with reference to FIG. **2** except that the embodiment of FIG. **6** includes an a priori specified timer that provides real-time or pseudo real-time output data. In particular, an interval timer **90**, operatively coupled to the encoder module **30**, is preloaded with a user specified time value. The role of the interval timer (as will be explained in greater detail below with reference to FIGS. **7***a* and **7***b*) is to limit the processing time for each input data block processed by the encoder module **30** so as to ensure that the real-time, pseudo real-time, or other time critical nature of the data compression processes is preserved.

The operation of the data compression system of FIG. **6** will now be discussed in further detail with reference to the

flow diagram of FIGS. **7***a* and **7***b*. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the data stream is received (step **700**), and its size is determined by the counter module **10** (step **702**). The data block is then stored in buffer **20** (step **704**).

Next, concurrent with the completion of the receipt and counting of the first data block, the interval timer **90** is initialized (step **706**) and starts counting towards a user-specified time limit. The input data block is then sent to the encoder module **30** wherein data compression of the data block by each (enabled) encoder E**1** . . . En commences (step **708**). Next, a determination is made as to whether the user specified time expires before the completion of the encoding process (steps **710** and **712**). If the encoding process is completed before or at the expiration of the timer, i.e., each encoder (E**1** through En) completes its respective encoding process (negative result in step **710** and affirmative result in step **712**), then an encoded data block is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **714**).

On the other hand, if the timer expires (affirmative result in **710**), the encoding process is halted (step **716**). Then, encoded data blocks from only those enabled encoders E**1** . . . En that have completed the encoding process are selected and maintained in buffers (step **718**). It is to be appreciated that it is not necessary (or in some cases desirable) that some or all of the encoders complete the encoding process before the interval timer expires. Specifically, due to encoder data dependency and natural variation, it is possible that certain encoders may not operate quickly enough and, therefore, do not comply with the timing constraints of the end use. Accordingly, the time limit ensures that the real-time or pseudo real-time nature of the data encoding is preserved.

After the encoded data blocks are buffered (step **714** or **718**), the size of each encoded data block is counted (step **720**). Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10**) to the size of the encoded data block output from each enabled encoder (step **722**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **724**). A determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **726**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **726**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **728**). The original unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **730**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **726**), then the encoded data block having the greatest compression ratio is selected (step **732**). An appropriate data compression type descriptor is then appended (step **734**). The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **736**).

After the encoded data block or the unencoded input data block is output (steps **730** or **736**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **738**). If the input data stream includes additional data blocks (affirmative result in step **738**), the next successive data block is received (step **740**), its block size is counted (return to step **702**) and the data compression process in repeated. This process is iterated for each data block in the input data stream, with each data block being processed within the user-specified time limit as discussed above. Once the final input data block is processed (negative result in step **738**), data compression of the input data stream is complete (step **742**).

Referring now to FIG. **8**, a block diagram illustrates a content independent data compression system according to another embodiment of the present system. The data compression system of FIG. **8** incorporates all of the features discussed above in connection with the system embodiments of FIGS. **2**, **4**, and **6**. For example, the system of FIG. **8** incorporates both the a priori specified timer for providing real-time or pseudo real-time of output data, as well as the enhanced metric for selecting an optimal encoding technique. Based on the foregoing discussion, the operation of the system of FIG. **8** is understood by those skilled in the art.

Referring now to FIG. **9**, a block diagram illustrates a data compression system according to a preferred embodiment of the present invention. The system of FIG. **9** contains many of the features of the previous embodiments discussed above. However, this embodiment advantageously includes a cascaded encoder module **30***c* having an encoding architecture comprising a plurality of sets of serially cascaded encoders Em,n, where "m" refers to the encoding path (i.e., the encoder set) and where "n" refers to the number of encoders in the respective path. It is to be understood that each set of serially cascaded encoders can include any number of disparate and/or similar encoders (i.e., n can be any value for a given path m).

The system of FIG. **9** also includes a output buffer module **40***c* which comprises a plurality of buffer/counters B/Cm,n, each associated with a corresponding one of the encoders Em,n. In this embodiment, an input data block is sequentially applied to successive encoders (encoder stages) in the encoder path so as to increase the data compression ratio. For example, the output data block from a first encoder E**1**,**1**, is buffered and counted in B/C**1**,**1**, for subsequent processing by a second encoder E**1**,**2**. Advantageously, these parallel sets of sequential encoders are applied to the input data stream to effect content free lossless data compression. This embodiment provides for multi-stage sequential encoding of data with the maximum number of encoding steps subject to the available real-time, pseudo real-time, or other timing constraints.

As with each previously discussed embodiment, the encoders Em,n may include those lossless encoding techniques currently well known within the art, including: run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. Encoding techniques are selected based upon their ability to effectively encode different types of input data. A full complement of encoders provides for broad coverage of existing and future data types. The input data blocks may be applied simultaneously to the encoder paths (i.e., the encoder paths may operate in parallel, utilizing task multiplexing on a single central processor, or via dedicated hardware, or by executing on a plurality of processor or dedicated hardware systems, or any combination thereof). In addition, an input data block may be sequentially applied to the encoder paths. Moreover, each serially cascaded encoder path may comprise a fixed (predetermined) sequence of encoders or a random sequence of encoders. Advantageously, by simultaneously or sequen-

tially processing input data blocks via a plurality of sets of serially cascaded encoders, content free data compression is achieved.

The operation of the data compression system of FIG. **9** will now be discussed in further detail with reference to the flow diagram of FIGS. **10***a* and **10***b*. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the data stream is received (step **100**), and its size is determined by the counter module **10** (step **102**). The data block is then stored in buffer **20** (step **104**).

Next, concurrent with the completion of the receipt and counting of the first data block, the interval timer **90** is initialized (step **106**) and starts counting towards a user-specified time limit. The input data block is then sent to the cascade encoder module **30**C wherein the input data block is applied to the first encoder (i.e., first encoding stage) in each of the cascaded encoder paths E**1**,**1** . . . Em,**1** (step **108**). Next, a determination is made as to whether the user specified time expires before the completion of the first stage encoding process (steps **110** and **112**). If the first stage encoding process is completed before the expiration of the timer, i.e., each encoder (E**1**,**1** . . . Em,**1**) completes its respective encoding process (negative result in step **110** and affirmative result in step **112**), then an encoded data block is output from each encoder E**1**,**1** . . . Em,**1** and maintained in a corresponding buffer (step **114**). Then for each cascade encoder path, the output of the completed encoding stage is applied to the next successive encoding stage in the cascade path (step **116**). This process (steps **110**, **112**, **114**, and **116**) is repeated until the earlier of the timer expiration (affirmative result in step **110**) or the completion of encoding by each encoder stage in the serially cascaded paths, at which time the encoding process is halted (step **118**).

Then, for each cascade encoder path, the buffered encoded data block output by the last encoder stage that completes the encoding process before the expiration of the timer is selected for further processing (step **120**). Advantageously, the interim stages of the multi-stage data encoding process are preserved. For example, the results of encoder E**1**,**1** are preserved even after encoder E**1**,**2** begins encoding the output of encoder E**1**,**1**. If the interval timer expires after encoder E**1**,**1** completes its respective encoding process but before encoder E**1**,**2** completes its respective encoding process, the encoded data block from encoder E**1**,**1** is complete and is utilized for calculating the compression ratio for the corresponding encoder path. The incomplete encoded data block from encoder E**1**,**2** is either discarded or ignored.

It is to be appreciated that it is not necessary (or in some cases desirable) that some or all of the encoders in the cascade encoder paths complete the encoding process before the interval timer expires. Specifically, due to encoder data dependency, natural variation and the sequential application of the cascaded encoders, it is possible that certain encoders may not operate quickly enough and therefore do not comply with the timing constraints of the end use. Accordingly, the time limit, ensures that the real-time or pseudo real-time nature of the data encoding is preserved.

After the encoded data blocks are selected (step **120**), the size of each encoded data block is counted (step **122**). Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10**) to the size of the encoded data block output from each encoder (step **124**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **126**). A determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **128**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **128**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **130**). The original unencoded data block and its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **132**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **128**), then a figure of merit is calculated for each encoded data block having a compression ratio which exceeds the compression ratio threshold limit (step **134**). Again, the figure of merit for a given encoded data block is comprised of a weighted average of the a priori user specified threshold and the corresponding encoder desirability factor associated with the encoded data block. Next, the encoded data block having the greatest figure of merit is selected (step **136**). An appropriate data compression type descriptor is then appended (step **138**) to indicate the data encoding technique applied to the encoded data block. For instance, the data type compression descriptor can indicate that the encoded data block was processed by either a single encoding type, a plurality of sequential encoding types, and a plurality of random encoding types. The encoded data block (which has the greatest figure of merit) along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **140**).

After the unencoded data block or the encoded data input data block is output (steps **132** and **140**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **142**). If the input data stream includes additional data blocks (affirmative result in step **142**), then the next successive data block is received (step **144**), its block size is counted (return to step **102**) and the data compression process is iterated for each successive data block in the input data stream. Once the final input data block is processed (negative result in step **142**), data compression of the input data stream is finished (step **146**).

Referring now to FIG. **11**, a block diagram illustrates a data decompression system according to one embodiment of the present invention. The data decompression system preferably includes an input buffer **1100** that receives as input an uncompressed or compressed data stream comprising one or more data blocks. The data blocks may range in size from individual bits through complete files or collections of multiple files. Additionally, the data block size may be fixed or variable. The input data buffer **1100** is preferably included (not required) to provide storage of input data for various hardware implementations. A descriptor extraction module **1102** receives the buffered (or unbuffered) input data block and then parses, lexically, syntactically, or otherwise analyzes the input data block using methods known by those skilled in the art to extract the data compression type descriptor associated with the data block. The data compression type descriptor may possess values corresponding to null (no encoding applied), a single applied encoding technique, or multiple encoding techniques applied in a specific or random order (in accordance with the data compression system embodiments and methods discussed above).

A decoder module **1104** includes a plurality of decoders D**1** . . . Dn for decoding the input data block using a decoder, set of decoders, or a sequential set of decoders corresponding to the extracted compression type descriptor. The decoders D**1** . . . Dn may include those lossless encoding techniques

currently well known within the art, including: run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. Decoding techniques are selected based upon their ability to effectively decode the various different types of encoded input data generated by the data compression systems described above or originating from any other desired source. As with the data compression systems discussed above, the decoder module **1104** may include multiple decoders of the same type applied in parallel so as to reduce the data decoding time.

The data decompression system also includes an output data buffer **1106** for buffering the decoded data block output from the decoder module **1104**.

The operation of the data decompression system of FIG. **11** will be discussed in further detail with reference to the flow diagram of FIG. **12**. A data stream comprising one or more data blocks of compressed or uncompressed data is input into the data decompression system and the first data block in the stream is received (step **1200**) and maintained in the buffer (step **1202**). As with the data compression systems discussed above, data decompression is performed on a per data block basis. The data compression type descriptor is then extracted from the input data block (step **1204**). A determination is then made as to whether the data compression type descriptor is null (step **1206**). If the data compression type descriptor is determined to be null (affirmative result in step **1206**), then no decoding is applied to the input data block and the original undecoded data block is output (or maintained in the output buffer) (step **1208**).

On the other hand, if the data compression type descriptor is determined to be any value other than null (negative result in step **1206**), the corresponding decoder or decoders are then selected (step **1210**) from the available set of decoders D**1** . . . Dn in the decoding module **1104**. It is to be understood that the data compression type descriptor may mandate the application of: a single specific decoder, an ordered sequence of specific decoders, a random order of specific decoders, a class or family of decoders, a mandatory or optional application of parallel decoders, or any combination or permutation thereof. The input data block is then decoded using the selected decoders (step **1212**), and output (or maintained in the output buffer **1106**) for subsequent data processing, storage, or transmittal (step **1214**). A determination is then made as to whether the input data stream contains additional data blocks to be processed (step **1216**). If the input data stream includes additional data blocks (affirmative result in step **1216**), the next successive data block is received (step **1220**), and buffered (return to step **1202**). Thereafter, the data decompression process is iterated for each data block in the input data stream. Once the final input data block is processed (negative result in step **1216**), data decompression of the input data stream is finished (step **1218**).

In other embodiments of the present invention described below, data compression is achieved using a combination of content dependent data compression and content independent data compression. For example, FIGS. **13***a* and **13***b* are block diagrams illustrating a data compression system employing both content independent and content dependent data compression according to one embodiment of the present invention, wherein content independent data compression is applied to a data block when the content of the data block cannot be identified or is not associable with a specific data compression algorithm. The data compression system comprises a counter module **10** that receives as input an uncompressed or compressed data stream. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the data block size may be fixed or variable. The counter module **10** counts the size of each input data block (i.e., the data block size is counted in bits, bytes, words, any convenient data multiple or metric, or any combination thereof).

An input data buffer **20**, operatively connected to the counter module **10**, may be provided for buffering the input data stream in order to output an uncompressed data stream in the event that, as discussed in further detail below, every encoder fails to achieve a level of compression that exceeds a priori specified content independent or content dependent minimum compression ratio thresholds. It is to be understood that the input data buffer **20** is not required for implementing the present invention.

A content dependent data recognition module **1300** analyzes the incoming data stream to recognize data types, data structures, data block formats, file substructures, file types, and/or any other parameters that may be indicative of either the data type/content of a given data block or the appropriate data compression algorithm or algorithms (in serial or in parallel) to be applied. Optionally, a data file recognition list(s) or algorithm(s) **1310** module may be employed to hold and/or determine associations between recognized data parameters and appropriate algorithms. Each data block that is recognized by the content data compression module **1300** is routed to a content dependent encoder module **1320**, if not the data is routed to the content independent encoder module **30**.

A content dependent encoder module **1320** is operatively connected to the content dependent data recognition module **1300** and comprises a set of encoders D**1**, D**2**, D**3** . . . Dm. The encoder set D**1**, D**2**, D**3** . . . Dm may include any number "n" of those lossless or lossy encoding techniques currently well known within the art such as MPEG4, various voice codecs, MPEG3, AC3, AAC, as well as lossless algorithms such as run length, Huffinan, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. It is to be understood that the encoding techniques are selected based upon their ability to effectively encode different types of input data. It is to be appreciated that a full complement of encoders and or codecs are preferably selected to provide a broad coverage of existing and future data types.

The content independent encoder module **30**, which is operatively connected to the content dependent data recognition module **1300**, comprises a set of encoders E**1**, E**2**, E**3** . . . En. The encoder set E**1**, E**2**, E**3** . . . En may include any number "n" of those lossless encoding techniques currently well known within the art such as run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. Again, it is to be understood that the encoding techniques are selected based upon their ability to effectively encode different types of input data. It is to be appreciated that a full complement of encoders are preferably selected to provide a broad coverage of existing and future data types.

The encoder modules (content dependent **1320** and content independent **30**) selectively receive the buffered input data blocks (or unbuffered input data blocks from the counter module **10**) from module **1300** based on the results of recognition. Data compression is performed by the respective encoder modules wherein some or all of the encoders D**1** . . . Dm or E**1** . . . En processes a given input data block and outputs a corresponding set of encoded data blocks. It is to be appreciated that the system affords a user the option to enable/disable any one or more of the encoders D**1** . . . Dm and E**1** . . . En prior to operation. As is understood by those skilled in the art, such feature allows the user to tailor the operation

of the data compression system for specific applications. It is to be further appreciated that the encoding process may be performed either in parallel or sequentially. In particular, the encoder set D**1** through Dm of encoder module **1320** and/or the encoder set E**1** through En of encoder module **30** may operate in parallel (i.e., simultaneously processing a given input data block by utilizing task multiplexing on a single central processor, via dedicated hardware, by executing on a plurality of processor or dedicated hardware systems, or any combination thereof). In addition, encoders D**1** through Dm and E**1** through Fn may operate sequentially on a given unbuffered or buffered input data block. This process is intended to eliminate the complexity and additional processing overhead associated with multiplexing concurrent encoding techniques on a single central processor and/or dedicated hardware, set of central processors and/or dedicated hardware, or any achievable combination. It is to be further appreciated that encoders of the identical type may be applied in parallel to enhance encoding speed. For instance, encoder E**1** may comprise two parallel Huffman encoders for parallel processing of an input data block. It should be further noted that one or more algorithms may be implemented in dedicated hardware such as an MPEG4 or MP3 encoding integrated circuit.

Buffer/counter modules **1330** and **40** are operatively connected to their respective encoding modules **1320** and **30**, for buffering and counting the size of each of the encoded data blocks output from the respective encoder modules. Specifically, the content dependent buffer/counter **1330** comprises a plurality of buffer/counters BCD**1**, BCD**2**, BCD**3** . . . BCDm, each operatively associated with a corresponding one of the encoders D**1** . . . Dm. Similarly the content independent buffer/counters BCE**1**, BCE**2**, BCE**3** . . . BCEn, each operatively associated with a corresponding one of the encoders E**1** . . . En. A compression ratio module **1340**, operatively connected to the content dependent output buffer/counters **1330** and content independent buffer/counters **40** determines the compression ratio obtained for each of the enabled encoders D**1** . . . Dm and or E**1** . . . En by taking the ratio of the size of the input data block to the size of the output data block stored in the corresponding buffer/counters BCD**1**, BCD**2**, BCD**3** . . . BCDm and or BCE**1**, BCE**2**, BCE**3** . . . BCEn. In addition, the compression ratio module **1340** compares each compression ratio with an a priori-specified compression ratio threshold limit to determine if at least one of the encoded data blocks output from the enabled encoders BCD**1**, BCD**2**, BCD**3** . . . BCDm and or BCE**1**, BCE**2**, BCE**3** . . . BCEn achieves a compression that meets an a priori-specified threshold. As is. understood by those skilled in the art, the threshold limit maybe specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It should be noted that different threshold values may be applied to content dependent and content independent encoded data. Further these thresholds may be adaptively modified based upon enabled encoders in either or both the content dependent or content independent encoder sets, along with any associated parameters. A compression type description module **1350**, operatively coupled to the compression ratio module **1340**, appends a corresponding compression type descriptor to each encoded data block which is selected for output so as to indicate the type of compression format of the encoded data block.

A mode of operation of the data compression system of FIGS. **13***a* and **13***b* will now be discussed with reference to the flow diagrams of FIGS. **14***a*-**14***d* which illustrates a method for performing data compression using a combination of content dependent and content independent data compression. In general, content independent data compression is applied to a given data block when the content of a data block cannot be identified or is not associated with a specific data compression algorithm. More specifically, referring to FIG. **14***a*, a data stream comprising one or more data blocks is input into the data compression system and the first data block in the stream is received (step **1400**). As stated above, data compression is performed on a per data block basis. As previously stated a data block may represent any quantity of data from a single bit through a multiplicity of files or packets and may vary from block to block. Accordingly, the first input data block in the input data stream is input into the counter module **10** that counts the size of the data block (step **1402**). The data block is then stored in the buffer **20** (step **1404**). The data block is then analyzed on a per block or multi-block basis by the content dependent data recognition module **1300** (step **1406**). If the data stream content is not recognized utilizing the recognition list(s) or algorithms(s) module **1310** (step **1408**) the data is routed to the content independent encoder module **30** and compressed by each (enabled) encoder E**1** . . . En (step **1410**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **1412**), and the encoded data block size is counted (step **1414**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1416**). Each compression ratio is then compared with an apriori-specified compression ratio threshold (step **1418**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1420**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1420**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **1434**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1436**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **1420**), then the encoded data block having the greatest compression ratio is selected (step **1422**). An appropriate data compression type descriptor is then appended (step **1424**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique

has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1426**).

As previously stated the data block stored in the buffer **20** (step **1404**) is analyzed on a per block or multi-block basis by the content dependent data recognition module **1300** (step **1406**). If the data stream content is recognized utilizing the recognition list(s) or algorithms(s) module **1310** (step **1434**) the appropriate content dependent algorithms are enabled and initialized (step **1436**), and the data is routed to the content dependent encoder module **1320** and compressed by each (enabled) encoder D**1** . . . Dm (step **1438**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder D**1** . . . Dm and maintained in a corresponding buffer (step **1440**), and the encoded data block size is counted (step **1442**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1444**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **1448**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that many of these algorithms may be lossy, and as such the limits may be subject to or modified by an end target storage, listening, or viewing device. Further notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1420**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1420**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **1434**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1436**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **1420**), then the encoded data block having the greatest compression ratio is selected (step **1422**). An appropriate data compression type descriptor is then appended (step **1424**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1426**).

After the encoded data block or the unencoded data input data block is output (steps **1426** and **1436**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **1428**). If the input data stream includes additional data blocks (affirmative result in step **1428**), the next successive data block is received (step **1432**), its block size is counted (return to step **1402**) and the data compression process in repeated. This process is iterated for each data block in the input data stream. Once the final input data block is processed (negative result in step **1428**), data compression of the input data stream is finished (step **1430**).

Since a multitude of data types may be present within a given input data block, it is often difficult and/or impractical to predict the level of compression that will be achieved by a specific encoder. Consequently, by processing the input data blocks with a plurality of encoding techniques and comparing the compression results, content free data compression is advantageously achieved. Further the encoding may be lossy or lossless dependent upon the input data types. Further if the data type is not recognized the default content independent lossless compression is applied. It is not a requirement that this process be deterministic—in fact a certain probability may be applied if occasional data loss is permitted. It is to be appreciated that this approach is scalable through future generations of processors, dedicated hardware, and software. As processing capacity increases and costs reduce, the benefits provided by the present invention will continue to increase. It should again be noted that the present invention may employ any lossless data encoding technique.

FIGS. **15***a* and **15***b* are block diagrams illustrating a data compression system employing both content independent and content dependent data compression according to another embodiment of the present invention. The system in FIGS. **15***a* and **15***b* is similar in operation to the system of FIGS. **13***a* and **13***b* in that content independent data compression is applied to a data block when the content of the data block cannot be identified or is not associable with a specific data compression algorithm. The system of FIGS. **15***a* and **15***b* additionally performs content independent data compression on a data block when the compression ratio obtained for the data block using the content dependent data compression does not meet a specified threshold.

A mode of operation of the data compression system of FIGS. **15***a* and **15***b* will now be discussed with reference to the flow diagram of FIGS. **16***a*-**16***d*, which illustrates a method for performing data compression using a combination of content dependent and content independent data compression. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the stream is received (step **1600**). As stated above, data compression is performed on a per data block basis. As previously stated a data block may represent any quantity of data from a single bit through a multiplicity of files or packets and may vary from block to block. Accordingly, the first input data block in the input data stream is input into the counter module **10** that counts the size of the data block (step **1602**). The data block is then stored in the buffer **20** (step **1604**). The data block is then analyzed on a per block or multi-block basis

by the content dependent data recognition module **1300** (step **1606**). If the data stream content is not recognized utilizing the recognition list(s) or algorithms(s) module **1310** (step **1608**) the data is routed to the content independent encoder module **30** and compressed by each (enabled) encoder E**1** . . . En (step **1610**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **1612**), and the encoded data block size is counted (step **1614**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1616**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **1618**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1620**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1620**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **1634**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1636**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **1620**), then the encoded data block having the greatest compression ratio is selected (step **1622**). An appropriate data compression type descriptor is then appended (step **1624**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1626**).

As previously stated the data block stored in the buffer **20** (step **1604**) is analyzed on a per block or multi-block basis by the content dependent data recognition module **1300** (step **1606**). If the data stream content is recognized utilizing the recognition list(s) or algorithms(s) module **1310** (step **1634**) the appropriate content dependent algorithms are enabled and initialized (step **1636**) and the data is routed to the content dependent encoder module **1620** and compressed by each (enabled) encoder D**1** . . . Dm (step **1638**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder D**1** . . . Dm and maintained in a corresponding buffer (step **1640**), and the encoded data block size is counted (step **1642**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1644**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **1648**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that many of these algorithms may be lossy, and as such the limits may be subject to or modified by an end target storage, listening, or viewing device. Further notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1648**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1620**), then the original unencoded input data block is routed to the content independent encoder module **30** and the process resumes with compression utilizing content independent encoders (step **1610**).

After the encoded data block or the unencoded data input data block is output (steps **1626** and **1636**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **1628**). If the input data stream includes additional data blocks (affirmative result in step **1628**), the next successive data block is received (step **1632**), its block size is counted (return to step **1602**) and the data compression process in repeated. This process is iterated for each data block in the input data stream. Once the final input data block is processed (negative result in step **1628**), data compression of the input data stream is finished (step **1630**).

FIGS. **17***a* and **17***b* are block diagrams illustrating a data compression system employing both content independent and content dependent data compression according to another embodiment of the present invention. The system in FIGS. **17***a* and **17***b* is similar in operation to the system of FIGS. **13***a* and **13***b* in that content independent data compression is applied to a data block when the content of the data Nock cannot be identified or is not associable with a specific data compression algorithm. The system of FIGS. **17***a* and **17***b* additionally uses a priori estimation algorithms or look-up tables to estimate the desirability of using content independent data compression encoders and/or content dependent data compression encoders and selecting appropriate algorithms or subsets thereof based on such estimation.

More specifically, a content dependent data recognition and or estimation module **1700** is utilized to analyze the incoming data stream for recognition of data types, data stric-

tures, data block formats, file substructures, file types, or any other parameters that may be indicative of the appropriate data compression algorithm or algorithms (in serial or in parallel) to be applied. Optionally, a data file recognition list(s) or algorithm(s) **1710** module may be employed to hold associations between recognized data parameters and appropriate algorithms. If the content data compression module recognizes a portion of the data, that portion is routed to the content dependent encoder module **1320**, if not the data is routed to the content independent encoder module **30**. It is to be appreciated that process of recognition (modules **1700** and **1710**) is not limited to a deterministic recognition, but may further comprise a probabilistic estimation of which encoders to select for compression from the set of encoders of the content dependent module **1320** or the content independent module **30**. For example, a method may be employed to compute statistics of a data block whereby a determination that the locality of repetition of characters in a data stream is determined is high can suggest a text document, which may be beneficially compressed with a lossless dictionary type algorithm. Further the statistics of repeated characters and relative frequencies may suggest a specific type of dictionary algorithm. Long strings will require a wide dictionary file while a wide diversity of strings may suggest a deep dictionary. Statistics may also be utilized in algorithms such as Huffman where various character statistics will dictate the choice of different Huffinan compression tables. This technique is not limited to lossless algorithms but may be widely employed with lossy algorithms. Header information in frames for video files can imply a specific data resolution. The estimator then may select the appropriate lossy compression algorithm and compression parameters (amount of resolution desired). As shown in previous embodiments of the present invention, desirability of various algorithms and now associated resolutions with lossy type algorithms may also be applied in the estimation selection process.

A mode of operation of the data compression system of FIGS. **17***a* and **17***b* will now be discussed with reference to the flow diagrams of FIGS. **18***a*-**18***d*. The method of FIGS. **18***a*-**18***d* use a priori estimation algorithms or look-up tables to estimate the desirability or probability of using content independent data compression encoders or content dependent data compression encoders, and select appropriate or desirable algorithms or subsets thereof based on such estimates. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the stream is received (step **1800**). As stated above, data compression is performed on a per data block basis. As previously stated a data block may represent any quantity of data from a single bit through a multiplicity of files or packets and may vary from block to block. Accordingly, the first input data block in the input data stream is input into the counter module **10** that counts the size of the data block (step **1802**). The data block is then stored in the buffer **20** (step **1804**). The data block is then analyzed on a per block or multi-block basis by the content dependent/content independent data recognition module **1700** (step **1806**). If the data stream content is not recognized utilizing the recognition list(s) or algorithms(s) module **1710** (step **1808**) the data is to the content independent encoder module **30**. An estimate of the best content independent encoders is performed (step **1850**) and the appropriate encoders are enabled and initialized as applicable. The data is then compressed by each (enabled) encoder E**1** . . . En (step **1810**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **1812**), and the encoded data block size is counted (step **1814**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1816**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **1818**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1820**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1820**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **1834**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1836**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **1820**), then the encoded data block having the greatest compression ratio is selected (step **1822**). An appropriate data compression type descriptor is then appended (step **1824**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1826**).

As previously stated the data block stored in the buffer **20** (step **1804**) is analyzed on a per block or multi-block basis by the content dependent data recognition module **1300** (step **1806**). If the data stream content is recognized or estimated utilizing the recognition list(s) or algorithms(s) module **1710** (affirmative result in step **1808**) the recognized data type/file or block is selected based on a list or algorithm (step **1838**) and an estimate of the desirability of using the associated content dependent algorithms can be determined (step **1840**). For instance, even though a recognized data type may be associated with three different encoders, an estimation of the desirability of using each encoder may result in only one or two of the encoders being actually selected for use. The data

is routed to the content dependent encoder module **1320** and compressed by each (enabled) encoder D1 . . . Dm (step **1842**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder D1 . . . Dm and maintained in a corresponding buffer (step **1844**), and the encoded data block size is counted (step **1846**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1848**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **1850**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that many of these algorithms may be lossy, and as such the limits may be subject to or modified by an end target storage, listening, or viewing device. Further notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1820**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1820**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **1834**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1836**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **1820**), then the encoded data block having the greatest compression ratio is selected (step **1822**). An appropriate data compression type descriptor is then appended (step **1824**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1826**).

After the encoded data block or the unencoded data input data block is output (steps **1826** and **1836**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **1828**). If the input data stream includes additional data blocks (affirmative result in step **1428**), the next successive data block is received (step **1832**), its block size is counted (return to step **1802**) and the data compression process in repeated. This process is iterated for each data block in the input data stream. Once the final input data block is processed (negative result in step **1828**), data compression of the input data stream is finished (step **1830**).

It is to be appreciated that in the embodiments described above with reference to FIGS. **13-18**, an a priori specified time limit or any other real-time requirement may be employed to achieve practical and efficient real-time operation.

Although illustrative embodiments have been described herein with reference to the accompanying drawings, it is to be understood that the present invention is not limited to those precise embodiments, and that various other changes and modifications may be affected therein by one skilled in the art without departing from the scope or spirit of the invention. All such changes and modifications are intended to be included within the scope of the invention as defined by the appended claims.

What is claimed is:

1. A method of decompressing in a data decompression engine one or more compressed data blocks included in one or more data packets, the one or more data packets being transmitted in sequence from one of an internal or an external source to the data decompression engine, wherein a data packet from among the one or more data packets comprises a header containing control information followed by one or more compressed data blocks of the data packet,the method comprising:

applying a plurality of decompression techniques to the one or more compressed data blocks using the data decompression engine;

identifying one or more associated recognizable data tokens of the data packet;

wherein the one or more associated recognizable data tokens identifies a selected compression encoder used to compress the one or more compressed data blocks associated with the data packet; and

wherein the selected compression encoder was selected based on content of a data block on which a compression algorithm was applied to provide the compressed data block;

applying one or more decompression decoders to the compressed data block corresponding to the data packet based on the one or more associated recognizable data tokens;

decompressing the compressed data block with an appropriate decompression decoder if the one or more associated recognizable data tokens indicates that the data block was encoded utilizing content dependent data compression; and

decompressing the compressed data block with an appropriate decompression decoder if the one or more associated recognizable data tokens indicates that the data block was encoded utilizing content independent data compression.

2. The method of claim **1**, wherein the decompressing is performed by an entity different than the compression encoder performing the compression.

3. The method of claim **1**, wherein the one or more recognizable data tokens include values corresponding to one or more decoding techniques to be applied by the one or more decompression decoders.

4. The method of claim **1**, wherein the step of decompressing the compressed data block with the appropriate decompression decoder, when the one or more recognizable data tokens indicate that the compressed data block was encoded

utilizing content independent data compression occurs prior to the step of decompressing the compressed data block with the appropriate decompression decoder, when the one or more recognizable data tokens indicate that the compressed data block was encoded utilizing content dependent data compression.

5. The method of claim **1**, wherein:

the applying the one or more data compression decoders includes applying a plurality of data compression decoders; and

the applying the one or more decompression decoders further includes applying a plurality of the one or more decompression decoders to decompress a plurality of compressed data blocks from among the one or more compressed data blocks corresponding to the data packet.

6. The method of claim **5**, wherein the applying the one or more decompression decoders further includes:

applying a plurality of the one or more decompression decoders to decompress a plurality of the one or more data packets to provide a plurality of decompressed data packets.

7. The method of claim **6**, further comprising:

generating one or more decompressed data blocks in sequence from the plurality of decompressed data packets.

8. The method of claim **1**, wherein the method of decompressing the one or more compressed data blocks is performed in real-time.

9. The method of claim **1**, wherein the one or more decompression decoders and their associated compression encoders utilize techniques to permit data that was selected and compressed by the selected compression encoder to be fully recovered when decompressed by the one or more decompression decoders.

10. The method of claim **1**, wherein the one or more decompression decoders and their associated compression encoders utilize lossy techniques.

11. The method of claim **1**, wherein the appropriate decompression decoder selected when the one or more recognizable data tokens indicate that the compressed data block was encoded utilizing content independent data compression applies a different decompression algorithm than the appropriate decompression decoder selected when the one or more recognizable data tokens indicate that the compressed data block was encoded utilizing content dependent data compression.

12. The method of claim **1**, wherein the appropriate decompression decoder selected when the one or more recognizable data tokens indicate that the compressed data block was encoded utilizing content independent data compression applies the same decompression algorithm than the appropriate decompression decoder selected when the one or more recognizable data tokens indicate that the compressed data block was encoded utilizing content dependent data compression.

13. The method of claim **1**, wherein the appropriate decompression decoder selected when the one or more recognizable data tokens indicate that the compressed data block was encoded utilizing content independent data compression is the same decompression decoder as the appropriate decompression decoder selected when the one or more recognizable data tokens indicate that the compressed data block was encoded utilizing content dependent data compression.

14. A system for decompressing, one or more compressed data blocks included in one or more data packets using a data decompression engine, the one or more data packets being transmitted in sequence from a source that is internal or external to the data decompression engine, wherein a data packet from among the one or more data packets comprises a header containing control information followed by one or more compressed data blocks of the data packet the system comprising:

a data decompression processor configured to analyze the data packet to identify one or more recognizable data tokens associated with the data packet, the one or more recognizable data identifying a selected encoder used to compress one or more data blocks to provide the one or more compressed data blocks, the encoder being selected based on content of the one or more data blocks on which a compression algorithm was applied;

one or more decompression decoders configured to decompress a compressed data block from among the one or more compressed data blocks associated with the data packet based on the one or more recognizable data tokens; wherein:

the one or more decompression decoders are further configured to decompress the compressed data block utilizing content dependent data decompression to provide a first decompressed data block when the one or more recognizable data tokens indicate that the data block was encoded utilizing content dependent data compression; and

the one or more decompression decoders are further configured to decompress the compressed data block utilizing content independent data decompression to provide a second decompressed data block when the one or more recognizable data tokens indicate that the data block was encoded utilizing content independent data compression; and

an output interface, coupled to the data decompression engine, configured to output a decompressed data packet including the first or the second decompressed data block.

15. The system of claim **14**, wherein the one or more decompression decoders are separate from the selected encoder used to compress the one or more data blocks.

16. The system of claim **14**, wherein the one or more recognizable data tokens include values corresponding to one or more applied decoding techniques utilized by the one or more decompression decoders.

17. The system of claim **14**, wherein the one or more decompression decoders are further configured to decompress the compressed data block utilizing one or more appropriate decoders for the data block encoded with content independent data compression prior to further decoding the data block utilizing one or more appropriate decoders for the data block encoded with content dependent data compression.

18. The system of claim **14**, wherein the one or more decompression decoders are further configured to decompress a subset of the one or more compressed data blocks corresponding to the data packet.

19. The system of claim **18**, wherein the one or more decompression decoders are further configured to decompress a subset of the one or more data packets.

20. The system of claim **14**, wherein the one or more decompression decoders are further configured to decompress the compressed data block in real-time.

21. A method of compressing a plurality of data blocks residing in data packets, the data packets being transmitted in sequence from a source that is internal or external to a source of the compression method, the one or more compressed data packets including one or more compressed data blocks, wherein a data packet from among the one or more data

packets comprises a header containing control information followed by one or more compressed data blocks of the data packet, the method comprising:

applying a plurality of compression techniques to the plurality of data blocks using a data compression engine;

analyzing content of a data block from among the plurality of data blocks to determine any characteristic, attribute, or parameter of the data block, wherein the analyzing of the data within the data block excludes analyzing based on a descriptor that is indicative of the characteristic, attribute, or parameter of the data block;

selecting one or more encoders based on the characteristic, attribute, or parameter of the data block and a file, wherein the file indicates the characteristic, attribute, or parameter of the data block and their associated encoders;

compressing the data block with the selected one or more encoders utilizing content dependent data compression when the characteristic, attribute, or parameter of the data residing within the data block is recognized as associated with an encoder utilizing content dependent data compression;

compressing the data block with the selected one or more encoders utilizing content independent data compression when the characteristic, attribute, or parameter of the data residing within the data block is not recognized as associated with an encoder utilizing content dependent data compression; and

providing a recognizable data token which identifies the selected one or more encoders utilized for compression of the data block in the one or more data blocks transmitted in sequence.

22. The method of claim **21**, wherein a plurality of the one or more encoders are applied to compress the plurality of data blocks.

23. The method of claim **21**, further comprising:

transmitting one or more data packets in sequence from outputs of the one or more encoders.

24. The method of claim **21**, wherein the data blocks contain financial data.

25. The method of claim **21**, wherein the method of compressing the plurality of data blocks is performed in real-time.

26. The method of claim **21**, wherein the encoders are lossy, and wherein the compression permits the compressed data block to be recovered in full when decompressed.

27. A system for compressing a plurality of data blocks that are compressed and placed into the payload portion of a data packet from among one or more data packets, the data packets being transmitted in sequence from a source that is internal or external to the compression system, wherein the data packet comprises a header containing control information followed by the plurality of compressed data blocks of the data packet, the system comprising:

a data compression processor configured to analyze content of a data block to determine any characteristic, attribute, or parameter of the data block, where in the analyzing of the data within the data block excludes analyzing based on a descriptor that is indicative of the any characteristic attribute or parameter of the data block;

one or more compression encoders configured to be selected based on the characteristic, attribute, or parameter of the data block and a file, wherein the file indicates the characteristic, attribute, or parameter of the data block and their associated compression encoders; wherein:

the data block is compressed by the selected one or more compression encoders utilizing content dependent data compression when the characteristic, attribute, or parameter of the data block is recognized as being associated with an encoder utilizing content dependent data compression; and

the data block is compressed by the selected one or more compression encoders utilizing content independent data compression when the characteristic, attribute, or parameter of the data block is not recognized as being associated with an encoder utilizing content dependent data compression; and

an output interface, coupled to the data compression processor, configured to output a recognizable data token identifying the selected one or more compression encoders, the recognizable data token including any recognizable data token representative of one or more values in the compressed data packet.

28. The system of claim **27**, wherein the one or more compression encoders are further configured to compress a plurality of data blocks associated with the compressed data packet.

29. The system of claim **28**, wherein the one or more compression encoders are further configured to output a plurality of compressed data blocks.

30. The system of claim **27**, wherein the one or more compression encoders are further configured to compress the data blocks in real-time.

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(54) **DATA COMPRESSION SYSTEMS AND METHODS**

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See application file for complete search history.

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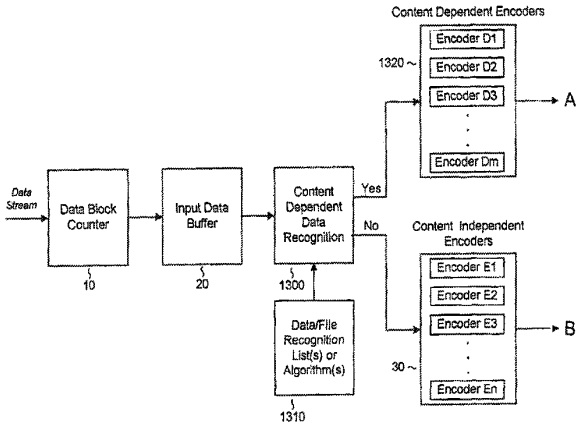
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(57) **ABSTRACT**

Data compression using a combination of content independent data compression and content dependent data compression. In one aspect, a system for compressing data comprises: a processor; one or more content dependent data compression encoders; and a single data compression encoder. The processor is configured to analyze data within a data block to identify one or more parameters or attributes of the data wherein the analyzing of the data within the data block to identify the one or more parameters or attributes of the data excludes analyzing based solely on a descriptor that is indicative of the one or more parameters or attributes of the data within the data block; to perform content dependent data compression with the one or more content dependent data compression if the one or more parameters or attributes of the data are identified; and to perform data compression with the single data compression encoder, if the one or more parameters or attributes of the data are not identified.

25 Claims, 34 Drawing Sheets



Related U.S. Application Data

continuation of application No. 14/035,561, filed on Sep. 24, 2013, now Pat. No. 8,717,203, which is a continuation of application No. 13/154,211, filed on Jun. 6, 2011, now Pat. No. 8,643,513, which is a continuation of application No. 12/703,042, filed on Feb. 9, 2010, now Pat. No. 8,502,707, which is a continuation of application No. 11/651,366, filed on Jan. 8, 2007, now abandoned, and a continuation of application No. 11/651,365, filed on Jan. 8, 2007, now Pat. No. 7,714,747, which is a continuation of application No. 10/668,768, filed on Sep. 22, 2003, now Pat. No. 7,161,506, said application No. 11/651,366 is a continuation of application No. 10/668,768, which is a continuation of application No. 10/016,355, filed on Oct. 29, 2001, now Pat. No. 6,624,761, which is a continuation-in-part of application No. 09/705,446, filed on Nov. 3, 2000, now Pat. No. 6,309,424, which is a continuation of application No. 09/210,491, filed on Dec. 11, 1998, now Pat. No. 6,195,024.

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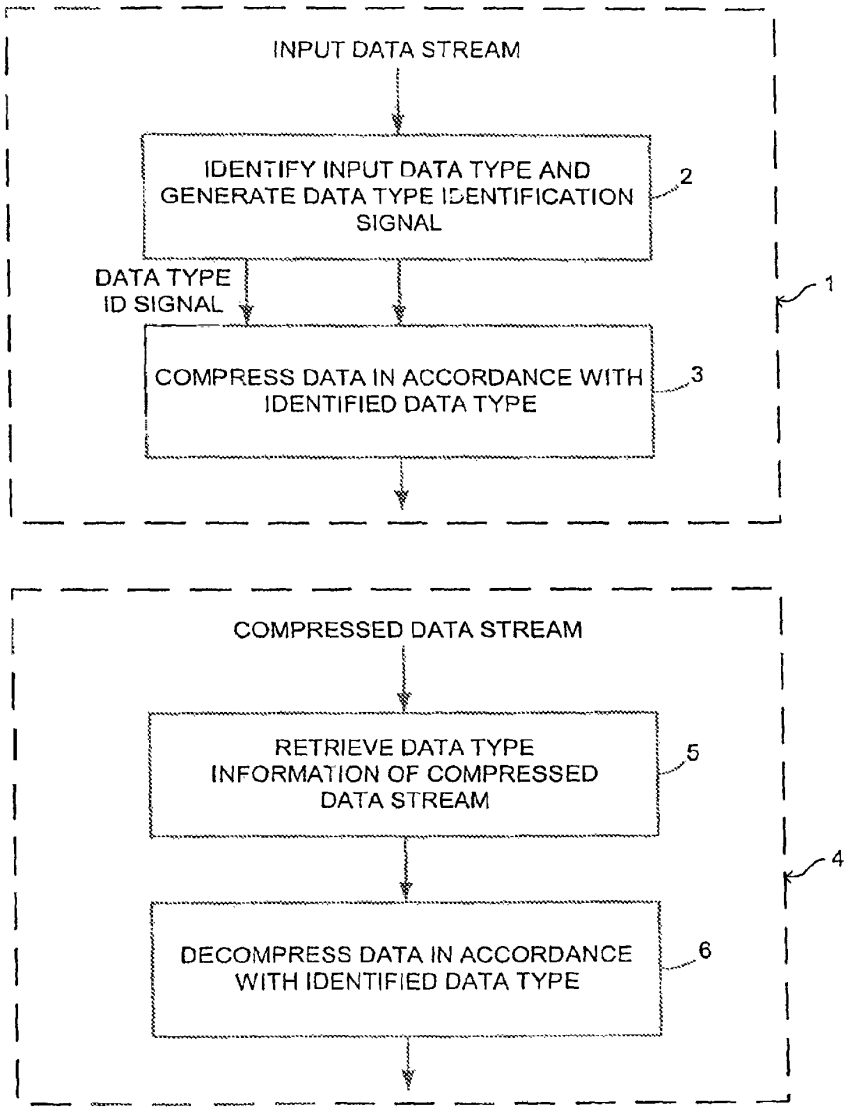


FIG. 1
PRIOR ART

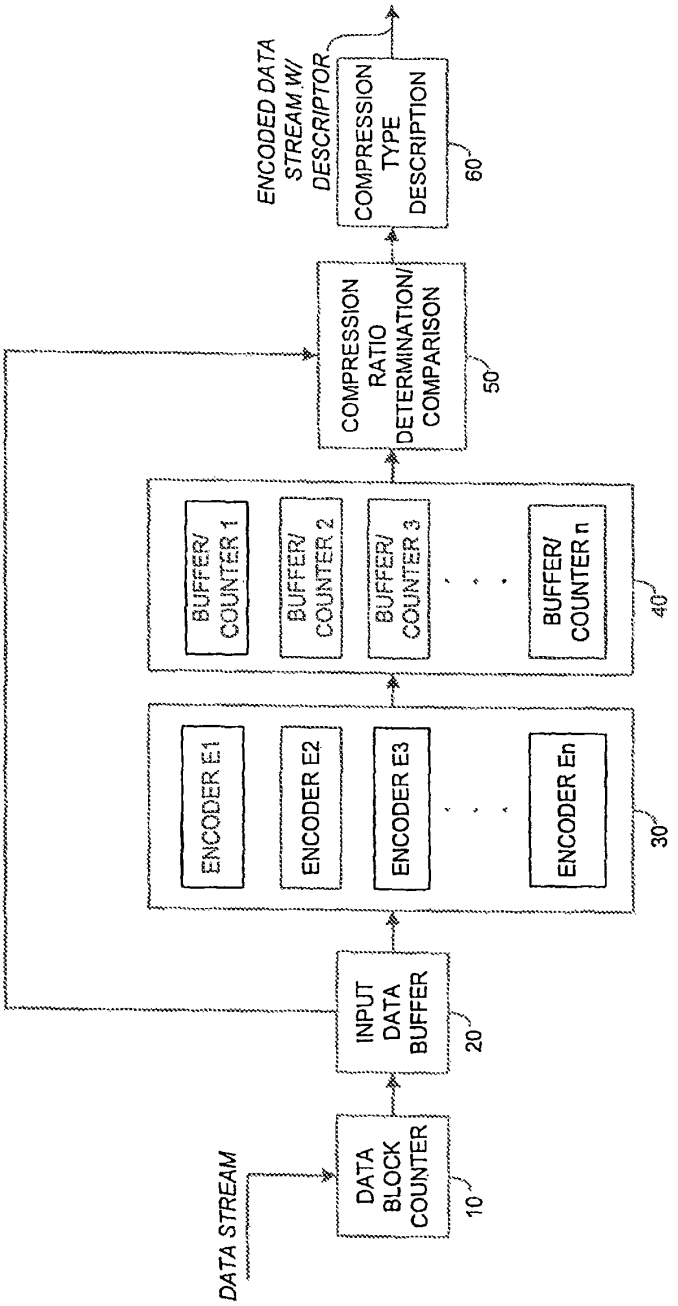

DATA STREAM
DATA BLOCK COUNTER
10
INPUT DATA BUFFER
20
ENCODER E1
ENCODER E2
ENCODER E3
ENCODER En
30
BUFFER/ COUNTER 1
BUFFER/ COUNTER 2
BUFFER/ COUNTER 3
BUFFER/ COUNTER n
40
COMPRESSION RATIO DETERMINATION/ COMPARISON
50
COMPRESSION TYPE DESCRIPTION
60
ENCODED DATA STREAM W/ DESCRIPTOR

FIG. 2

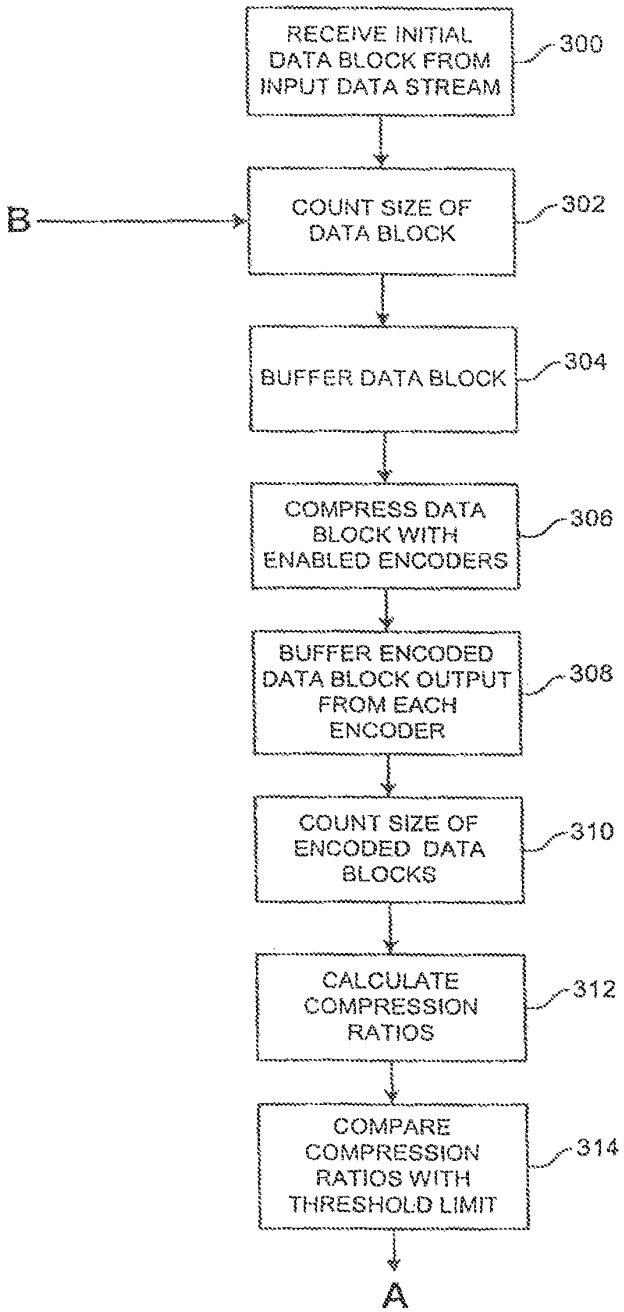

RECEIVE INITIAL DATA BLOCK FROM INPUT DATA STREAM
300
B
COUNT SIZE OF DATA BLOCK
302
BUFFER DATA BLOCK
304
COMPRESS DATA BLOCK WITH ENABLED ENCODERS
306
BUFFER ENCODED DATA BLOCK OUTPUT FROM EACH ENCODER
308
COUNT SIZE OF ENCODED DATA BLOCKS
310
CALCULATE COMPRESSION RATIOS
312
COMPARE COMPRESSION RATIOS WITH THRESHOLD LIMIT
314
A

FIG. 3a

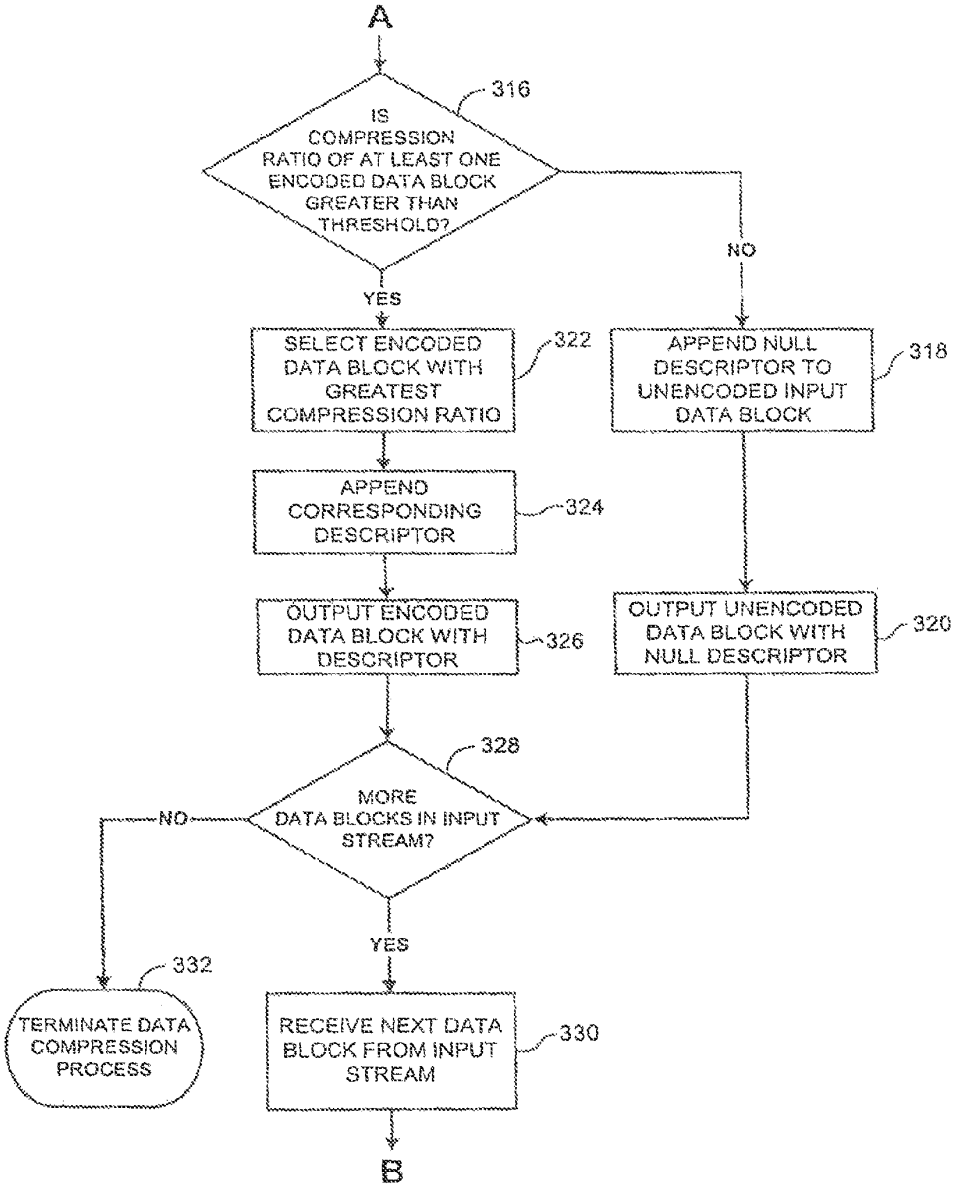

A
316
IS COMPRESSION RATIO OF AT LEAST ONE ENCODED DATA BLOCK GREATER THAN THRESHOLD?
NO
YES
SELECT ENCODED DATA BLOCK WITH GREATEST COMPRESSION RATIO
322
APPEND NULL DESCRIPTOR TO UNENCODED INPUT DATA BLOCK
318
APPEND CORRESPONDING DESCRIPTOR
324
OUTPUT ENCODED DATA BLOCK WITH DESCRIPTOR
326
OUTPUT UNENCODED DATA BLOCK WITH NULL DESCRIPTOR
320
328
MORE DATA BLOCKS IN INPUT STREAM?
NO
YES
332
TERMINATE DATA COMPRESSION PROCESS
RECEIVE NEXT DATA BLOCK FROM INPUT STREAM
330
B

FIG. 3b

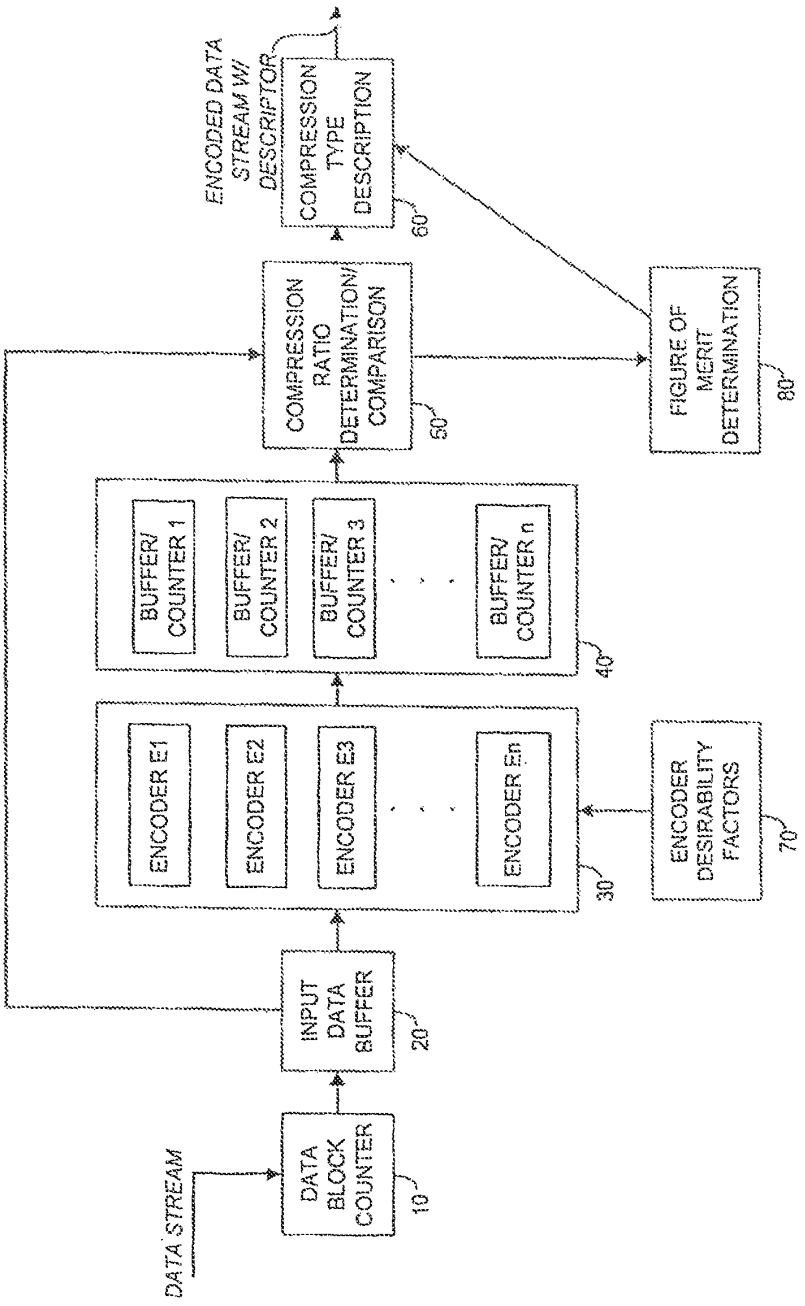

DATA STREAM
DATA BLOCK COUNTER
10
INPUT DATA BUFFER
20
ENCODER E1
ENCODER E2
ENCODER E3
ENCODER En
30
ENCODER DESIRABILITY FACTORS
70
BUFFER/ COUNTER 1
BUFFER/ COUNTER 2
BUFFER/ COUNTER 3
BUFFER/ COUNTER n
40
COMPRESSION RATIO DETERMINATION/ COMPARISON
50
FIGURE OF MERIT DETERMINATION
80
COMPRESSION TYPE DESCRIPTION
60
ENCODED DATA STREAM W/ DESCRIPTOR

FIG. 4

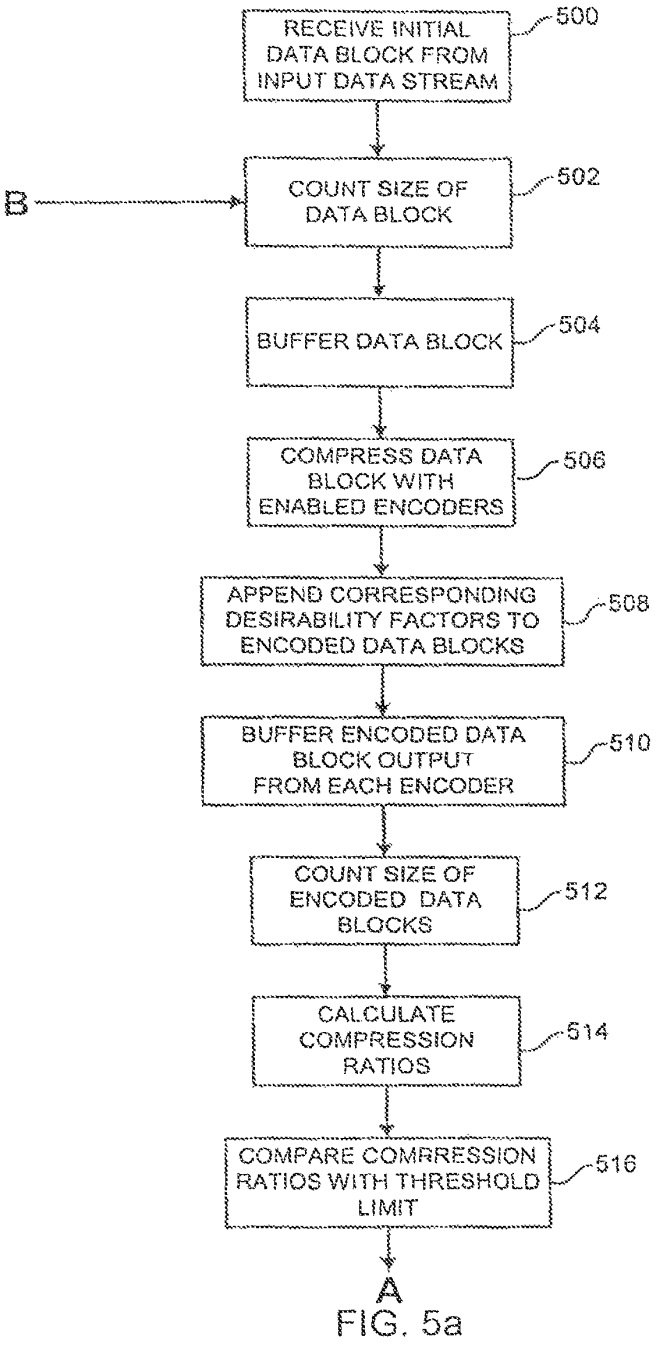

RECEIVE INITIAL DATA BLOCK FROM INPUT DATA STREAM
500
B
COUNT SIZE OF DATA BLOCK
502
BUFFER DATA BLOCK
504
COMPRESS DATA BLOCK WITH ENABLED ENCODERS
506
APPEND CORRESPONDING DESIRABILITY FACTORS TO ENCODED DATA BLOCKS
508
BUFFER ENCODED DATA BLOCK OUTPUT FROM EACH ENCODER
510
COUNT SIZE OF ENCODED DATA BLOCKS
512
CALCULATE COMPRESSION RATIOS
514
COMPARE COMRRESSION RATIOS WITH THRESHOLD LIMIT
516
A

FIG. 5a

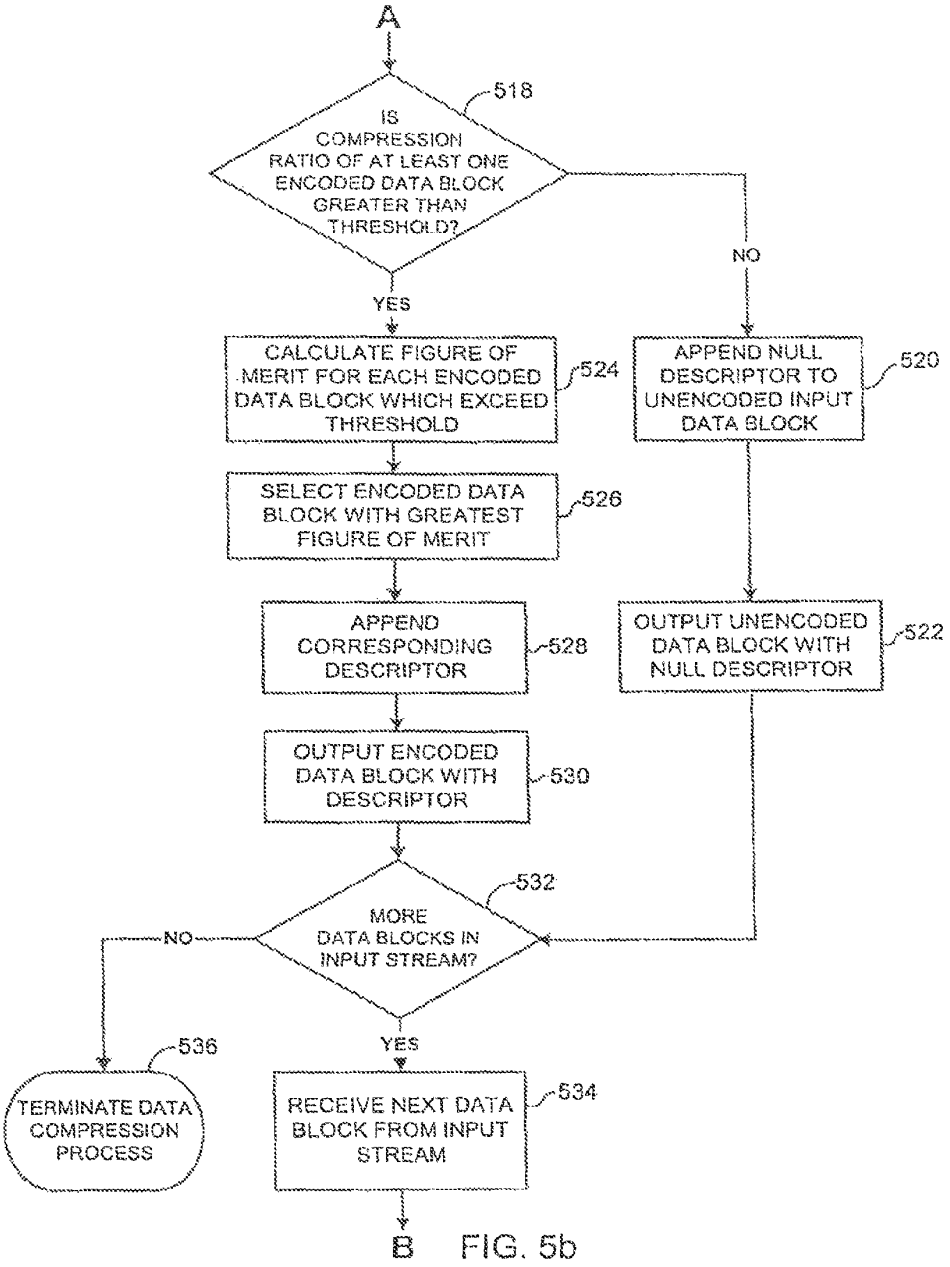

A
518
IS COMPRESSION RATIO OF AT LEAST ONE ENCODED DATA BLOCK GREATER THAN THRESHOLD?
NO
YES
CALCULATE FIGURE OF MERIT FOR EACH ENCODED DATA BLOCK WHICH EXCEED THRESHOLD
524
APPEND NULL DESCRIPTOR TO UNENCODED INPUT DATA BLOCK
520
SELECT ENCODED DATA BLOCK WITH GREATEST FIGURE OF MERIT
526
APPEND CORRESPONDING DESCRIPTOR
528
OUTPUT UNENCODED DATA BLOCK WITH NULL DESCRIPTOR
522
OUTPUT ENCODED DATA BLOCK WITH DESCRIPTOR
530
532
MORE DATA BLOCKS IN INPUT STREAM?
NO
YES
536
TERMINATE DATA COMPRESSION PROCESS
RECEIVE NEXT DATA BLOCK FROM INPUT STREAM
534
B

FIG. 5b

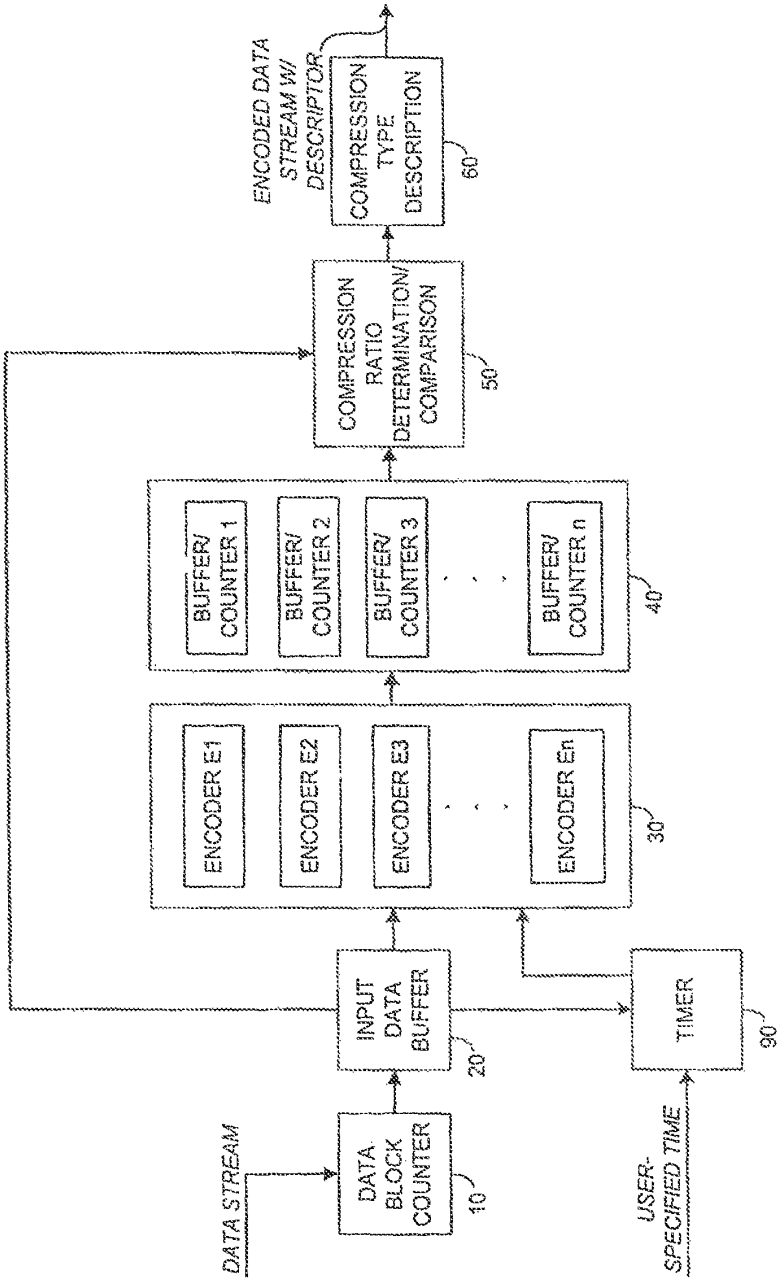

DATA STREAM
DATA BLOCK COUNTER
10
INPUT DATA BUFFER
20
ENCODER E1
ENCODER E2
ENCODER E3
ENCODER En
30
BUFFER/ COUNTER 1
BUFFER/ COUNTER 2
BUFFER/ COUNTER 3
BUFFER/ COUNTER n
40
COMPRESSION RATIO DETERMINATION/ COMPARISON
50
COMPRESSION TYPE DESCRIPTION
60
ENCODED DATA STREAM W/ DESCRIPTOR
TIMER
90
USER-SPECIFIED TIME

FIG. 6

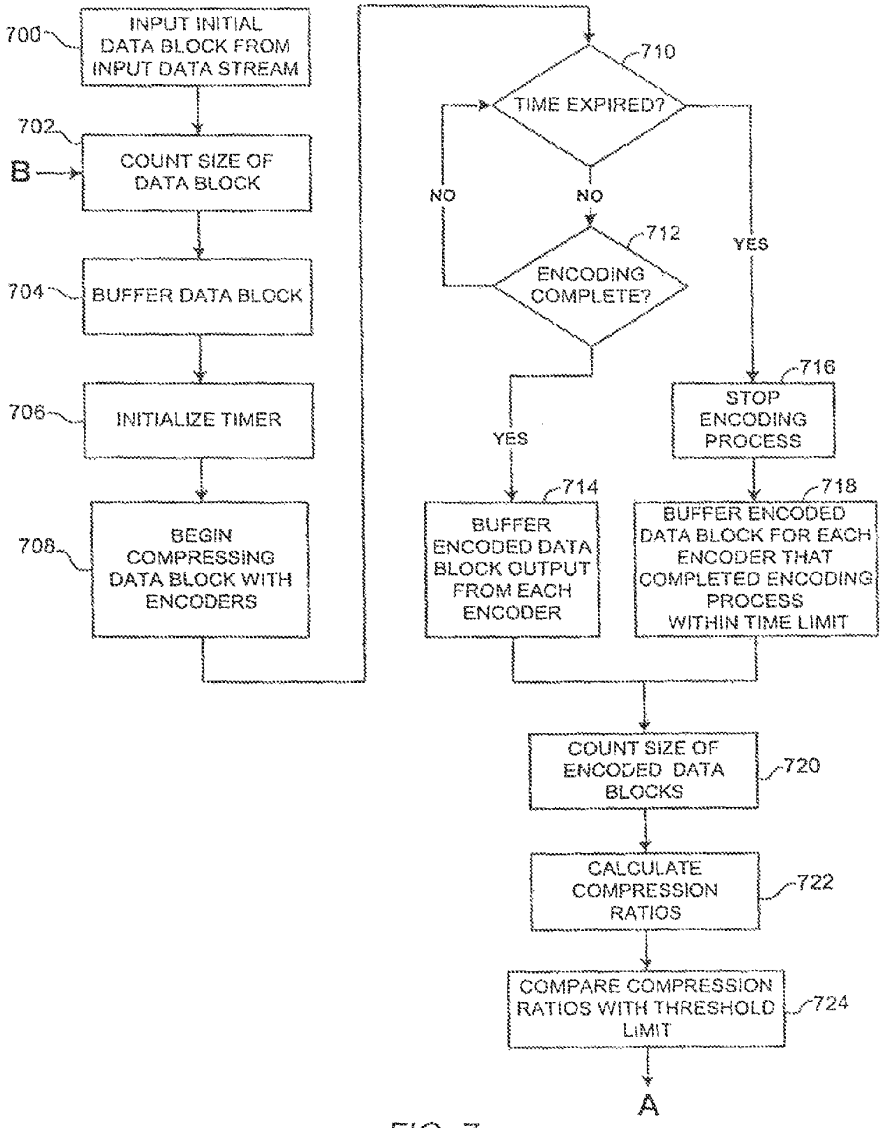

700
INPUT INITIAL DATA BLOCK FROM INPUT DATA STREAM
702
B
COUNT SIZE OF DATA BLOCK
704
BUFFER DATA BLOCK
706
INITIALIZE TIMER
708
BEGIN COMPRESSING DATA BLOCK WITH ENCODERS
710
TIME EXPIRED?
NO
712
ENCODING COMPLETE?
NO
YES
YES
714
BUFFER ENCODED DATA BLOCK OUTPUT FROM EACH ENCODER
716
STOP ENCODING PROCESS
718
BUFFER ENCODED DATA BLOCK FOR EACH ENCODER THAT COMPLETED ENCODING PROCESS WITHIN TIME LIMIT
720
COUNT SIZE OF ENCODED DATA BLOCKS
722
CALCULATE COMPRESSION RATIOS
724
COMPARE COMPRESSION RATIOS WITH THRESHOLD LIMIT
A

FIG. 7a

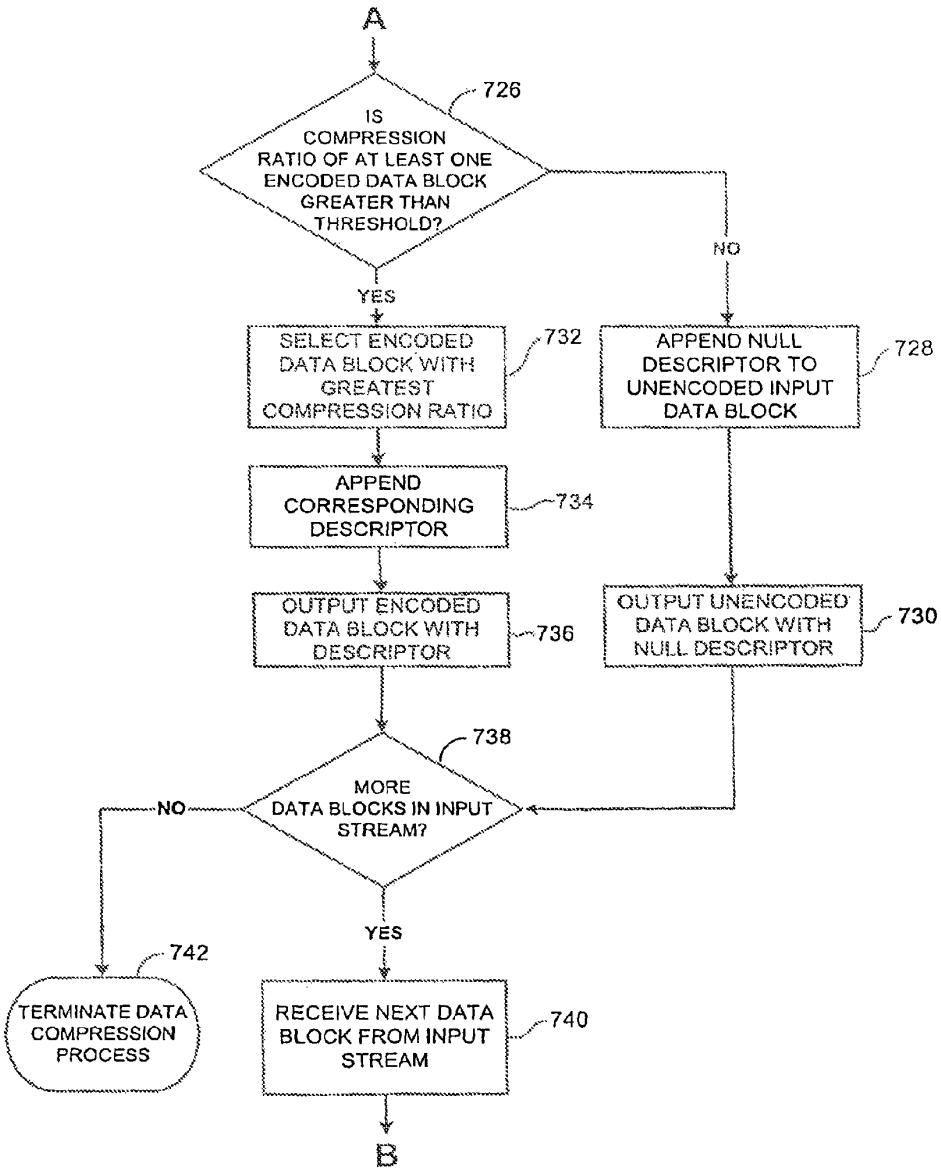

A
726
IS COMPRESSION RATIO OF AT LEAST ONE ENCODED DATA BLOCK GREATER THAN THRESHOLD?
NO
YES
SELECT ENCODED DATA BLOCK WITH GREATEST COMPRESSION RATIO
732
APPEND NULL DESCRIPTOR TO UNENCODED INPUT DATA BLOCK
728
APPEND CORRESPONDING DESCRIPTOR
734
OUTPUT ENCODED DATA BLOCK WITH DESCRIPTOR
736
OUTPUT UNENCODED DATA BLOCK WITH NULL DESCRIPTOR
730
738
MORE DATA BLOCKS IN INPUT STREAM?
NO
YES
742
TERMINATE DATA COMPRESSION PROCESS
RECEIVE NEXT DATA BLOCK FROM INPUT STREAM
740
B

FIG. 7b

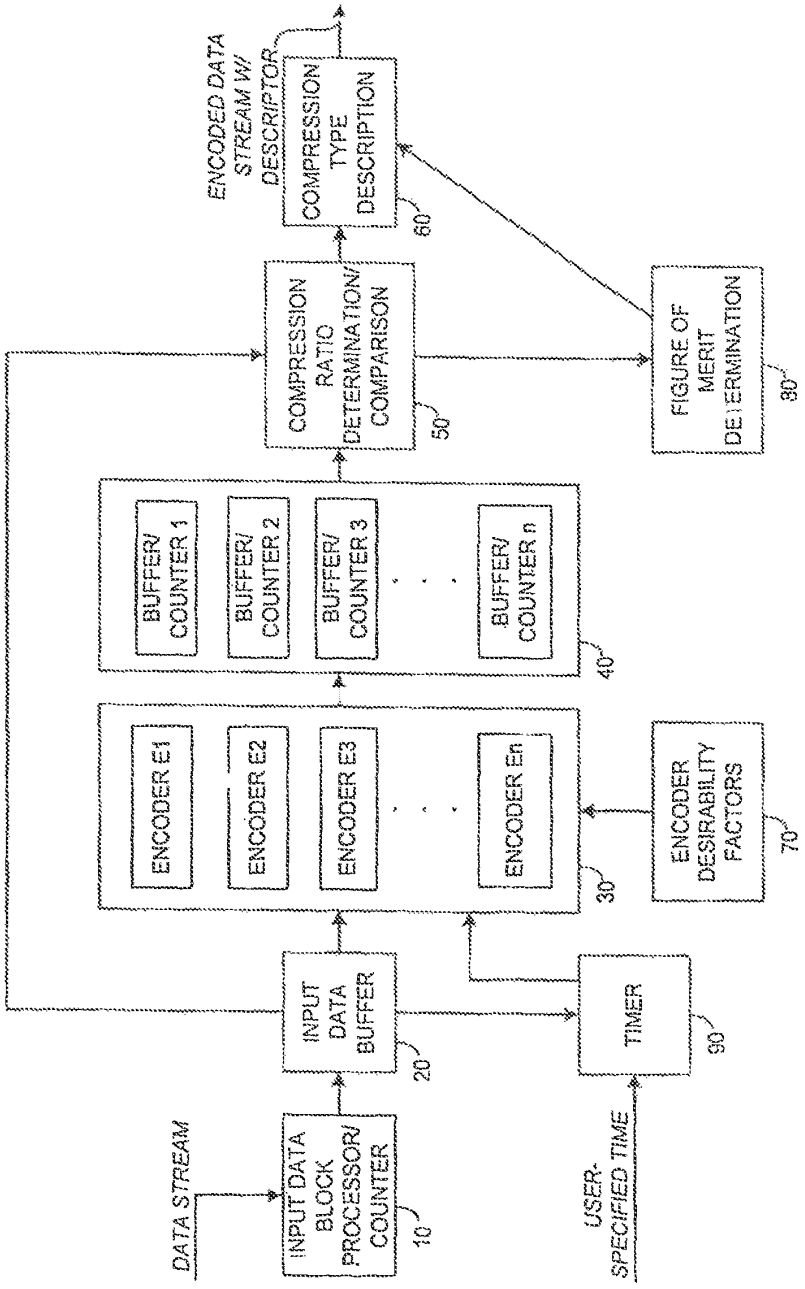


FIG. 8

Appx220

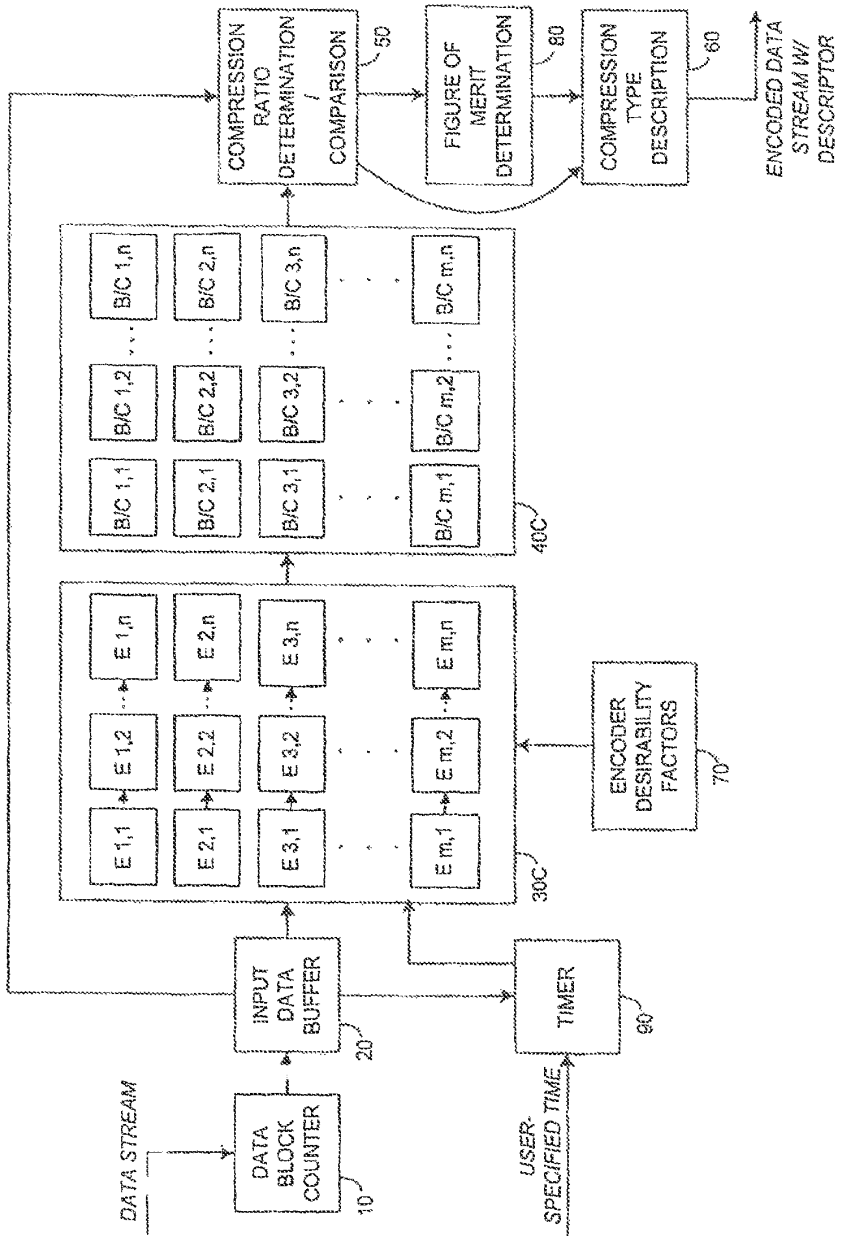


FIG. 9

Appx221

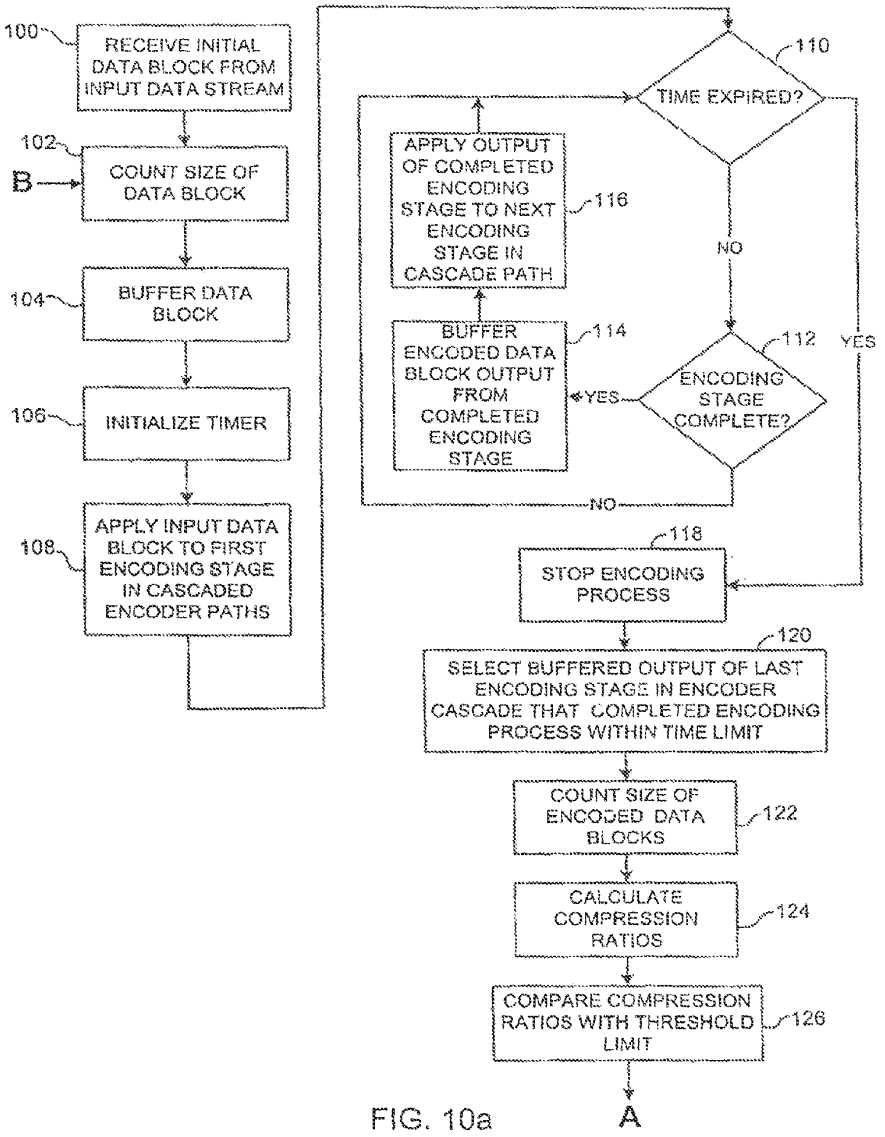

100
RECEIVE INITIAL DATA BLOCK FROM INPUT DATA STREAM
102
B
COUNT SIZE OF DATA BLOCK
104
BUFFER DATA BLOCK
106
INITIALIZE TIMER
108
APPLY INPUT DATA BLOCK TO FIRST ENCODING STAGE IN CASCADED ENCODER PATHS
110
TIME EXPIRED?
NO
YES
112
ENCODING STAGE COMPLETE?
YES
114
BUFFER ENCODED DATA BLOCK OUTPUT FROM COMPLETED ENCODING STAGE
116
APPLY OUTPUT OF COMPLETED ENCODING STAGE TO NEXT ENCODING STAGE IN CASCADE PATH
NO
118
STOP ENCODING PROCESS
120
SELECT BUFFERED OUTPUT OF LAST ENCODING STAGE IN ENCODER CASCADE THAT COMPLETED ENCODING PROCESS WITHIN TIME LIMIT
122
COUNT SIZE OF ENCODED DATA BLOCKS
124
CALCULATE COMPRESSION RATIOS
126
COMPARE COMPRESSION RATIOS WITH THRESHOLD LIMIT
A

FIG. 10a

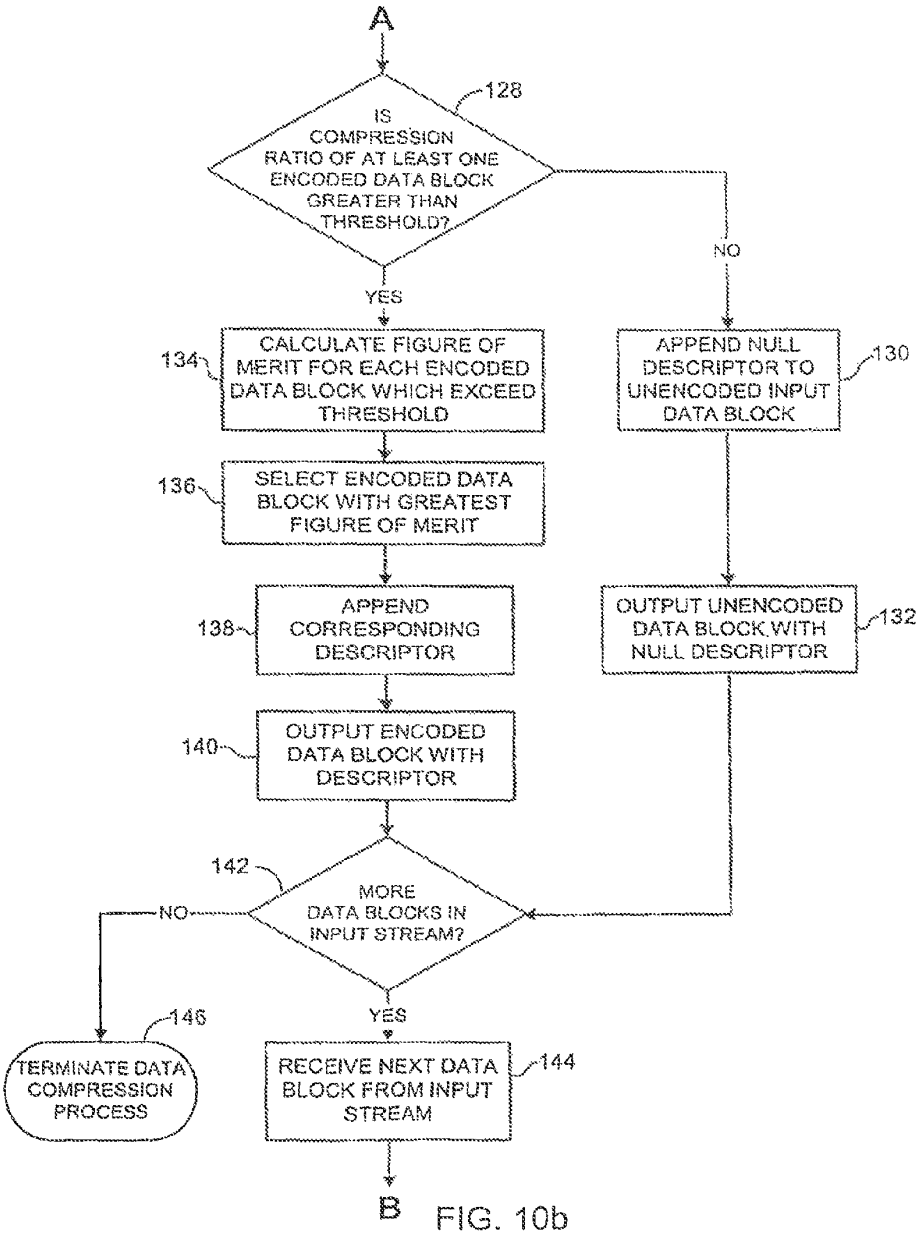

A
128
IS COMPRESSION RATIO OF AT LEAST ONE ENCODED DATA BLOCK GREATER THAN THRESHOLD?
NO
YES
134
CALCULATE FIGURE OF MERIT FOR EACH ENCODED DATA BLOCK WHICH EXCEED THRESHOLD
APPEND NULL DESCRIPTOR TO UNENCODED INPUT DATA BLOCK
130
136
SELECT ENCODED DATA BLOCK WITH GREATEST FIGURE OF MERIT
138
APPEND CORRESPONDING DESCRIPTOR
OUTPUT UNENCODED DATA BLOCK WITH NULL DESCRIPTOR
132
140
OUTPUT ENCODED DATA BLOCK WITH DESCRIPTOR
142
MORE DATA BLOCKS IN INPUT STREAM?
NO
YES
146
TERMINATE DATA COMPRESSION PROCESS
RECEIVE NEXT DATA BLOCK FROM INPUT STREAM
144
B

FIG. 10b

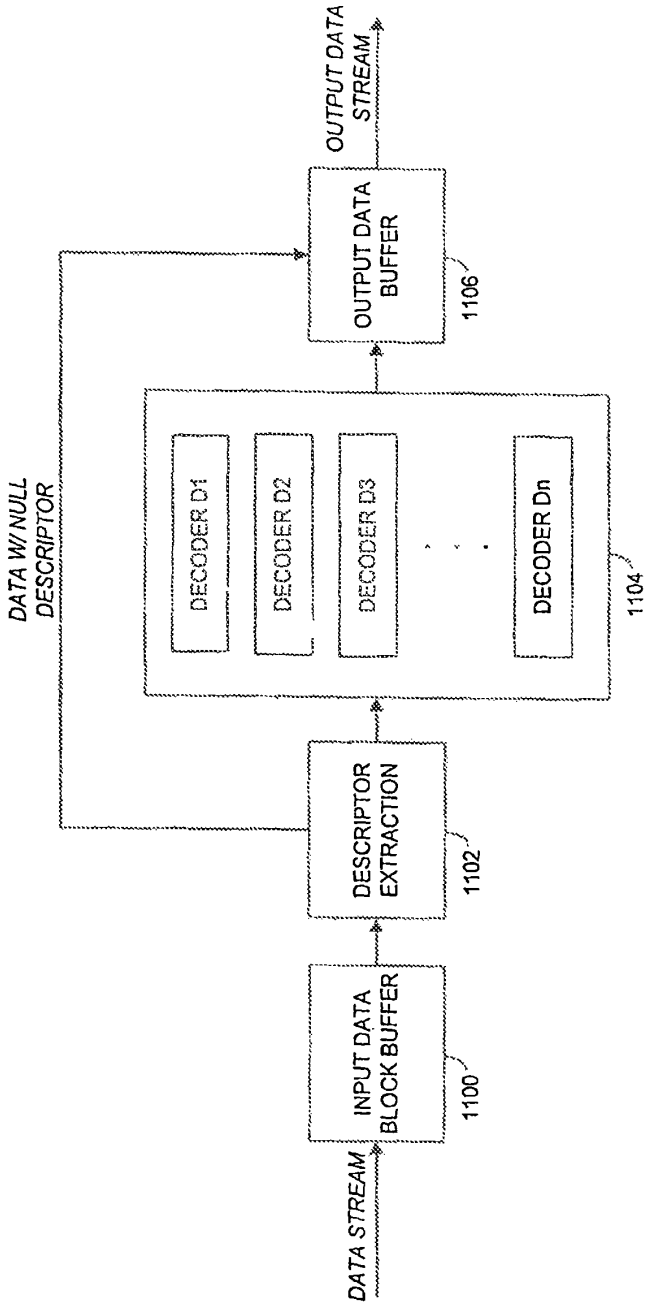

DATA STREAM
INPUT DATA BLOCK BUFFER
1100
DESCRIPTOR EXTRACTION
1102
DATA W/ NULL DESCRIPTOR
DECODER D1
DECODER D2
DECODER D3
DECODER Dn
1104
OUTPUT DATA BUFFER
1106
OUTPUT DATA STREAM

FIG. 11

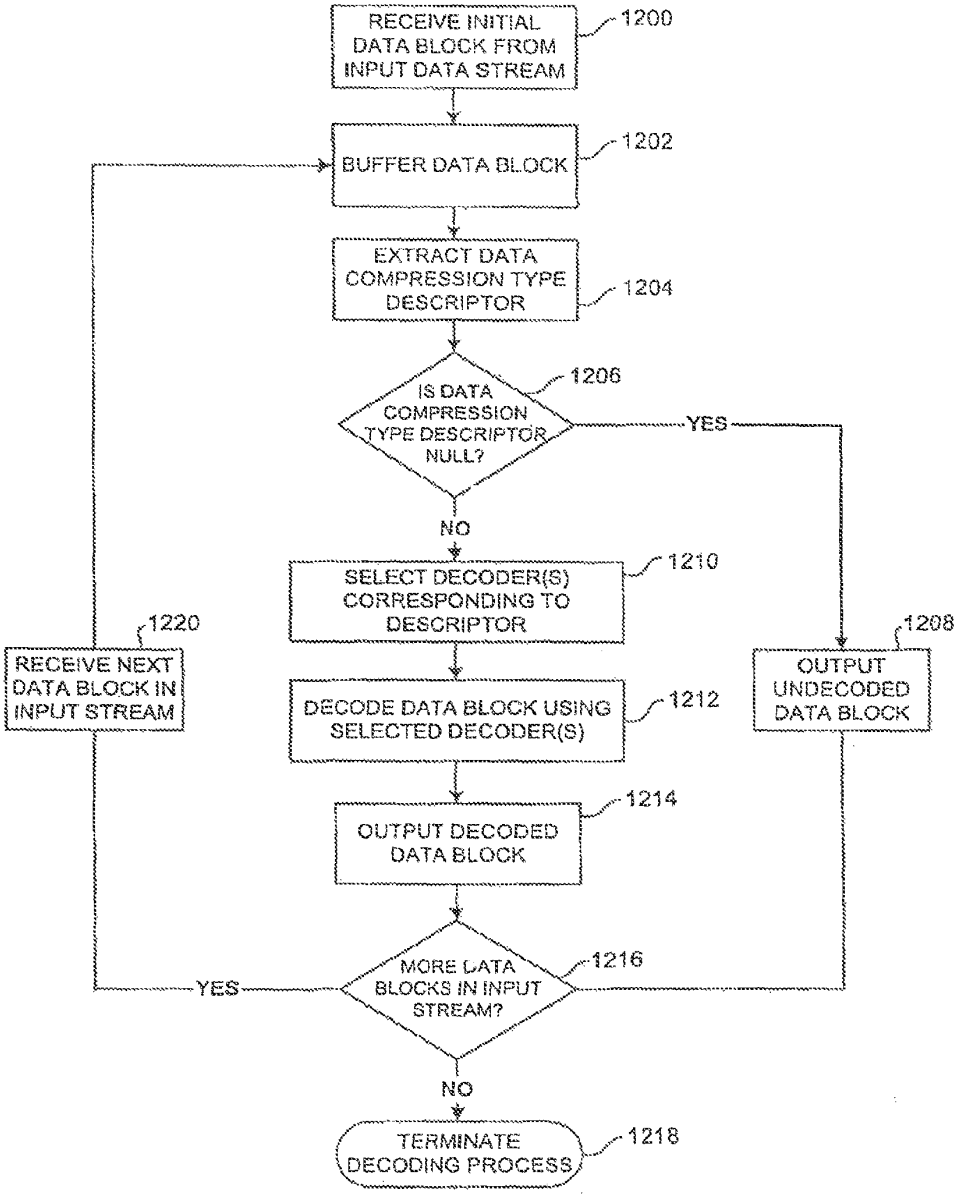

RECEIVE INITIAL DATA BLOCK FROM INPUT DATA STREAM
1200
BUFFER DATA BLOCK
1202
EXTRACT DATA COMPRESSION TYPE DESCRIPTOR
1204
IS DATA COMPRESSION TYPE DESCRIPTOR NULL?
1206
YES
NO
SELECT DECODER(S) CORRESPONDING TO DESCRIPTOR
1210
DECODE DATA BLOCK USING SELECTED DECODER(S)
1212
OUTPUT DECODED DATA BLOCK
1214
MORE DATA BLOCKS IN INPUT STREAM?
1216
YES
NO
TERMINATE DECODING PROCESS
1218
RECEIVE NEXT DATA BLOCK IN INPUT STREAM
1220
OUTPUT UNDECODED DATA BLOCK
1208

FIG. 12

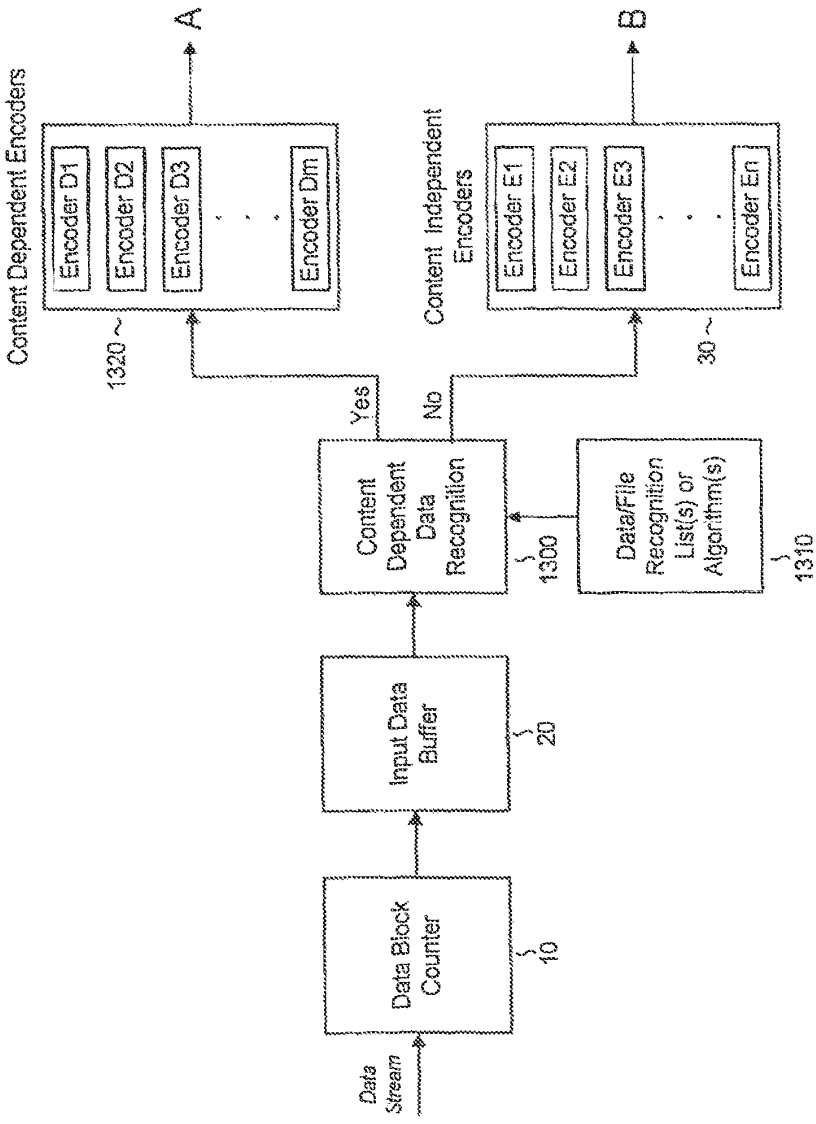

Data Stream
Data Block Counter
10
Input Data Buffer
20
Content Dependent Data Recognition
1300
Data/File Recognition List(s) or Algorithm(s)
1310
Yes
No
Content Dependent Encoders
Encoder D1
Encoder D2
Encoder D3
Encoder Dm
1320
A
Content Independent Encoders
Encoder E1
Encoder E2
Encoder E3
Encoder En
30
B

FIGURE 13A

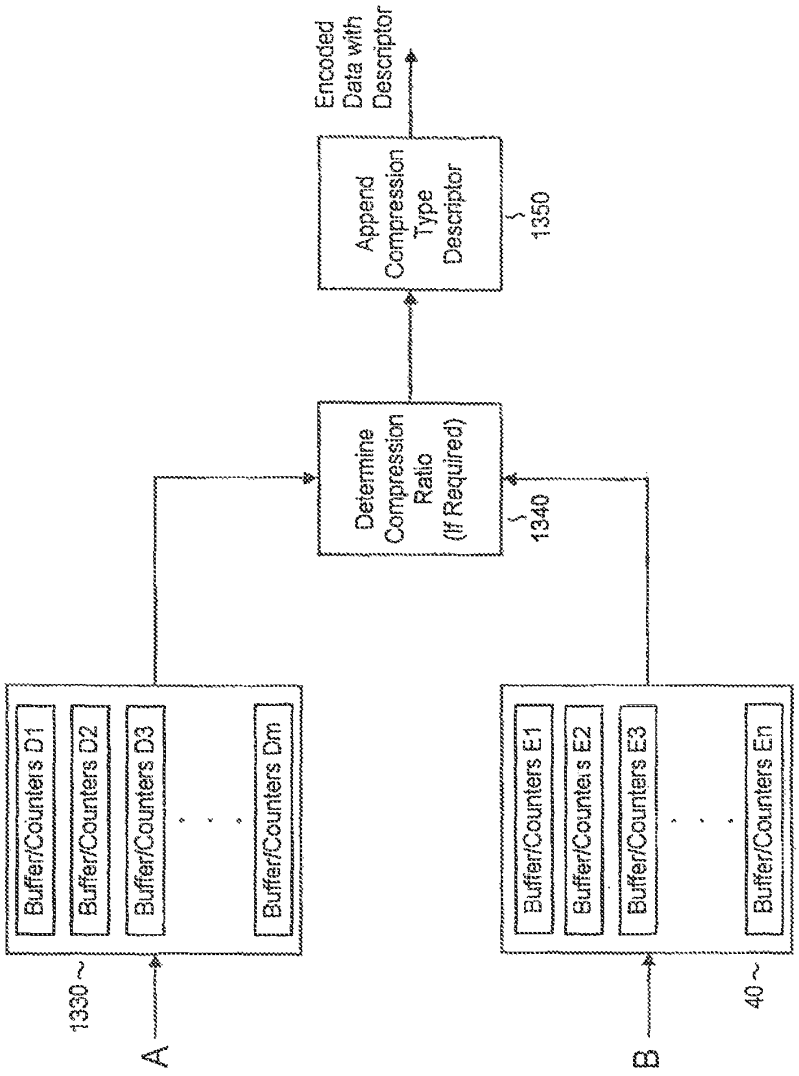

Encoded Data with Descriptor
Append Compression Type Descriptor
1350
Determine Compression Ratio (If Required)
1340
Buffer/Counters D1
Buffer/Counters D2
Buffer/Counters D3
Buffer/Counters Dm
1330
A
Buffer/Counters E1
Buffer/Counters E2
Buffer/Counters E3
Buffer/Counters En
40
B

FIGURE 13B

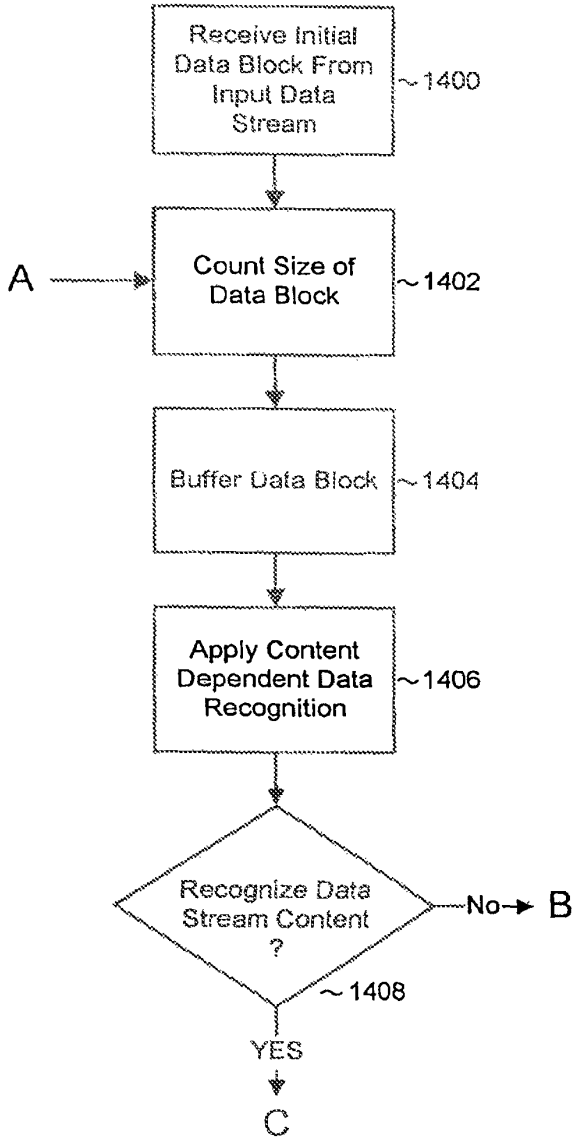

Receive Initial Data Block From Input Data Stream
1400
A
Count Size of Data Block
1402
Buffer Data Block
1404
Apply Content Dependent Data Recognition
1406
Recognize Data Stream Content ?
No
B
1408
YES
C

FIGURE 14A

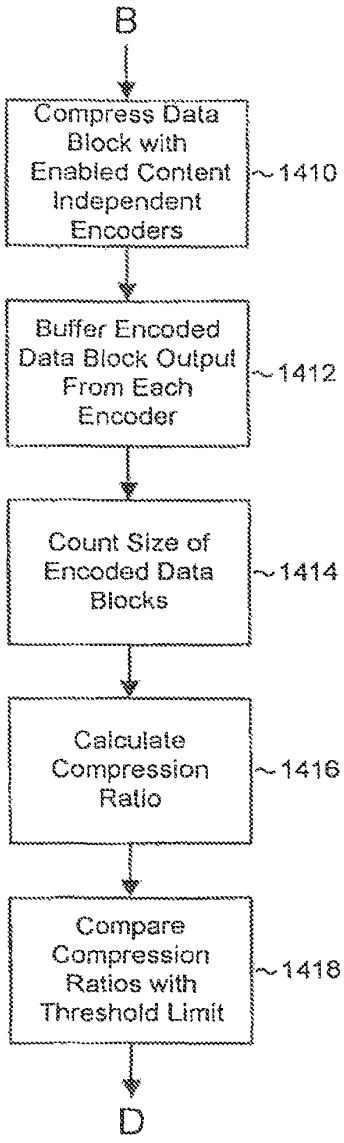

B
Compress Data Block with Enabled Content Independent Encoders
1410
Buffer Encoded Data Block Output From Each Encoder
1412
Count Size of Encoded Data Blocks
1414
Calculate Compression Ratio
1416
Compare Compression Ratios with Threshold Limit
1418
D

FIGURE 14B

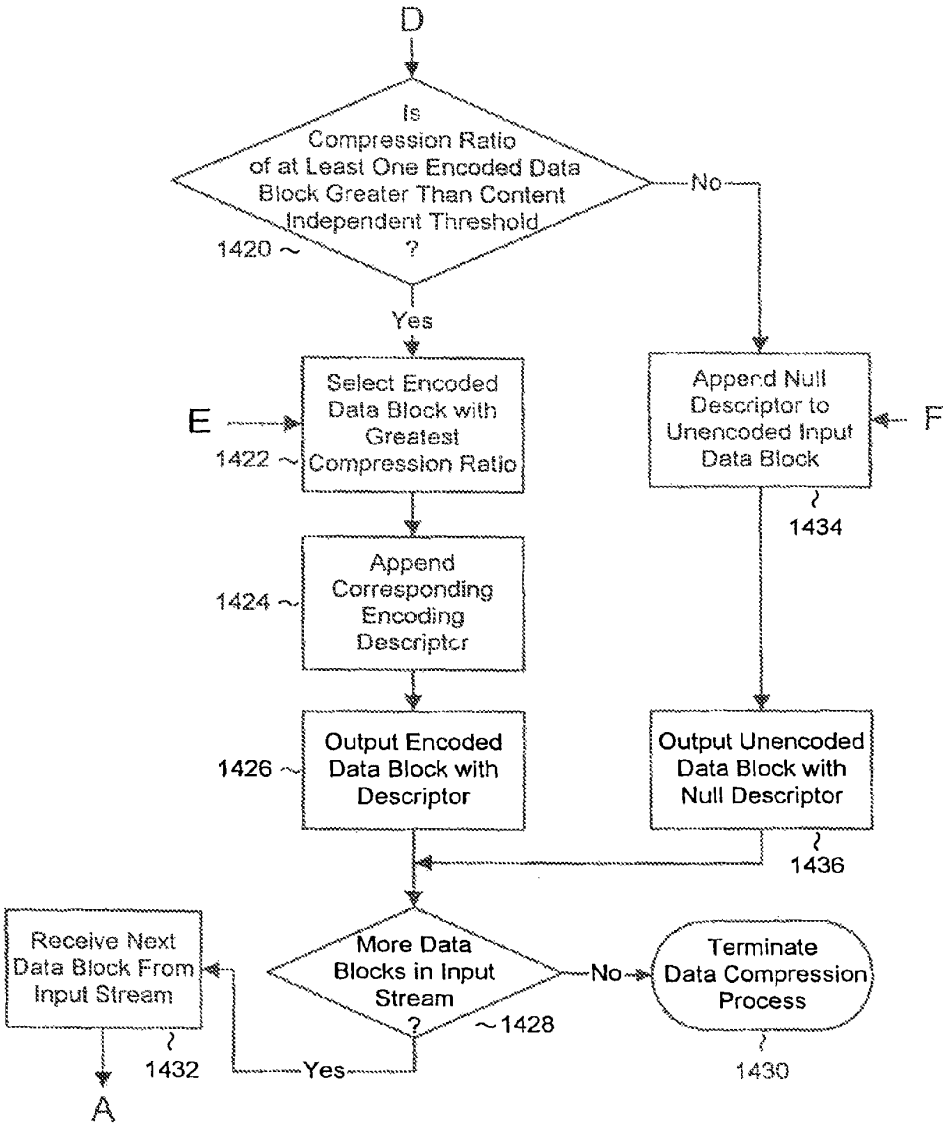

D
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Independent Threshold ?
1420
No
Yes
E
Select Encoded Data Block with Greatest Compression Ratio
1422
Append Null Descriptor to Unencoded Input Data Block
F
1434
Append Corresponding Encoding Descriptor
1424
Output Encoded Data Block with Descriptor
1426
Output Unencoded Data Block with Null Descriptor
1436
Receive Next Data Block From Input Stream
1432
A
More Data Blocks in Input Stream ?
1428
No
Yes
Terminate Data Compression Process
1430

FIGURE 14C

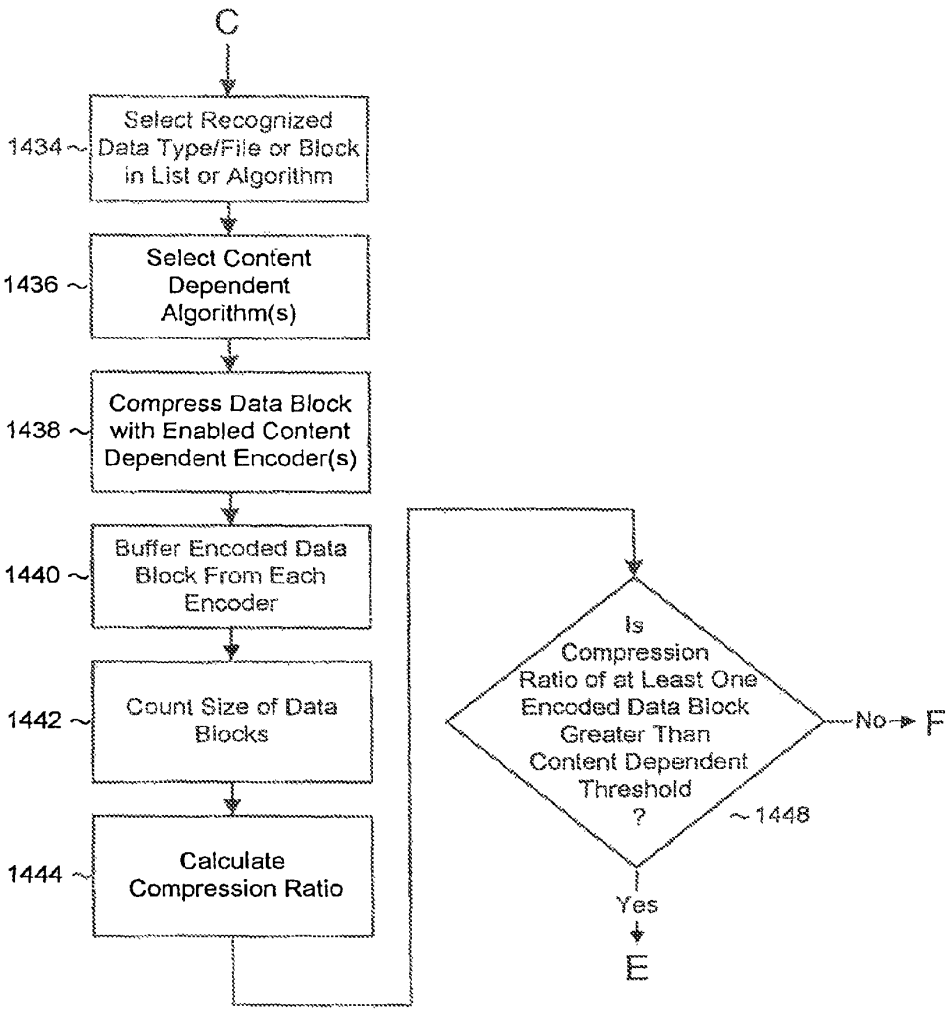

C
1434
Select Recognized Data Type/File or Block in List or Algorithm
1436
Select Content Dependent Algorithm(s)
1438
Compress Data Block with Enabled Content Dependent Encoder(s)
1440
Buffer Encoded Data Block From Each Encoder
1442
Count Size of Data Blocks
1444
Calculate Compression Ratio
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Dependent Threshold ?
1448
No
F
Yes
E

FIGURE 14D

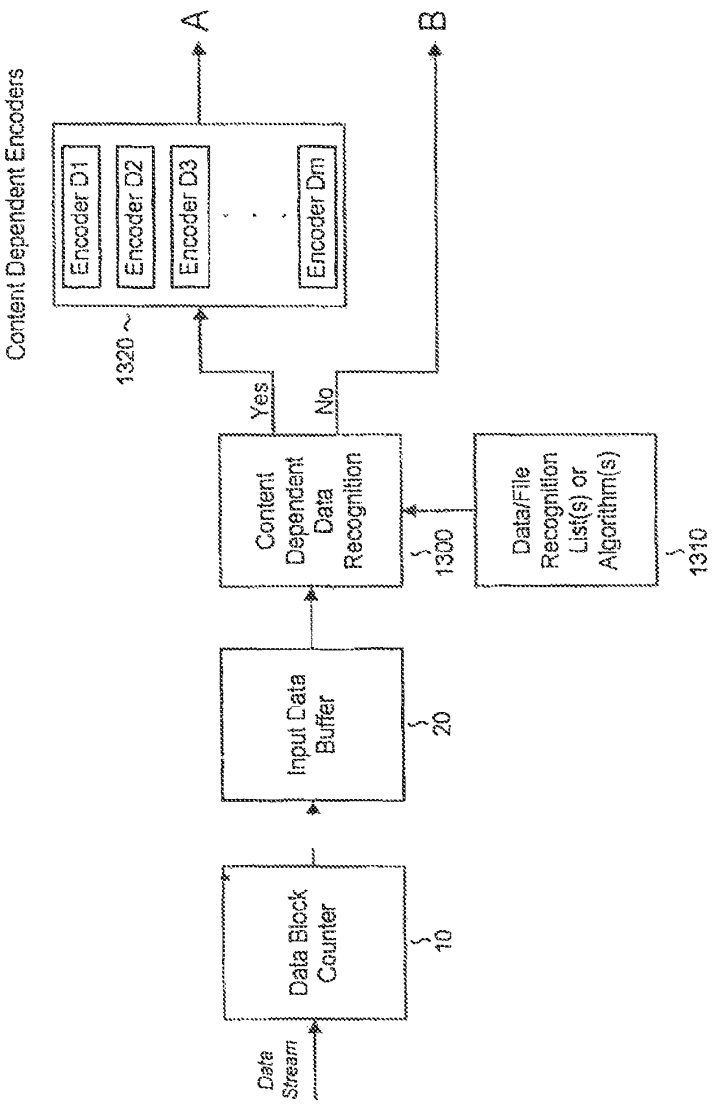

Data Stream
Data Block Counter
10
Input Data Buffer
20
Content Dependent Data Recognition
1300
Data/File Recognition List(s) or Algorithm(s)
1310
Yes
No
A
B
Content Dependent Encoders
1320
Encoder D1
Encoder D2
Encoder D3
Encoder Dm

FIGURE 15A

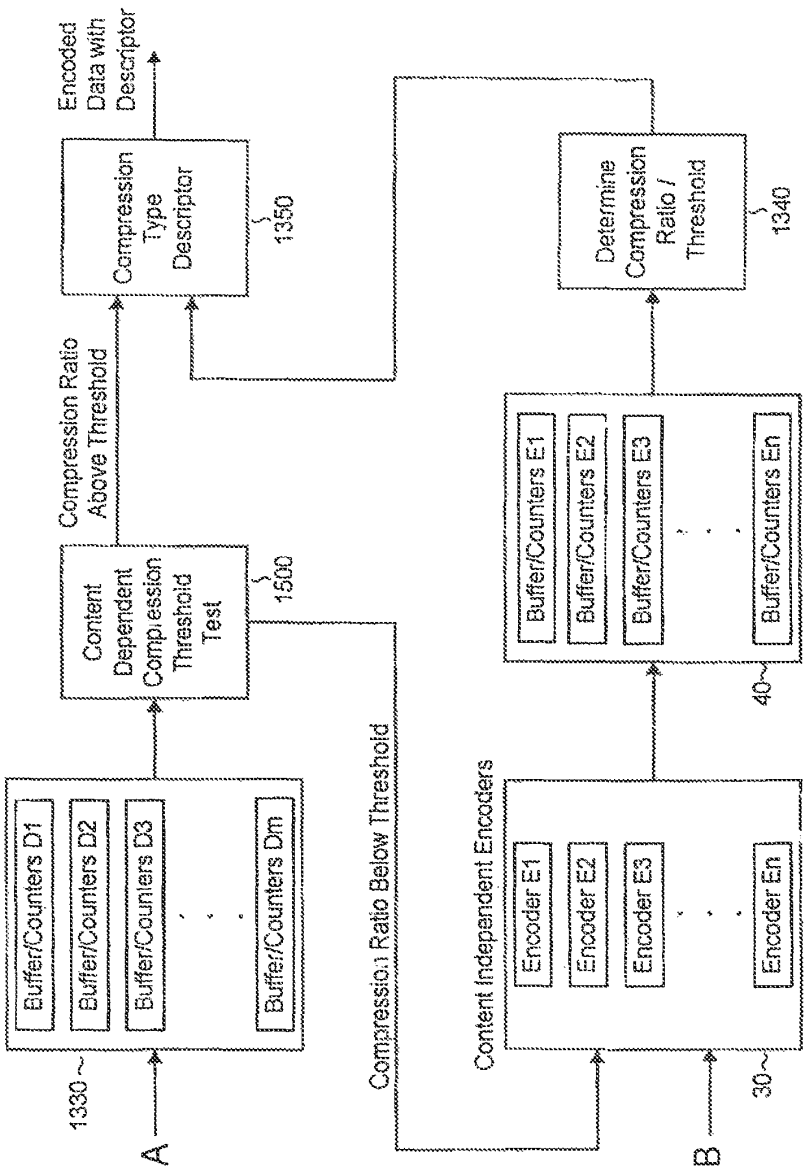

Encoded Data with Descriptor
Compression Type Descriptor
1350
Compression Ratio Above Threshold
Content Dependent Compression Threshold Test
1500
Compression Ratio Below Threshold
Determine Compression Ratio / Threshold
1340
Content Independent Encoders
Buffer/Counters D1
Buffer/Counters D2
Buffer/Counters D3
Buffer/Counters Dm
Encoder E1
Encoder E2
Encoder E3
Encoder En
Buffer/Counters E1
Buffer/Counters E2
Buffer/Counters E3
Buffer/Counters En
1330
30
40
A
B

FIGURE 15B

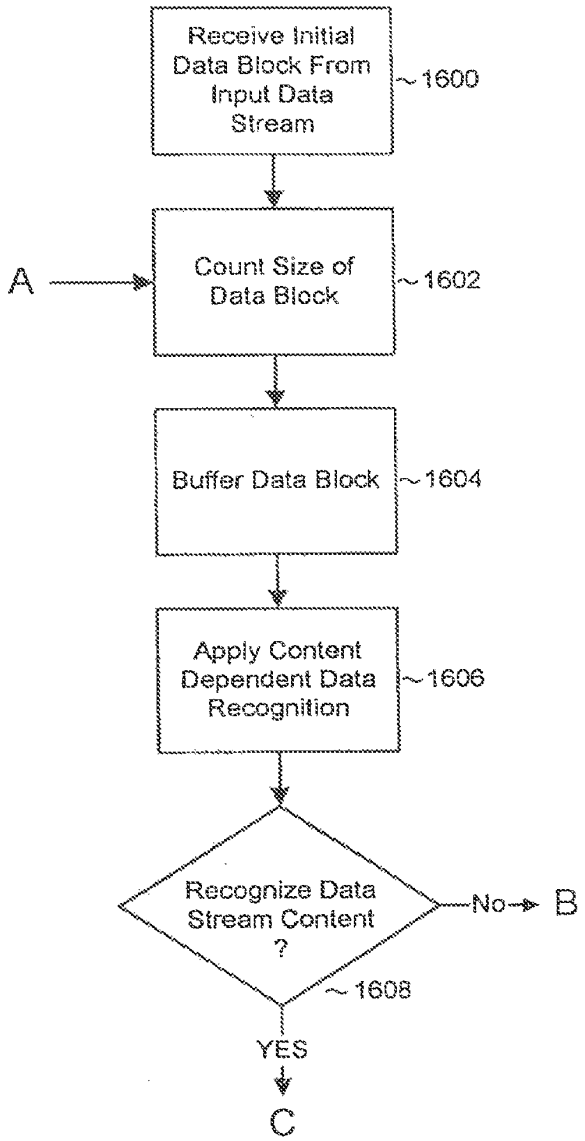

Receive Initial Data Block From Input Data Stream
1600
A
Count Size of Data Block
1602
Buffer Data Block
1604
Apply Content Dependent Data Recognition
1606
Recognize Data Stream Content ?
No
B
1608
YES
C

FIGURE 16A

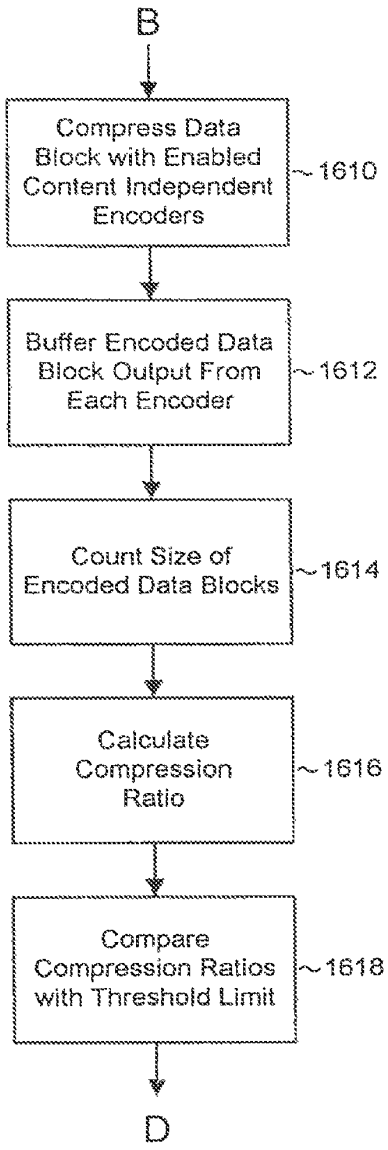

B
Compress Data Block with Enabled Content Independent Encoders
1610
Buffer Encoded Data Block Output From Each Encoder
1612
Count Size of Encoded Data Blocks
1614
Calculate Compression Ratio
1616
Compare Compression Ratios with Threshold Limit
1618
D

FIGURE 16B

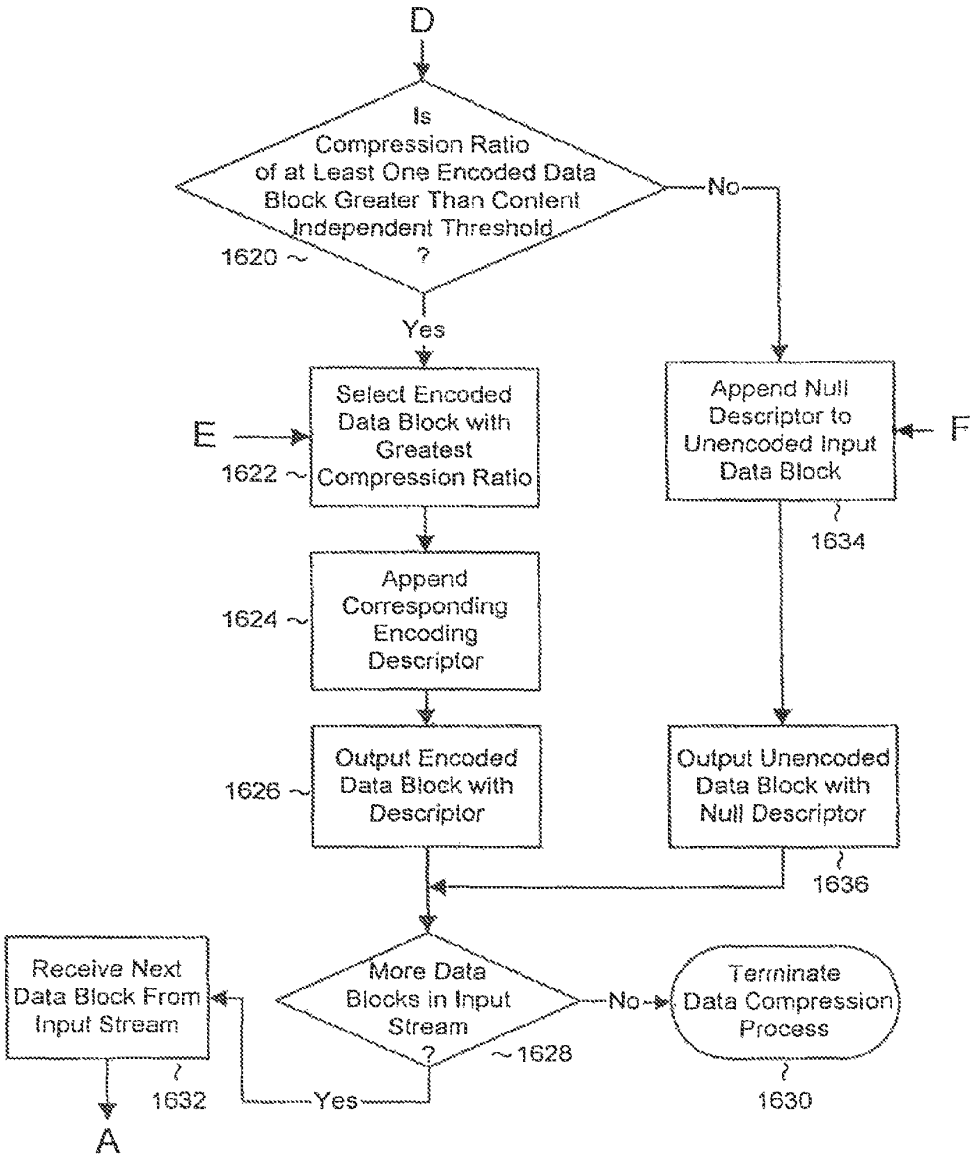

D
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Independent Threshold ?
1620
No
Yes
E
Select Encoded Data Block with Greatest Compression Ratio
1622
Append Null Descriptor to Unencoded Input Data Block
F
1634
Append Corresponding Encoding Descriptor
1624
Output Encoded Data Block with Descriptor
1626
Output Unencoded Data Block with Null Descriptor
1636
Receive Next Data Block From Input Stream
1632
More Data Blocks in Input Stream ?
1628
No
Terminate Data Compression Process
1630
Yes
A

FIGURE 16C

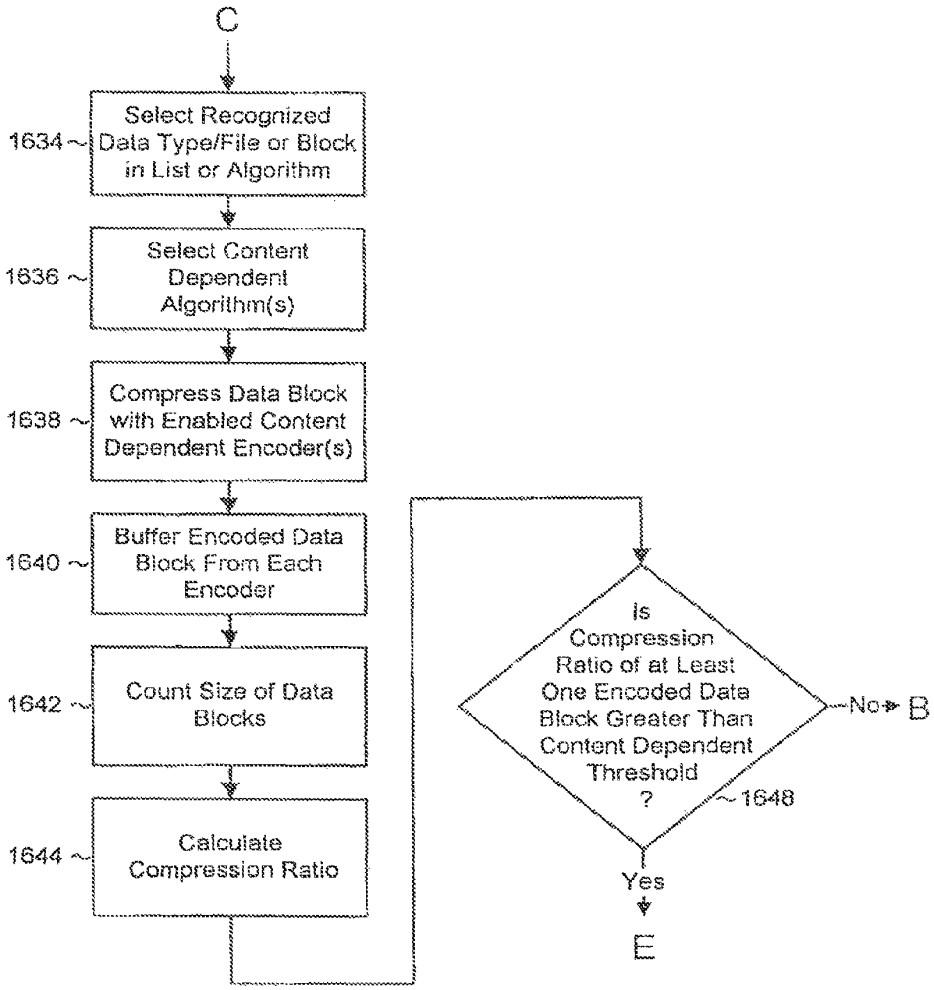

C
1634
Select Recognized Data Type/File or Block in List or Algorithm
1636
Select Content Dependent Algorithm(s)
1638
Compress Data Block with Enabled Content Dependent Encoder(s)
1640
Buffer Encoded Data Block From Each Encoder
1642
Count Size of Data Blocks
1644
Calculate Compression Ratio
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Dependent Threshold ?
1648
No
B
Yes
E

FIGURE 16D

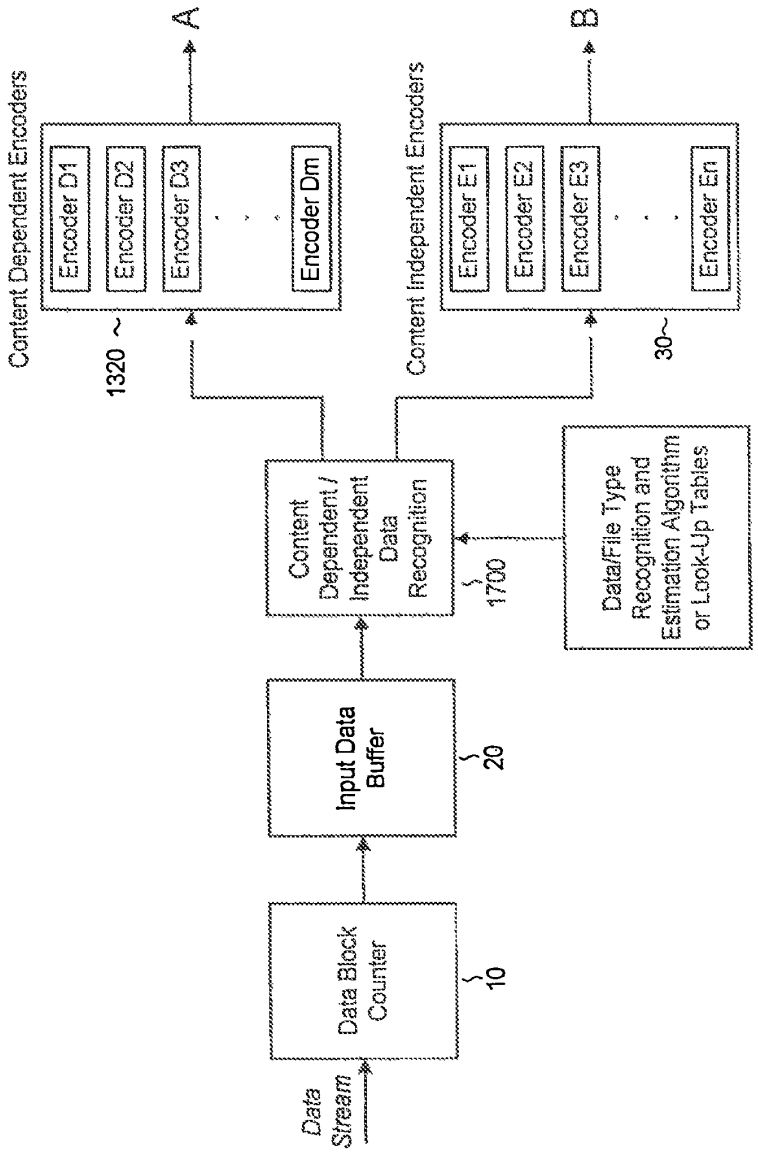

Data Stream
Data Block Counter
10
Input Data Buffer
20
Content Dependent / Independent Data Recognition
1700
Data/File Type Recognition and Estimation Algorithm or Look-Up Tables
1710
Content Dependent Encoders
1320
Encoder D1
Encoder D2
Encoder D3
Encoder Dm
A
Content Independent Encoders
30
Encoder E1
Encoder E2
Encoder E3
Encoder En
B

FIGURE 17A

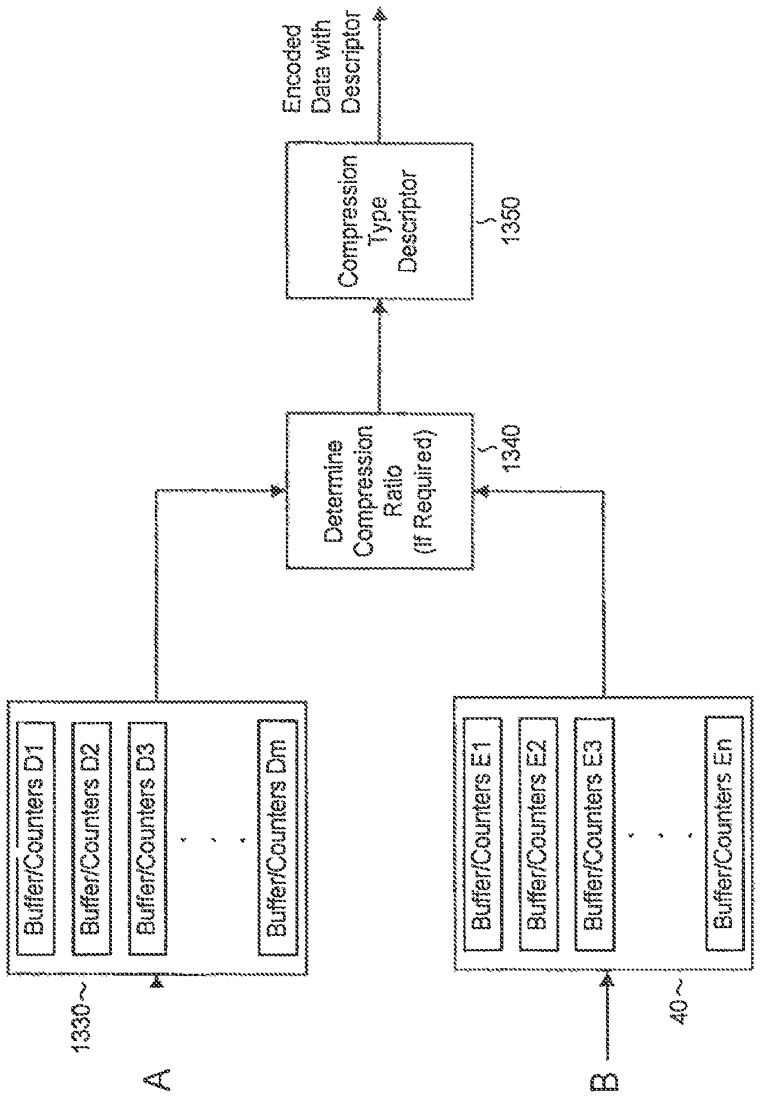

Encoded Data with Descriptor
Compression Type Descriptor
1360
Determine Compression Ratio (If Required)
1340
Buffer/Counters D1
Buffer/Counters D2
Buffer/Counters D3
Buffer/Counters Dm
1330
A
Buffer/Counters E1
Buffer/Counters E2
Buffer/Counters E3
Buffer/Counters En
40
B

FIGURE 17B

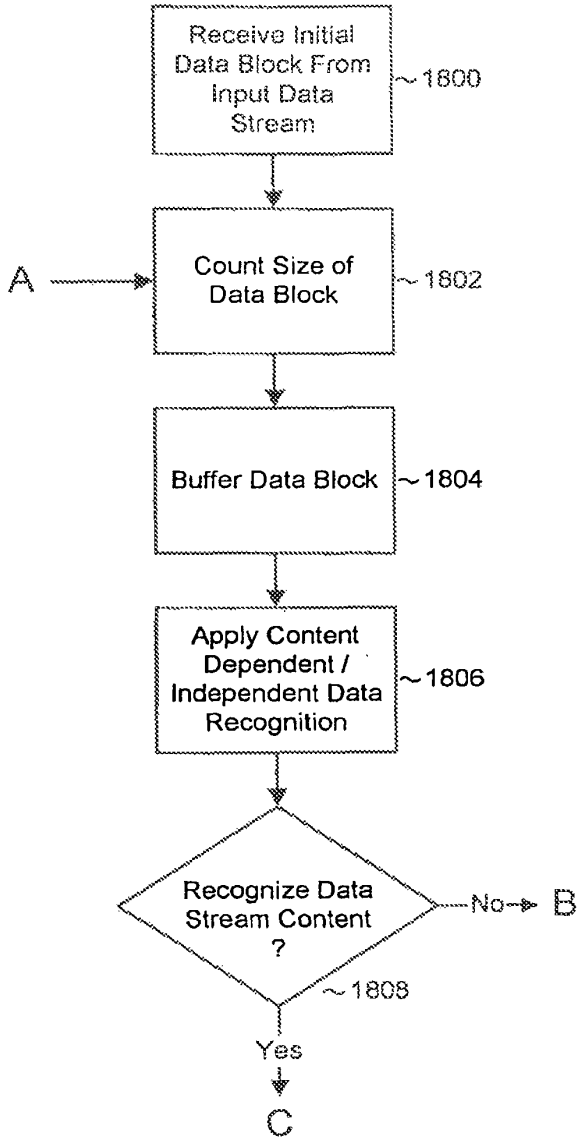

Receive Initial Data Block From Input Data Stream
1800
A
Count Size of Data Block
1802
Buffer Data Block
1804
Apply Content Dependent / Independent Data Recognition
1806
Recognize Data Stream Content ?
No
B
1808
Yes
C

FIGURE 18A

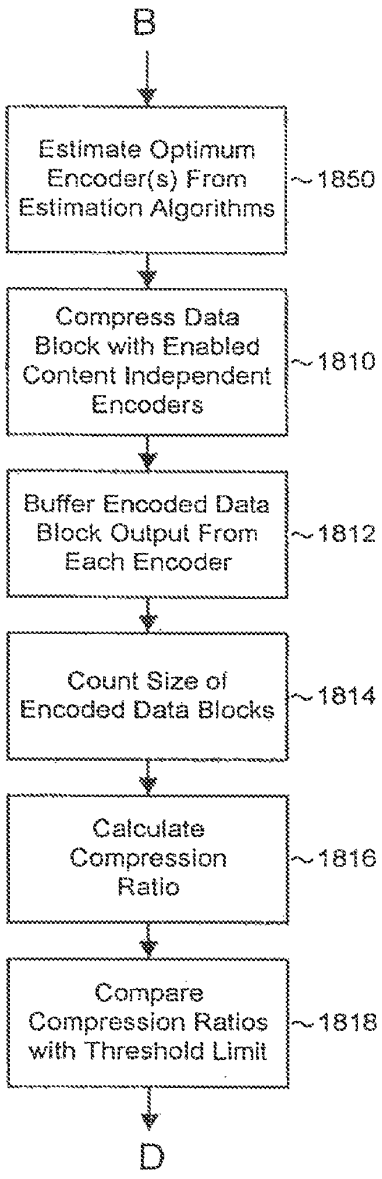

B
Estimate Optimum Encoder(s) From Estimation Algorithms
1850
Compress Data Block with Enabled Content Independent Encoders
1810
Buffer Encoded Data Block Output From Each Encoder
1812
Count Size of Encoded Data Blocks
1814
Calculate Compression Ratio
1816
Compare Compression Ratios with Threshold Limit
1818
D

FIGURE 18B

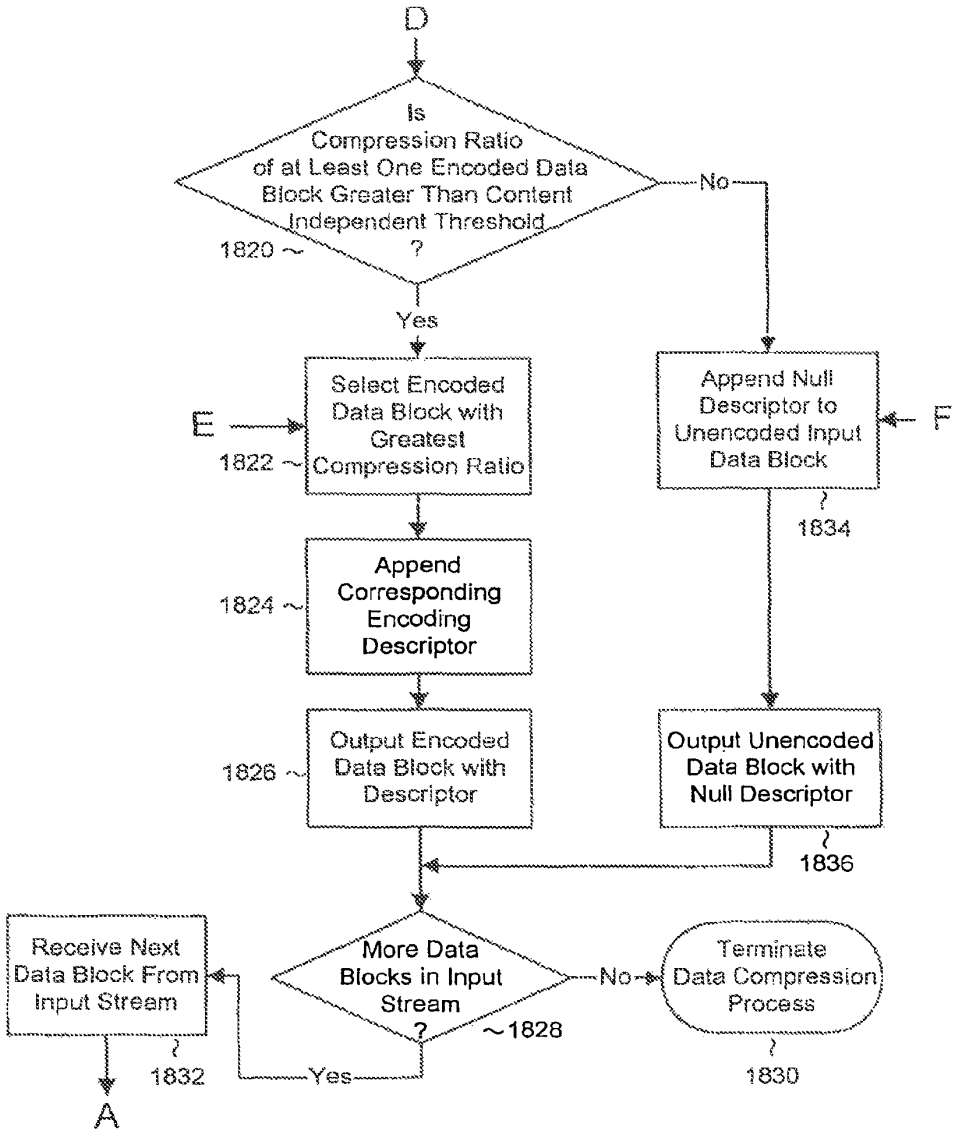

D
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Independent Threshold ?
1820
No
Yes
E
Select Encoded Data Block with Greatest Compression Ratio
1822
Append Null Descriptor to Unencoded Input Data Block
F
1834
Append Corresponding Encoding Descriptor
1824
Output Encoded Data Block with Descriptor
1826
Output Unencoded Data Block with Null Descriptor
1836
Receive Next Data Block From Input Stream
1832
A
More Data Blocks in Input Stream ?
1828
No
Yes
Terminate Data Compression Process
1830

FIGURE 18C

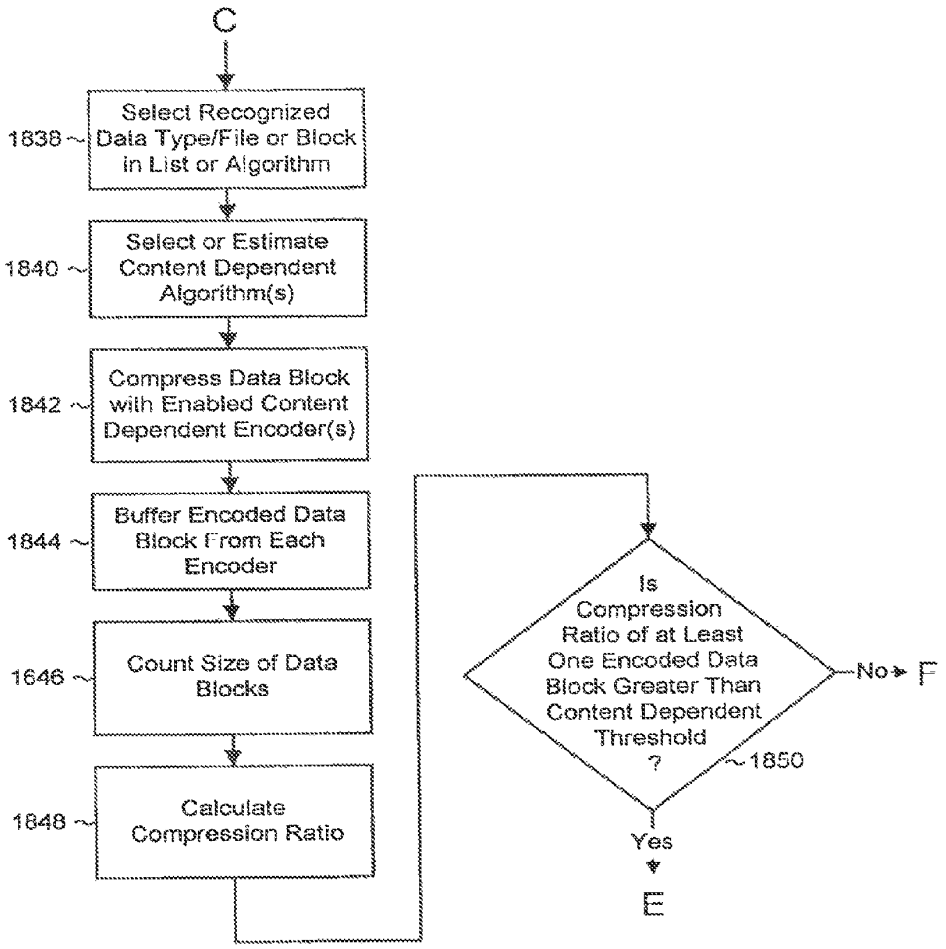

C
1838
Select Recognized Data Type/File or Block in List or Algorithm
1840
Select or Estimate Content Dependent Algorithm(s)
1842
Compress Data Block with Enabled Content Dependent Encoder(s)
1844
Buffer Encoded Data Block From Each Encoder
1646
Count Size of Data Blocks
1848
Calculate Compression Ratio
Is Compression Ratio of at Least One Encoded Data Block Greater Than Content Dependent Threshold ?
1850
No
F
Yes
E

FIGURE 18D

DATA COMPRESSION SYSTEMS AND METHODS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Continuation of U.S. patent application Ser. No. 14/251,453, filed Apr. 11, 2014, which is a Continuation of U.S. patent application Ser. No. 14/035,561, filed Sep. 24, 2013, now U.S. Pat. No. 8,717,203, which is a Continuation of U.S. patent application Ser. No. 13/154,211, now U.S. Pat. No. 8,643,513, filed Jun. 6, 2011, which is a Continuation of U.S. patent application Ser. No. 12/703,042, filed Feb. 9, 2010, now U.S. Pat. No. 8,502,707, which is a Continuation of both U.S. patent application Ser. No. 11/651,366, filed Jan. 8, 2007, now abandoned, and U.S. patent application Ser. No. 11/651,365, filed Jan. 8, 2007, now U.S. Pat. No. 7,714,747. Each of application Ser. No. 11/651,366 and application Ser. No. 11/651,365 is a Continuation of U.S. patent application Ser. No. 10/668,768, filed Sep. 22, 2003, now U.S. Pat. No. 7,161,506, which is a Continuation of U.S. patent application Ser. No. 10/016,355, filed Oct. 29, 2001, now U.S. Pat. No. 6,624,761, which is a Continuation-In-Part of U.S. patent application Ser. No. 09/705,446, filed Nov. 3, 2000, now U.S. Pat. No. 6,309,424, which is a Continuation of U.S. patent application Ser. No. 09/210,491, filed Dec. 11, 1998, which is now U.S. Pat. No. 6,195,024. Each of the listed applications are incorporated herein by reference in their entireties.

BACKGROUND

1. Technical Field

The present invention relates generally to a data compression and decompression and, more particularly, to systems and methods for data compression using content independent and content dependent data compression and decompression.

2. Description of Related Art

Information may be represented in a variety of manners. Discrete information such as text and numbers are easily represented in digital data. This type of data representation is known as symbolic digital data. Symbolic digital data is thus an absolute representation of data such as a letter, figure, character, mark, machine code, or drawing.

Continuous information such as speech, music, audio, images and video, frequently exists in the natural world as analog information. As is well known to those skilled in the art, recent advances in very large scale integration (VLSI) digital computer technology have enabled both discrete and analog information to be represented with digital data. Continuous information represented as digital data is often referred to as diffuse data. Diffuse digital data is thus a representation of data that is of low information density and is typically not easily recognizable to humans in its native form.

There are many advantages associated with digital data representation. For instance, digital data is more readily processed, stored, and transmitted due to its inherently high noise immunity. In addition, the inclusion of redundancy in digital data representation enables error detection and/or correction. Error detection and/or correction capabilities are dependent upon the amount and type of data redundancy, available error detection and correction processing, and extent of data corruption.

One outcome of digital data representation is the continuing need for increased capacity in data processing, storage, and transmittal. This is especially true for diffuse data where increases in fidelity and resolution create exponentially

greater quantities of data. Data compression is widely used to reduce the amount of data required to process, transmit, or store a given quantity of information. In general, there are two types of data compression techniques that may be utilized either separately or jointly to encode/decode data: lossless and lossy data compression.

Lossy data compression techniques provide for an inexact representation of the original uncompressed data such that the decoded (or reconstructed) data differs from the original unencoded/uncompressed data. Lossy data compression is also known as irreversible or noisy compression. Entropy is defined as the quantity of information in a given set of data. Thus, one obvious advantage of lossy data compression is that the compression ratios can be larger than the entropy limit, all at the expense of information content. Many lossy data compression techniques seek to exploit various traits within the human senses to eliminate otherwise imperceptible data. For example, lossy data compression of visual imagery might seek to delete information content in excess of the display resolution or contrast ratio.

On the other hand, lossless data compression techniques provide an exact representation of the original uncompressed data. Simply stated, the decoded (or reconstructed) data is identical to the original unencoded/uncompressed data. Lossless data compression is also known as reversible or noiseless compression. Thus, lossless data compression has, as its current limit, a minimum representation defined by the entropy of a given data set.

There are various problems associated with the use of lossless compression techniques. One fundamental problem encountered with most lossless data compression techniques are their content sensitive behavior. This is often referred to as data dependency. Data dependency implies that the compression ratio achieved is highly contingent upon the content of the data being compressed. For example, database files often have large unused fields and high data redundancies, offering the opportunity to losslessly compress data at ratios of 5 to 1 or more. In contrast, concise software programs have little to no data redundancy and, typically, will not losslessly compress better than 2 to 1.

Another problem with lossless compression is that there are significant variations in the compression ratio obtained when using a single lossless data compression technique for data streams having different data content and data size. This process is known as natural variation.

A further problem is that negative compression may occur when certain data compression techniques act upon many types of highly compressed data. Highly compressed data appears random and many data compression techniques will substantially expand, not compress this type of data.

For a given application, there are many factors that govern the applicability of various data compression techniques. These factors include compression ratio, encoding and decoding processing requirements, encoding and decoding time delays, compatibility with existing standards, and implementation complexity and cost, along with the is adaptability and robustness to variations in input data. A direct relationship exists in the current art between compression ratio and the amount and complexity of processing required. One of the limiting factors in most existing prior art lossless data compression techniques is the rate at which the encoding and decoding processes are performed. Hardware and software implementation tradeoffs are often dictated by encoder and decoder complexity along with cost.

Another problem associated with lossless compression methods is determining the optimal compression technique for a given set of input data and intended application. To

combat this problem, there are many conventional content dependent techniques that may be utilized. For instance, file type descriptors are typically appended to file names to describe the application programs that normally act upon the data contained within the file. In this manner data types, data structures, and formats within a given file may be ascertained. Fundamental limitations with this content dependent technique include:

(1) the extremely large number of application programs, some of which do not possess published or documented file formats, data structures, or data type descriptors;

(2) the ability for any data compression supplier or consortium to acquire, store, and access the vast amounts of data required to identify known file descriptors and associated data types, data structures, and formats; and

(3) the rate at which new application programs are developed and the need to update file format data descriptions accordingly.

An alternative technique that approaches the problem of selecting an appropriate lossless data compression technique is disclosed, for example, in U.S. Pat. No. 5,467,087 to Chu entitled "High Speed Lossless Data Compression System" ("Chu"). FIG. 1 illustrates an embodiment of this data compression and decompression technique. Data compression 1 comprises two phases, a data pre-compression phase 2 and a data compression phase 3. Data decompression 4 of a compressed input data stream is also comprised of two phases, a data type retrieval phase 5 and a data decompression phase 6. During the data compression process 1, the data pre-compressor 2 accepts an uncompressed data stream, identifies the data type of the input stream, and generates a data type identification signal. The data compressor 3 selects a data compression method from a preselected set of methods to compress the input data stream, with the intention of producing the best available compression ratio for that particular data type.

There are several limitations associated with the Chu method. One such limitation is the need to unambiguously identify various data types. While these might include such common data types as ASCII, binary, or unicode, there, in fact, exists a broad universe of data types that fall outside the three most common data types. Examples of these alternate data types include: signed and unsigned integers of various lengths, differing types and precision of floating point numbers, pointers, other forms of character text, and a multitude of user defined data types. Additionally, data types may be interspersed or partially compressed, making data type recognition difficult and/or impractical. Another limitation is that given a known data type, or mix of data types within a specific set or subset of input data, it may be difficult and/or impractical to predict which data encoding technique yields the highest compression ratio.

Accordingly, there is a need for a data compression system and method that would address limitations in conventional data compression techniques as described above.

SUMMARY OF THE INVENTION

The present invention is directed to systems and methods for providing fast and efficient data compression using a combination of content independent data compression and content dependent data compression. In one aspect of the invention, a method for compressing data comprises the steps of:

analyzing a data block of an input data stream to identify a data type of the data block, the input data stream comprising a plurality of disparate data types;

performing content dependent data compression on the data block, if the data type of the data block is identified;

performing content independent data compression on the data block, if the data type of the data block is not identified.

In another aspect, the step of performing content independent data compression comprises: encoding the data block with a plurality of encoders to provide a plurality of encoded data blocks; determining a compression ratio obtained for each of the encoders; comparing each of the determined compression ratios with a first compression threshold; selecting for output the input data block and appending a null compression descriptor to the input data block, if all of the encoder compression ratios do not meet the first compression threshold; and selecting for output the encoded data block having the highest compression ratio and appending a corresponding compression type descriptor to the selected encoded data block, if at least one of the compression ratios meet the first compression threshold.

In another aspect, the step of performing content dependent compression comprises the steps of: selecting one or more encoders associated with the identified data type and encoding the data block with the selected encoders to provide a plurality of encoded data blocks; determining a compression ratio obtained for each of the selected encoders; comparing each of the determined compression ratios with a second compression threshold; selecting for output the input data block and appending a null compression descriptor to the input data block, if all of the encoder compression do not meet the second compression threshold; and selecting for output the encoded data block having the highest compression ratio and appending a corresponding compression type descriptor to the selected encoded data block, if at least one of the compression ratios meet the second compression threshold.

In yet another aspect, the step of performing content independent data compression on the data block, if the data type of the data block is not identified, comprises the steps of: estimating a desirability of using of one or more encoder types based one characteristics of the data block; and compressing the data block using one or more desirable encoders.

In another aspect, the step of performing content dependent data compression on the data block, if the data type of the data block is identified, comprises the steps of: estimating a desirability of using of one or more encoder types based on characteristics of the data block; and compressing the data block using one or more desirable encoders.

In another aspect, the step of analyzing the data block comprises analyzing the data block to recognize one of a data type, data structure, data block format, file substructure, and/or file types. A further step comprises maintaining an association between encoder types and data types, data structures, data block formats, file substructure, and/or file types.

In yet another aspect of the invention, a method for compressing data comprises the steps of:

analyzing a data block of an input data stream to identify a data type of the data block, the input data stream comprising a plurality of disparate data types;

performing content dependent data compression on the data block, if the data type of the data block is identified;

determining a compression ratio of the compressed data block obtained using the content dependent compression and comparing the compression ratio with a first compression threshold; and

performing content independent data compression on the data block, if the data type of the data block is not identified or if the compression ratio of the compressed data block obtained using the content dependent compression does not meet the first compression threshold.

Advantageously, the present invention employs a plurality of encoders applying a plurality of compression techniques on an input data stream so as to achieve maximum compression in accordance with the real-time or pseudo real-time data rate constraint. Thus, the output bit rate is not fixed and the amount, if any, of permissible data quality degradation is user or data specified.

These and other aspects, features and advantages of the present invention will become apparent from the following detailed description of preferred embodiments, which is to be read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block/flow diagram of a content dependent high-speed lossless data compression and decompression system/method according to the prior art;

FIG. **2** is a block diagram of a content independent data compression system according to one embodiment of the present invention;

FIGS. **3***a* and **3***b* comprise a flow diagram of a data compression method according to one aspect of the present invention, which illustrates the operation of the data compression system of FIG. **2**;

FIG. **4** is a block diagram of a content independent data compression system according to another embodiment of the present invention having an enhanced metric for selecting an optimal encoding technique;

FIGS. **5***a* and **5***b* comprise a flow diagram of a data compression method according to another aspect of the present invention, which illustrates the operation of the data compression system of FIG. **4**;

FIG. **6** is a block diagram of a content independent data compression system according to another embodiment of the present invention having an a priori specified timer that provides real-time or pseudo real-time of output data;

FIGS. **7***a* and **7***b* comprise a flow diagram of a data compression method according to another aspect of the present invention, which illustrates the operation of the data compression system of FIG. **6**;

FIG. **8** is a block diagram of a content independent data compression system according to another embodiment having an a priori specified timer that provides real-time or pseudo real-time of output data and an enhanced metric for selecting an optimal encoding technique;

FIG. **9** is a block diagram of a content independent data compression system according to another embodiment of the present invention having an encoding architecture comprising a plurality of sets of serially cascaded encoders;

FIGS. **10***a* and **10***b* comprise a flow diagram of a data compression method according to another aspect of the present invention, which illustrates the operation of the data compression system of FIG. **9**;

FIG. **11** is block diagram of a content independent data decompression system according to one embodiment of the present invention;

FIG. **12** is a flow diagram of a data decompression method according to one aspect of the present invention, which illustrates the operation of the data compression system of FIG. **11**;

FIGS. **13***a* and **13***b* comprise a block diagram of a data compression system comprising content dependent and content independent data compression, according to an embodiment of the present invention;

FIGS. **14***a*-**14***d* comprise a flow diagram of a data compression method using both content dependent and content independent data compression, according to one aspect of the present invention;

FIGS. **15***a* and **15***b* comprise a block diagram of a data compression system comprising content dependent and content independent data compression, according to another embodiment of the present invention;

FIGS. **16***a*-**16***d* comprise a flow diagram of a data compression method using both content dependent and content independent data compression, according to another aspect of the present invention;

FIGS. **17***a* and **17***b* comprise a block diagram of a data compression system comprising content dependent and content independent data compression, according to another embodiment of the present invention; and

FIGS. **18***a*-**18***d* comprise a flow diagram of a data compression method using both content dependent and content independent data compression, according to another aspect of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to systems and methods for providing data compression and decompression using content independent and content dependent data compression and decompression. In the following description, it is to be understood that system elements having equivalent or similar functionality are designated with the same reference numerals in the Figures. It is to be further understood that the present invention may be implemented in various forms of hardware, software, firmware, or a combination thereof. In particular, the system modules described herein are preferably implemented in software as an application program that is executable by, e.g., a general purpose computer or any machine or device having any suitable and preferred microprocessor architecture. Preferably, the present invention is implemented on a computer platform including hardware such as one or more central processing units (CPU), a random access memory (RAM), and input/output (I/O) interface(s). The computer platform also includes an operating system and microinstruction code. The various processes and functions described herein may be either part of the microinstruction code or application programs which are executed via the operating system. In addition, various other peripheral devices may be connected to the computer platform such as an additional data storage device and a printing device.

It is to be further understood that, because some of the constituent system components described herein are preferably implemented as software modules, the actual system connections shown in the Figures may differ depending upon the manner in which the systems are programmed. It is to be appreciated that special purpose microprocessors may be employed to implement the present invention. Given the teachings herein, one of ordinary skill in the related art will be able to contemplate these and similar implementations or configurations of the present invention.

Referring now to FIG. **2** a block diagram illustrates a content independent data compression system according to one embodiment of the present invention. The data compression system includes a counter module **10** that receives as input an uncompressed or compressed data stream. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the data block size may be fixed or variable. The counter module **10** counts the size of each input data block (i.e., the

data block size is counted in bits, bytes, words, any convenient data multiple or metric, or any combination thereof).

An input data buffer **20**, operatively connected to the counter module **10**, may be provided for buffering the input data stream in order to output an uncompressed data stream in the event that, as discussed in further detail below, every encoder fails to achieve a level of compression that exceeds an a priori specified minimum compression ratio threshold. It is to be understood that the input data buffer **20** is not required for implementing the present invention.

An encoder module **30** is operatively connected to the buffer **20** and comprises a set of encoders E**1**, E**2**, E**3** . . . En. The encoder set E**1**, E**2**, E**3** . . . En may include any number "n" of those lossless encoding techniques currently well known within the art such as run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. It is to be understood that the encoding techniques are selected based upon their ability to effectively encode different types of input data. It is to be appreciated that a full complement of encoders are preferably selected to provide a broad coverage of existing and future data types.

The encoder module **30** successively receives as input each of the buffered input data blocks (or unbuffered input data blocks from the counter module **10**). Data compression is performed by the encoder module **30** wherein each of the encoders E**1** . . . En processes a given input data block and outputs a corresponding set of encoded data blocks. It is to be appreciated that the system affords a user the option to enable/disable any one or more of the encoders E**1** . . . En prior to operation. As is understood by those skilled in the art, such feature allows the user to tailor the operation of the data compression system for specific applications. It is to be further appreciated that the is encoding process may be performed either in parallel or sequentially. In particular, the encoders E**1** through En of encoder module **30** may operate in parallel (i.e., simultaneously processing a given input data block by utilizing task multiplexing on a single central processor, via dedicated hardware, by executing on a plurality of processor or dedicated hardware systems, or any combination thereof). In addition, encoders E**1** through En may operate sequentially on a given unbuffered or buffered input data block. This process is intended to eliminate the complexity and additional processing overhead associated with multiplexing concurrent encoding techniques on a single central processor and/or dedicated hardware, set of central processors and/or dedicated hardware, or any achievable combination. It is to be further appreciated that encoders of the identical type may be applied in parallel to enhance encoding speed. For instance, encoder E**1** may comprise two parallel Huffman encoders for parallel processing of an input data block.

A buffer/counter module **40** is operatively connected to the encoding module **30** for buffering and counting the size of each of the encoded data blocks output from encoder module **30**. Specifically, the buffer/counter **30** comprises a plurality of buffer/counters BC**1**, BC**2**, BC**3** . . . BCn, each operatively associated with a corresponding one of the encoders E**1** . . . En. A compression ratio module **50**, operatively connected to the output buffer/counter **40**, determines the compression ratio obtained for each of the enabled encoders E**1** . . . En by taking the ratio of the size of the input data block to the size of the output data block stored in the corresponding buffer/counters BC**1** . . . BCn. In addition, the compression ratio module **50** compares each compression ratio with an a priori-specified compression ratio threshold limit to determine if at least one of the encoded data blocks output from the enabled encoders E**1** . . . En achieves a compression that exceeds an a priori-specified threshold. As is understood by those skilled in the art, the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. A description module **60**, operatively coupled to the compression ratio module **50**, appends a corresponding compression type descriptor to each encoded data block which is selected for output so as to indicate the type of compression format of the encoded data block.

The operation of the data compression system of FIG. **2** will now be discussed in is further detail with reference to the flow diagram of FIGS. **3***a* and **3***b*. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the stream is received (step **300**). As stated above, data compression is performed on a per data block basis. Accordingly, the first input data block in the input data stream is input into the counter module **10** that counts the size of the data block (step **302**). The data block is then stored in the buffer **20** (step **304**). The data block is then sent to the encoder module **30** and compressed by each (enabled) encoder E**1** . . . En (step **306**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **308**), and the encoded data block size is counted (step **310**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10**) to the size of each encoded data block output from the enabled encoders (step **312**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **314**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art.

After the compression ratios are compared with the threshold, a determination is s made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **316**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **316**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **318**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **320**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **316**), then the encoded data block having the greatest compression ratio is selected (step **322**). An appropriate data compression type descriptor is then appended (step **324**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to

enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **326**).

After the encoded data block or the unencoded data input data block is output (steps **326** and **320**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **328**). If the input data stream includes additional data blocks (affirmative result in step **328**), the next successive data block is received (step **330**), its block size is counted (return to step **302**) and the data compression process in repeated. This process is iterated for each data block in the input data stream. Once the final input data block is processed (negative result in step **328**), data compression of the input data stream is finished (step **322**).

Since a multitude of data types may be present within a given input data block, it is often difficult and/or impractical to predict the level of compression that will be achieved by a specific encoder. Consequently, by processing the input data blocks with a plurality of encoding techniques and comparing the compression results, content free data compression is advantageously achieved. It is to be appreciated that this approach is scalable through future generations of processors, dedicated hardware, and software. As processing capacity increases and costs reduce, the benefits provided by the present invention will continue to increase. It should again be noted that the present invention may employ any lossless data encoding technique.

Referring now to FIG. **4**, a block diagram illustrates a content independent data compression system according to another embodiment of the present invention. The data compression system depicted in FIG. **4** is similar to the data compression system of FIG. **2** except that the embodiment of FIG. **4** includes an enhanced metric functionality for selecting an optimal encoding technique. In particular, each of the encoders E**1** . . . En in the encoder module **30** is tagged with a corresponding one of user-selected encoder desirability factors **70**. Encoder desirability is defined as an a priori user specified factor that takes into account any number of user considerations including, but not limited to, compatibility of the encoded data with existing standards, data error robustness, or any other aggregation of factors that the user wishes to consider for a particular application. Each encoded data block output from the encoder module **30** has a corresponding desirability factor appended thereto. A figure of merit module **80**, operatively coupled to the compression ratio module **50** and the descriptor module **60**, is provided for calculating a figure of merit for each of the encoded data blocks which possess a compression ratio greater than the compression ratio threshold limit. The figure of merit for each encoded data block is comprised of a weighted average of the a priori user specified threshold and the corresponding encoder desirability factor. As discussed below in further detail with reference to FIGS. **5***a* and **5***b*, the figure of merit substitutes the a priori user compression threshold limit for selecting and outputting encoded data blocks.

The operation of the data compression system of FIG. **4** will now be discussed in further detail with reference to the flow diagram of FIGS. **5***a* and **5***b*. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the stream is received (step **500**). The size of the first data block is then determined by the counter module **10** (step **502**). The data block is then stored in the buffer **20** (step **504**). The data block is then sent to the encoder module **30** and compressed by each (enabled) encoder in the encoder set E**1** . . . En (step **506**). Each encoded data block processed in the encoder module **30** is tagged with an encoder desirability factor that corresponds the particular encoding technique applied to the encoded data block (step **508**). Upon completion of the encoding of the input data block, an encoded data block with its corresponding desirability factor is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **510**), and the encoded data block size is counted (step **512**).

Next, a compression ratio obtained by each enabled encoder is calculated by taking the ratio of the size of the input data block (as determined by the input counter **10**) to the size of the encoded data block output from each enabled encoder (step **514**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **516**). A determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **518**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **518**), then the original unencoded input data block is selected for output and a null data compression type descriptor (as discussed above) is appended thereto (step **520**). Accordingly, the original unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **522**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **518**), then a figure of merit is calculated for each encoded data block having a compression ratio which exceeds the compression ratio threshold limit (step **524**). Again, the figure of merit for a given encoded data block is comprised of a weighted average of the a priori user specified threshold and the corresponding encoder desirability factor associated with the encoded data block. Next, the encoded data block having the greatest figure of merit is selected for output (step **526**). An appropriate data compression type descriptor is then appended (step **528**) to indicate the data encoding technique applied to the encoded data block. The encoded data block (which has the greatest figure of merit) along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **530**).

After the encoded data block or the unencoded input data block is output (steps **530** and **522**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **532**). If the input data stream includes additional data blocks (affirmative result in step **532**), then the next successive data block is received (step **534**), its block size is counted (return to step **502**) and the data compression process is iterated for each successive data block in the input data stream. Once the final input data block is processed (negative result in step **532**), data compression of the input data stream is finished (step **536**).

Referring now to FIG. **6**, a block diagram illustrates a data compression system according to another embodiment of the present invention. The data compression system depicted in FIG. **6** is similar to the data compression system discussed in detail above with reference to FIG. **2** except that the embodiment of FIG. **6** includes an a priori specified timer that provides real-time or pseudo real-time output data. In particular, an interval timer **90**, operatively coupled to the encoder module **30**, is preloaded with a user specified time value. The role of the interval timer (as will be explained in greater detail below with reference to FIGS. **7***a* and **7***b*) is to limit the processing time for each input data block processed by the

encoder module **30** so as to ensure that the real-time, pseudo real-time, or other time critical nature of the data compression processes is preserved.

The operation of the data compression system of FIG. **6** will now be discussed in further detail with reference to the flow diagram of FIGS. **7***a* and **7***b*. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the data stream is received (step **700**), and its size is determined by the counter module **10** (step **702**). The data block is then stored in buffer **20** (step **704**).

Next, concurrent with the completion of the receipt and counting of the first data block, the interval timer **90** is initialized (step **706**) and starts counting towards a user-specified time limit. The input data block is then sent to the encoder module **30** wherein data compression of the data block by each (enabled) encoder E**1** . . . En commences (step **708**). Next, a determination is made as to whether the user specified time expires before the completion of the encoding process (steps **710** and **712**). If the encoding process is completed before or at the expiration of the timer, i.e., each encoder (E**1** through En) completes its respective encoding process (negative result in step **710** and affirmative result in step **712**), then an encoded data block is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **714**).

On the other hand, if the timer expires (affirmative result in **710**), the encoding process is halted (step **716**). Then, encoded data blocks from only those enabled encoders E**1** . . . En that have completed the encoding process are selected and maintained in buffers (step **718**). It is to be appreciated that it is not necessary (or in some cases desirable) that some or all of the encoders complete the encoding process before the interval timer expires. Specifically, due to encoder data dependency and natural variation, it is possible that certain encoders may not operate quickly enough and, therefore, do not comply with the timing constraints of the end use. Accordingly, the time limit ensures that the real-time or pseudo real-time nature of the data encoding is preserved.

After the encoded data blocks are buffered (step **714** or **718**), the size of each encoded data block is counted (step **720**). Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10**) to the size of the encoded data block output from each enabled encoder (step **722**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **724**). A determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **726**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **726**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **728**). The original unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **730**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **726**), then the encoded data block having the greatest compression ratio is selected (step **732**). An appropriate data compression type descriptor is then appended (step **734**). The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **736**).

After the encoded data block or the unencoded input data block is output (steps **730** or **736**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **738**). If the input data stream includes additional data blocks (affirmative result in step **738**), the next successive data block is received (step **740**), its block size is counted (return to step **702**) and the data compression process in repeated. This process is iterated for each data block in the input data stream, with each data block being processed within the user-specified time limit as discussed above. Once the final input data block is processed (negative result in step **738**), data compression of the input data stream is complete (step **742**).

Referring now to FIG. **8**, a block diagram illustrates a content independent data compression system according to another embodiment of the present system. The data compression system of FIG. **8** incorporates all of the features discussed above in connection with the system embodiments of FIGS. **2**, **4**, and **6**. For example, the system of FIG. **8** incorporates both the a priori specified timer for providing real-time or pseudo real-time of output data, as well as the enhanced metric for selecting an optimal encoding technique. Based on the foregoing discussion, the operation of the system of FIG. **8** is understood by those skilled in the art.

Referring now to FIG. **9**, a block diagram illustrates a data compression system according to a preferred embodiment of the present invention. The system of FIG. **9** contains many of the features of the previous embodiments discussed above. However, this embodiment advantageously includes a cascaded encoder module **30***c* having an encoding architecture comprising a plurality of sets of serially cascaded encoders Em,n, where "m" refers to the encoding path (i.e., the encoder set) and where "n" refers to the number of encoders in the respective path. It is to be understood that each set of serially cascaded encoders can include any number of disparate and/or similar encoders (i.e., n can be any value for a given path m).

The system of FIG. **9** also includes a output buffer module **40***c* which comprises a plurality of buffer/counters B/Cm,n, each associated with a corresponding one of the encoders Em,n. In this embodiment, an input data block is sequentially applied to successive encoders (encoder stages) in the encoder path so as to increase the data compression ratio. For example, the output data block from a first encoder E**1**,**1**, is buffered and counted in B/C**1**,**1**, for subsequent processing by a second encoder E**1**,**2**. Advantageously, these parallel sets of sequential encoders are applied to the input data stream to effect content free lossless data compression. This embodiment provides for multi-stage sequential encoding of data with the maximum number of encoding steps subject to the available real-time, pseudo real-time, or other timing constraints.

As with each previously discussed embodiment, the encoders Em,n may include those lossless encoding techniques currently well known within the art, including: run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. Encoding techniques are selected based upon their ability to effectively encode different types of input data. A full complement of encoders provides for broad coverage of existing and future data types. The input data blocks may be applied simultaneously to the encoder paths (i.e., the encoder paths may operate in parallel, utilizing task multiplexing on a single central processor, or via dedicated hardware, or by executing

on a plurality of processor or dedicated hardware systems, or any combination thereof). In addition, an input data block may be sequentially applied to the encoder paths. Moreover, each serially cascaded encoder path may comprise a fixed (predetermined) sequence of encoders or a random sequence of encoders. Advantageously, by simultaneously or sequentially processing input data blocks via a plurality of sets of serially cascaded encoders, content free data compression is achieved.

The operation of the data compression system of FIG. **9** will now be discussed in further detail with reference to the flow diagram of FIGS. **10***a* and **10***b*. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the data stream is received (step **100**), and its size is determined by the counter module **10** (step **102**). The data block is then stored in buffer **20** (step **104**).

Next, concurrent with the completion of the receipt and counting of the first data block, the interval timer **90** is initialized (step **106**) and starts counting towards a user-specified time limit. The input data block is then sent to the cascade encoder module **30**C wherein the input data block is applied to the first encoder (i.e., first encoding stage) in each of the cascaded encoder paths E**1**,**1** . . . Em,**1** (step **108**). Next, a determination is made as to whether the user specified time expires before the completion of the first stage encoding process (steps **110** and **112**). If the first stage encoding process is completed before the expiration of the timer, i.e., each encoder (E**1**,**1** . . . Em,**1**) completes its respective encoding process (negative result in step **110** and affirmative result in step **112**), then an encoded data block is output from each encoder E**1**,**1** . . . Em,**1** and maintained in a corresponding buffer (step **114**). Then for each cascade encoder path, the output of the completed encoding stage is applied to the next successive encoding stage in the cascade path (step **116**). This process (steps **110**, **112**, **114**, and **116**) is repeated until the earlier of the timer expiration (affirmative result in step **110**) or the completion of encoding by each encoder stage in the serially cascaded paths, at which time the encoding process is halted (step **118**).

Then, for each cascade encoder path, the buffered encoded data block output by the last encoder stage that completes the encoding process before the expiration of the timer is selected for further processing (step **120**). Advantageously, the interim stages of the multi-stage data encoding process are preserved. For example, the results of encoder E**1**,**1** are preserved even after encoder E**1**,**2** begins encoding the output of encoder E**1**,**1**. If the interval timer expires after encoder E**1**,**1** completes its respective encoding process but before encoder E**1**,**2** completes its respective encoding process, the encoded data block from encoder E**1**,**1** is complete and is utilized for calculating the compression ratio for the corresponding encoder path. The incomplete encoded data block from encoder E**1**,**2** is either discarded or ignored.

It is to be appreciated that it is not necessary (or in some cases desirable) that some or all of the encoders in the cascade encoder paths complete the encoding process before the interval timer expires. Specifically, due to encoder data dependency, natural variation and the sequential application of the cascaded encoders, it is possible that certain encoders may not operate quickly enough and therefore do not comply with the timing constraints of the end use. Accordingly, the time limit ensures that the real-time or pseudo real-time nature of the data encoding is preserved.

After the encoded data blocks are selected (step **120**), the size of each encoded data block is counted (step **122**). Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10**) to the size of the encoded data block output from each encoder (step **124**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **126**). A determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **128**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **128**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **130**). The original unencoded data block and its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **132**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **128**), then a figure of merit is calculated for each encoded data block having a compression ratio which exceeds the compression ratio threshold limit (step **134**). Again, the figure of merit for a given encoded data block is comprised of a weighted average of the a priori user specified threshold and the corresponding encoder desirability factor associated with the encoded data block. Next, the encoded data block having the greatest figure of merit is selected (step **136**). An appropriate data compression type descriptor is then appended (step **138**) to indicate the data encoding technique applied to the encoded data block. For instance, the data type compression descriptor can indicate that the encoded data block was processed by either a single encoding type, a plurality of sequential encoding types, and a plurality of random encoding types. The encoded data block (which has the greatest figure of merit) along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **140**).

After the unencoded data block or the encoded data input data block is output (steps **132** and **140**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **142**). If the input data stream includes additional data blocks (affirmative result in step **142**), then the next successive data block is received (step **144**), its block size is counted (return to step **102**) and the data compression process is iterated for each successive data block in the input data stream. Once the final input data block is processed (negative result in step **142**), data compression of the input data stream is finished (step **146**).

Referring now to FIG. **11**, a block diagram illustrates a data decompression system according to one embodiment of the present invention. The data decompression system preferably includes an input buffer **1100** that receives as input an uncompressed or compressed data stream comprising one or more data blocks. The data blocks may range in size from individual bits through complete files or collections of multiple files. Additionally, the data block size may be fixed or variable. The input data buffer **1100** is preferably included (not required) to provide storage of input data for various hardware implementations. A descriptor extraction module **1102** receives the buffered (or unbuffered) input data block and then parses, lexically, syntactically, or otherwise analyzes the input data block using methods known by those skilled in the art to extract the data compression type descriptor associated with the data block. The data compression type descriptor may possess values corresponding to null (no encoding applied), a single applied encoding technique, or multiple encoding techniques applied in a specific or random order (in

accordance with the data compression system embodiments and methods discussed above).

A decoder module **1104** includes a plurality of decoders D**1** . . . Dn for decoding the input data block using a decoder, set of decoders, or a sequential set of decoders corresponding to the extracted compression type descriptor. The decoders D**1** . . . Dn may include those lossless encoding techniques currently well known within the art, including: run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. Decoding techniques are selected based upon their ability to effectively decode the various different types of encoded input data generated by the data compression systems described above or originating from any other desired source. As with the data compression systems discussed above, the decoder module **1104** may include multiple decoders of the same type applied in parallel so as to reduce the data decoding time.

The data decompression system also includes an output data buffer **1106** for buffering the decoded data block output from the decoder module **1104**.

The operation of the data decompression system of FIG. **11** will be discussed in further detail with reference to the flow diagram of FIG. **12**. A data stream comprising one or more data blocks of compressed or uncompressed data is input into the data decompression system and the first data block in the stream is received (step **1200**) and maintained in the buffer (step **1202**). As with the data compression systems discussed above, data decompression is performed on a per data block basis. The data compression type descriptor is then extracted from the input data block (step **1204**). A determination is then made as to whether the data compression type descriptor is null (step **1206**). If the data compression type descriptor is determined to be null (affirmative result in step **1206**), then no decoding is applied to the input data block and the original undecoded data block is output (or maintained in the output buffer) (step **1208**).

On the other hand, if the data compression type descriptor is determined to be any value other than null (negative result in step **1206**), the corresponding decoder or decoders are then selected (step **1210**) from the available set of decoders D**1** . . . Dn in the decoding module **1104**. It is to be understood that the data compression type descriptor may mandate the application of: a single specific decoder, an ordered sequence of specific decoders, a random order of specific decoders, a class or family of decoders, a mandatory or optional application of parallel decoders, or any combination or permutation thereof. The input data block is then decoded using the selected decoders (step **1212**), and output (or maintained in the output buffer **1106**) for subsequent data processing, storage, or transmittal (step **1214**). A determination is then made as to whether the input data stream contains additional data blocks to be processed (step **1216**). If the input data stream includes additional data blocks (affirmative result in step **1216**), the next successive data block is received (step **1220**), and buffered (return to step **1202**). Thereafter, the data decompression process is iterated for each data block in the input data stream. Once the final input data block is processed (negative result in step **1216**), data decompression of the input data stream is finished (step **1218**).

In other embodiments of the present invention described below, data compression is achieved using a combination of content dependent data compression and content independent data compression. For example, FIGS. **13***a* and **13***b* are block diagrams illustrating a data compression system employing both content independent and content dependent data compression according to one embodiment of the present invention, wherein content independent data compression is applied to a data block when the content of the data block cannot be identified or is not associable with a specific data compression algorithm. The data compression system comprises a counter module **10** that receives as input an uncompressed or compressed data stream. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the data block size may be fixed or variable. The counter module **10** counts the size of each input data block (i.e., the data block size is counted in bits, bytes, words, any convenient data multiple or metric, or any combination thereof).

An input data buffer **20**, operatively connected to the counter module **10**, may be provided for buffering the input data stream in order to output an uncompressed data stream in the event that, as discussed in further detail below, every encoder fails to achieve a level of compression that exceeds a priori specified content independent or content dependent minimum compression ratio thresholds. It is to be understood that the input data buffer **20** is not required for implementing the present invention.

A content dependent data recognition module **1300** analyzes the incoming data stream to recognize data types, data structures, data block formats, file substructures, file types, and/or any other parameters that may be indicative of either the data type/content of a given data block or the appropriate data compression algorithm or algorithms (in serial or in parallel) to be applied. Optionally, a data file recognition list(s) or algorithm(s) **1310** module may be employed to hold and/or determine associations between recognized data parameters and appropriate algorithms. Each data block that is recognized by the content data compression module **1300** is routed to a content dependent encoder module **1320**, if not the data is routed to the content independent encoder module **30**.

A content dependent encoder module **1320** is operatively connected to the content dependent data recognition module **1300** and comprises a set of encoders D**1**, D**2**, D**3** . . . Dm. The encoder set D**1**, D**2**, D**3** . . . Dm may include any number "n" of those lossless or lossy encoding techniques currently well known within the art such as MPEG4, various voice codecs, MPEG3, AC3, AAC, as well as lossless algorithms such as run length, Huffinan, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. It is to be understood that the encoding techniques are selected based upon their ability to effectively encode different types of input data. It is to be appreciated that a full complement of encoders and or codecs are preferably selected to provide a broad coverage of existing and future data types.

The content independent encoder module **30**, which is operatively connected to the content dependent data recognition module **1300**, comprises a set of encoders E**1**, E**2**, E**3** . . . En. The encoder set E**1**, E**2**, E**3** . . . En may include any number "n" of those lossless encoding techniques currently well known within the art such as run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. Again, it is to be understood that the encoding techniques are selected based upon their ability to effectively encode different types of input data. It is to be appreciated that a full complement of encoders are preferably selected to provide a broad coverage of existing and future data types.

The encoder modules (content dependent **1320** and content independent **30**) selectively receive the buffered input data blocks (or unbuffered input data blocks from the counter module **10**) from module **1300** based on the results of recognition. Data compression is performed by the respective

encoder modules wherein some or all of the encoders D1 . . . Dm or E1 . . . En processes a given input data block and outputs a corresponding set of encoded data blocks. It is to be appreciated that the system affords a user the option to enable/disable any one or more of the encoders D1 . . . Dm and E1 . . . En prior to operation. As is understood by those skilled in the art, such feature allows the user to tailor the operation of the data compression system for specific applications. It is to be further appreciated that the encoding process may be performed either in parallel or sequentially. In particular, the encoder set D1 through Dm of encoder module **1320** and/or the encoder set E1 through En of encoder module **30** may operate in parallel (i.e., simultaneously processing a given input data block by utilizing task multiplexing on a single central processor, via dedicated hardware, by executing on a plurality of processor or dedicated hardware systems, or any combination thereof). In addition, encoders D1 through Dm and E1 through En may operate sequentially on a given unbuffered or buffered input data block. This process is intended to eliminate the complexity and additional processing overhead associated with multiplexing concurrent encoding techniques on a single central processor and/or dedicated hardware, set of central processors and/or dedicated hardware, or any achievable combination. It is to be further appreciated that encoders of the identical type may be applied in parallel to enhance encoding speed. For instance, encoder E1 may comprise two parallel Huffman encoders for parallel processing of an input data block. It should be further noted that one or more algorithms may be implemented in dedicated hardware such as an MPEG4 or MP3 encoding integrated circuit.

Buffer/counter modules **1330** and **40** are operatively connected to their respective encoding modules **1320** and **30**, for buffering and counting the size of each of the encoded data blocks output from the respective encoder modules. Specifically, the content dependent buffer/counter **1330** comprises a plurality of buffer/counters BCD1, BCD2, BCD3 . . . BCDm, each operatively associated with a corresponding one of the encoders D1 . . . Dm. Similarly the content independent buffer/counters BCE1, BCE2, BCE3 . . . BCEn, each operatively associated with a corresponding one of the encoders E1 . . . En. A compression ratio module **1340**, operatively connected to the content dependent output buffer/counters **1330** and content independent buffer/counters **40** determines the compression ratio obtained for each of the enabled encoders D1 . . . Dm and or E1 . . . En by taking the ratio of the size of the input data block to the size of the output data block stored in the corresponding buffer/counters BCD1, BCD2, BCD3 . . . BCDm and or BCE1, BCE2, BCE3 . . . BCEn. In addition, the compression ratio module **1340** compares each compression ratio with an a priori-specified compression ratio threshold limit to determine if at least one of the encoded data blocks output from the enabled encoders BCD1, BCD2, BCD3 . . . BCDm and or BCE1, BCE2, BCE3 . . . BCEn achieves a compression that meets an a priori-specified threshold. As is. understood by those skilled in the art, the threshold limit maybe specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It should be noted that different threshold values may be applied to content dependent and content independent encoded data. Further these thresholds may be adaptively modified based upon enabled encoders in either or both the content dependent or content independent encoder sets, along with any associated parameters. A compression type description module **1350**, operatively coupled to the compression ratio module **1340**, appends a corresponding compression type descriptor to each encoded data block which is selected for output so as to indicate the type of compression format of the encoded data block.

A mode of operation of the data compression system of FIGS. **13***a* and **13***b* will now be discussed with reference to the flow diagrams of FIGS. **14***a*-**14***d*, which illustrates a method for performing data compression using a combination of content dependent and content independent data compression. In general, content independent data compression is applied to a given data block when the content of a data block cannot be identified or is not associated with a specific data compression algorithm. More specifically, referring to FIG. **14***a*, a data stream comprising one or more data blocks is input into the data compression system and the first data block in the stream is received (step **1400**). As stated above, data compression is performed on a per data block basis. As previously stated a data block may represent any quantity of data from a single bit through a multiplicity of files or packets and may vary from block to block. Accordingly, the first input data block in the input data stream is input into the counter module **10** that counts the size of the data block (step **1402**). The data block is then stored in the buffer **20** (step **1404**). The data block is then analyzed on a per block or multi-block basis by the content dependent data recognition module **1300** (step **1406**). If the data stream content is not recognized utilizing the recognition list(s) or algorithms(s) module **1310** (step **1408**) the data is routed to the content independent encoder module **30** and compressed by each (enabled) encoder E1 . . . En (step **1410**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder E1 . . . En and maintained in a corresponding buffer (step **1412**), and the encoded data block size is counted (step **1414**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1416**). Each compression ratio is then compared with an apriori-specified compression ratio threshold (step **1418**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1420**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1420**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **1434**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1436**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **1420**), then the encoded data block having the greatest compression ratio is selected (step **1422**). An appropriate data compression type descriptor is then appended (step **1424**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1426**).

As previously stated the data block stored in the buffer **20** (step **1404**) is analyzed on a per block or multi-block basis by the content dependent data recognition module **1300** (step **1406**). If the data stream content is recognized utilizing the recognition list(s) or algorithms(s) module **1310** (step **1434**) the appropriate content dependent algorithms are enabled and initialized (step **1436**), and the data is routed to the content dependent encoder module **1320** and compressed by each (enabled) encoder D**1** . . . Dm (step **1438**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder D**1** . . . Dm and maintained in a corresponding buffer (step **1440**), and the encoded data block size is counted (step **1442**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1444**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **1448**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that many of these algorithms may be lossy, and as such the limits may be subject to or modified by an end target storage, listening, or viewing device. Further notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1420**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1420**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **1434**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1436**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **1420**), then the encoded data block having the greatest compression ratio is selected (step **1422**). An appropriate data compression type descriptor is then appended (step **1424**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1426**).

After the encoded data block or the unencoded data input data block is output (steps **1426** and **1436**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **1428**). If the input data stream includes additional data blocks (affirmative result in step **1428**), the next successive data block is received (step **1432**), its block size is counted (return to step **1402**) and the data compression process in repeated. This process is iterated for each data block in the input data stream. Once the final input data block is processed (negative result in step **1428**), data compression of the input data stream is finished (step **1430**).

Since a multitude of data types may be present within a given input data block, it is often difficult and/or impractical to predict the level of compression that will be achieved by a specific encoder. Consequently, by processing the input data blocks with a plurality of encoding techniques and comparing the compression results, content free data compression is advantageously achieved. Further the encoding may be lossy or lossless dependent upon the input data types. Further if the data type is not recognized the default content independent lossless compression is applied. It is not a requirement that this process be deterministic—in fact a certain probability may be applied if occasional data loss is permitted. It is to be appreciated that this approach is scalable through future generations of processors, dedicated hardware, and software. As processing capacity increases and costs reduce, the benefits provided by the present invention will continue to increase. It should again be noted that the present invention may employ any lossless data encoding technique.

FIGS. **15***a* and **15***b* are block diagrams illustrating a data compression system employing both content independent and content dependent data compression according to another embodiment of the present invention. The system in FIGS. **15***a* and **15***b* is similar in operation to the system of FIGS. **13***a* and **13***b* in that content independent data compression is applied to a data block when the content of the data block cannot be identified or is not associable with a specific data compression algorithm. The system of FIGS. **15***a* and **15***b* additionally performs content independent data compression on a data block when the compression ratio obtained for the data block using the content dependent data compression does not meet a specified threshold.

A mode of operation of the data compression system of FIGS. **15***a* and **15***b* will now be discussed with reference to the flow diagram of FIGS. **16***a*-**16***d*, which illustrates a method for performing data compression using a combination of content dependent and content independent data compression. A data stream comprising one or more data blocks is input into the data compression system and the first data block

in the stream is received (step **1600**). As stated above, data compression is performed on a per data block basis. As previously stated a data block may represent any quantity of data from a single bit through a multiplicity of files or packets and may vary from block to block. Accordingly, the first input data block in the input data stream is input into the counter module **10** that counts the size of the data block (step **1602**). The data block is then stored in the buffer **20** (step **1604**). The data block is then analyzed on a per block or multi-block basis by the content dependent data recognition module **1300** (step **1606**). If the data stream content is not recognized utilizing the recognition list(s) or algorithms(s) module **1310** (step **1608**) the data is routed to the content independent encoder module **30** and compressed by each (enabled) encoder E**1** . . . En (step **1610**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **1612**), and the encoded data block size is counted (step **1614**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1616**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **1618**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1620**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1620**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **1634**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1636**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **1620**), then the encoded data block having the greatest compression ratio is selected (step **1622**). An appropriate data compression type descriptor is then appended (step **1624**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1626**).

As previously stated the data block stored in the buffer **20** (step **1604**) is analyzed on a per block or multi-block basis by the content dependent data recognition module **1300** (step **1606**). If the data stream content is recognized utilizing the recognition list(s) or algorithms(s) module **1310** (step **1634**) the appropriate content dependent algorithms are enabled and initialized (step **1636**) and the data is routed to the content dependent encoder module **1620** and compressed by each (enabled) encoder D**1** . . . Dm (step **1638**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder D**1** . . . Dm and maintained in a corresponding buffer (step **1640**), and the encoded data block size is counted (step **1642**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1644**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **1648**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that many of these algorithms may be lossy, and as such the limits may be subject to or modified by an end target storage, listening, or viewing device. Further notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1648**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1620**), then the original unencoded input data block is routed to the content independent encoder module **30** and the process resumes with compression utilizing content independent encoders (step **1610**).

After the encoded data block or the unencoded data input data block is output (steps **1626** and **1636**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **1628**). If the input data stream includes additional data blocks (affirmative result in step **1628**), the next successive data block is received (step **1632**), its block size is counted (return to step **1602**) and the data compression process in repeated. This process is iterated for each data block in the input data stream. Once the final input data block is processed (negative result in step **1628**), data compression of the input data stream is finished (step **1630**).

FIGS. **17***a* and **17***b* are block diagrams illustrating a data compression system employing both content independent and content dependent data compression according to another embodiment of the present invention. The system in FIGS. **17***a* and **17***b* is similar in operation to the system of FIGS. **13***a* and **13***b* in that content independent data compression is applied to a data block when the content of the data block cannot be identified or is not associable with a specific data

compression algorithm. The system of FIGS. **17***a* and **17***b* additionally uses a priori estimation algorithms or look-up tables to estimate the desirability of using content independent data compression encoders and/or content dependent data compression encoders and selecting appropriate algorithms or subsets thereof based on such estimation.

More specifically, a content dependent data recognition and or estimation module **1700** is utilized to analyze the incoming data stream for recognition of data types, data strictures, data block formats, file substructures, file types, or any other parameters that may be indicative of the appropriate data compression algorithm or algorithms (in serial or in parallel) to be applied. Optionally, a data file recognition list(s) or algorithm(s) **1710** module may be employed to hold associations between recognized data parameters and appropriate algorithms. If the content data compression module recognizes a portion of the data, that portion is routed to the content dependent encoder module **1320**, if not the data is routed to the content independent encoder module **30**. It is to be appreciated that process of recognition (modules **1700** and **1710**) is not limited to a deterministic recognition, but may further comprise a probabilistic estimation of which encoders to select for compression from the set of encoders of the content dependent module **1320** or the content independent module **30**. For example, a method may be employed to compute statistics of a data block whereby a determination that the locality of repetition of characters in a data stream is determined is high can suggest a text document, which may be beneficially compressed with a lossless dictionary type algorithm. Further the statistics of repeated characters and relative frequencies may suggest a specific type of dictionary algorithm. Long strings will require a wide dictionary file while a wide diversity of strings may suggest a deep dictionary. Statistics may also be utilized in algorithms such as Huffman where various character statistics will dictate the choice of different Huffinan compression tables. This technique is not limited to lossless algorithms but may be widely employed with lossy algorithms. Header information in frames for video files can imply a specific data resolution. The estimator then may select the appropriate lossy compression algorithm and compression parameters (amount of resolution desired). As shown in previous embodiments of the present invention, desirability of various algorithms and now associated resolutions with lossy type algorithms may also be applied in the estimation selection process.

A mode of operation of the data compression system of FIGS. **17***a* and **17***b* will now be discussed with reference to the flow diagrams of FIGS. **18***a*-**18***d*. The method of FIGS. **18***a*-**18***d* use a priori estimation algorithms or look-up tables to estimate the desirability or probability of using content independent data compression encoders or content dependent data compression encoders, and select appropriate or desirable algorithms or subsets thereof based on such estimates. A data stream comprising one or more data blocks is input into the data compression system and the first data block in the stream is received (step **1800**). As stated above, data compression is performed on a per data block basis. As previously stated a data block may represent any quantity of data from a single bit through a multiplicity of files or packets and may vary from block to block. Accordingly, the first input data block in the input data stream is input into the counter module **10** that counts the size of the data block (step **1802**). The data block is then stored in the buffer **20** (step **1804**). The data block is then analyzed on a per block or multi-block basis by the content dependent/content independent data recognition module **1700** (step **1806**). If the data stream content is not recognized utilizing the recognition list(s) or algorithms(s) module **1710** (step **1808**) the data is to the content independent encoder module **30**. An estimate of the best content independent encoders is performed (step **1850**) and the appropriate encoders are enabled and initialized as applicable. The data is then compressed by each (enabled) encoder E**1** . . . En (step **1810**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder E**1** . . . En and maintained in a corresponding buffer (step **1812**), and the encoded data block size is counted (step **1814**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1816**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **1818**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1820**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1820**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **1834**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1836**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **1820**), then the encoded data block having the greatest compression ratio is selected (step **1822**). An appropriate data compression type descriptor is then appended (step **1824**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1826**).

As previously stated the data block stored in the buffer **20** (step **1804**) is analyzed on a per block or multi-block basis by the content dependent data recognition module **1300** (step **1806**). If the data stream content is recognized or estimated utilizing the recognition list(s) or algorithms(s) module **1710** (affirmative result in step **1808**) the recognized data type/file

or block is selected based on a list or algorithm (step **1838**) and an estimate of the desirability of using the associated content dependent algorithms can be determined (step **1840**). For instance, even though a recognized data type may be associated with three different encoders, an estimation of the desirability of using each encoder may result in only one or two of the encoders being actually selected for use. The data is routed to the content dependent encoder module **1320** and compressed by each (enabled) encoder D**1** . . . Dm (step **1842**). Upon completion of the encoding of the input data block, an encoded data block is output from each (enabled) encoder D**1** . . . Dm and maintained in a corresponding buffer (step **1844**), and the encoded data block size is counted (step **1846**).

Next, a compression ratio is calculated for each encoded data block by taking the ratio of the size of the input data block (as determined by the input counter **10** to the size of each encoded data block output from the enabled encoders (step **1848**). Each compression ratio is then compared with an a priori-specified compression ratio threshold (step **1850**). It is to be understood that the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. It is to be further understood that many of these algorithms may be lossy, and as such the limits may be subject to or modified by an end target storage, listening, or viewing device. Further notwithstanding that the current limit for lossless data compression is the entropy limit (the present definition of information content) for the data, the present invention does not preclude the use of future developments in lossless data compression that may increase lossless data compression ratios beyond what is currently known within the art. Additionally the content independent data compression threshold may be different from the content dependent threshold and either may be modified by the specific enabled encoders.

After the compression ratios are compared with the threshold, a determination is made as to whether the compression ratio of at least one of the encoded data blocks exceeds the threshold limit (step **1820**). If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit (negative determination in step **1820**), then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto (step **1834**). A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1836**).

On the other hand, if one or more of the encoded data blocks possess a compression ratio greater than the compression ratio threshold limit (affirmative result in step **1820**), then the encoded data block having the greatest compression ratio is selected (step **1822**). An appropriate data compression type descriptor is then appended (step **1824**). A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal (step **1826**).

After the encoded data block or the unencoded data input data block is output (steps **1826** and **1836**), a determination is made as to whether the input data stream contains additional data blocks to be processed (step **1828**). If the input data stream includes additional data blocks (affirmative result in step **1428**), the next successive data block is received (step **1832**), its block size is counted (return to step **1802**) and the data compression process in repeated. This process is iterated for each data block in the input data stream. Once the final input data block is processed (negative result in step **1828**), data compression of the input data stream is finished (step **1830**).

It is to be appreciated that in the embodiments described above with reference to FIGS. **13-18**, an a priori specified time limit or any other real-time requirement may be employed to achieve practical and efficient real-time operation.

Although illustrative embodiments have been described herein with reference to the accompanying drawings, it is to be understood that the present invention is not limited to those precise embodiments, and that various other changes and modifications may be affected therein by one skilled in the art without departing from the scope or spirit of the invention. All such changes and modifications are intended to be included within the scope of the invention as defined by the appended claims.

What is claimed is:

1. A system for compressing data comprising;

a processor;

one or more content dependent data compression encoders; and

a single data compression encoder;

wherein the processor is configured:

to analyze data within a data block to identify one or more parameters or attributes of the data wherein the analyzing of the data within the data block to identify the one or more parameters or attributes of the data excludes analyzing based solely on a descriptor that is indicative of the one or more parameters or attributes of the data within the data block;

to perform content dependent data compression with the one or more content dependent data compression encoders if the one or more parameters or attributes of the data are identified; and

to perform data compression with the single data compression encoder, if the one or more parameters or attributes of the data are not identified.

2. The system of claim **1**, wherein the data block is received in an uncompressed form, the data block being included in one or more data blocks transmitted in sequence originating from an external source.

3. The system of claim **1**, wherein the data block is received in an uncompressed form, the data block being included in one or more data blocks transmitted in sequence originating from internal source.

4. The system of claim **1** wherein the compressing, is performed in real-time.

5. The system of claim **1**, wherein the content dependent data compression with the one or more content dependent data compression encoders is performed in real-time.

6. The system of claim **1**, wherein the data compression with the single data compression encoder is performed in real-time.

7. The system of claim **1** wherein the compressing is performed in real-time if the parameter or attribute of the data in the data block is not identified.

8. The system of claim 1 wherein the compressing is performed in real-time if the one or more parameters or attributes of the data in the data block is identified.

9. The system of claim 1, wherein the processor is further configured to associate a data token indicative of the content dependent data compression applied to the data block to create a compressed data block.

10. The system of claim 1, wherein the processor is further configured to associate a data token indicative of the single data compression encoder applied to the data block to create a compressed data block.

11. The system of claim 1, wherein the content dependent data compression further comprises associating a plurality of encoders to the one or more parameters or attributes of the data, wherein at least one of the plurality of encoders provides lossy compression and at least another one of the plurality of encoders provides lossless compression.

12. The system of claim 1, wherein the content dependent data compression is lossy or lossless depending on the one or more parameters or attributes of the data.

13. The system of claim 1, wherein the content dependent data compression is lossy and an amount of desired resolution of the lossy compression is selected.

14. The system of claim 1, wherein the single data compression encoder is lossy.

15. The system of claim 1, wherein a compressed data block is stored.

16. The system of claim 1, wherein the processor is further configured to output the data block in uncompressed form if the content dependent data compression results in a compressed data block indicative of data expansion.

17. The system of claim 1, wherein the processor is further configured to output the data block in uncompressed form if the data compression with the single data compression encoder results in a compressed data block indicative of data expansion.

18. The system of claim 1, wherein a compressed data block is transmitted, received, and decompressed, and wherein a time taken to compress, transmit, receive, and decompress is less than a time to transmit and receive the data block.

19. The system of claim 1, wherein the content dependent data compression further comprises providing a compressed data block from one of a plurality of encoders, associated with the one or more of the parameters or attributes of the data;

wherein the one of the plurality of encoders has a higher desirability factor for the data block than another of the plurality of encoders.

20. The system of claim 1, wherein the processor is further configured to output a compressed data block with a token representative of a compression technique used to compress the data block.

21. The system of claim 1, wherein a compressed data block is the result of a lossy compression technique.

22. The system of claim 1, wherein a compressed data block is the result of a lossy compression technique and an amount of resolution of the lossy compression technique is selectable.

23. The system of claim 1, wherein at least one content dependent data compression technique performed by the one or more content dependent data compression encoders is lossy and a data compression technique performed by the single data compression encoder is lossless.

24. A system for compressing data comprising;

a processor;

one or more data compression encoders; and

a default data compression encoder;

wherein the processor is configured:

to analyze data within a data block to identify one or more parameters or attributes of the data wherein the analyzing of the data within the data block to identify the one or more parameters or attributes of the data excludes analyzing based solely on a descriptor that is indicative of the one or more parameters or attributes of the data within the data block; and

to compress the data block to provide a compressed data block, wherein if one or more encoders are associated with the one or more parameters or attributes of the data, compressing the data block with at least one of the one or more data compression encoders, otherwise compressing the data block with the default data compression encoder.

25. A computer implemented method comprising:

analyzing, using a processor, data within a data block to identify one or more parameters or attributes of the data within the data block;

determining, using the processor, whether to output the data block in a received form or in a compressed form; and

outputting, using the processor, the data block in the received form or the compressed form based on the determination,

wherein the outputting the data block in the compressed form comprises determining whether to compress the data block with content dependent data compression based on the one or more parameters or attributes of the data within the data block or to compress the data block with a single data compression encoder; and

wherein the analyzing of the data within the data block to identify the one or more parameters or attributes of the data excludes analyzing based only on a descriptor that is indicative of the one or more parameters or attributes of the data within the data block.

* * * * *

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(54) **SYSTEM AND METHODS FOR ACCELERATED DATA STORAGE AND RETRIEVAL**

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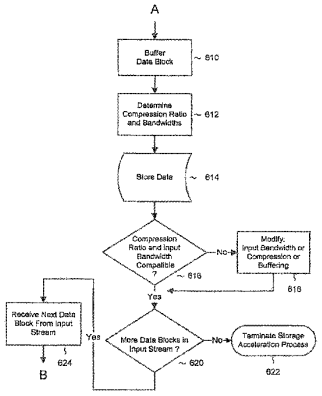
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(57) **ABSTRACT**

Systems and methods for providing accelerated data storage and retrieval utilizing lossless data compression and decompression. A data storage accelerator includes one or a plurality of high speed data compression encoders that are configured to compress data. The compressed data is subsequently stored in a target memory or other storage device whose input data storage bandwidth is lower than the original input data stream bandwidth. Similarly, a data retrieval accelerator includes one or a plurality of high speed data decompression decoders that are configured to decompress data at a rate equivalent to or faster than the input data stream from the target memory or storage device. The decompressed data is then output at rate data that is greater than the output rate from the target memory or data storage device.

30 Claims, 20 Drawing Sheets



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Exhibit B, Invalidity Claim Charts B1-B45 for U.S. Pat. No. 7,161,506, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.* , 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Oct. 19, 2010, 1513 pages.

Exhibit C, Invalidity Claim Charts C1-C7, C9-C31, C33-C45 for U.S. Pat. No. 7,400,274, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.* , 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Oct. 19, 2010, 1528 pages.

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Exhibit 50, Prior Art Chart for U.S. Pat. No. 7,777,651, 172 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing O'Brien et al., U.S. Pat. No. 4,929,946.

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Exhibit 54, Prior Art Chart for U.S. Pat. No. 7,777,651, 335 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Payne et al, U.S. Pat. No. 6,021,433.

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Exhibit 61, Prior Art Chart for U.S. Pat. No. 7,777,651, 399 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Seroussi et al., U.S. Patent No. 5,243,341.

Exhibit 62, Prior Art Chart for U.S. Pat. No. 7,777,651, 322 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Seroussi et al., U.S. Pat. No. 5,389,922.

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Exhibit 64, Prior Art Chart for U.S. Pat. No. 7,777,651, 126 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Taaffe et al., U.S. Pat. No. 5,179,651.

Exhibit 65, Prior Art Chart for U.S. Pat. No. 7,777,651, 313 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Telekurs Ticker—"Telekurs Ticker Service: Programmer's Reference," Telekurs (North America), Inc. (Jan. 11, 1993); C. Helck. "Encapsulated Ticker: Ver. 1.0," Telekurs NA, 1-22 (Jul. 14, 1993); A-T Financial Offers Manipulation, Redistribution of Ticker III, Micro Ticker Report, v 4, n 14 (Sep. 5, 1989); V. Kulkosky, "Upping the Ante" Wall Street & Technology, v11 n5 pp. 8-11 (Oct. 1993); "Telekurs to Launch New Int's Feed/Internet Server," Wall Street & Technology, v15 n1 pp. 14 (Jan. 1997); I. Schmerken, "Time running out for old technologies", Wall Street Computer Review, v47 n7 p. 14(7) (Apr. 1990); Scrolling News, Inside Market Data, v 10, n 11 (Feb. 27, 1995); Telekurs Buys S&P Trading Systems and Its Debut 128 KPS Ticker by Year's End, Inside Market Data, v 9, n 21 (Jul. 18, 1994); Telekurs Now Carries All Dow Jones' News on 56-KBPS Ticker, Inside Market Data, v9, N7 (Dec. 20, 1993); Telekurs Sells No. American Division in Mgmt. Buyout, Inside Market Data, v11, n.3 (Oct. 23, 1995).

Exhibit 66, Prior Art Chart for U.S. Pat. No. 7,777,651, 265 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Tyler et al., U.S. Pat. No. 5,638,498.

Exhibit 67, Prior Art Chart for U.S. Pat. No. 7,777,651, 386 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing UNI International Standard ISO 3309-1984 (E) [1984]. "Information Processing Systems—Data Communication—High-level Data Link Control Procedures—Frame Structure," 1-6 (1984).

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Exhibit 69, Prior Art Chart for U.S. Pat. No. 7,777,651, 80 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Vange et al., U.S. Pat. No. 7,127,518.

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Exhibit 72, Prior Art Chart for U.S. Pat. No. 7,777,651, 277 pages, Exhibit 71, Prior Art Chart for U.S. Pat. No. 7,777,651, 253 pages. Exhibit 70, Prior Art Chart for U.S. Pat. No. 7,777,651, 197 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing XMill—Harmut Liefke & Dan Suciu, "XMill: an Efficient Compressor for XML Data," University of Pennsylvania, Philadelphia, Pennsylvania, MS-CIS-99-26 (Oct. 18, 1999); Harmut Liefke & Dan Suciu, "XMill: an Efficient Compressor for XML Data," Proceeding of SIGMOD, 2000; Harmut Liefke & Dan Suciu, "An Extensible Compressor for XML Data," SIGMOD Record, vol. 29, No. 1 (Mar. 2000); Dan Suciu, "Data Management on the Web," Presentation at University of Washington College of Computer Science & Engineering, Seattle, WA (Apr. 4, 2000).

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Appendix A: U.S. Pat. No. 6,624,761 (The "761 Patent"), from Defendant Bloomberg L.P.'s Invalidity Contentions Pursuant to Patent Local Rule 3-3, *Realtime Data, LLC d/b/a IXO* v. *Thomson Reuters Corp., et al.*, 6:2009-cv-00333 LED-JDL, 6:2010-cv-00247 LED-JDL, 6:2010-cv-00425 LED-JDL, Oct. 29, 2010, 37 pages.

Appendix B: U.S. Pat. No. 7,161,506 (The "506 Patent"), from Defendant Bloomberg L.P.'s Invalidity Contentions Pursuant to Patent Local Rule 3-3, *Realtime Data, LLC d/b/a IXO* v. *Thomson Reuters Corp., et al.*, 6:2009-cv-00333 LED-JDL, 6:2010-cv-00247 LED-JDL, 6:2010-cv-00425 LED-JDL, Oct. 29, 2010, 63 pages.

Appendix C: U.S. Pat. No. 7,400,274 (The 274 Patent), from Defendant Bloomberg L.P.'s Invalidity Contentions Pursuant to Patent Local Rule 3-3, *Realtime Data, LLC d/b/a IXO* v. *Thomson Reuters Corp., et al.*, 6:2009-cv-00333 LED-JDL, 6:2010-cv-00247 LED-JDL, 6:2010-cv-00425 LED-JDL, Oct. 29, 2010, 95 pages.

Appendix D: U.S. Pat. No. 7,417,568 (The 568 Patent) from Defendant Bloomberg L.P.'s Invalidity Contentions Pursuant to Patent Local Rule 3-3, *Realtime Data, LLC d/b/a IXO* vs. *Thomson Reuters Corp., et al.*, 6:2009-cv-00333 LED-JDL, 6:2010-cv-00247 LED-JDL, 6:2010-cv-00425 LED-JDL, Oct. 29, 2010, 147 pages.

Appendix E: U.S. Pat. No. 7,714,747 (The "747 Patent"), from Defendant Bloomberg L.P.'s Invalidity Contentions Pursuant to Patent Local Rule 3-3, *Realtime Data, LLC d/b/a IXO* vs. *Thomson Reuters Corp., et al.*, 6:2009-cv-00333 LED-JDL, 6:2010-cv-00247 LED-JDL, 6:2010-cv-00425 LED-JDL, Oct. 29, 2010, 137 pages.

Appendix F: Comparison of FAST to the Prior Art, from Defendant Bloomberg L.P.'s Invalidity Contentions Pursuant to Patent Local Rule 3-3, *Realtime Data, LLC d/b/a IXO* vs. *Thomson Reuters Corp., et al*, 6:2009-cv-00333 LED-JDL, 6:2010-cv-00247 LED-JDL, 6:2010-cv-00425 LED-JDL, Oct. 29, 2010, 7 pages.

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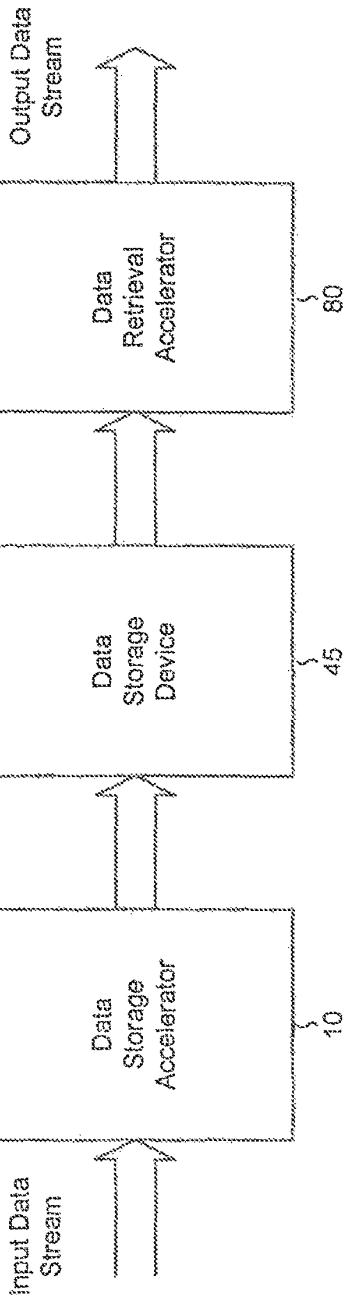

Output Data Stream
Data Retrieval Accelerator
80
Data Storage Device
45
Data Storage Accelerator
10
Input Data Stream

FIGURE 1

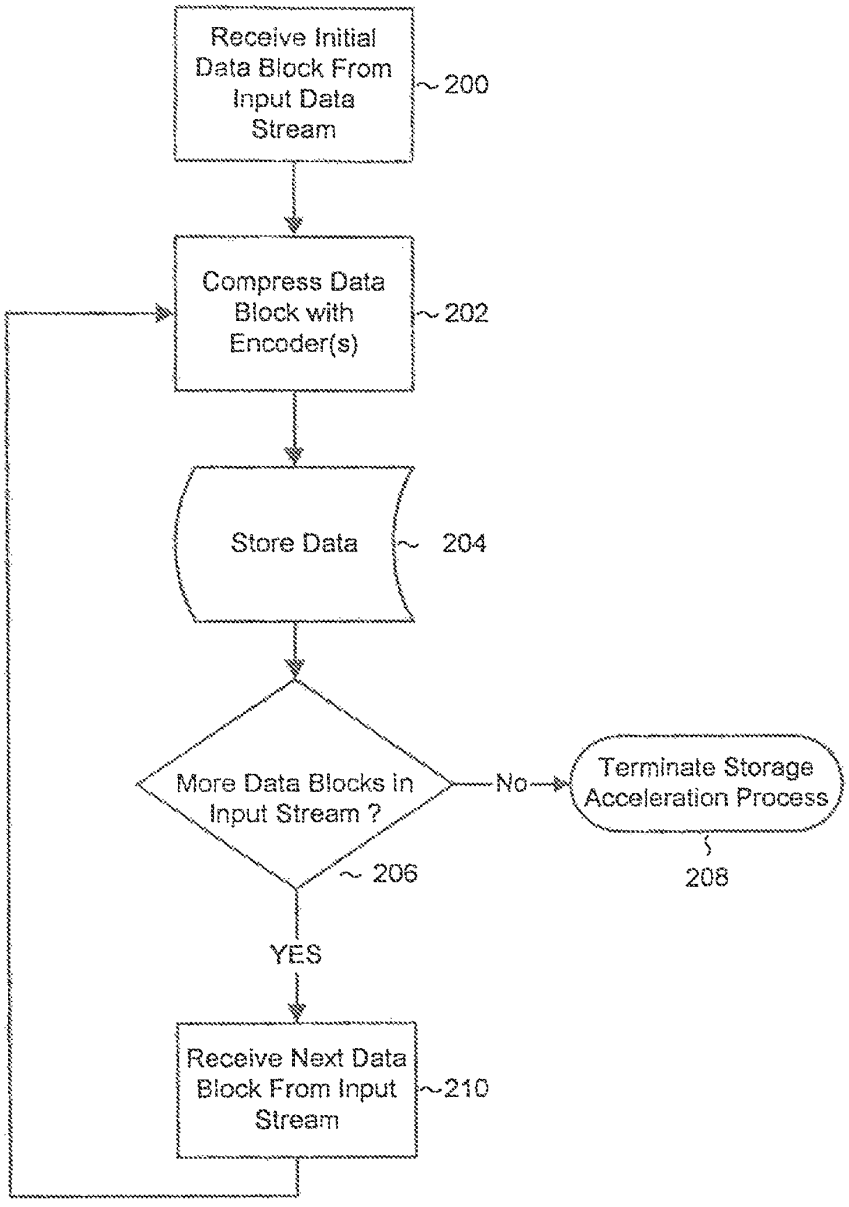

Receive Initial Data Block From Input Data Stream
200
Compress Data Block with Encoder(s)
202
Store Data
204
More Data Blocks in Input Stream ?
206
No
Terminate Storage Acceleration Process
208
YES
Receive Next Data Block From Input Stream
210

FIGURE 2

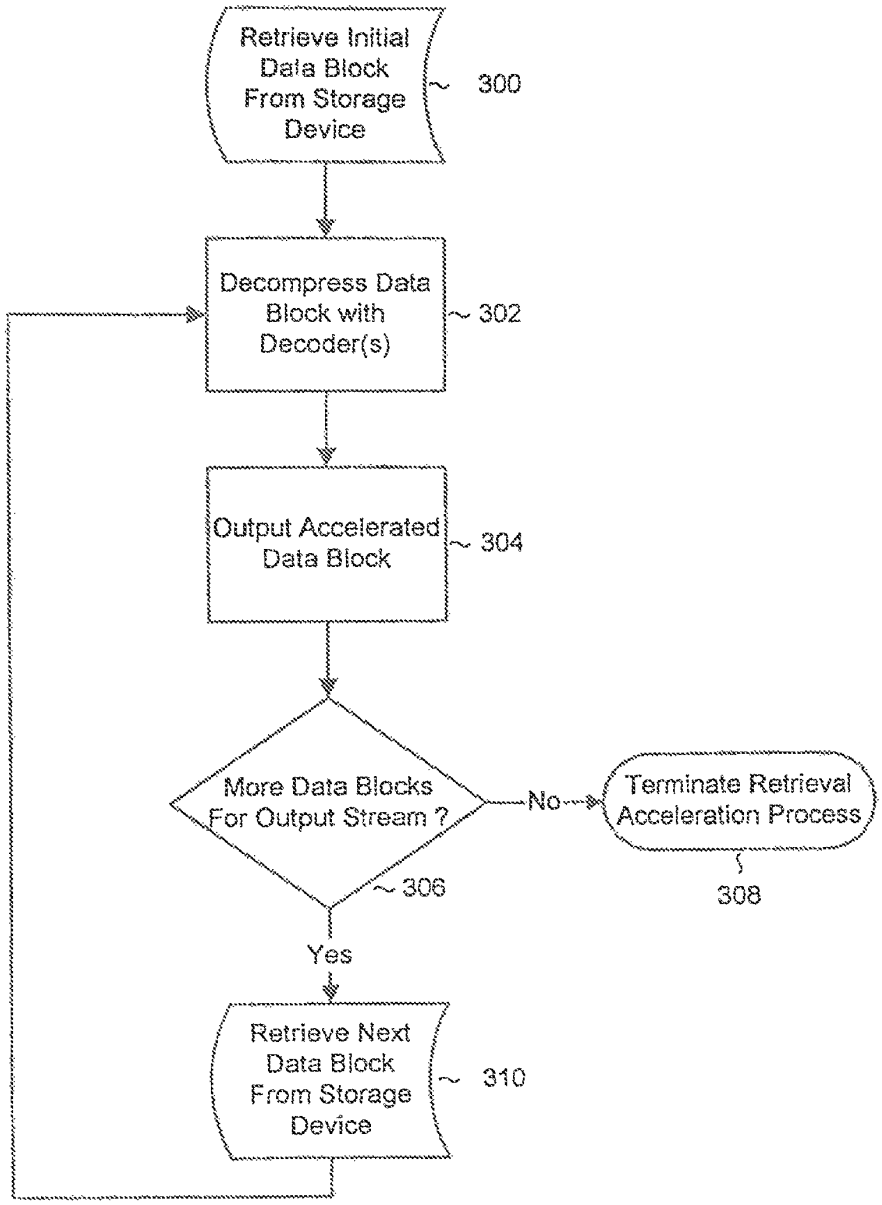

Retrieve Initial Data Block From Storage Device
300
Decompress Data Block with Decoder(s)
302
Output Accelerated Data Block
304
More Data Blocks For Output Stream ?
306
No
Terminate Retrieval Acceleration Process
308
Yes
Retrieve Next Data Block From Storage Device
310

FIGURE 3

Time Interval	T1	T2	T3	T4	Ti
Receive Data Block	Receive Data Block 1	Receive Data Block 2	Receive Data Block 3	Receive Data Block 4	Receive Data Block i
METHOD 1					
Compress Data Block	Compress Data Block 1	Compress Data Block 2	Compress Data Block 3	Compress Data Block 4	Compress Data Block i
Store Encoded Data Block	Store Encoded Data Block 1	Store Encoded Data Block 2	Store Encoded Data Block 3	Store Encoded Data Block 4	Store Encoded Data Block i
METHOD 2					
Compress Data Block		Compress Data Block 1	Compress Data Block 2	Compress Data Block 3	Compress Data Block (i-1)
Store Encoded Data Block			Store Encoded Data Block 1	Store Encoded Data Block 2	Store Encoded Data Block (i-2)

FIGURE 4a

Time interval	T(i+1)	T(i+2)	Tn	T(n+1)	T(n+2)	
Receive Data Block	Receive Data Block (i+1)	Receive Data Block (i+2)	Receive Data Block n			
METHOD 1						
Compress Data Block	Compress Data Block (i+1)	Compress Data Block (i+2)	Compress Data Block n			
Store Encoded Data Block	Store Encoded Data Block (i+1)	Store Encoded Data Block (i+2)	Store Encoded Data Block n			
METHOD 2						
Compress Data Block	Compress Data Block i	Compress Data Block (i+1)	Compress Data Block (n-1)	Compress Data Block n		
Store Encoded Data Block	Store Encoded Data Block (i-1)	Store Encoded Data Block i	Store Encoded Data Block (n-2)	Store Encoded Data Block (n-1)	Store Encoded Data Block n	

FIGURE 4b

Time Interval	T1	T2	T3	T4	Ti
Retrieve Data Block	Retrieve Data Block 1	Retrieve Data Block 2	Retrieve Data Block 3	Retrieve Data Block 4	Retrieve Data Block i
METHOD 1					
Decompress Data Block	Decompress Data Block 1	Decompress Data Block 2	Decompress Data Block 3	Decompress Data Block 4	Decompress Data Block i
Output Decoded Data Block	Output Decoded Data Block 1	Output Decoded Data Block 2	Output Decoded Data Block 3	Output Decoded Data Block 4	Output Decoded Data Block i
METHOD 2					
Decompress Data Block		Decompress Data Block 1	Decompress Data Block 2	Decompress Data Block 3	Decompress Data Block (i-1)
Output Decoded Data Block			Output Decoded Data Block 1	Output Decoded Data Block 2	Output Decoded Data Block (i-2)

FIGURE 5a

Time Interval	T(i+1)	T(i+2)	Tn	T(n+1)	T(n+2)
Retrieve Data Block	Retrieve Data Block (i+1)	Retrieve Data Block (i+2)	Retrieve Data Block n		
METHOD 1					
Decompress Data Block	Decompress Data Block (i+1)	Decompress Data Block (i+2)	Decompress Data Block n		
Output Decoded Data Block	Output Decoded Data Block (i+1)	Output Decoded Data Block (i+2)	Output Decoded Data Block n		
METHOD 2					
Decompress Data Block	Decompress Data Block i	Decompress Data Block (i+1)	Decompress Data Block (n-1)	Decompress Data Block n	
Output Decoded Data Block	Output Decoded Data Block (i-1)	Output Decoded Data Block i	Output Decoded Data Block (n-2)	Output Decoded Data Block (n-1)	Output Decoded Data Block n

FIGURE 5b

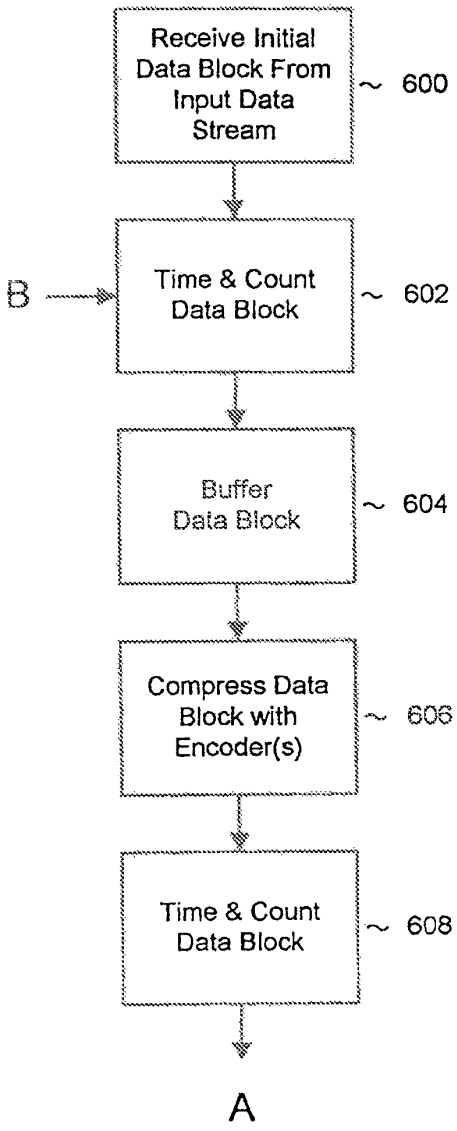

Receive Initial Data Block From Input Data Stream
600
B
Time & Count Data Block
602
Buffer Data Block
604
Compress Data Block with Encoder(s)
606
Time & Count Data Block
608
A

FIGURE 6a

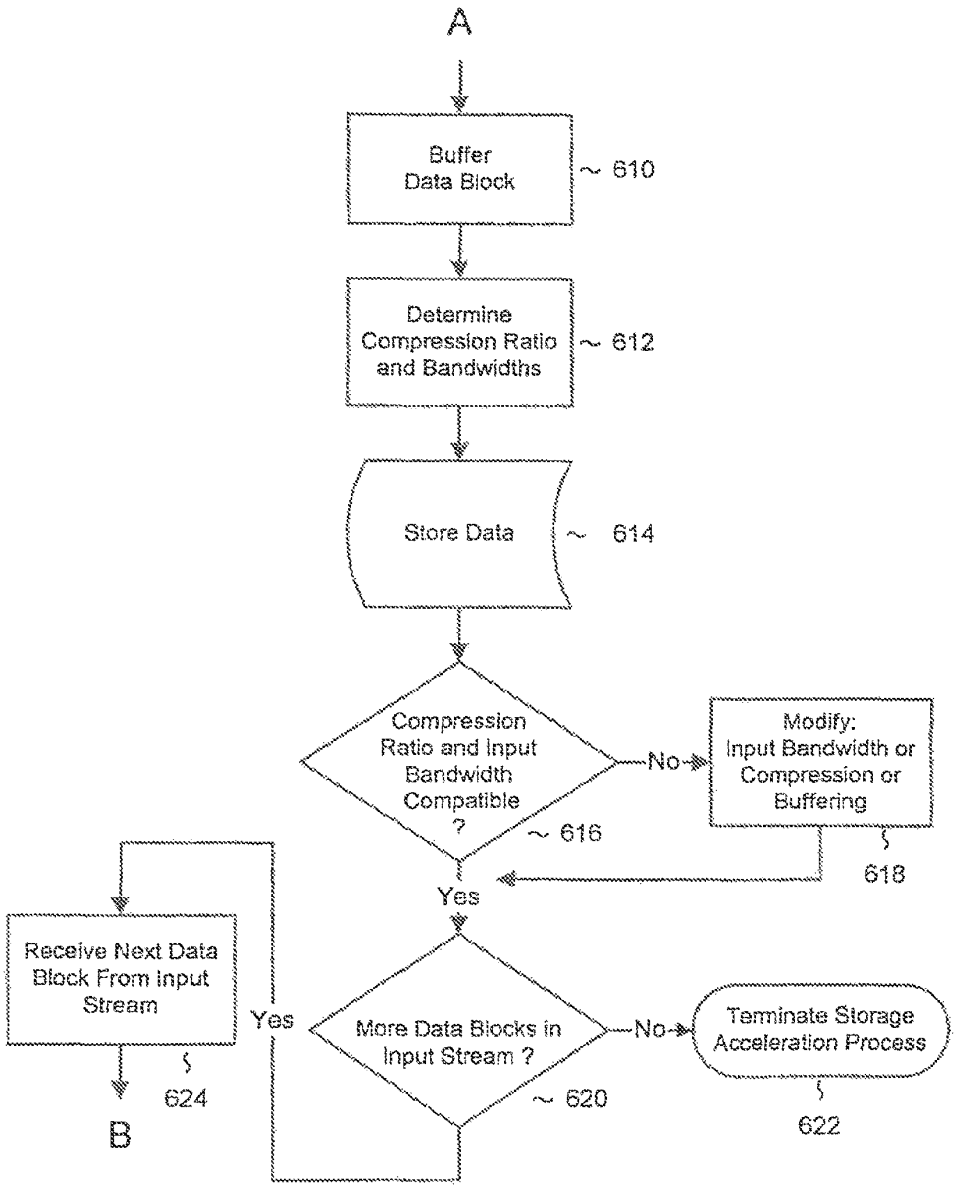

A
Buffer Data Block
610
Determine Compression Ratio and Bandwidths
612
Store Data
614
Compression Ratio and Input Bandwidth Compatible ?
616
No
Modify: Input Bandwidth or Compression or Buffering
618
Yes
Receive Next Data Block From Input Stream
624
B
Yes
More Data Blocks in Input Stream ?
620
No
Terminate Storage Acceleration Process
622

FIGURE 6b

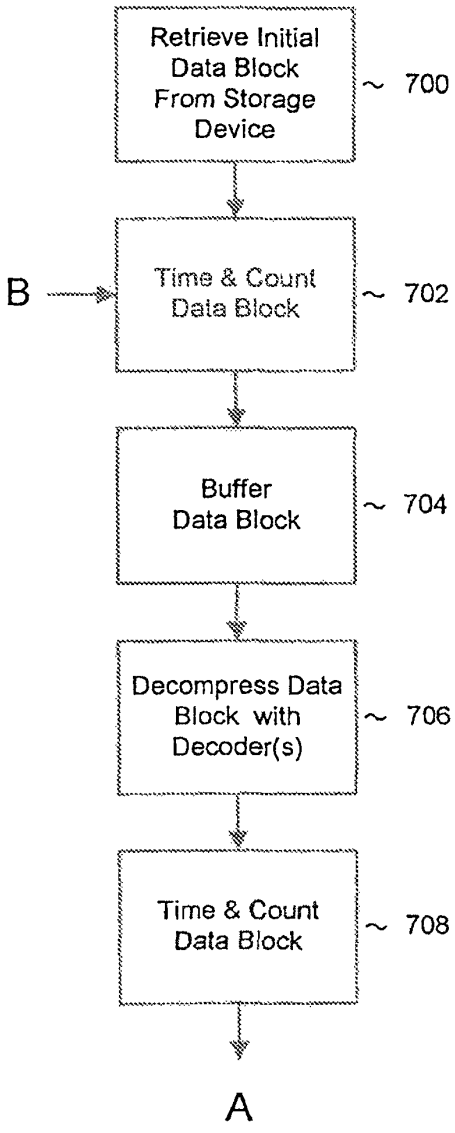

Retrieve Initial Data Block From Storage Device
700
B
Time & Count Data Block
702
Buffer Data Block
704
Decompress Data Block with Decoder(s)
706
Time & Count Data Block
708
A

FIGURE 7a

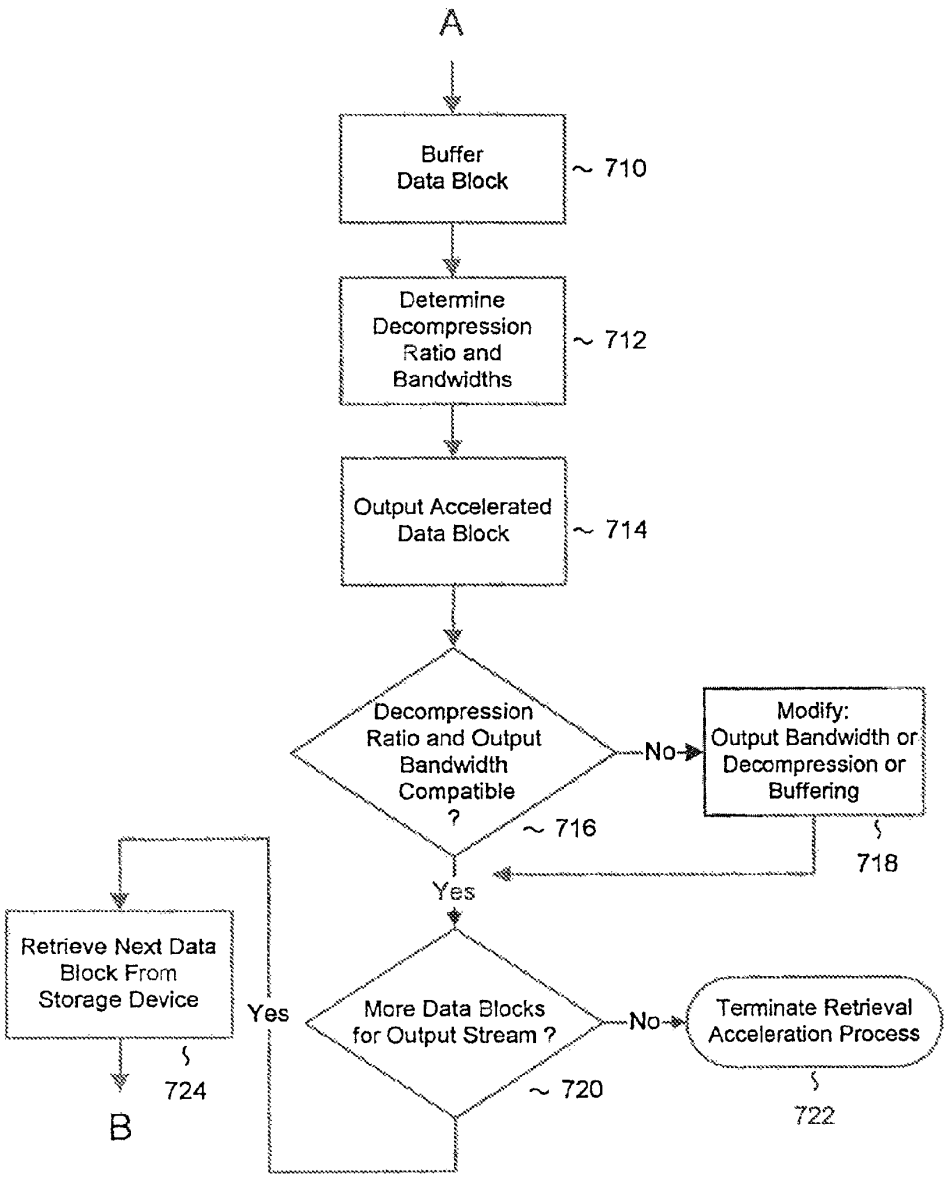

A
Buffer Data Block
710
Determine Decompression Ratio and Bandwidths
712
Output Accelerated Data Block
714
Decompression Ratio and Output Bandwidth Compatible ?
716
No
Modify: Output Bandwidth or Decompression or Buffering
718
Yes
Retrieve Next Data Block From Storage Device
724
B
Yes
More Data Blocks for Output Stream ?
720
No
Terminate Retrieval Acceleration Process
722

FIGURE 7b

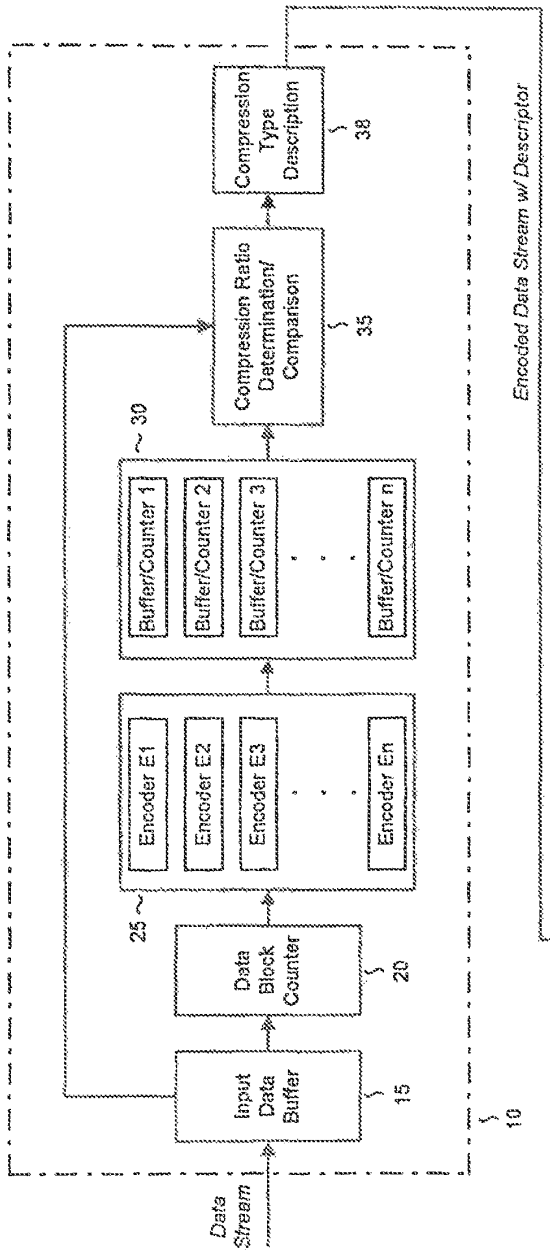


FIGURE 8

Appx299

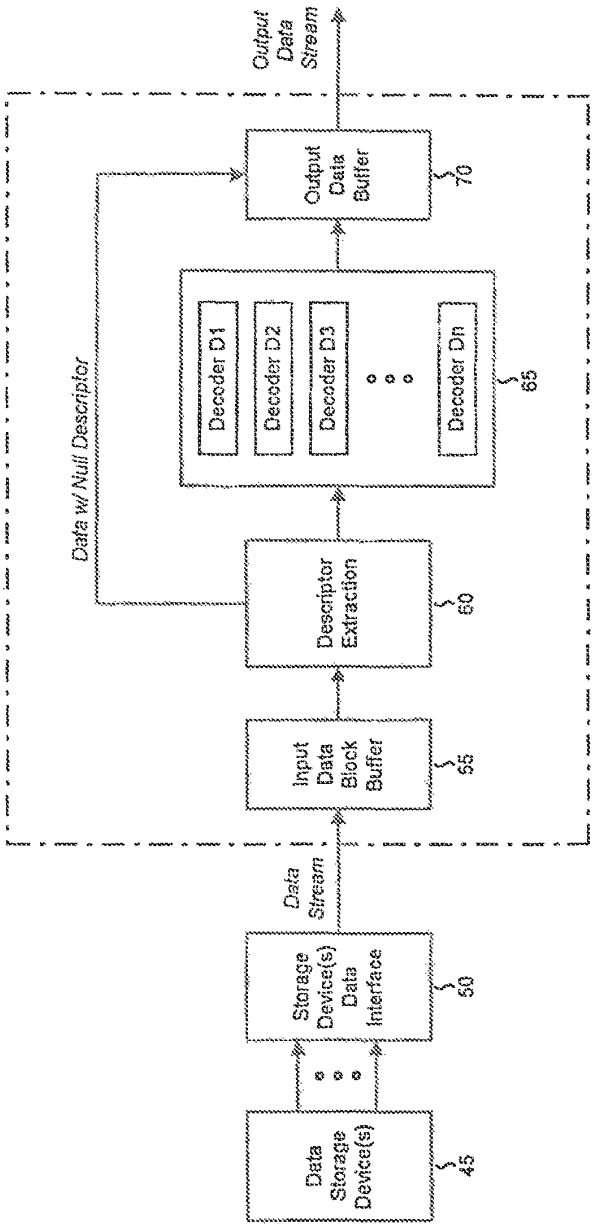

Data Storage Device(s)
45
Storage Device(s) Data Interface
50
Data Stream
Input Data Block Buffer
55
Descriptor Extraction
60
Data w/ Null Descriptor
Decoder D1
Decoder D2
Decoder D3
Decoder Dn
65
Output Data Buffer
70
Output Data Stream
80

FIGURE 9

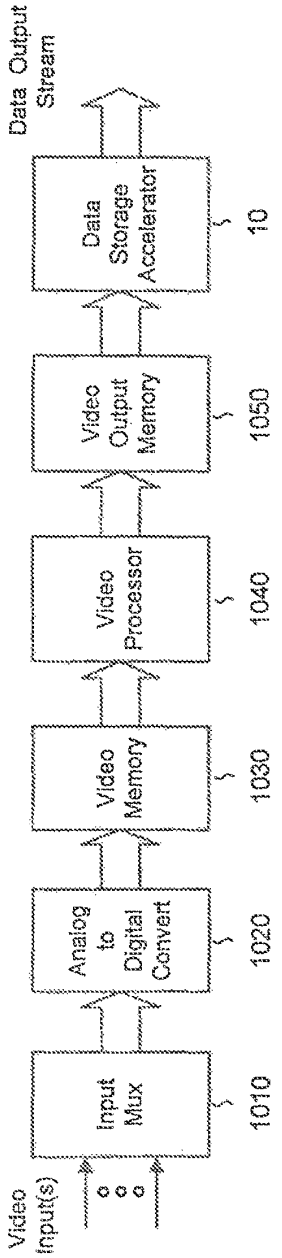

Video Input(s)
Input Mux
1010
Analog to Digital Convert
1020
Video Memory
1030
Video Processor
1040
Video Output Memory
1050
Data Storage Accelerator
10
Data Output Stream

FIGURE 10

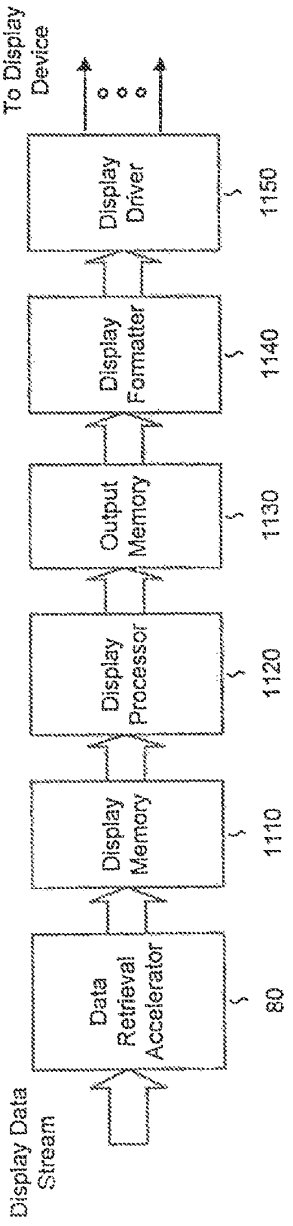

Display Data Stream
Data Retrieval Accelerator
80
Display Memory
1110
Display Processor
1120
Output Memory
1130
Display Formatter
1140
Display Driver
1150
To Display Device

FIGURE 11

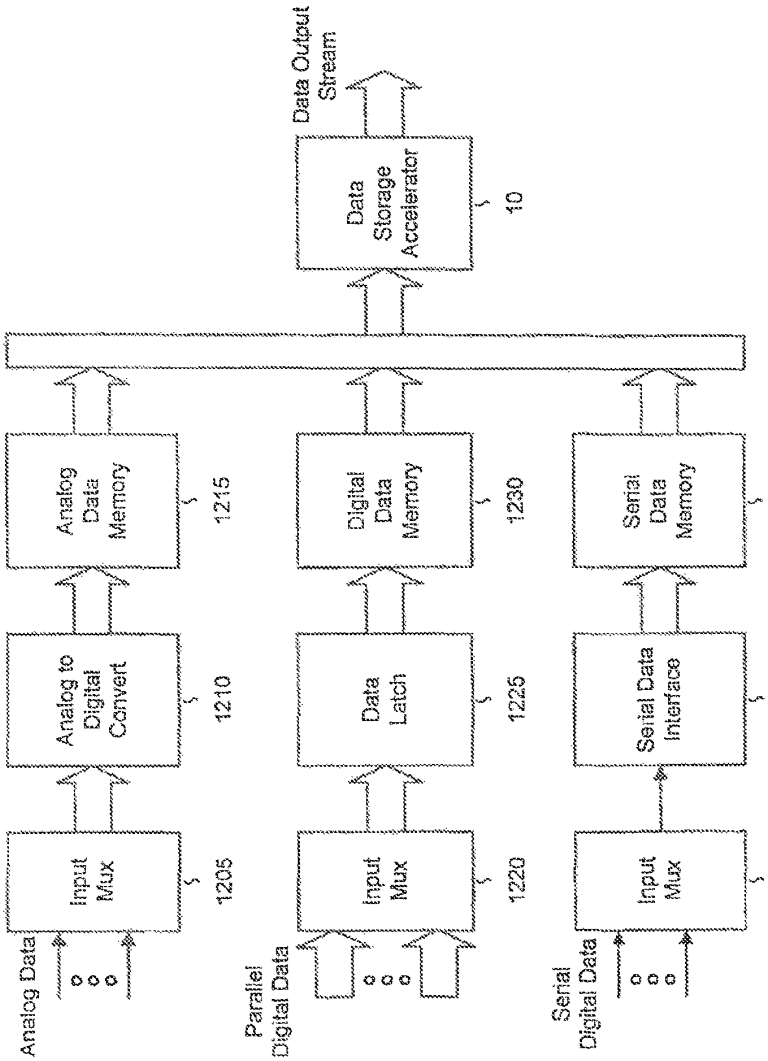

Data Output Stream
Data Storage Accelerator
10
Analog Data
Input Mux
1205
Analog to Digital Convert
1210
Analog Data Memory
1215
Parallel Digital Data
Input Mux
1220
Data Latch
1225
Digital Data Memory
1230
Serial Digital Data
Input Mux
1235
Serial Data Interface
1240
Serial Data Memory
1245

FIGURE 12

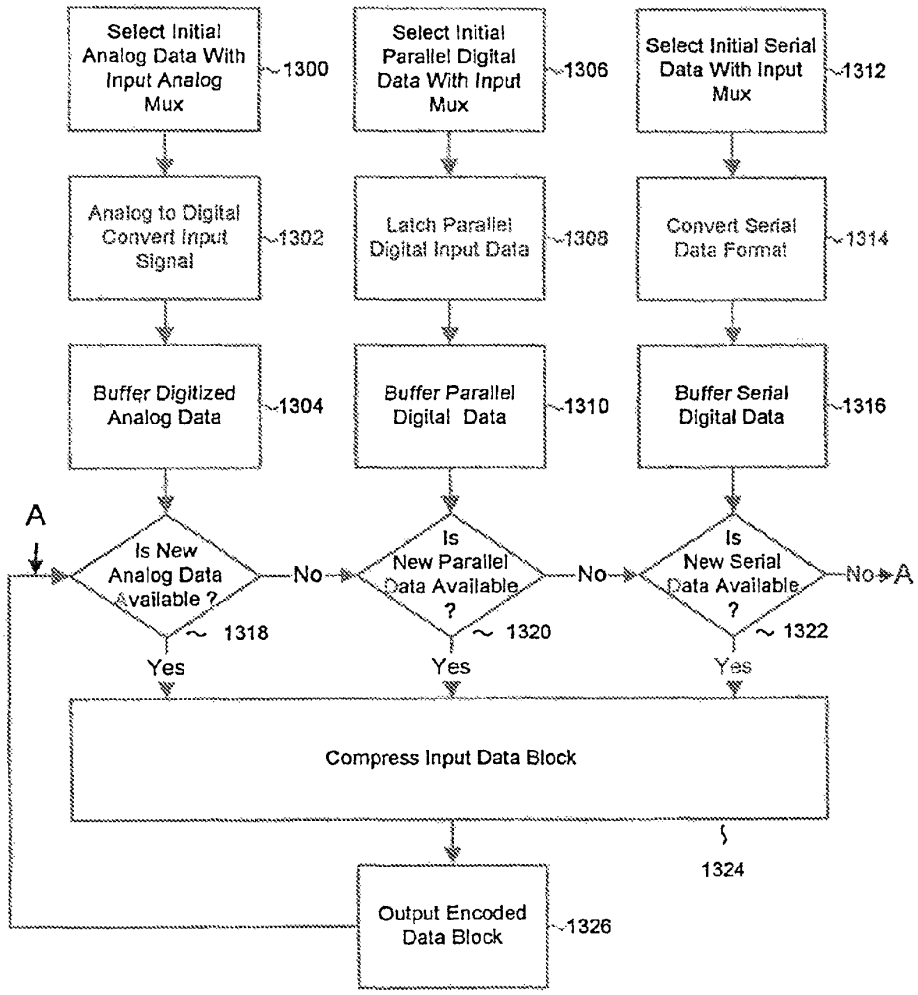

Select Initial Analog Data With Input Analog Mux
1300
Select Initial Parallel Digital Data With Input Mux
1306
Select Initial Serial Data With Input Mux
1312
Analog to Digital Convert Input Signal
1302
Latch Parallel Digital Input Data
1308
Convert Serial Data Format
1314
Buffer Digitized Analog Data
1304
Buffer Parallel Digital Data
1310
Buffer Serial Digital Data
1316
A
Is New Analog Data Available ?
1318
No
Is New Parallel Data Available ?
1320
No
Is New Serial Data Available ?
1322
No
A
Yes
Yes
Yes
Compress Input Data Block
1324
Output Encoded Data Block
1326

FIGURE 13

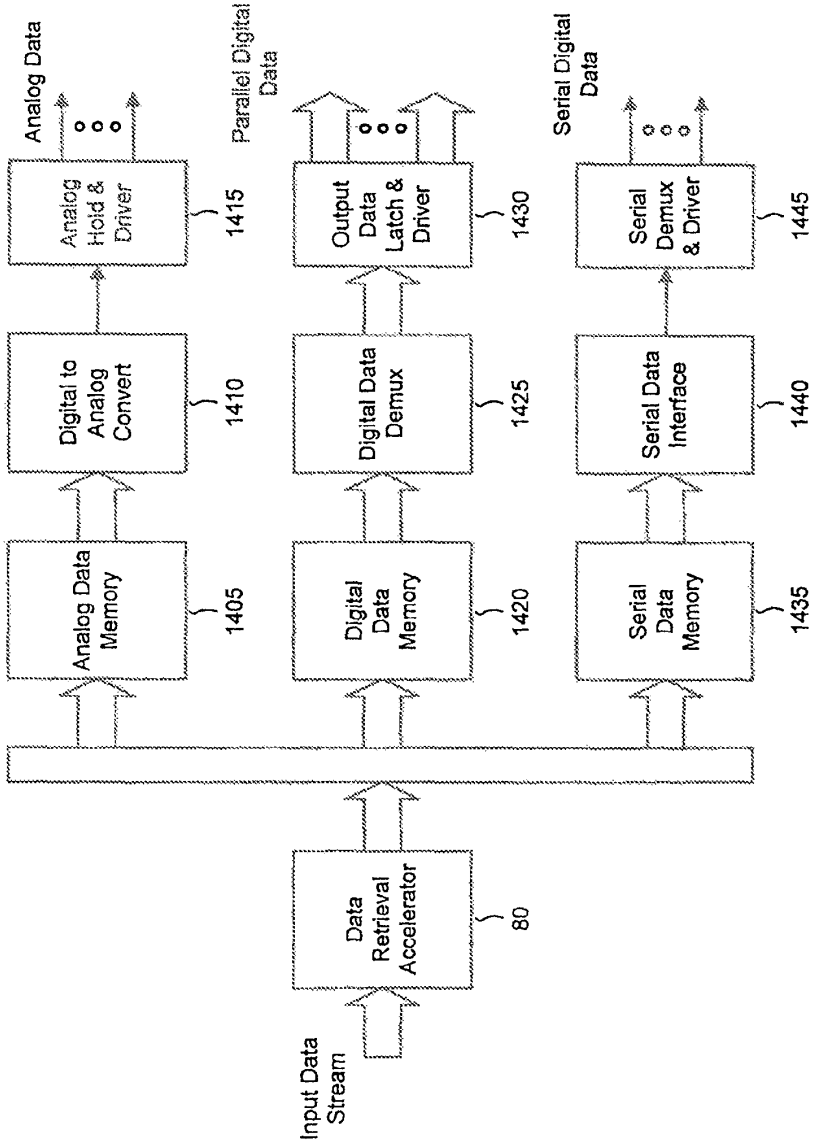

Analog Data
Parallel Digital Data
Serial Digital Data
Analog Hold & Driver
1415
Output Data Latch & Driver
1430
Serial Demux & Driver
1445
Digital to Analog Convert
1410
Digital Data Demux
1425
Serial Data Interface
1440
Analog Data Memory
1405
Digital Data Memory
1420
Serial Data Memory
1435
Data Retrieval Accelerator
80
Input Data Stream

FIGURE 14

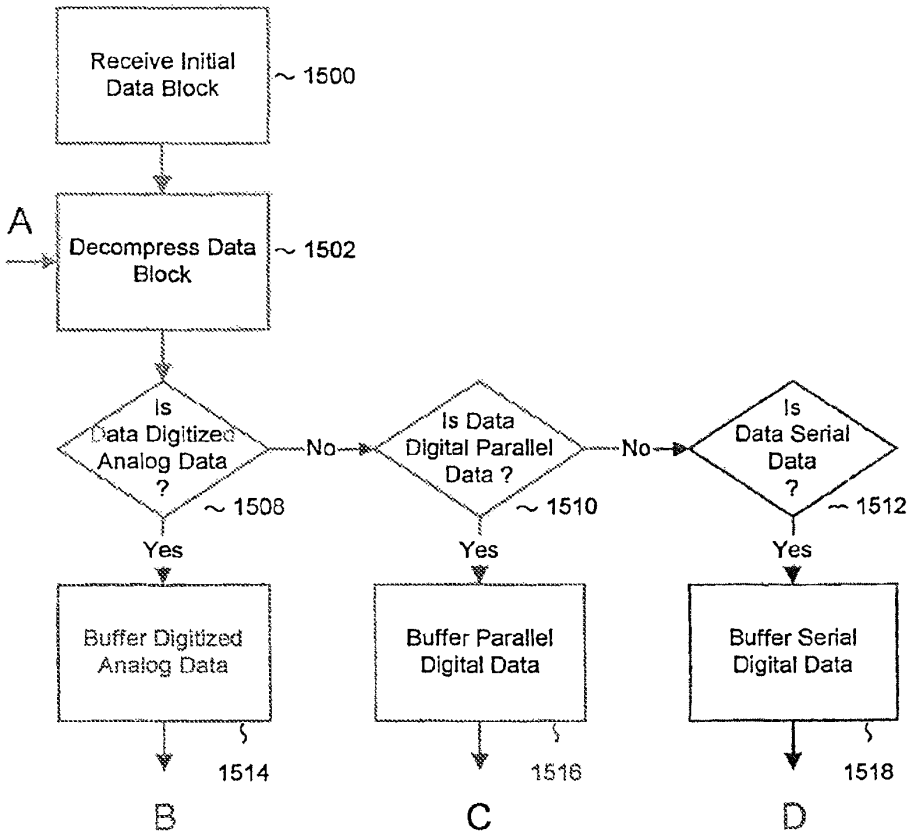

Receive Initial Data Block
1500
A
Decompress Data Block
1502
Is Data Digitized Analog Data ?
1508
No
Is Data Digital Parallel Data ?
1510
No
Is Data Serial Data ?
1512
Yes
Yes
Yes
Buffer Digitized Analog Data
Buffer Parallel Digital Data
Buffer Serial Digital Data
1514
1516
1518
B
C
D

FIGURE 15a

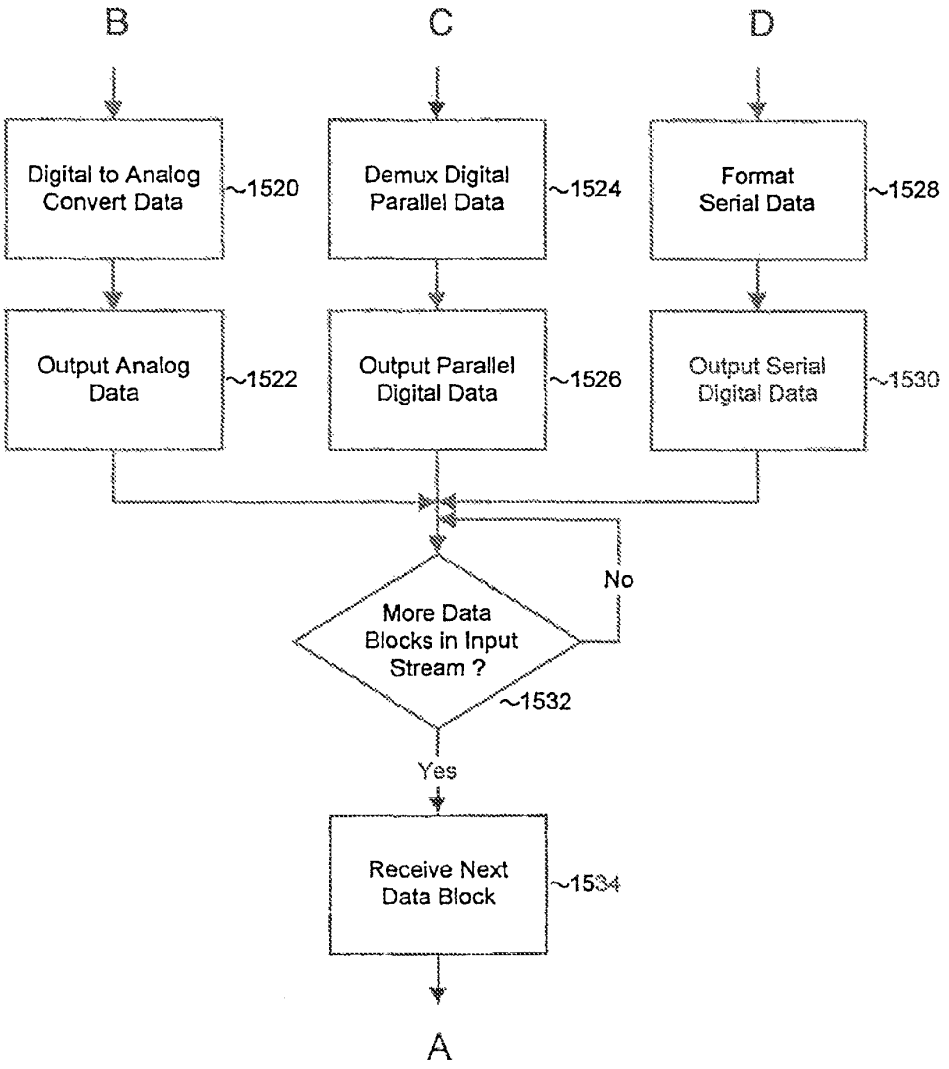

B
C
D
Digital to Analog Convert Data
1520
Demux Digital Parallel Data
1524
Format Serial Data
1528
Output Analog Data
1522
Output Parallel Digital Data
1526
Output Serial Digital Data
1530
No
More Data Blocks in Input Stream ?
1532
Yes
Receive Next Data Block
1534
A

FIGURE 15b

SYSTEM AND METHODS FOR ACCELERATED DATA STORAGE AND RETRIEVAL

This application is a continuation of U.S. patent application Ser. No. 11/553,419, filed on Oct. 26, 2006, which is a continuation of U.S. patent application Ser. No. 10/628,795, filed on Jul. 28, 2003, now U.S. Pat. No. 7,130,913, which is a continuation of U.S. patent application Ser. No. 09/266,394 filed on Mar. 11, 1999, now U.S. Pat. No. 6,601,104, all of which are incorporated by reference in their entirety.

BACKGROUND

The present invention relates generally to data storage and retrieval and, more particularly to systems and methods for improving data storage and retrieval bandwidth utilizing lossless data compression and decompression.

DESCRIPTION OF THE RELATED ART

Information may be represented in a variety of manners. Discrete information such as text and numbers are easily represented in digital data. This type of data representation is known as symbolic digital data. Symbolic digital data is thus an absolute representation of data such as a letter, figure, character, mark, machine code, or drawing.

Continuous information such as speech, music, audio, images and video frequently exists in the natural world as analog information. As is well-known to those skilled in the art, recent advances in very large scale integration (VLSI) digital computer technology have enabled both discrete and analog information to be represented with digital data. Continuous information represented as digital data is often referred to as diffuse data. Diffuse digital data is thus a representation of data that is of low information density and is typically not easily recognizable to humans in its native form.

There are many advantages associated with digital data representation. For instance, digital data is more readily processed, stored, and transmitted due to its inherently high noise immunity. In addition, the inclusion of redundancy in digital data representation enables error detection and/or correction. Error detection and/or correction capabilities are dependent upon the amount and type of data redundancy, available error detection and correction processing, and extent of data corruption.

One outcome of digital data representation is the continuing need for increased capacity in data processing, storage, and transmittal. This is especially true for diffuse data where increases in fidelity and resolution create exponentially greater quantities of data. Data compression is widely used to reduce the amount of data required to process, transmit, or store a given quantity of information. In general, there are two types of data compression techniques that may be utilized either separately or jointly to encode/decode data: lossy and lossless data compression.

Lossy data compression techniques provide for an inexact representation of the original uncompressed data such that the decoded (or reconstructed) data differs from the original unencoded/uncompressed data. Lossy data compression is also known as irreversible or noisy compression. Negentropy is defined as the quantity of information in a given set of data. Thus, one obvious advantage of lossy data compression is that the compression ratios can be larger than that dictated by the negentropy limit, all at the expense of information content. Many lossy data compression techniques seek to exploit various traits within the human senses to eliminate otherwise imperceptible data. For example, lossy data compression of visual imagery might seek to delete information content in excess of the display resolution or contrast ratio of the target display device.

On the other hand, lossless data compression techniques provide an exact representation of the original uncompressed data. Simply stated, the decoded (or reconstructed) data is identical to the original unencoded/uncompressed data. Lossless data compression is also known as reversible or noiseless compression. Thus, lossless data compression has, as its current limit, a minimum representation defined by the negentropy of a given data set.

It is well known within the current art that data compression provides several unique benefits. First, data compression can reduce the time to transmit data by more efficiently utilizing low bandwidth data links. Second, data compression economizes on data storage and allows more information to be stored for a fixed memory size by representing information more efficiently.

One problem with the current art is that existing memory storage devices severely limit the performance of consumer, entertainment, office, workstation, servers, and mainframe computers for all disk and memory intensive operations. For example, magnetic disk mass storage devices currently employed in a variety of home, business, and scientific computing applications suffer from significant seek-time access delays along with profound read/write data rate limitations. Currently the fastest available (10,000) rpm disk drives support only a 17.1 Megabyte per second data rate (MB/sec). This is in stark contrast to the modern Personal Computer's Peripheral Component Interconnect (PCI) Bus's input/output capability of 264 MB/sec and internal local bus capability of 800 MB/sec.

Another problem within the current art is that emergent high performance disk interface standards such as the Small Computer Systems Interface (SCSI-3) and Fibre Channel offer only the promise of higher data transfer rates through intermediate data buffering in random access memory. These interconnect strategies do not address the fundamental problem that all modern magnetic disk storage devices for the personal computer marketplace are still limited by the same physical media restriction of 17.1 MB/sec. Faster disk access data rates are only achieved by the high cost solution of simultaneously accessing multiple disk drives with a technique known within the art as data striping.

Additional problems with bandwidth limitations similarly occur within the art by all other forms of sequential, pseudo-random, and random access mass storage devices. Typically mass storage devices include magnetic and optical tape, magnetic and optical disks, and various solid-state mass storage devices. It should be noted that the present invention applies to all forms and manners of memory devices including storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof.

SUMMARY OF THE INVENTION

The present invention is directed to systems and methods for providing accelerated data storage and retrieval by utilizing lossless data compression and decompression. The present invention provides an effective increase of the data storage and retrieval bandwidth of a memory storage device. In one aspect of the present invention, a method for providing accelerated data storage and retrieval comprises the steps of:

receiving a data stream at an input data transmission rate which is greater than a data storage rate of a target storage device;

compressing the data stream at a compression ratio which provides a data compression rate that is greater than the data storage rate;

storing the compressed data stream in the target storage device;

retrieving the compressed data stream from the target storage device at a rate equal to a data access rate of the target storage device; and

decompressing the compressed data at a decompression ratio to provide an output data stream having an output transmission rate which is greater than the data access rate of the target storage device.

In another aspect of the present invention, the method for providing accelerated data storage and retrieval utilizes a compression ratio that is at least equal to the ratio of the input data transmission rate to the data storage rate so as to provide continuous storage of the input data stream at the input data transmission rate.

In another aspect of the present invention, the method for providing accelerated data storage and retrieval utilizes a decompression ratio which is equal to or greater than the ratio of the data access rate to a maximum accepted output data transmission rate so as to provide a continuous and optimal data output transmission rate.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in a disk storage adapter to reduce the time required to store and retrieve data from computer to a disk memory device.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in conjunction with random access memory to reduce the time required to store and retrieve data from random access memory.

In another aspect of the present invention a data storage and retrieval accelerator method and system is employed in a video data storage system to reduce the time required to store digital video data.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in a display controller to reduce the time required to send display data to the display controller or processor.

In another aspect of the present invention the data storage and retrieval accelerator method and system is employed in an input/output controller to reduce the time required to store, retrieve, or transmit data various forms of data.

The present invention is realized due to recent improvements in processing speed, inclusive of dedicated analog and digital hardware circuits, central processing units, digital signal processors, dedicated finite state machines (and any hybrid combinations thereof), that, coupled with advanced data compression and decompression algorithms, are enabling of ultra high bandwidth data compression and decompression methods that enable improved data storage and retrieval bandwidth.

These and other aspects, features and advantages, of the present invention will become apparent from the following detailed description of preferred embodiments, that is to be read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a system for accelerated data storage and retrieval according to one embodiment of the present invention;

FIG. **2** is a flow diagram of a method for accelerated data storage in accordance with one aspect of the present invention;

FIG. **3** is a flow diagram of a method for accelerated data retrieval in accordance with one aspect of the present invention;

FIGS. **4***a* and **4***b* are timing diagrams of methods for accelerated data storage according to the present invention;

FIGS. **5***a* and **5***b* are timing diagrams of methods for accelerated data retrieval according to the present invention;

FIGS. **6***a* and **6***b* comprise a flow diagram of a method for accelerated data storage in accordance with a further aspect of the present invention;

FIGS. **7***a* and **7***b* comprise a flow diagram of a method for accelerated data retrieval in accordance with a further aspect of the present invention;

FIG. **8** is a detailed block diagram of a system for accelerated data storage according to a preferred embodiment of the present invention;

FIG. **9** is a detailed block diagram of a system for accelerated data retrieval according to a preferred embodiment of the present invention;

FIG. **10** is a block diagram of a system for accelerated video storage according to one embodiment of the present invention;

FIG. **11** is a block diagram of a system for accelerated retrieval of video data according to one embodiment of the present invention;

FIG. **12** is a block diagram of an input/output controller system for accelerated storage of analog, digital, and serial data according to one embodiment of the present invention;

FIG. **13** is a flow diagram of a method for accelerated storage of analog, digital, and serial data according to one aspect of the present invention;

FIG. **14** is a block diagram of an input/output system for accelerated retrieval of analog, digital, and serial data according to one embodiment of the present invention; and

FIGS. **15***a* and **15***b* comprise a flow diagram of method for accelerated retrieval of analog, digital, and serial data according to one aspect of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention is directed to systems and methods for providing improved data storage and retrieval bandwidth utilizing lossless data compression and decompression. In the following description, it is to be understood that system elements having equivalent or similar functionality are designated with the same reference numerals in the Figures. It is to be further understood that the present invention may be implemented in various forms of hardware, software, firmware, or a combination thereof. Preferably, the present invention is implemented on a computer platform including hardware such as one or more central processing units (CPU) or digital signal processors (DSP), a random access memory (RAM), and input/output (I/O) interface(s). The computer platform may also include an operating system, microinstruction code, and dedicated processing hardware utilizing combinatorial logic or finite state machines. The various processes and functions described herein may be either part of the hardware, microinstruction code or application programs that are executed via the operating system, or any combination thereof.

Systems and methods for providing accelerated data storage and retrieval utilizing lossless data compression and decompression. A data storage accelerator includes one or a plurality of high speed data compression encoders that are configured to simultaneously or sequentially losslessly compress data at a rate equivalent to or faster than the transmission

rate of an input data stream. The compressed data is subsequently stored in a target memory or other storage device whose input data storage bandwidth is lower than the original input data stream bandwidth. Similarly, a data retrieval accelerator includes one or a plurality of high speed data decompression decoders that are configured to simultaneously or sequentially losslessly decompress data at a rate equivalent to or faster than the input data stream from the target memory or storage device. The decompressed data is then output at rate data that is greater than the output rate from the target memory or data storage device. The data storage and retrieval accelerator method and system may employed: in a disk storage adapter to reduce the time required to store and retrieve data from computer to disk; in conjunction with random access memory to reduce the time required to store and retrieve data from random access memory; in a display controller to reduce the time required to send display data to the display controller or processor; and/or in an input/output controller to reduce the time required to store, retrieve, or transmit data.

It is to be further understood that, because some of the constituent system components described herein are preferably implemented as software modules, the actual system connections shown in the Figures may differ depending upon the manner in that the systems are programmed. It is to be appreciated that special purpose microprocessors, digital signal processors, dedicated hardware, or and combination thereof may be employed to implement the present invention. Given the teachings herein, one of ordinary skill in the related art will be able to contemplate these and similar implementations or configurations of the present invention.

Referring now to FIG. **1**, a block diagram illustrates a system for accelerated data storage and retrieval in accordance with an embodiment of the present invention. The system includes a data storage accelerator **10**, operatively coupled to a data storage device **45**. The data storage accelerator operates to increase the effective data storage rate of the data storage device **45**. It is to be appreciated that the data storage device **45** may be any form of memory device including all forms of sequential, pseudo-random, and random access storage devices. The memory storage device **45** may be volatile or non-volatile in nature, or any combination thereof. Storage devices as known within the current art include all forms of random access memory, magnetic and optical tape, magnetic and optical disks, along with various other forms of solid-state mass storage devices. Thus it should be noted that the current invention applies to all forms and manners of memory devices including, but not limited to, storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof.

The data storage accelerator **10** receives and processes data blocks from an input data stream. The data blocks may range in size from individual bits through complete files or collections of multiple files, and the data block size may be fixed or variable. In order to achieve continuous data storage acceleration, the data storage accelerator **10** must be configured to compress a given input data block at a rate that is equal to or faster than receipt of the input data. Thus, to achieve optimum throughput, the rate that data blocks from the input data stream may be accepted by the data storage accelerator **10** is a function of the size of each input data block, the compression ratio achieved, and the bandwidth of the target storage device. For example, if the data storage device **45** (e.g., a typical target mass storage device) is capable of storing 20 megabytes per second and the data storage accelerator **10** is capable of providing an average compression ratio of 3:1, then 60 megabytes per second may be accepted as input and the data storage acceleration is precisely 3:1, equivalent to the average compression ratio.

It should be noted that it is not a requirement of the present invention to configure the storage accelerator **10** to compress a given input data block at a rate that is equal to or faster than receipt of the input data. Indeed, if the storage accelerator **10** compresses data at a rate that is less than the input data rate, buffering may be applied to accept data from the input data stream for subsequent compression.

Additionally, it is not a requirement that the data storage accelerator **10** utilize data compression with a ratio that is at least the ratio of the input data stream to the data storage access rate of the data storage device **45**. Indeed, if the compression ratio is less than this ratio, the input data stream may be periodically halted to effectively reduce the rate of the input data stream. Alternatively, the input data stream or the output of the data accelerator **10** may be buffered to temporarily accommodate the mismatch in data bandwidth. An additional alternative is to reduce the input data rate to rate that is equal to or slower than the ratio of the input data rate to the data storage device access rate by signaling the data input source and requesting a slower data input rate, if possible.

Referring again to FIG. **1**, a data retrieval accelerator **80** is operatively connected to and receives data from the data storage device **45**. The data retrieval accelerator **80** receives and processes compressed data from data storage device **45** in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. The data retrieval accelerator **80** is configured to decompress each compressed data block which is received from the data storage device **45**. In order to achieve continuous accelerated data retrieval, the data retrieval accelerator must decompress a given input data block at a rate that is equal to or faster than receipt of the input data.

In a manner analogous to the data storage accelerator **10**, achieving optimum throughput with the data retrieval accelerator **80** is a function of the rate that compressed data blocks are retrieved from the data storage device **45**, the size of each data block, the decompression ratio achieved, and the limitation on the bandwidth of the output data stream, if any. For example, if the data storage device **45** is capable of continuously supplying 20 megabytes per second and the data retrieval accelerator **80** is capable of providing an average decompression ratio of 1:3, then a 60 megabytes per second output data stream is achieved, and the corresponding data retrieval acceleration is precisely 1:3, equivalent to the average decompression ratio.

It is to be understood that it is not required that the data retrieval accelerator **80** utilize data decompression with a ratio that is at most equal to the ratio of the retrieval rate of the data storage device **45** to the maximum rate data output stream. Indeed, if the decompression ratio is greater than this ratio, retrieving data from the data storage device may be periodically halted to effectively reduce the rate of the output data stream to be at or below its maximum. Alternatively, the compressed data retrieved from the data storage device **45** or the output of the data decompressor may be buffered to temporarily accommodate the mismatch in data bandwidth. An additional alternative is to increase the output data rate by signaling or otherwise requesting the data output device(s) receiving the output data stream to accept a higher bandwidth, if possible.

Referring now to FIG. **2**, a flow diagram of a method for accelerated data storage according to one aspect of the present invention illustrates the operation of the data storage accel-

eration shown in FIG. **1**. As previously stated above, data compression is performed on a per data block basis. Accordingly, the initial input data block in the input data stream (step **200**) is input into and compressed by the data storage accelerator **10** (step **202**). Upon completion of the encoding of the input data block, the encoded data block is then stored in the data storage device **45** (step **204**). A check or other form of test is performed to see if there are additional data blocks available in the input stream (step **206**). If no more data blocks are available, the storage acceleration process is terminated (step **208**). If more data blocks are available in the input data stream, the next data block is received (step **210**) and the process repeats beginning with data compression (step **202**).

Referring now to FIG. **3**, a flow diagram of a method for accelerated data retrieval according to one aspect of the present invention illustrates the operation of the data retrieval accelerator **80** shown in FIG. **1**. Data decompression is also performed on a per data block basis. The initial compressed data block is retrieved from the storage device **45** (step **300**) and is decompressed by the data retrieval accelerator **80** (step **302**). Upon completion of the decoding of the initial data block, the decoded data block is then output for subsequent processing, storage, or transmittal (step **304**). A check or other form of test is performed to see if additional data blocks available from the data storage device (step **306**). If no more data blocks are available, the data retrieval acceleration process is terminated (step **308**). If more data blocks are available from the data storage device, the next data block is retrieved (step **310**) and the process repeats beginning with data decompression (step **302**).

Referring now to FIGS. **4***a* and **4***b*, a timing diagram illustrates methods for accelerated data storage utilizing data compression in accordance with the present invention. Successive time intervals of equal duration are represented as T1 through T(n+2). Data block 1 is received from an input stream of one or more data blocks. Similarly, data block 2 through data block n are received during time intervals T2 through Tn, respectively. For the purposes of discussion, FIGS. **4***a* and **4***b* demonstrate one embodiment of the data storage utilizing a stream of n data blocks. As previously stated, the input data stream is comprised of one or more data blocks data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable.

In accordance with Method 1, compression of data block 1 and subsequent storage of the encoded data block 1 occurs within time interval T1. Similarly, the compression and storage of each successive data block occurs within the time interval the data block is received. Specifically, data blocks 2 . . . n are compressed in time intervals T2 . . . Tn, respectively, and the corresponding encoded data blocks 2 . . . n are stored during the time intervals T2 . . . Tn, respectively. It is to be understood that Method 1 relies on data compression and encoding techniques that process data as a contiguous stream, i.e., are not block oriented. It is well known within the current art that certain data compression techniques including, but not limited to, dictionary compression, run length encoding, null suppression and arithmetic compression are capable of encoding data when received. Method 1 possesses the advantage of introducing a minimum delay in the time from receipt of input to storage of encoded data blocks.

Referring again to FIGS. **4***a* and **4***b*, Method 2 illustrates compressing and storing data utilizing pipelined data processing. For Method 2, successive time intervals of equal duration are represented as T1 through T(n+2). Data block 1 is received from an input stream of one or more data blocks during time interval T1. Similarly, data block 2 through data block n are received during time intervals T2 through Tn, respectively. Compression of data block 1 occurs during time interval T2 and the storage of encoded data block 1 occurs during time interval T3. As shown by Method 2, compression of each successive data block occurs within the next time interval after the data block is received and data storage of the corresponding encoded data block occur in the next time interval after completion of data compression.

The pipelining of Method 2, as shown, utilizes successive single time interval delays for data compression and data storage. Within the current invention, it is permissible to have increased pipelining to facilitate additional data processing or storage delays. For example, data compression processing for a single input data block may utilize more than one time interval. Accommodating more than one time interval for data compression requires additional data compressors to process successive data blocks, e.g., data compression processing of a single data block through three successive time intervals requires three data compressors, each processing a successive input data block. Due to the principle of causality, encoded data blocks are output only after compression encoding.

Method 2 provides for block oriented processing of the input data blocks. Within the current art, block oriented data compression techniques provide the opportunity for increased data compression ratios. The disadvantage of Method 2 is increased delay from receipt of input data block to storage of encoded data. Depending on factors such as the size of input data blocks, the rate that they are received, the time required for data compression processing, the data compression ratio achieved, the bandwidth of the data storage device, and the intended application, the delay may or may not be significant. For example, in a modern database system, recording data for archival purposes, the opportunity for increased data compression may far outweigh the need for minimum delay. Conversely, in systems such as a military real-time video targeting system, minimizing delay is often of the essence. It should be noted that Method 1 and Method 2 are not mutually exclusive, and may be utilized in any combination.

Referring now to FIGS. **5***a* and **5***b*, a timing diagram illustrates methods for accelerated data retrieval utilizing data decompression in accordance the present invention shown. Successive time intervals of equal duration are represented as T1 through T(n+2). Data block 1 is retrieved or otherwise accepted as input from one or more compressed data blocks retrieved from a data storage device. As shown, data block 2 through data block n are retrieved during time intervals T2 through Tn, respectively. For the purposes of discussion, FIGS. **5***a* and **5***b* demonstrate one embodiment of the data retrieval accelerator utilizing a stream of n data blocks. Once again, the retrieved data stream is comprised of one or more data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the retrieved data block size may be fixed or variable.

In accordance with Method 1, decompression of data block 1 and subsequent outputting of the decoded data block 1 occurs within time interval T1. Similarly, decompression and outputting of each successive data block occurs within the time intervals they are retrieved. In particular, data block 2 through data block n are decompressed and decoded data block 2 through decoded data block n are output during time intervals T2 . . . Tn, respectively. It is to be understood that Method 1 relies on data decompression and decoding techniques that process compressed data as a contiguous stream, i.e., are not block oriented. It is well known within the current art that certain data decompression techniques including, but not limited to, dictionary compression, run length encoding,

null suppression and arithmetic compression are capable of decoding data when received. Method 1 possesses the advantage of introducing a minimum delay in the time from retrieval of compressed data to output of decoded data blocks.

Referring again to FIGS. **5***a* and **5***b*, Method 2 involves decompressing and outputting data utilizing pipelined data processing. For Method 2, successive time intervals of equal duration are represented as T1 through T(n+2). Data block 1 through data block n are retrieved or otherwise accepted as input from a data storage device during time intervals T1 through Tn, respectively. Decompression of data block 1 occurs during time interval T2 and the decoded data block 1 is output during time interval T3. Similarly, decompression of each successive data block occurs within the next time interval after the data block is retrieved and the outputting of the decoded data block occurs during the next time interval after completion of data decompression.

The pipelining of Method 2, utilizes successive single time interval delays for data decompression and data output. Within the current invention, it is permissible to have increased pipelining to facilitate additional data retrieval or data decompression processing delays. For example, data decompression processing for a single input data block may utilize more than one time interval. Accommodating more than one time interval for data compression requires additional data decompressors to process successive compressed data blocks, e.g., data decompression processing of a single data block through three successive time intervals requires three data decompressors, each processing a successive input data block. Due to the principle of causality, decoded data blocks are only output after decompression decoding.

As before, Method 2 provides for block oriented processing of the retrieved data blocks. Within the current art, block oriented data decompression techniques provide the opportunity to utilize data compression encoders that increase data compression ratios. The disadvantage of method 2 is increased delay from retrieval of compressed data block to output of decompressed data. As previously discussed for data storage acceleration, depending on the size of retrieved data blocks, the rate that they are retrieved, the time required for data decompression processing, the data decompression ratio achieved, the bandwidth of the data output, and the intended application, the delay may or may not be significant.

Referring now to FIGS. **6***a* and **6***b*, a flow diagram illustrates a method for accelerated data storage according to a further aspect of the present invention. With this method, the data compression rate of the storage accelerator **10** is not required to be equal to or greater than the ratio of the input data rate to the data storage access rate. As previously stated above, data compression is performed on a per data block basis. Accordingly, the initial input data block in the input data stream is received (step **600**) and then timed and counted (step **602**). Timing and counting enables determination of the bandwidth of the input data stream. The input data block is then buffered (step **604**) and compressed by the data storage accelerator **10** (step **606**). During and after the encoding of the input data block, the encoded data block is then timed and counted (step **608**), thus enabling determination of the compression ratio and compression bandwidth. The compressed, timed and counted data block is then buffered (step **610**). The compression ratio and bandwidths of the input data stream and the encoder are then determined (step **612**). The compressed data block is then stored in the data storage device **45** (step **614**). Checks or other forms of testing are applied to ensure that the data bandwidths of the input data stream, data compressor, and data storage device are compatible (step **616**). If the bandwidths are not compatible, then one or more system parameters may be modified to make the bandwidths compatible (step **618**). For instance, the input bandwidth may be adjusted by either not accepting input data requests, lowering the duty cycle of input data requests, or by signaling one or more of the data sources that transmit the input data stream to request or mandate a lower data rate. In addition, the data compression ratio of the data storage accelerator **10** may be adjusted by applying a different type of encoding process such as employing a single encoder, multiple parallel or sequential encoders, or any combination thereof. Furthermore, additional temporary buffering of either the input data stream or the compressed data stream (or both) may be utilized.

By way of example, assuming the input data rate is 90 MB/sec and the data storage accelerator **10** provides a compression ratio of 3:1, then the output of the data storage accelerator **10** would be 30 MB/sec. If the maximum data storage rate of the data storage device **45** is 20 MB/sec (which is less than the data rate output from the data storage accelerator **10**), data congestion and backup would occur at the output of the data storage accelerator **10**. This problem may be solved by adjusting any one of the system parameters as discussed above, e.g., by adjusting the compression ratio to provide a data output rate from the data storage accelerator **10** to be equal to the data storage rate of the data storage device **45**.

On the other hand, if the bandwidths are compatible (or made compatible by adjusting one or more of the system parameters), then a check or other form of test is performed to determine if there are additional data blocks available in the input stream (step **620**). If no more data blocks are available, the storage acceleration process is terminated (step **622**). If more data blocks are available in the input data stream, the next data block is received (step **624**) and the process repeats beginning with timing and counting of the input data block (step **602**).

Referring now to FIGS. **7***a* and **7***b*, a flow diagram illustrates a method for accelerated data retrieval according to one aspect of the present invention. With this method, the data decompression ratio is not required to be less than or equal to the ratio of the data retrieval access rate to the maximum output data rate. As previously stated above, data decompression is performed on a per data block basis. Accordingly, the initial input data block is retrieved from the storage device (step **700**) and is timed and counted (step **702**). Timing and counting enables determination of the bandwidth of data retrieval. The retrieved data block is then buffered (step **704**) and decompressed by the data retrieval accelerator **80** (step **706**). During and after the decoding of the input data block, the decoded data block is then timed and counted (step **708**), thus enabling determination of the decompression ratio and decompression bandwidth. The decompressed, timed and counted data block is then buffered (step **710**). The decompression ratio and bandwidths of the retrieved data and the decoder are then determined (step **712**). The decompressed data block is then output (step **714**). Checks or other forms of testing are applied to ensure that the data bandwidths of the retrieved data, data decompressor, and data output are compatible (step **716**). If the bandwidths are not compatible, then one or more system parameters may be modified to make the bandwidths compatible (step **718**). For instance, the data retrieval bandwidth may be adjusted either not accepting (continuously) data blocks retrieved from the data storage device or lowering the duty cycle of data blocks retrieved from the data storage device. In addition, one or more of the output data devices that receive the output data stream may be signaled or otherwise requested to accept a higher data rate.

Moreover, a different type of decoding process may be applied to adjust the data decompression rate by applying, for example, a single decoder, multiple parallel or sequential decoders, or any combination thereof. Also, additional temporary buffering of either the retrieved or output data or both may be utilized.

By way of example, assuming the data storage device **45** has a data retrieval rate of 20 MB/sec and the data retrieval accelerator **80** provides a 1:4 decompression ratio, then the output of the data retrieval accelerator **80** would be 80 MB/sec. If the maximum output data transmission rate that can be accepted from the data retrieval accelerator **80** is 60 MB/sec (which is lower than the data output data rate of 80 MB/sec of the data retrieval accelerator **80**), data congestion and backup would occur at the output of the data retrieval accelerator **80**. This problem may be solved by adjusting any one of the system parameters as discussed above, e.g., by adjusting the decompression ratio to provide a data output rate from the data storage accelerator **80** to be equal to the maximum accepted output data transmission rate.

On the other hand, if the bandwidths are compatible (or made compatible by adjusting one or more system parameters), then a check or other form of test is performed to see if there are additional data blocks available from the data storage device (step **720**). If no more data blocks are available for output, the retrieval acceleration process is terminated (step **722**). If more data blocks are available to be retrieved from the data storage device, the next data block is retrieved (step **724**) and the process repeats beginning with timing and counting of the retrieved data block (return to step **702**).

It is to be understood that any conventional compression/decompression system and method (which comply with the above mentioned constraints) may be employed in the data storage accelerator **10** and data retrieval accelerator **80** for providing accelerated data storage and retrieval in accordance with the present invention. Preferably, the present invention employs the data compression/decompression techniques disclosed in U.S. Ser. No. 09/210,491 entitled "Content Independent Data Compression Method and System," filed on Dec. 11, 1998, which is commonly assigned and which is fully incorporated herein by reference. It is to be appreciated that the compression and decompression systems and methods disclosed in U.S. Ser. No. 09/210,491 are suitable for compressing and decompressing data at rates which provide accelerated data storage and retrieval.

Referring now to FIG. **8**, a detailed block diagram illustrates a preferred system for accelerated data storage which employs a compression system as disclosed in the above-incorporated U.S. Ser. No. 09/210,491. In this embodiment, the data storage accelerator **10** accepts data blocks from an input data stream and stores the input data block in an input buffer or cache **15**. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. A counter **20** counts or otherwise enumerates the size of input data block in any convenient units including bits, bytes, words, double words. It should be noted that the input buffer **15** and counter **20** are not required elements of the present invention. The input data buffer **15** may be provided for buffering the input data stream in order to output an uncompressed data stream in the event that, as discussed in further detail below, every encoder fails to achieve a level of compression that exceeds an a priori specified minimum compression ratio threshold.

Data compression is performed by an encoder module **25** which may comprise a set of encoders E1, E2, E3 . . . En. The encoder set E1, E2, E3 . . . En may include any number "n" (where n may=1) of those lossless encoding techniques currently well known within the art such as run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. It is to be understood that the encoding techniques are selected based upon their ability to effectively encode different types of input data. It is to be appreciated that a full complement of encoders are preferably selected to provide a broad coverage of existing and future data types.

The encoder module **25** successively receives as input each of the buffered input data blocks (or unbuffered input data blocks from the counter module **20**). Data compression is performed by the encoder module **25** wherein each of the encoders E1 . . . En processes a given input data block and outputs a corresponding set of encoded data blocks. It is to be appreciated that the system affords a user the option to enable/disable any one or more of the encoders E1 . . . En prior to operation. As is understood by those skilled in the art, such feature allows the user to tailor the operation of the data compression system for specific applications. It is to be further appreciated that the encoding process may be performed either in parallel or sequentially. In particular, the encoders E1 through En of encoder module **25** may operate in parallel (i.e., simultaneously processing a given input data block by utilizing task multiplexing on a single central processor, via dedicated hardware, by executing on a plurality of processor or dedicated hardware systems, or any combination thereof). In addition, encoders E1 through En may operate sequentially on a given unbuffered or buffered input data block. This process is intended to eliminate the complexity and additional processing overhead associated with multiplexing concurrent encoding techniques on a single central processor and/or dedicated hardware, set of central processors and/or dedicated hardware, or any achievable combination. It is to be further appreciated that encoders of the identical type may be applied in parallel to enhance encoding speed. For instance, encoder E1 may comprise two parallel Huffman encoders for parallel processing of an input data block.

A buffer/counter module **30** is operatively connected to the encoder module **25** for buffering and counting the size of each of the encoded data blocks output from encoder module **25**. Specifically, the buffer/counter **30** comprises a plurality of buffer/counters BC1, BC2, BC3 . . . BCn, each operatively associated with a corresponding one of the encoders E1 . . . En. A compression ratio module **35**, operatively connected to the output buffer/counter **30**, determines the compression ratio obtained for each of the enabled encoders E1 . . . En by taking the ratio of the size of the input data block to the size of the output data block stored in the corresponding buffer/counters BC1 . . . BCn. In addition, the compression ratio module **35** compares each compression ratio with an a priori-specified compression ratio threshold limit to determine if at least one of the encoded data blocks output from the enabled encoders E1 . . . En achieves a compression that exceeds an a priori-specified threshold. As is understood by those skilled in the art, the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. A description module **38**, operatively coupled to the compression ratio module **35**, appends a corresponding compression type descriptor to each encoded data block which is selected for output so as to indicate the type of compression format of the encoded data block. A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the

identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing, storage, or transmittal. If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit, then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto. A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing, storage, or transmittal.

The data storage acceleration device **10** is connected to a data storage device interface **40**. The function of the data storage interface **40** is to facilitate the formatting and transfer of data to one or more data storage devices **45**. The data storage interface may be any of the data interfaces known to those skilled in the art such as SCSI (Small Computer Systems Interface), Fibre Channel, "Firewire", IEEE P1394, SSA (Serial Storage Architecture), IDE (Integrated Disk Electronics), and ATA/ATAPI interfaces. It should be noted that the storage device data interface **40** is not required for implementing the present invention. As before, the data storage device **45** may be any form of memory device including all forms of sequential, pseudo-random, and random access storage devices. The data storage device **45** may be volatile or non-volatile in nature, or any combination thereof. Storage devices as known within the current art include all forms of random access memory (RAM), magnetic and optical tape, magnetic and optical disks, along with various other forms of solid-state mass storage devices (e.g., ATA/ATAPI IDE disk). Thus it should be noted that the current invention applies to all forms and manners of memory devices including, but not limited to, storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof.

Again, it is to be understood that the embodiment of the data storage accelerator **10** of FIG. **8** is exemplary of a preferred compression system which may be implemented in the present invention, and that other compression systems and methods known to those skilled in the art may be employed for providing accelerated data storage in accordance with the teachings herein. Indeed, in another embodiment of the compression system disclosed in the above-incorporated U.S. Ser. No. 09/210,491, a timer is included to measure the time elapsed during the encoding process against an a priori-specified time limit. When the time limit expires, only the data output from those encoders (in the encoder module **25**) that have completed the present encoding cycle are compared to determine the encoded data with the highest compression ratio. The time limit ensures that the real-time or pseudo real-time nature of the data encoding is preserved. In addition, the results from each encoder in the encoder module **25** may be buffered to allow additional encoders to be sequentially applied to the output of the previous encoder, yielding a more optimal lossless data compression ratio. Such techniques are discussed in greater detail in the above-incorporated U.S. Ser. No. 09/210,491.

Referring now to FIG. **9**, a detailed block diagram illustrates a preferred system for accelerated data retrieval employing a decompression system as disclosed in the above-incorporated U.S. Ser. No. 09/210,491. In this embodiment, the data retrieval accelerator **80** retrieves or otherwise accepts data blocks from one or more data storage devices **45** and inputs the data via a data storage interface **50**. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. As stated above, the memory storage device **45** may be volatile or non-volatile in nature, or any combination thereof. Storage devices as known within the current art include all forms of random access memory, magnetic and optical tape, magnetic and optical disks, along with various other forms of solid-state mass storage devices. Thus it should be noted that the current invention applies to all forms and manners of memory devices including storage devices utilizing magnetic, optical, and chemical techniques, or any combination thereof. The data storage device interface **50** converts the input data from the storage device format to a format useful for data decompression.

The storage device data interface **50** is operatively connected to the data retrieval accelerator **80** which is utilized for decoding the stored (compressed) data, thus providing accelerated retrieval of stored data. In this embodiment, the data retrieval accelerator **80** comprises an input buffer **55** which receives as input an uncompressed or compressed data stream comprising one or more data blocks. The data blocks may range in size from individual bits through complete files or collections of multiple files. Additionally, the data block size may be fixed or variable. The input data buffer **55** is preferably included (not required) to provide storage of input data for various hardware implementations. A descriptor extraction module **60** receives the buffered (or unbuffered) input data block and then parses, lexically, syntactically, or otherwise analyzes the input data block using methods known by those skilled in the art to extract the data compression type descriptor associated with the data block. The data compression type descriptor may possess values corresponding to null (no encoding applied), a single applied encoding technique, or multiple encoding techniques applied in a specific or random order (in accordance with the data compression system embodiments and methods discussed above).

A decoder module **65** includes one or more decoders D1 . . . Dn for decoding the input data block using a decoder, set of decoders, or a sequential set of decoders corresponding to the extracted compression type descriptor. The decoders D1 . . . Dn may include those lossless encoding techniques currently well known within the art, including: run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. Decoding techniques are selected based upon their ability to effectively decode the various different types of encoded input data generated by the data compression systems described above or originating from any other desired source.

As with the data compression systems discussed in U.S. application Ser. No. 09/210,491, the decoder module **65** may include multiple decoders of the same type applied in parallel so as to reduce the data decoding time. The data retrieval accelerator **80** also includes an output data buffer or cache **70** for buffering the decoded data block output from the decoder module **65**. The output buffer **70** then provides data to the output data stream. It is to be appreciated by those skilled in the art that the data retrieval accelerator **80** may also include an input data counter and output data counter operatively coupled to the input and output, respectively, of the decoder module **65**. In this manner, the compressed and corresponding decompressed data block may be counted to ensure that sufficient decompression is obtained for the input data block.

Again, it is to be understood that the embodiment of the data retrieval accelerator **80** of FIG. **9** is exemplary of a preferred decompression system and method which may be implemented in the present invention, and that other data decompression systems and methods known to those skilled in the art may be employed for providing accelerated data retrieval in accordance with the teachings herein.

In accordance with another aspect of the present invention, the data storage and retrieval accelerator system and method may be employed in for increasing the storage rate of video data. In particular, referring now to FIG. **10**, a block diagram illustrates a system for providing accelerated video data storage in accordance with one embodiment of the present invention. The video data storage acceleration system accepts as input one or more video data streams that are analog, digital, or any combination thereof in nature. The input multiplexer **1010** selects the initial video data stream for data compression and acceleration. The input multiplexer **1010** is operatively connected to an analog to digital converter **1020** which converts analog video inputs to digital format of desired resolution. The analog to digital converter **1020** may also include functions to strip video data synchronization to perform other data formatting functions. It should be noted that the analog to digital conversion process is not required for digital video inputs. The analog to digital converter **1020** is operatively connected a video memory **1030** that is, in turn, operatively connected to a video processor **1040**. The video processor **1040** performs manipulation of the digital video data in accordance with any user desired processing functions. The video processor **1040** is operatively coupled to a video output memory **1050**, that is operatively connected to a data storage accelerator **10** which compresses the video data to provide accelerated video data to the output data stream for subsequent data processing, storage, or transmittal of the video data. This video data acceleration process is repeated for all data blocks in the input data stream. If more video data blocks are available in the input data stream, the video multiplexer selects the next block of video for accelerated processing. Again, it is to be understood that the data storage accelerator **10** may employ any compression system which is capable of compressing data at a rate suitable for providing accelerated video data storage in accordance with the teachings herein.

In accordance with another aspect of the present invention, the accelerated data storage and retrieval system may be employed in a display controller to reduce the time required to send display data to a display controller or processor. In particular, referring now to FIG. **11**, a block diagram illustrates a display accelerator system in accordance with one embodiment of the present invention. The video display accelerator accepts as input one or more digital display data blocks from an input display data stream. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input video data block size may be fixed or variable. The input data blocks are processed by a data retrieval accelerator **80** which employs a data decompression system in accordance with the teachings herein. Upon completion of data decompression, the decompressed data block is then output to a display memory **1110** that provides data to a display processor **1120**. The display processor **1120** performs any user desired processing function. It is well known within the current art that display data is often provided in one or more symbolic formats such as Open Graphics Language (Open GL) or another display or image language. The display processor **1120** is operatively connected an output memory buffer **1130**. The output memory **1130** supplies data to a display formatter **1140** that converts the data to a format compatible with the output display device or devices. Data from the display formatter **1140** is provided to the display driver **1150** that outputs data in appropriate format and drive signal levels to one or more display devices. It should be noted that the display memory **1110**, display processor **1120**, output memory **1130**, display formatter **1140**, and display driver **1150** are not required elements of the present invention.

In accordance with yet another aspect of the present invention, the data storage and retrieval accelerator system and method may be employed in an I/O controller to reduce the time for storing, retrieving or transmitting parallel data streams. In particular, referring now to FIG. **12**, a block diagram illustrates a system for accelerated data storage of analog, digital, and serial data in accordance with one embodiment of the present invention. The data storage accelerator **10** is capable of accepting one or more simultaneous analog, parallel digital, and serial data inputs. An analog input multiplexer **1205** selects the initial analog data for data compression and acceleration. The analog input multiplexer **1205** is operatively connected to an analog to digital converter **1210** that converts the analog input signal to digital data of the desired resolution. The digitized data output of the analog to digital converter **1210** is stored in an analog data memory buffer **1215** for subsequent data storage acceleration. Similarly, a parallel digital data input multiplexer **1220** selects the initial parallel digital data for data compression and acceleration. The parallel digital data input multiplexer **1220** is operatively connected to an input data latch **1225** that holds the input parallel digital data. The parallel digital data is then stored in digital data memory buffer **1245** for subsequent data storage acceleration. In addition, a serial digital data input multiplexer **1235** selects the initial serial digital data for data compression and acceleration. The serial digital data input multiplexer **1235** is operatively connected to a serial data interface **1240** that converts the serial data stream to a format useful for data acceleration. The formatted serial digital data is then stored in serial data memory buffer **1245** for subsequent data acceleration. The analog data memory **1215**, parallel digital data memory **1230**, and serial data memory **1245** are operatively connected to the data storage accelerator device **10**. Data is selected from each data memory subsystem based upon a user defined algorithm or other selection criteria. It should be noted that the analog input multiplexer **1205**, analog to digital converter **1210**, analog data memory **1215**, parallel data input multiplexer **1220**, data latch **1225**, digital data memory **1230**, serial data input multiplexer **1235**, serial data interface **1240**, serial data memory **1245**, and counter **20** are not required elements of the present invention. As stated above, the data storage accelerator **10** employs any of the data compression methods disclosed in the above-incorporated U.S. Ser. No. 09/210,491, or any conventional data compression method suitable for compressing data at a rate necessary for obtaining accelerated data storage. The data storage accelerator supplies accelerated data to the output data stream for subsequent data processing, storage, or transmittal.

Referring now to FIG. **13**, a flow diagram illustrates a method for accelerated data storage of analog, digital, and serial data according to one aspect of the present invention. The analog input multiplexer selects the initial analog data for data compression and acceleration (step **1300**). The analog input multiplexer provides analog data to the analog to digital converter that converts the analog input signal to digital data of the desired resolution (step **1302**). The digitized data output of the analog to digital converter is then buffered in the analog data memory buffer (step **1304**) for subsequent data acceleration. Similarly, the parallel digital data multiplexer

selects the initial parallel digital data for data compression and acceleration (step **1306**). The parallel digital data multiplexer provides data to the input data latch that then holds the input parallel digital data (step **1308**). The parallel digital data is then stored in digital data memory buffer for subsequent data acceleration (step **1310**). The serial digital data input multiplexer selects the initial serial digital data for data compression and acceleration (step **1312**). The serial digital data input multiplexer provides serial data to the serial data interface that converts the serial data stream to a format useful for data acceleration (step **1314**). The formatted serial digital data is then stored in the serial data memory buffer for subsequent data acceleration (step **1316**). A test or other check is performed to see if new analog data is available (step **1318**). If no new analog data is available a second check is performed to see if new parallel data is available (step **1320**). If no new parallel data is available, a third test is performed to see if new serial data is available (step **1322**). If no new serial data is available (step **1322**) the test sequence repeats with the test for new analog data (step **1318**). If new analog data block is available (step **1318**), or if new parallel data block is available (step **1320**), or if new serial data block is available (step **1322**), the input data block is compressed by the data storage accelerator (step **1324**) utilizing any compression method suitable for providing accelerated data storage in accordance with the teachings herein. After data compression is complete, the compressed data block is then output subsequent accelerated data processing, storage, or transmittal (step **1326**). After outputting data the process repeats beginning with a test for new analog data (return to step **1318**).

Referring now to FIG. **14**, a block diagram illustrates a system for accelerated retrieval of analog, digital, and serial data in accordance with one embodiment of the present invention. A data retrieval accelerator **80** receives data from an input data stream. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. The data retrieval accelerator **80** decompresses the input data utilizing any of the decompression methods suitable for providing accelerated data retrieval in accordance with the teachings herein. The data retrieval accelerator **80** is operatively connected to analog data memory **1405**, digital data memory **1420**, and serial data memory **1435**. Dependent upon the type of input data block, the decoded data block is stored in the appropriate analog **1405**, digital **1420**, or serial **1435** data memory.

The analog data memory **1405** is operatively connected to a digital to analog converter **1410** that converts the decompressed digital data block into an analog signal. The digital to analog converter **1410** is further operatively connected to an analog hold and output driver **1415**. The analog hold and output driver **1415** demultiplexes the analog signal output from the digital to analog converter **1410**, samples and holds the analog data, and buffers the output analog data.

In a similar manner, the digital data memory **1420** is operatively connected to a digital data demultiplexer **1425** that routes the decompressed parallel digital data to the output data latch and driver **1430**. The output latch and driver **1430** holds the digital data and buffers the parallel digital output.

Likewise, the serial data memory **1435** is operatively connected to a serial data interface **1440** that converts the decompressed data block to an output serial data stream. The serial data interface **1440** is further operatively connected to the serial demultiplexer and driver **1445** that routes the serial digital data to the appropriate output and buffers the serial data output.

Referring now to FIGS. **15***a* and **15***b*, a flow diagram illustrates a method for accelerated retrieval of analog, digital, and serial data according to one aspect of the present invention. An initial data block is received (step **1500**) and then decompressed by the data storage retrieval accelerator (step **1502**). Upon completion of data decompression, a test or other check is performed to see if the data block is digitized analog data (step **1508**). If the data block is not digitized analog data, a second check is performed to see if the data block is parallel digital data (step **1510**). If the data block is not parallel digital data, a third test is performed to see if the data block serial data (step **1512**). The result of at least one of the three tests will be affirmative.

If the data block is comprised of digitized analog data, the decoded data block is buffered in an "analog" digital data memory (step **1514**). The decoded data block is then converted to an analog signal by a digital to analog converter (step **1520**). The analog signal is then output (step **1522**).

If the data block is comprised of parallel digital data, the decoded data block is buffered in a "parallel" digital data memory (step **1516**). The decoded data block is then demultiplexed (step **1524**) and routed to the appropriate the output data latch and driver. The output latch and driver then holds the digital data and buffers the parallel digital output (step **1526**).

If the data block is comprised of serial data, the decoded data block is buffered in "serial" digital data memory (step **1518**). The decoded data is then formatted to a serial data format (step **1528**). The serial data is then demultiplexed, routed to the appropriate output, and output to a buffer (step **1530**).

Upon output of analog data (step **1522**), parallel digital data (step **1526**), or serial digital data (step **1530**), a test or other form of check is performed for more data blocks in the input stream (step **1532**). If no more data blocks are available, the test repeats (return to step **1532**). If a data block is available, the next data block is received (step **1534**) and the process repeats beginning with step **1502**.

Although illustrative embodiments have been described herein with reference to the accompanying drawings, it is to be understood that the present invention is not limited to those precise embodiments, and that various other changes and modifications may be affected therein by one skilled in the art without departing from the scope or spirit of the invention. All such changes and modifications are intended to be included within the scope of the invention as defined by the appended claims.

What is claimed is:

1. A system comprising:

a memory device; and

a data accelerator configured to compress: (i) a first data block with a first compression technique to provide a first compressed data block; and (ii) a second data block with a second compression technique, different from the first compression technique, to provide a second compressed data block;

wherein the compressed first and second data blocks are stored on the memory device, and the compression and storage occurs faster than the first and second data blocks are able to be stored on the memory device in uncompressed form.

2. The system of claim **1**, wherein the data accelerator stores a first data descriptor on the memory device indicative of the first compression technique such that the first descriptor is capable of being utilized to decompress at least a portion of the first data block.

3. The system of claim 2, wherein the data accelerator stores a second data descriptor on the memory device indicative of the second compression technique such that the second descriptor is capable of being utilized to decompress at least a portion of the second data block.

4. The system of claim 2, wherein the data accelerator retrieves the first descriptor and the first compressed data block from the memory device.

5. The system of claim 1, wherein the data accelerator retrieves the first compressed and second data blocks from the memory device.

6. The system of claim 1, wherein the data accelerator retrieves the first compressed data block from the memory device and decompresses the first compressed data block.

7. The system of claim 6, wherein the retrieval of the first compressed data block from the memory device and the decompression occurs faster than the first data block is able to be retrieved from the memory device in uncompressed form.

8. The system of claim 1, wherein the data accelerator is coupled to the memory device via an industry standard disk interface.

9. The system of claim 1, wherein the first compression technique applied to the first data block is a fonn of dictionary compression and the second compression technique applied to the second data block is a form of Lempel-Ziv compression.

10. The system of claim 1, wherein the first compression technique includes compressing with Lempel-Ziv encoding.

11. The system of claim 1, wherein the first compression technique includes compressing with a form of dictionary encoding.

12. The system of claim 1, wherein the first compression technique includes compressing with a plurality of encoders in a serial configuration.

13. The system of claim 1, wherein the first compression technique includes compressing with a plurality of encoders in a parallel configuration, each of the plurality of encoders having an identical type.

14. The system of claim 1, wherein the data accelerator is configured to compress a third data block with a third compression technique to provide a third compressed data block.

15. The system of claim 14 wherein the first compression technique is content dependent, the second compression technique is a form of dictionary compression, and the third compression technique is a different form of dictionary compression.

16. The system of claim 15, wherein the third data block is compressed by the third compression technique in real-time.

17. The system of claim 15, wherein the third data block is compressed by the third compression technique not in real-time.

18. The system of claim 1, wherein the first and second data blocks comprise audio or video information.

19. The system of claim 1, wherein the first and second data blocks are received over a communications channel.

20. The system of claim 1 wherein the first compression technique is content dependent and the second compression technique is a form of dictionary compression.

21. A method for accelerated data storage of data, comprising:

compressing a first data block with a first data compression technique to provide a first compressed data block; and

compressing a second data block with a second data compression technique to provide a second compressed data block, wherein the first data compression technique and the second data compression technique are different;

storing the first and second data compressed blocks on a memory device wherein the compression and storage occurs faster than the first and second data blocks are able to be stored on the memory device in uncompressed form.

22. The method of claim 21, further comprising:

storing, on the memory device, a first data descriptor indicative of the first compression technique such that the first descriptor is capable of being utilized to decompress the first compressed data block.

23. The method of claim 21, wherein retrieval of the first compressed data block from the memory device and decompression of the first compressed data block occurs faster than the first data block is able to be retrieved from the memory device in uncompressed form.

24. The system of claim 21, wherein the first compression technique applied to the first data block is a form of dictionary compression and the second compression technique applied to the second data block is a form of Lempel-Ziv compression.

25. A method for accelerated storage of data, comprising:

receiving a first and a second data block over a communications channel;

compressing the first data block with a first data compression technique to provide a first compressed data block;

compressing the second data block with a second data compression technique to provide a second compressed data block, wherein the first data compression technique and the second data compression technique are different; and

storing the first and second data compressed blocks on a memory device wherein the compression and storage occurs faster than the first and second data blocks are able to be stored on the memory device in uncompressed form.

26. The method of claim 25, further comprising:

determining a bandwidth at which the first and the second data blocks are received; and

adjusting a system parameter to make a bandwidth of the first and compressed second data blocks compatible with a bandwidth of the memory device.

27. The method of claim 25, wherein a data token is associated with the first and second compressed data blocks, and wherein the token includes values corresponding to a one or more encoding techniques that were applied to either or both of the first and second compressed data blocks.

28. The method of claim 25, wherein retrieval of compressed first data block from the memory device and decompression occurs faster than the first data block is able to be retrieved from the memory device in uncompressed form.

29. A method for accelerated retrieval of data comprising:

retrieving a first compressed data block and a second compressed data block from a memory device; and

decompressing the first compressed data block and the second compressed data block, wherein the retrieval and decompression occurs faster than the first data block is able to be retrieved from the memory device in uncompressed form;

wherein the first compressed data block was compressed with a first data compression technique to provide a first compressed data block;

wherein the second compressed data block was compressed with a second data compression technique to provide a second compressed data block, wherein the first data compression technique and the second data compression techniques are different; and

wherein the first and second data compression blocks were stored on the memory device.

30. The method of claim **29**, wherein the first compression technique applied to the first data block was a form of dictionary compression and the second compression technique applied to the second data block was a form of Lempel-Ziv compression.

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(54) **DATA FEED ACCELERATION**

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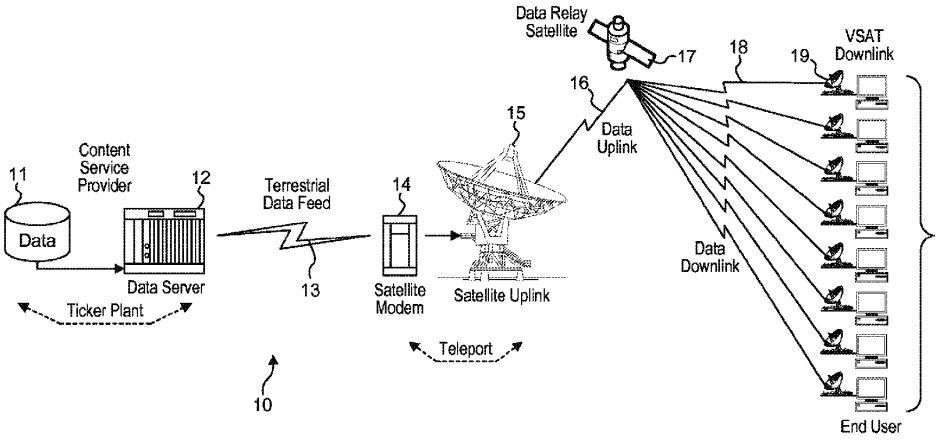
Order Adopting Report and Recommendation of United States Magistrate Judge, filed in *Realtime Data, LLC d/b/a IXO* v. *Action Corporation, et al.*, Case No. 6:15-cv-00463-RWS-JDL (E.D. Texas), filed Jan. 21, 2016; 4 pages.
(Continued)

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(57) **ABSTRACT**

The transmission of broadcast data, such as financial data and news feeds, is accelerated over a communication channel using data compression and decompression to provide secure transmission and transparent multiplication of communication bandwidth, as well as reduce the latency. Broadcast data may include packets having fields. Encoders associated with particular fields may be selected to compress those particular fields.

48 Claims, 6 Drawing Sheets



Related U.S. Application Data

continuation of application No. 12/857,238, filed on Aug. 16, 2010, now Pat. No. 8,692,695, which is a continuation of application No. 12/131,631, filed on Jun. 2, 2008, now Pat. No. 7,777,651, which is a continuation of application No. 10/434,305, filed on May 7, 2003, now Pat. No. 7,417,568, which is a continuation-in-part of application No. 09/969,987, filed on Oct. 3, 2001, now Pat. No. 9,143,546.

(60) Provisional application No. 60/237,571, filed on Oct. 3, 2000, provisional application No. 60/378,517, filed on May 7, 2002.

(51) **Int. Cl.**

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H04L 29/08	(2006.01)
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H03M 7/30	(2006.01)
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(52) **U.S. Cl.**

CPC ***H04L 12/1895*** (2013.01); ***H04L 29/06027*** (2013.01); ***H04L 29/06176*** (2013.01); ***H04L 65/4076*** (2013.01); ***H04L 65/607*** (2013.01); ***H04L 65/80*** (2013.01); ***H04L 67/26*** (2013.01); *H01L 51/52* (2013.01)

(58) **Field of Classification Search**

CPC H04L 67/26; H04L 65/80; H04L 65/607; H04L 12/1895; H04L 29/06027; H04L 65/4076; H01L 51/52

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See application file for complete search history.

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Exhibit 18, Prior Art Chart for U.S. Patent No. 7,777,651, 132 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Eastman et al., U.S. Patent No. 4,464,650.

Exhibit 19, Prior Art Chart for U.S. Patnt No. 7,777,651, 125 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Elgamal et al., U.S. Patent No. 5,410,671.

Exhibit 20, Prior Art Chart for U.S. Patent No. 7,777,651, 122 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Enari et al., EP 0493103.

Exhibit 21, Prior Art Chart for U.S. Patent No. 7,777,651, 379 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Fascenda, U.S. Patent No. 5,045,848.

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Exhibit 26, Prior Art Chart for U.S. Patent No. 7,777,651, 219 pages, *Realtime Data, LLC D/B/A IXO* v. *Morgan Stanley, et al.*, 6:09-cv-326-LED-JDL, 6:10-cv-248-LED-JDL, 6:10-cv-426-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *CME Group Inc., et al.*, 6:09-cv-327-LED-JDL, 6:10-cv-246-LED-JDL, 6:10-cv-424-LED-JDL, *Realtime Data, LLC D/B/A IXO* v. *Thomson Reuters Corp., et al.*, 6:09-cv-333-LED-JDL, 6:10-cv-247-LED-JDL, 6:10-cv-425-LED-JDL, United States District Court for the Eastern District of Texas Tyler Division, Feb. 4, 2011, citing Gentile, U.S. Patent No. 5,504,842.

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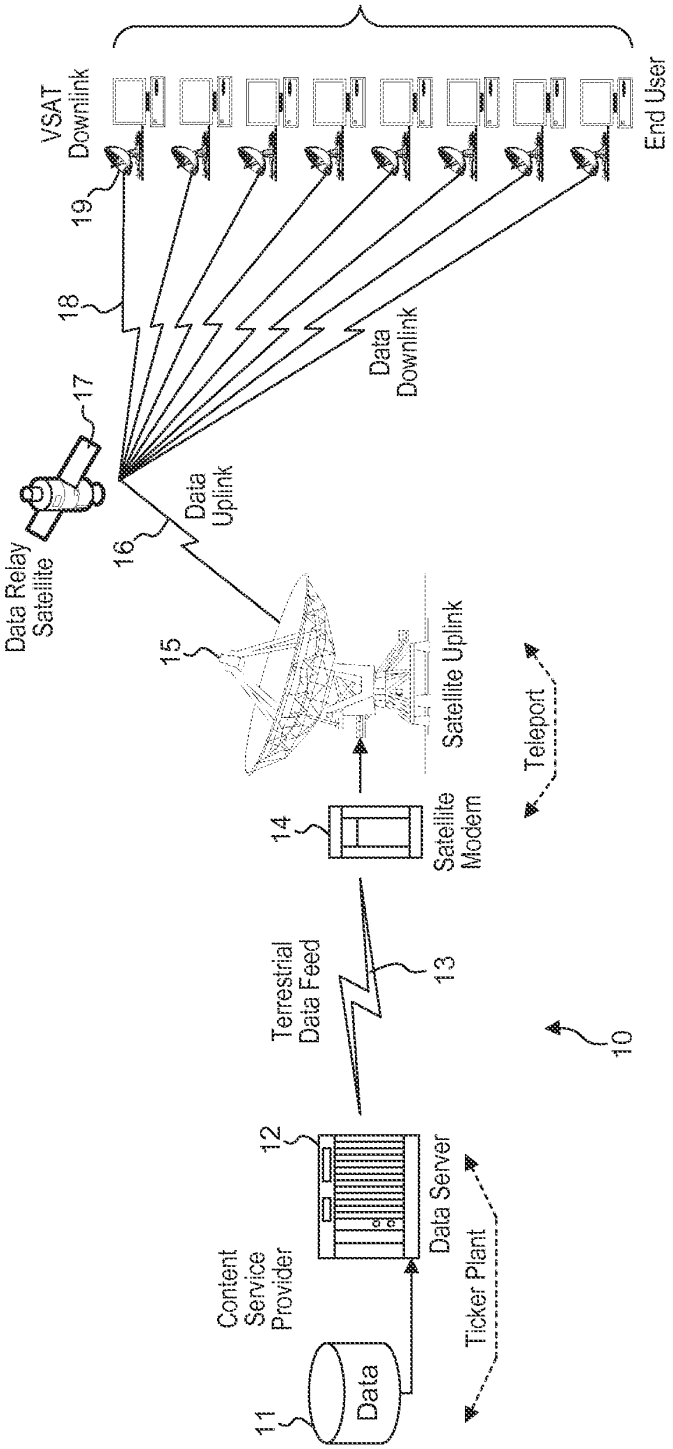

End User
VSAT Downlink
19
18
17
Data Downlink
Data Uplink
16
Data Relay Satellite
15
Satellite Uplink
Teleport
14
Satellite Modem
Terrestrial Data Feed
13
10
12
Data Server
Content Service Provider
Ticker Plant
11
Data

FIG. 1

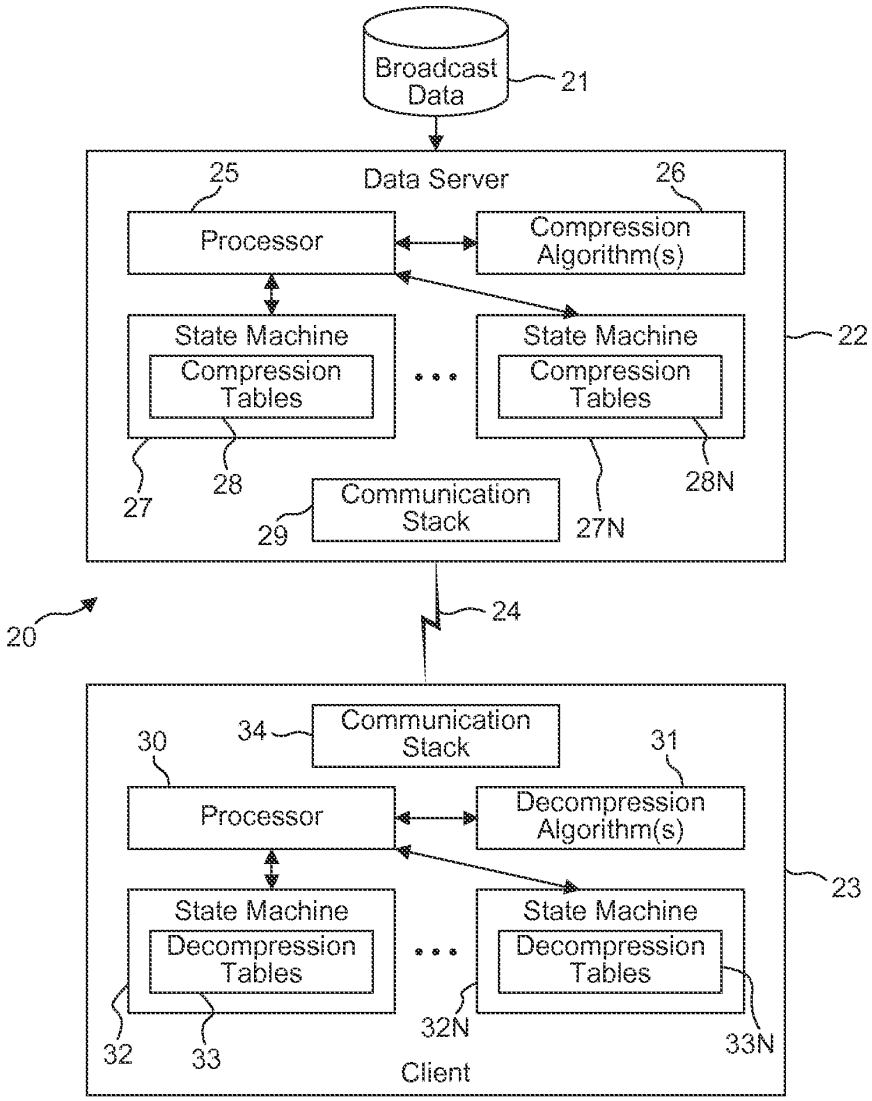

Broadcast Data
21
Data Server
25
26
Processor
Compression Algorithm(s)
State Machine
Compression Tables
State Machine
Compression Tables
22
27
28
28N
Communication Stack
29
27N
20
24
30
34
Communication Stack
31
Processor
Decompression Algorithm(s)
23
State Machine
Decompression Tables
State Machine
Decompression Tables
32
33
32N
33N
Client

FIG. 2

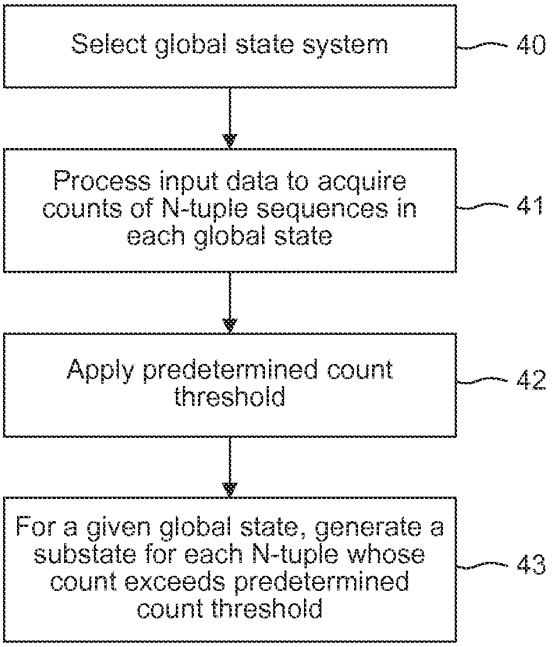

Select global state system
40
Process input data to acquire counts of N-tuple sequences in each global state
41
Apply predetermined count threshold
42
For a given global state, generate a substate for each N-tuple whose count exceeds predetermined count threshold
43

FIG. 3

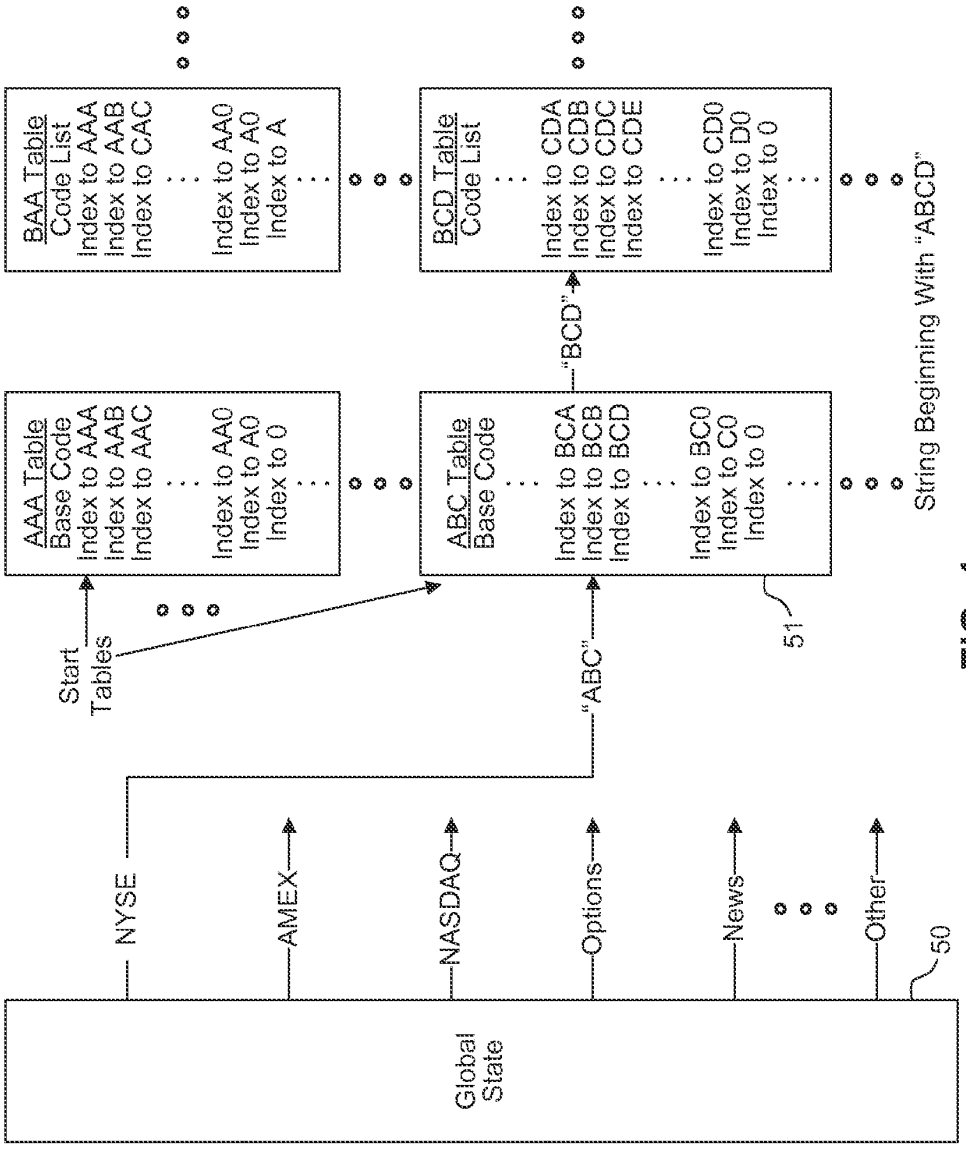

Global State
50
NYSE
AMEX
NASDAQ
Options
News
Other
"ABC"
Start Tables
AAA Table
Base Code
Index to AAA
Index to AAB
Index to AAC
Index to AA0
Index to A0
Index to 0
ABC Table
Base Code
Index to BCA
Index to BCB
Index to BCD
Index to BC0
Index to C0
Index to 0
51
"BCD"
BAA Table
Code List
Index to AAA
Index to AAB
Index to CAC
Index to AA0
Index to A0
Index to A
BCD Table
Code List
Index to CDA
Index to CDB
Index to CDC
Index to CDE
Index to CD0
Index to D0
Index to 0
String Beginning With "ABCD"

FIG. 4

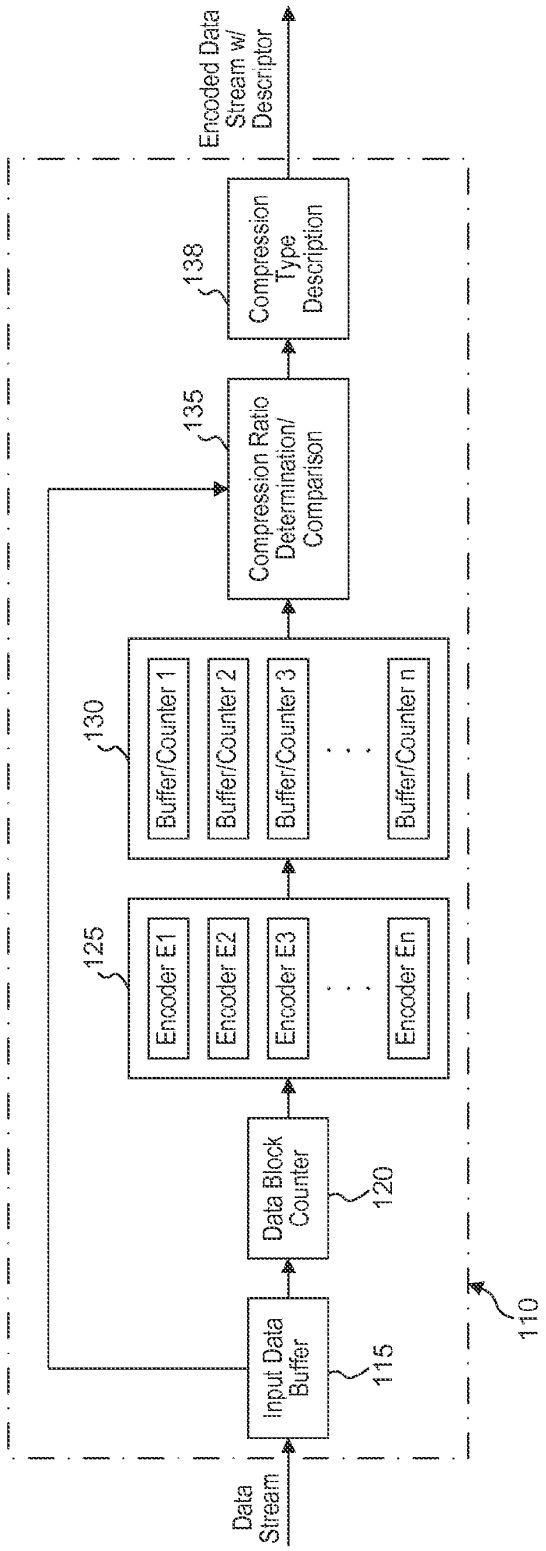

Data Stream
Input Data Buffer
115
Data Block Counter
120
Encoder E1
Encoder E2
Encoder E3
Encoder En
125
Buffer/Counter 1
Buffer/Counter 2
Buffer/Counter 3
Buffer/Counter n
130
Compression Ratio Determination/ Comparison
135
Compression Type Description
138
Encoded Data Stream w/ Descriptor
110

FIG. 5

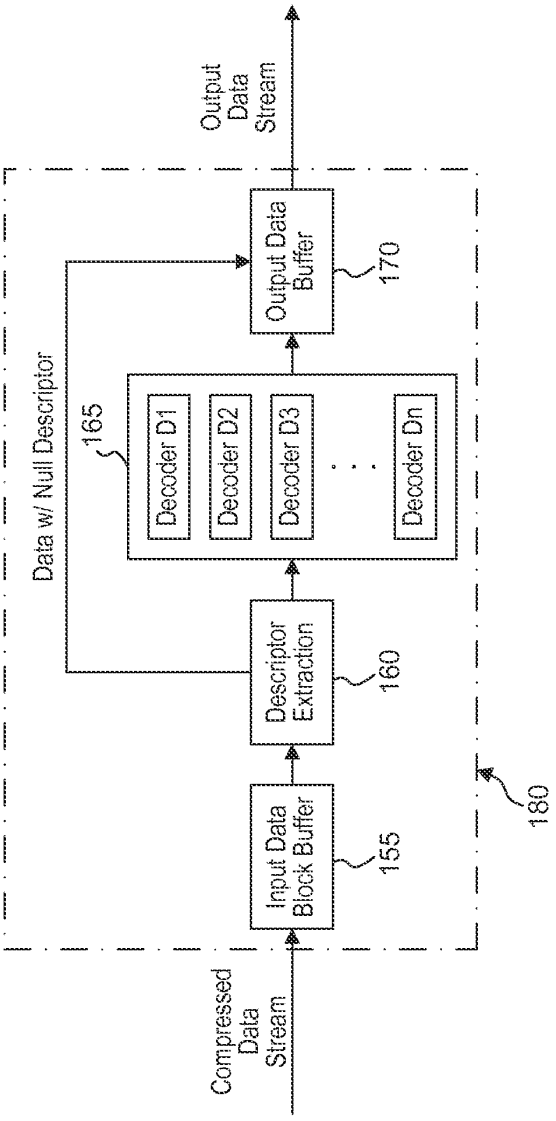

Compressed Data Stream
Input Data Block Buffer
155
Descriptor Extraction
160
Data w/ Null Descriptor
165
Decoder D1
Decoder D2
Decoder D3
Decoder Dn
Output Data Buffer
170
Output Data Stream
180

FIG. 6

DATA FEED ACCELERATION

CROSS REFERENCE TO RELATED APPLICATIONS

This is a continuation of U.S. patent application Ser. No. 13/403,785, filed Feb. 23, 2012, which is a continuation of U.S. patent application Ser. No. 12/857,238, filed Aug. 16, 2010, now U.S. Pat. No. 8,692,695, which is a continuation of U.S. patent application Ser. No. 12/131,631, filed Jun. 2, 2008, now U.S. Pat. No. 7,777,651, which is a continuation of U.S. patent application Ser. No. 10/434,305, filed May 7, 2003, now U.S. Pat. No. 7,417,568, which is a continuation-in-part of U.S. patent application Ser. No. 09/969,987, filed Oct. 3, 2001, which claims the benefit of U.S. Provisional Patent Application No. 60/237,571, filed on Oct. 3, 2000, each of which are fully incorporated herein by reference. In addition, U.S. patent application Ser. No. 10/434,305 claims the benefit of U.S. Provisional Patent Application No. 60/378,517, filed May 7, 2002, which is fully incorporated herein by reference.

TECHNICAL FIELD

The present invention relates generally to systems and method for providing data transmission, and in particular, to systems and method for providing accelerated transmission of data, such as financial trading data, financial services data, financial analytical data, company background data and news feeds, advertisements, and all other forms or information over a communication channel using data compression and decompression to provide data broadcast feeds, bi-directional data transfers, and all other forms of communication with or without security and effectively increase the bandwidth of the communication channel and/or reduce the latency of data transmission.

BACKGROUND

The financial markets and financial information services industry encompass a broad range of financial information ranging from basic stock quotations, bids, order, fulfillment, financial and quotations to analyst reports to detailed pricing of Treasury Bills and Callable bonds. Users of financial information can now generally be divided into three segments—Traders, Information Users and Analytics Users, although some users constitute components from one or more of these categories.

Traders utilize data from financial markets such as NASDAQ, the American Stock Exchange, the New York Stock Exchange, the Tokyo Exchange, the London Exchange, the Chicago Options Board, and similar institutions that offer the ability to buy and sell stocks, options, futures, bonds, derivatives, and other financial instruments. The need for vast quantities of information is vital for making informed decisions and executing optimal transactions

Thus given the importance of receiving this information over computer networks, an improved system and method for providing secure point-to-point solution for transparent multiplication of bandwidth over conventional communication channels is highly desirable.

For example, with the introduction of Nasdaq's next generation trading system SuperMontage, Nasdaq will offer market data users an unparalleled view into the activity, liquidity, and transparency of the Nasdaq market.

For example, currently Nasdaq provides each market participant's best-attributed quotation in each stock in which it makes a market. This system known as SuperMontage allows Nasdaq to accept multiple orders from each market participate in each stock for execution within SuperMontage. Nasdaq offers that data, with multiple levels of interest from individual market participants, through new data services.

Nasdaq provides this data on both an aggregated and a detailed basis for the top five price levels in SuperMontage. This data is currently offered through market data vendors and broker/dealer distributors via the following four entitlement packages:

QuoteView^{SM} Each SuperMontage participant's best bid and offer, as well as the best bid and offer available on SuperMontage.

DepthView^{SM} The aggregate size, by price level, of all Nasdaq market participants' attributed and unattributed quotations/orders that are in the top five price levels in SuperMontage.

PowerView^{SM} Bundled QuoteView and DepthView.

TotalView^{SM} PowerView plus all Nasdaq market participants' attributed quotations/orders that are in the top five price levels in SuperMontage, in addition to the aggregate size of all unattributed quotes/orders at each of the top five price levels.

The NASDAQ SuperMontage trading system has been cited to be representative of trend for explosive growth in the quantity of information for all emergent and future trading and financial information distribution systems. Increases in processing power at the end user sites will allow traders, analysts, and all other interested parties to process substantially larger quantities of data in far shorter periods of time, increasing the demand substantially.

The ever increasing need for liquidity in the financials markets, coupled with the competitive pressures on reducing bid/ask spreads and instantaneous order matching/fulfillment, along the need for synchronized low latency data dissemination makes the need for the present invention ever more important. Depth of market information, required to achieve many of these goals requires orders of magnitude increases in Realtime trade information and bid/ask pricing (Best, 2^{nd} best, . . .).

A fundamental problem within the current art is the high cost of implementing, disseminating, and operating trading systems such as SuperMontage within the financial services industry. This is in large part due to the high bandwidth required to transfer the large quantities of data inherent in the operation of these systems. In addition the processing power required to store, transmit, route, and display the information further compounds cost and complexity.

This fundamental problem is in large part the result of utilizing multiple simultaneous T1 lines to transmit data. The data must be multiplexed into separate data streams, transmitted on separate data lines, and de-multiplexed and checked. Software solutions have high latency and cost while hardware solutions have even higher cost and complexity with somewhat lower latency. In addition the synchronization and data integrity checking require substantial cost, complexity, inherent unreliability, and latency. These and other limitations are solved by the present invention.

Further compounding this issue is a globalization and consolidation taking place amongst the various financial exchanges. The emergence of localized exchanges (ECNS-Electronic Computer Networks) coupled with the goal of 24 hour/7 day global trading will, in and of itself, drive another exponential increase in long haul international bandwidth requirements, while ECNs and other localized trading networks will similarly drive domestic bandwidth require-

ments. Clearly long haul links are orders of magnitude more expensive than domestic links and the value and significance of the present invention is at least proportionately more important.

Information users range from non-finance business professionals to curious stock market investors and tend to seek basic financial information and data. Analytical users on the other hand, tend to be finance professionals who require more arcane financial information and utilize sophisticated analytical tools to manipulate and analyze data (e.g. for writing option contracts).

Historically, proprietary systems, such as Thomson, Bloomberg, Reuters and Bridge Information, have been the primary electronic source for financial information to both the informational and analytical users. These closed systems required dedicated telecommunications lines and often product-specific hardware and software. The most typical installations are land-based networking solutions such as T1, or ISDN, and satellite-based "wireless" solutions at speeds of 384 kbps.

Latency of financial data is critical to the execution of financial transactions. Indeed the more timely receipt of financial data from various sources including the New York Stock Exchange, American Stock Exchange, National Association of Securities Dealers (NASDAQ), Options Exchange, Commodities Exchanges, and Futures presents a fundamental advantage to those who trade. Latency is induced by the long time taken transmit and receive uncompressed data or to compress and encrypt data prior to transmission, along with the associated time to decrypt and decompress. Often current methods of encryption and compression take as much or substantially more time than the actual time to transmit the uncompressed, unencrypted data. Thus another problem within the current art is the latency induced by the act of encryption, compression, decryption, and decompression. The present invention overcomes this limitation within the current art.

Modern data compression algorithms suffer from poor compression, high latency, or both. Within the present art algorithms such as Lempel-Ziv, modified/embellished Lempel-Ziv, Binary Arithmetic, and Huffman coding are essentially generic algorithm having a varied effectiveness on different data types. Also small increases in compression to the negentropy limit of the data generally require exponentially greater periods of time and substantially higher latency. Negentropy is herein defined as the information content within a given piece of data. Generic algorithms are currently utilized as data types and content format is constantly changed within the financial industry. Many changes are gradual however there are also abrupt changes, such as the recent switch to decimalization to reduce granularity that has imposed substantial requirements on data transmission bandwidth infrastructure within the financial industry. Thus another problem within the current art is the high latency and poor compression due to the use of generic data compression algorithms on financial data and news feeds. This limitation is also overcome by the present invention.

Within the financial and news feeds, data is often segregated into packets for transmission. Further, in inquiry-response type systems, as found in many financial research systems, the size of request packets and also response packets is quite small. As such, response servers often wait for long periods of time (for example 500 msec) to aggregate data packets prior to transmission back to the inquirer. By aggregating the data, and then applying compression, somewhat higher compression ratios are often achieved. This then translates to lower data communications costs or more customers served for a given amount of available communications bandwidth. Thus another problem within the current art is the substantial latency caused by aggregating data packets due to poor data compression efficiency and packet overhead. This limitation is also solved by the present invention.

Another problem within the current art is the need for data redundancy. Currently many trading systems utilize two independent links to compare data to verify integrity. Second, the bandwidth of discrete last mile links, typically T1s, is limited to 1.5 Megabits/second.

Increases in bandwidth beyond this point require complex protocols to fuse data from multiple links, adding cost and complexity, while also increasing latency and inherent data error rates. This limitation is also solved by the present invention.

Another limitation within the current art is that nearly all financial institutions use one or more T1 lines to transfer information to and from their customers. While the costs of bandwidth have moderately decreased over recent years this trend is slowing and the need forever increased bandwidth will substantively overshadow any future reductions. Indeed with the recent fall-out of the telecommunications companies the data communications price wars will end and we could easily see an increase in the cost of bandwidth. US Domestic T1 lines currently range from several hundred dollars to upwards of a thousand dollars per link, dependent upon quantity of T1 lines purchased, geographic location, length of connection, and quality/conditioning of line. Fractional T1 lines may also be purchased in 64 Kilobit/second increments with some cost savings.

A standard T1 line transmits data at a rate of 1.544 megabits per second. Accounting for framing and data transmission overhead this means that a T1 line is capable of transmitting a 150 Kilobytes per second. While 30× faster than a modem line (which provides only 5 kilobytes per second), both are relatively slow in relation to any reasonable level of information flow. For example, transferring the contents of data on a single CDROM would take well over an hour!

Thus it is likely that the capacity of many existing T1 lines will be exceeded in the near future. For our current example let's assume that we need to double the capacity of a T1 line. Normally this is done by adding a second T1 line and combining the contents of both with Multi-Link Point to Point Protocol (MLPP) or another relatively complex protocol. Within the current art this is neither necessary nor desirable. In fact any increase over the current limitation of a T1 line results in the addition of a second line. This limitation is overcome by the present invention.

Another limitation with the current art is the extraordinary bandwidth required for real-time (hot) co-location processing which has been dramatically increased as a result of the acts of terror committed against the United States of America on Sep. 11, 2001. In order for the redundancy of any co-location to be effective, it must be resident in a geographically disparate location; this could be a different state, a different coast, or even a different country. The trend towards globalization will further compound the need for the ability to simultaneously process transactions at geographically diverse co-locations.

It is a widely known fact within the financial industry that the overall throughput of transactions is governed by the bandwidth and latency of the co-location data link, along with delays associated with synchronization, i.e. the trans-

action must be complete at both locations and each location must know that the other location is complete before the transaction is finalized.

High bandwidth links such as T3's are often utilized as part of this backbone structure. A single T3 line has the bandwidth of Twenty-Eight T1 lines (28×1.544=43.232 megabits/second). Thus, in the best case, a T3 line is capable of transmitting 5.4 megabytes/second. By way of comparison, the contents of a single CDROM may be transferred in approximately two minutes with a T3 link. As stated earlier, a single T1 line would take over an hour to transmit the same quantity of data.

The volume of real-time data that is required to operate any major financial institution is staggering by comparison. To deal with this issue only critical account and transaction information is currently processed by co-locations in real-time. In fact, many institutions use batch mode processing where the transactions are only repeated "backed up" at the co-locations some time period later, up to 15 minutes or longer. The limitation of highly significant bandwidth and/or long delays with co-location processing and long latency times is solved by the present invention.

Thus given the importance of receiving financial information over computer networks, an improved system and method for providing secure point-to-point solution for transparent multiplication of bandwidth over conventional communication channels is highly desirable.

As previously stated, these and other limitations within the current art are solved by the present invention.

SUMMARY OF THE INVENTION

The present invention is directed to systems and methods for providing accelerated data transmission, and in particular to systems and methods of providing accelerated transmission of data, such as financial trading data, financial services data, financial analytical data, company background data, news, advertisements, and all other forms of information over a communications channel utilizing data compression and decompression to provide data transfer (secure or non-secure) and effectively increase the bandwidth of the communication channel and/or reduce the latency of data transmission. The present invention is universally applicable to all forms of data communication including broadcast type systems and bi-directional systems of any manner and any number of users or sites.

These and other aspects, features and advantages, of the present invention will become apparent from the following detailed description of preferred embodiments that is to be read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. **1** is a block diagram of a system in which the present invention may be implemented for transmitting broadcast data;

FIG. **2** is a block diagram of a system and method for providing accelerated transmission of data over a communication channel according to an embodiment of the present invention;

FIG. **3** is a flow diagram illustrating a method for generating compression/decompression state machines according to one aspect of the present invention;

FIG. **4** is a diagram illustrating an exemplary encoding table structure according to the present invention, which may be generated using the process of FIG. **3**.

FIG. **5** is a diagram of a system/method for providing content independent data compression, which may be implemented for providing accelerated data transmission according to the present invention; and

FIG. **6** is a diagram of a system/method for providing content independent data decompression, which may be implemented for providing accelerated data transmission according to the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention is directed to systems and methods for providing accelerated transmission of broadcast data, such as financial data and news feeds, over a communication channel using data compression and decompression to provide secure transmission and transparent multiplication of communication bandwidth, as well as reduce the latency associated with data transmission of conventional systems.

In this disclosure, the following patents and patent applications, all of which are commonly owned, are fully incorporated herein by reference: U.S. Pat. No. 6,195,024, issued on Feb. 27, 2001, and U.S. Pat. No. 6,309,424, issued on Oct. 30, 2001 and U.S. patent application Ser. No. 10/076,013 filed on Feb. 13, 2002, Ser. No. 10/016,355, filed on Oct. 29, 2001, Ser. No. 09/481,243 filed on Jan. 11, 2000, and Ser. No. 09/266,394 filed on Mar. 11, 1999.

In general, the term "accelerated" data transmission refers to a process of receiving a data stream for transmission over a communication channel, compressing the broadcast data stream in real-time (wherein the term "real time" as used herein collectively refers to substantially real time, or at real time, or greater than real time) at a compression rate that increases the effective bandwidth of the communication channel, and transmitting the compressed broadcast data over the communication channel. The effective increase in bandwidth and reduction of latency of the communication channel is achieved by virtue of the fast than real-time, real-time, near real time, compression of a received data stream prior to transmission.

For instance, assume that the communication channel has a bandwidth of "B" megabytes per second. If a data transmission controller is capable of compressing (in substantially real time, real time, or faster than real time) an input data stream with an average compression rate of 3:1, then data can be transmitted over the communication channel at an effective rate of up to 3*B megabytes per second, thereby effectively increasing the bandwidth of the communication channel by a factor of three.

Further, when the receiver is capable decompressing (in substantially real time, real time, or faster than real time) the compressed data stream at a rate approximately equal to the compression rate, the point-to-point transmission rate between the transmitter and receiver is transparently increased. Advantageously, accelerated data transmission can mitigate the traditional bottleneck associated with, e.g., local and network data transmission.

If the compression and decompression are accomplished in real-time or faster, the compressed, transmitted and decompressed data is available before the receipt of an equivalent uncompressed stream. The "acceleration" of data transmission over the communication channel is achieved when the total time for compression, transmission, and decompression, is less than the total time for transmitting the data in uncompressed form. The fundamental operating principle of data acceleration is governed by the following relationship:

$$[T_{Compress}+T_{Transmit\ Accelerated}+T_{Decompress}]< T_{Transmit\ w/o\ Compression} \quad \text{EQ [1]}$$

Where:

$T_{Compress}$=Time to Compress a Packet of Data

$T_{Transmit\ Accelerated}$=Time to Transmit Compressed Data Packet

$T_{Decompress}$=Time to Decompress the Compresse Data Packet

$T_{Transmit\ w/o\ Compression}$=Time to Transmit the Uncompressed (Original) Data Packet

As stated in Equation [1] above, if the time to compress, transmit, and decompress a data packet is less than the time to transmit the data in original format, then the delivery of the data is said to be accelerated.

In the above relationship, a fundamental premise is that all information is preferably fully preserved. As such, lossless data compression is preferably applied. While this disclosure is directed to transmission of data in financial networks, for example, the concept of "acceleration" may be applied to the storage and retrieval of data to any memory or storage device using the compression methods disclosed in the above-incorporated U.S. Pat. Nos. 6,195,024 and 6,309,424, and U.S. application Ser. No. 10/016,355, and the storage acceleration techniques disclosed in the above-incorporated application Ser. Nos. 09/481,243 and 09/266,394.

Returning to Equation [1], data acceleration depends on several factors including the creation of compression and decompression algorithms that are both effective (achieve good compression ratios) and efficient (operate rapidly with a minimum of computing processor and memory resources).

Rearranging the terms of Equation [1] we can see that the total time to transmit data in an "accelerated" form (transmit compressed data) is the sum of the original time to transmit the data in an uncompressed fashion divided by the actual compression ratio achieved, plus the time to compress and decompress the data.

$$T_{Transmit\ Accelerated}=[T_{Transmit\ w/o\ Compression}/CR]+T_{Compress}+T_{Decompress} \quad \text{EQ [2]}$$

Where:

CR=Compression Ratio

Thus the latency reduction is the simple arithmetic difference between the time to transmit the original data minus the total time to transmit the accelerated data (per Equation 2 above), resulting in:

$$T_{Latency\ Reduction}=T_{Transmit\ w/o\ Compression}-T_{Transmit\ Accelerated} \quad \text{EQ [3]}$$

And finally the achieved "Acceleration Ratio" is defined as:

$$\text{Acceleration Ratio}=T_{Transmit\ w/o\ Compression}/T_{Transmit\ Accelerated} \quad \text{EQ [4]}$$

A number of interesting observations come to light from these relatively simple algebraic relationships and are implemented within the present invention:

Compression Ratio: The present inventions achieve a consistent reduction in latency. The data compression ratio is substantial and repeatable on each data packet.

Compression Rate: The present invention achieves a consistent reduction in latency. Both the time to compress and decompress the data packet must be an absolute minimum, repeatable on each data packet, and always within predefined allowable bounds.

Packet Independence: The present invention has no packet-to-packet data dependency. By way of example, in UDP and Multicast operations there are no guarantees on delivery of data packets, nor on the order of delivered data packets. IP data packets, similarly, have no guarantee on the order of delivery also. Thus algorithms that rely on dictionaries (Zlib, Glib, Lempel Ziv, etc.) are inherently unreliable in any financial real-world financial data applications.

It is to be understood that the present invention may be implemented in various forms of hardware, software, firmware, or a combination thereof. Preferably, the present invention is implemented on a computer platform including hardware such as one or more central processing units (CPU) or digital signal processors (DSP), a random access memory (RAM), and input/output (I/O) interface(s). The computer platform may also include an operating system, microinstruction code, and dedicated processing hardware utilizing combinatorial logic or finite state machines. The various processes and functions described herein may be either part of the hardware, microinstruction code or application programs that are executed via the operating system, or any combination thereof.

It is to be further understood that, because some of the constituent system components described herein are preferably implemented as software modules, the actual system connections shown in the Figures may differ depending upon the manner in that the systems are programmed. General purpose computers, servers, workstations, personal digital assistants, special purpose microprocessors, dedicated hardware, or and combination thereof may be employed to implement the present invention. Given the teachings herein, one of ordinary skill in the related art will be able to contemplate these and similar implementations or configurations of the present invention.

It should be noted that the techniques, methods, and algorithms and teachings of the present invention are representative and the present invention may be applied to any financial network, trading system, data feed or other information system.

FIG. **1** is a diagram illustrating a system in which the present invention may be implemented. The system **10** comprises content **11** and data server **12** associated with a service provider of broadcast data. The content **11** comprises information that is processed by the data server **12** to generate a broadcast, e.g., a news feed or financial data feed. As explained in further detail below, the data server **12** employs data compression to encode/encrypt the broadcast data **11** prior to transmission over various communication channels to one or more client site systems **20** of subscribing users, which comprise the necessary software and hardware to decode/decrypt the compressed broadcast data in real-time. In the exemplary embodiment of FIG. **1**, the communication channels comprise a landline **13** that feeds the compressed broadcast data to a satellite system comprising modem **14** and an uplink system **15**, which provides a data uplink **16** to a relay **17**. The relay **17** provides data downlinks **18** to one or more downlink systems **19**.

Advantageously, the proprietary software used by the data server **12** to compress the data stream in real-time and software used by the workstations **19** to decompress the data stream in real-time effectively provides a seamless and transparent increase in the transmission bandwidth of the various communication channels used, without requiring modification of existing network infrastructure.

Referring now to FIG. **2**, a block diagram illustrates a system/method for providing accelerated transmission of data according to one embodiment of the present invention. More specifically, FIG. **2** illustrates embodiments of a broadcast data server (transmitter) and client system (receiver) for implementing accelerated transmission and real-time processing of broadcast data. Broadcast data **21** (comprising one or more different broadcast types) is processed

by data server **22** prior to transmission to client **23** over a communication channel **24**. The data server **22** utilizes a processor **25** (e.g., microprocessor, digital signal processor, etc.) for executing one or more compression algorithms **26** for compressing (in real-time) the broadcast data **21** prior to transmission. In preferred embodiments, compression is achieved using Huffman or Arithmetic encoding, wherein one or more state machines **27-27***n* are constructed based on a-priori knowledge of the structure and content of one or more given broadcast and data feeds.

As explained in further detail below, each state machine **27-27***n* comprises a set of compression tables that comprise information for encoding the next character (text, integer, etc.) or sequence of characters in the broadcast data feed, as well as pointers which point to the next state (encoding table) based on the character or character sequence. As explained in greater detail below, a skeleton for each state machine **27-27***n* (nodes and pointers) is preferably built by finding sequences of characters (n-tuples) that frequently appear in a given data input. Once a skeleton has been determined, a large set of data is processed through the system and counts are kept of character n-tuples for each state. These counts are then used to construct the compression tables associated with the state machine to provide statistical compression. The compressed data is transmitted over the communication channel **24** via a communication stack using any suitable protocol (e.g., RTP (real time protocol) using RTCP (real-time control protocol), TCP/IP, UDP, or any real-time streaming protocol with suitable control mechanism).

Similarly, the client **23** comprises a processor **30** for executing one or more decompression algorithms **31**. Depending one the data feed type, one of a plurality of decompression state machines **32-32***n* are used to decompress the compressed data stream received by the client **23** via communication stack **34**. Each state machine **32-32***n* comprises a set of decompression tables **33-33***n* that comprise information for decode the next encoded character (or symbol) or sequence of symbols in the compressed broadcast data feed, as well as pointers which point to the next state based on the symbol or symbol sequence. For each compression state machine **27-27***n* in the data server, a corresponding decompression state machine **32-32***n* is needed in the client **23** to decompress the associated data stream.

Advantageously, a compression/decompression scheme according to the present invention using Huffman or Arithmetic encoding provides secure transmission via de facto or virtual "encryption" in a real-time environment. Indeed, virtual encryption is achieved by virtue of the fast, yet complex, data compression using Huffman tree, for example, without necessarily requiring actual encryption of the compressed data and decryption of the compressed data. Because of the time-sensitive nature of the market data, and the ever-changing and data-dependent nature of the arithmetic scheme, decryption is virtually impractical, or so complex and useless as to render the data worthless upon eventual decoding.

However, data compression using Huffman or Arithmetic encoding yields encoded data that is very difficult to decode than current encryption schemes such as plain text or simple bit shuffling codes as currently used by broadcast service providers. An attacker must have the compression model and the tables used to compress the data stream to be able to obtain useful information from it. Thus, at one level of security, the client-side decompression tables are preferably stored in encrypted form and are decrypted on being loaded into the processor **30** (e.g., general purpose processor, DSP, etc.) using an encryption/decryption key that is validated for a subscribing user. In this manner, a client will be unable to use the tables on other processors or sites or after terminating a service contract.

Since Huffman compression uses the same bit code for a character each time it appears in a given context, an attacker with a very large data set of compressed and uncompressed data could possibly reconstruct the tables, assuming the overall model were known. Arithmetic compression, on the other hand, generates different bit patterns for the same character in the same context depending on surrounding characters. Arithmetic encoding provides at least an order of magnitude more difficult to recover the tables from the compressed and uncompressed data streams.

The following is a detailed discussion of a compression scheme using Huffman or Arithmetic encoding for providing accelerated transmission of broadcast data according to one aspect of the present invention. It is to be appreciated that the present invention is applicable with any data stream whose statistical regularity may be captured and represented in a state machine model. For example, the present invention applies to packetized data streams, in which the packets are limited in type format and content.

In one embodiment using Huffman or Arithmetic encoding, each character or character sequence is encoded (converted to a binary code) based on the frequency of character or character sequence in a given "context". For a given context, frequently appearing characters are encoded with few bits while infrequently appearing characters are encoded with more bits. High compression ratios are obtained if the frequency distribution of characters in most contexts is highly skewed with few frequently appearing characters and many characters seldomly (or never) appear.

Referring now to FIG. **3**, a flow diagram illustrates a method for generating compression/decompression state machines according to one aspect of the present invention. The "context" in which a character (or character sequence) is encoded in a given broadcast stream is based on a "global state" that represents packet type and large-scale structure and the previous few characters. The first step in building a compression scheme involves selecting a global state system based on the packet structure of the broadcast model (step **40**). More specifically, a global state system is constructed based on a priori knowledge of the data stream model, e.g., the packet type frequency and structure of the broadcast model. By way of example, one model for financial data may comprise four global states representing: a beginning of packet, an options packet, a NYSE (New York Stock Exchange) packet and some other packet type. Further, additional codes may be added to the encoding tables to indicate global state transitions (e.g., for an end of packet code in the broadcast model). If there is internal structure to packets, such as a header with different statistics than the body, additional global states could be added.

Once a global state system is selected, training samples from an associated data stream are passed through the global model to acquire counts of frequencies of the occurrence of n-tuple character sequences ending in each of the model states (step **41**). In a preferred embodiment, the n-tuples comprise character sequences having 1, 2 and 3 characters. Using the acquired counts, sub-states (or "local states") of the predefined global states are constructed based on previous characters in the data stream. A local state may depend on either none, 1, 2, or 3 (or more) previous characters in the stream. To provide a practical limitation, a predetermined count threshold is preferably applied to the count data (step

42) and only those sequences that occur more often than the count threshold are added as local states (step **43**). For example, if a three-character sequence does not occur sufficiently frequently, the count for the last two characters is tested, etc.

It is to be understood that any character sequence length "n" may be implemented depending on the application. The longer the allowed character sequence, the more memory is needed to store the encoding tables and/or the lower the count threshold should be set.

As samples of the data are passed through the state model, character (and transition code) counts for each context are accumulated. These counts are used to build the Huffman or Arithmetic coding tables. The construction of the global and local models is an iterative process. The count threshold for forming local states can be adjusted depending on the application. For instance, a larger threshold will result in less local states but less compression as well. Further, a comparison of statistics in local or global states may suggest adding or deleting global states.

The construction of the global model requires knowledge of the data stream packet structure. The construction of the local states is automatic (once the threshold is set).

FIG. **4** is a diagram of an exemplary state diagram (or encoding table structure) according to the present invention, which may be generated using the process of FIG. **3**.

As noted above with reference to FIGS. **1** and **2**, a compression scheme according to the present invention may be implemented in any system to provide accelerated data transmission to multiple client site systems. Preferably, the client site systems may connect at any time, so minimal immediate history may be used (since a newly connected site must be able to pick up quickly). A system according to an embodiment of the present invention uses statistical compression (Huffman or Arithmetic coding) using fixed (or adaptive) tables based on the statistics of a data feed sample. As noted above, it has been determined that the statistical compression schemes described herein are well adapted for use with structured data streams having repetitive data content (e.g., stock symbols and quotes, etc.) to provide fast and efficient data compression/decompression.

The following discussion provides further details regarding the preparation of statistical-based encoding tables and their use for compression/decompression according to the present invention. During a data compression process, the selection of which encoding table to use for compression is preferably based on up to n (where n is preferably equal to 3) preceding characters of the message. In an exemplary broadcast model tested by the present inventors, a data stream comprises messages that begin with an ID code in the range 0-31 with the remainder of the message being characters in the range 32-127. It was found that approximately half of the messages in a given sample began with ID code 0x0c and half of the remainder began with ID code 0x0f. Thus, a separate encoding table is preferably used for a message ID code. Further, separate table sets are used for messages beginning with 0x0c and with 0x0f, with the remaining messages lumped together in another table.

Each table has an additional termination code. The termination code in a "start table" indicates the end of a compression block. The termination code in all other tables indicates the end of the message. Thus, the start table comprises 33 entries and all other tables have 97 entries.

Using one table for each 3-character context would require prohibitive amounts of memory. For example, a complete one-character context would require 33+3*97=324 tables. Then, a complete two-character context would require 324*97=31,428 tables. And finally, a complete three-character context would require 324*97*97=3,048,516 tables. Preferably, as described above, the application of a count threshold at each context size reduces the amount of tables. Only when a context occurs at greater than the threshold rate in the sample will a table be created for that context.

Each table entry includes a link to the next table to be used. For instance, in an "abc" context table, the entry for next character "d" would point to the "bed" table, if such table was created. If such table was not created, the entry for next character "d" would point to the "cd" table, if such table existed. If no "cd" table exists, the "d" table would be used and if that fails, a base table for the message type would be used.

For a client site system to pick up the broadcast feed at any time, clearly identifiable synchronization points are preferably included in the compressed data stream. In a preferred embodiment, data is compressed in blocks with each block comprising some number of complete messages. Preferably, each compressed block ends with at least four bytes with each bit being logic 1 and no interior point in the compressed block will comprise 32 consecutive 1 bits. The compressed block preferably begins with two bytes giving the decompressed size of the block shifted to guarantee that the first byte of the compressed block is not all 1's. Thus, to achieve synchronization, the client site system can scan the input compressed data stream for 4 bytes of 0xff, wherein the next byte not equal to 0xff is deemed the start of a compressed block. In other words, the receiver will accumulate the compressed data until at least a sequence of 4 bytes each having a value of 0xff is detected in the input stream, at which point decompression will commence on the compressed input stream.

In another embodiment of the present invention, if a compressed block is more than 6 bytes longer than the uncompressed data, the data block is transmitted uncompressed preceded by the shifted two-byte count with the high bit set and trailed by 4 bytes of 0xff.

The following is discussion of a method for preparing Huffman Tables according to one aspect of the present invention. The Huffman codes generated by a conventional optimal algorithm have been modified in various ways in accordance with the present invention. First, in order that there not be 32 consecutive one bits in the data stream except at the end of a compression block, a termination code in each table comprises all 1 bits.

Further, to reduce space required for decompression tables, and ensure no sequence of 32 1 bits, each code is preferably decoded as follows:

a) The first 7 bits are used to index into a table. If the character code is no more than 7 bits, it can be read directly;

b) otherwise, some number N of initial bits is discarded and the next 7 bits are used to index a second table to find the character.

Based on these steps, preferably, no character code can use more than 14 bits and all codes of more than 7 bits must fit into the code space of the N initial bits. If N is 3, for instance, then no code can use more than 10 bits.

To achieve this, the code space required for all optimal codes of more than 7 bits is first determined, following by a determining the initial offset N. Every code comprising more than N+7 bits is preferably shortened, and other codes are lengthened to balance the code tree. It is possible that this may cause the code space for codes over 7 bits to increase

so that N may need to be decreased. Preferably, this process is performed in a manner that causes minimal reduction in the efficiency of the codes.

The above modifications to convention optimal algorithm yields codes in which no non-termination code ends in more than 7 1 bits, no non-termination code begins with more than 6 1 bits, no termination code is more than 14 1 bits and no non-termination packet start code begins with more than 5 1 bits. Thus, in the middle of a packet, a sequence of no more than 13 bits of logic 1 can occur, while, at the end of a packet, a sequence of no more than 26 bits of logic 1 can occur.

In another embodiment of the present invention, Arithmetic compression can be used instead of Huffman encoding. The tables for Arithmetic encoding are preferably constructed such that a sequence of 32 bits of logic 1 will not occur in the interior of a message (which is important for a random sign-on in the middle of the stream).

Arithmetic compression provides an advantage of about 6% better compression than Huffman and uses half as much memory for tables, which allows the number of tables to be increased). Indeed, the addition of more tables and/or another level of tables yields more efficient compression. Although Arithmetic compression may take about 6 times as long as Huffman, this can certainly be improved by flattening the subroutine call tree (wherein there is a subroutine call for each output bit.)

In summary, a compression scheme according to one aspect of the invention utilizes a state machine, wherein in each state, there is a compression/decompression table comprising information on how to encode/decode the next character, as well as pointers that indicated which state to go to based on that character. A skeleton of the state machine (nodes and pointers) is preferably built by finding sequences of characters that appear often in the input. Once the skeleton has been determined, a large set of data is run through the system and counts are kept of characters seen in each state. These counts are then used to construct the encode/decode tables for the statistical compression.

Other approaches may be used to build the skeleton of the state machine. A very large fraction of the traffic on a certain feed consists of messages in the digital data feed format, which is fairly constrained. It may be possible to build by hand a skeleton that takes into account this format. For instance, capital letters only appear in the symbol name at the beginning. This long-range context information can be represented with our current approach. Once a basic skeleton is in place, the structure could be extended for sequences that occur frequently.

The above-described statistical compression schemes provide content-dependent compression and decompression. In other words, for a given data stream, the above schemes are preferably structured based on the data model associated with the given stream. It is to be appreciated, however, that other compression schemes may be employed for providing accelerated data transmission in accordance with the present invention for providing effectively increased communication bandwidth and/or reduction in latency. For instance, in another embodiment of the present invention, the data compression/decompression techniques disclosed in the above-incorporated U.S. Pat. No. 6,195,024, entitled "Content Independent Data Compression Method and System" may be used in addition to, or in lieu of, the statistical based compression schemes described above.

In general, a content-independent data compression system is a data compression system that provides an optimal compression ratio for an encoded stream regardless of the data content of the input data stream. A content-independent data compression method generally comprises the steps of compressing an input data stream, which comprises a plurality of disparate data types, using a plurality of different encoders. In other words, each encoder compresses the input data stream and outputs blocks of compressed data. An encoded data stream is then generated by selectively combining compressed data blocks output from the encoders based on compression ratios obtained by the encoders. Because a multitude of different data types may be present within a given input data stream, or data block, to it is often difficult and/or impractical to predict the level of compression that will be achieved by any one encoding technique. Indeed, rather than having to first identify the different data types (e.g., ASCII, image data, multimedia data, signed and unsigned integers, pointers, etc.) comprising an input data stream and selecting a data encoding technique that yields the highest compression ratio for each of the identified data types, content-independent data compression advantageously applies the input data stream to each of a plurality of different encoders to, in effect, generate a plurality of encoded data streams. The plurality of encoders are preferably selected based on their ability to effectively encode different types of input data. Ultimately, the final compressed data stream is generated by selectively combining blocks of the compressed streams output from the plurality of encoders. Thus, the resulting compressed output stream will achieve the greatest possible compression, regardless of the data content.

In accordance with another embodiment of the present invention, a compression system may employ both a content-dependent scheme and a content-independent scheme, such as disclosed in the above-incorporated application Ser. No. 10/016,355. In this embodiment, the content-dependent scheme is used as the primary compression/decompression system and the content-independent scheme is used in place of, or in conjunction with, the content dependent scheme, when periodically checked "compression factor" meets a predetermined threshold. For instance, the compression factor may comprise a compression ratio, wherein the compression scheme will be modified when the compression ratio falls below a certain threshold. Further, the "compression factor" may comprise the latency of data transmission, wherein the data compression scheme with be modified when the latency of data transmission exceeds a predetermined threshold.

Indeed, as explained above, the efficiency of the content-dependent compression/decompression schemes described herein is achieved, e.g., by virtue of the fact that the encoding tables are based on, and specifically designed for, the known data model. However, in situations where the data model is may be modified, the efficiency of the content-dependent scheme may be adversely affected, thereby possibly resulting in a reduction in compression efficiency and/or an increase in the overall latency of data transmission. In such a situation, as a backup system, the data compression controller can switch to a content-independent scheme that provides improved compression efficiency and reduction in latency as compared to the primary content-dependent scheme.

In yet another embodiment of the present invention, when the efficiency of a content-dependent scheme falls below a predetermined threshold based on, e.g., a change in the data structure of the data stream, the present invention preferably comprises an automatic mechanism to adaptively modify the encoding tables to generate optimal encoding tables (using the process described above with reference to FIG. **3**).

FIG. **5** is a detailed block diagram illustrates an exemplary content-independent data compression system **110** that may be employed herein. Details of this data compression system are provided in U.S. Pat. No. 6,195,024, which is fully incorporated herein by reference. In this embodiment, the data compression system **110** accepts data blocks from an input data stream and stores the input data block in an input buffer or cache **115**. It is to be understood that the system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable. A counter **120** counts or otherwise enumerates the size of input data block in any convenient units including bits, bytes, words, and double words. It should be noted that the input buffer **115** and counter **120** are not required elements of the present invention. The input data buffer **115** may be provided for buffering the input data stream in order to output an uncompressed data stream in the event that, as discussed in further detail below, every encoder fails to achieve a level of compression that exceeds an a priori specified minimum compression ratio threshold.

Data compression is performed by an encoder module **125** that may comprise a set of encoders E**1**, E**2**, E**3** . . . En. The encoder set E**1**, E**2**, E**3** . . . En may include any number "n" (where n may=1) of those lossless encoding techniques currently well known within the art such as run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. It is to be understood that the encoding techniques are selected based upon their ability to effectively encode different types of input data. It is to be appreciated that a full complement of encoders are preferably selected to provide a broad coverage of existing and future data types.

The encoder module **125** successively receives as input each of the buffered input data blocks (or unbuffered input data blocks from the counter module **120**). Data compression is performed by the encoder module **125** wherein each of the encoders E**1** . . . En processes a given input data block and outputs a corresponding set of encoded data blocks. It is to be appreciated that the system affords a user the option to enable/disable any one or more of the encoders E**1** . . . En prior to operation. As is understood by those skilled in the art, such feature allows the user to tailor the operation of the data compression system for specific applications. It is to be further appreciated that the encoding process may be performed either in parallel or sequentially. In particular, the encoders E**1** through En of encoder module **125** may operate in parallel (i.e., simultaneously processing a given input data block by utilizing task multiplexing on a single central processor, via dedicated hardware, by executing on a plurality of processor or dedicated hardware systems, or any combination thereof). In addition, encoders E**1** through En may operate sequentially on a given unbuffered or buffered input data block. This process is intended to eliminate the complexity and additional processing overhead associated with multiplexing concurrent encoding techniques on a single central processor and/or dedicated hardware, set of central processors and/or dedicated hardware, or any achievable combination. It is to be further appreciated that encoders of the identical type may be applied in parallel to enhance encoding speed. For instance, encoder E**1** may comprise two parallel Huffman encoders for parallel processing of an input data block.

A buffer/counter module **130** is operatively connected to the encoder module **125** for buffering and counting the size of each of the encoded data blocks output from encoder module **125**. Specifically, the buffer/counter **130** comprises a plurality of buffer/counters BC**1**, BC**2**, BC**3** . . . BCn, each operatively associated with a corresponding one of the encoders E**1** . . . En. A compression ratio module **135**, operatively connected to the output buffer/counter **130**, determines the compression ratio obtained for each of the enabled encoders E**1** . . . En by taking the ratio of the size of the input data block to the size of the output data block stored in the corresponding buffer/counters BC**1** . . . BCn. In addition, the compression ratio module **135** compares each compression ratio with an a priori-specified compression ratio threshold limit to determine if at least one of the encoded data blocks output from the enabled encoders E**1** . . . En achieves a compression that exceeds an a priori-specified threshold. As is understood by those skilled in the art, the threshold limit may be specified as any value inclusive of data expansion, no data compression or expansion, or any arbitrarily desired compression limit. A description module **138**, operatively coupled to the compression ratio module **135**, appends a corresponding compression type descriptor to each encoded data block which is selected for output so as to indicate the type of compression format of the encoded data block. A data compression type descriptor is defined as any recognizable data token or descriptor that indicates which data encoding technique has been applied to the data. It is to be understood that, since encoders of the identical type may be applied in parallel to enhance encoding speed (as discussed above), the data compression type descriptor identifies the corresponding encoding technique applied to the encoded data block, not necessarily the specific encoder. The encoded data block having the greatest compression ratio along with its corresponding data compression type descriptor is then output for subsequent data processing or transmittal. If there are no encoded data blocks having a compression ratio that exceeds the compression ratio threshold limit, then the original unencoded input data block is selected for output and a null data compression type descriptor is appended thereto. A null data compression type descriptor is defined as any recognizable data token or descriptor that indicates no data encoding has been applied to the input data block. Accordingly, the unencoded input data block with its corresponding null data compression type descriptor is then output for subsequent data processing or transmittal.

Again, it is to be understood that the embodiment of the data compression engine of FIG. **5** is exemplary of a preferred compression system which may be implemented in the present invention, and that other compression systems and methods known to those skilled in the art may be employed for providing accelerated data transmission in accordance with the teachings herein. Indeed, in another embodiment of the compression system disclosed in the above-incorporated U.S. Pat. No. 6,195,024, a timer is included to measure the time elapsed during the encoding process against an a priori-specified time limit. When the time limit expires, only the data output from those encoders (in the encoder module **125**) that have completed the present encoding cycle are compared to determine the encoded data with the highest compression ratio. The time limit ensures that the real-time or pseudo real-time nature of the data encoding is preserved. In addition, the results from each encoder in the encoder module **125** may be buffered to allow additional encoders to be sequentially applied to the output of the previous encoder, yielding a more optimal lossless data compression ratio. Such techniques are discussed in greater detail in the above-incorporated U.S. Pat. No. 6,195,024.

Referring now to FIG. **6**, a detailed block diagram illustrates an exemplary decompression system that may be employed herein or accelerated data transmission as disclosed in the above-incorporated U.S. Pat. No. 6,195,024. In this embodiment, the data compression engine **180** accepts compressed data blocks received over a communication channel. The decompression system processes the input data stream in data blocks that may range in size from individual bits through complete files or collections of multiple files. Additionally, the input data block size may be fixed or variable.

The data decompression engine **180** comprises an input buffer **155** that receives as input an uncompressed or compressed data stream comprising one or more data blocks. The data blocks may range in size from individual bits through complete files or collections of multiple files. Additionally, the data block size may be fixed or variable. The input data buffer **55** is preferably included (not required) to provide storage of input data for various hardware implementations. A descriptor extraction module **160** receives the buffered (or unbuffered) input data block and then parses, lexically, syntactically, or otherwise analyzes the input data block using methods known by those skilled in the art to extract the data compression type descriptor associated with the data block. The data compression type descriptor may possess values corresponding to null (no encoding applied), a single applied encoding technique, or multiple encoding techniques applied in a specific or random order (in accordance with the data compression system embodiments and methods discussed above).

A decoder module **165** includes one or more decoders D**1** . . . Dn for decoding the input data block using a decoder, set of decoders, or a sequential set of decoders corresponding to the extracted compression type descriptor. The decoders D**1** . . . Dn may include those lossless encoding techniques currently well known within the art, including: run length, Huffman, Lempel-Ziv Dictionary Compression, arithmetic coding, data compaction, and data null suppression. Decoding techniques are selected based upon their ability to effectively decode the various different types of encoded input data generated by the data compression systems described above or originating from any other desired source.

As with the data compression systems discussed in the above-incorporated U.S. Pat. No. 6,195,024, the decoder module **165** may include multiple decoders of the same type applied in parallel so as to reduce the data decoding time. An output data buffer or cache **170** may be included for buffering the decoded data block output from the decoder module **165**. The output buffer **70** then provides data to the output data stream. It is to be appreciated by those skilled in the art that the data compression system **180** may also include an input data counter and output data counter operatively coupled to the input and output, respectively, of the decoder module **165**. In this manner, the compressed and corresponding decompressed data block may be counted to ensure that sufficient decompression is obtained for the input data block.

Again, it is to be understood that the embodiment of the data decompression system **180** of FIG. **6** is exemplary of a preferred decompression system and method which may be implemented in the present invention, and that other data decompression systems and methods known to those skilled in the art may be employed for providing accelerated data transmission in accordance with the teachings herein.

It is to be appreciated that a data transmission acceleration system according to the present invention offers a business model by which market data vendors and users in the financial information services industry can receive various benefits. For example, the present invention affords transparent multiplication of bandwidth with minimal latency. Experiments have shown that increased bandwidth of up to 3 times can be achieved with minimal latency. Furthermore, proprietary hardware, including chip and board designs, as well as custom embedded and application software and algorithms associated with accelerated data transmission provide a cost-effective solution that can be seamlessly integrated with existing products and infrastructure. Moreover, the data acceleration through "real-time" compression and decompression affords a dramatic reduction in ongoing bandwidth costs. Further, the present invention provides mechanism to differentiate data feeds from other vendors via enriched content or quantity of the data feed.

In addition, a data compression scheme according to the present invention provides dramatically more secure and encrypted feed from current levels, thus, providing the ability to employ a secure and accelerated virtual private network over the Internet for authorized subscribers or clients with proprietary hardware and software installed.

Moreover, the present invention offers the ability to reduce a client's ongoing monthly bandwidth costs as an incentive to subscribe to a vendor's data feed service.

The present invention is readily extendable for use on a global computer network such as the Internet. This is significant since it creates a virtual private network and is important for the market data vendors and others due to its reduced cost in closed network/bandwidth solutions. In effect, the data vendors get to "ride for free" over the world's infrastructure, while still providing the same (and enhanced) services to their customers.

In yet another embodiment of the present invention a highly optimized data compression and decompression system is utilized to accelerate data transfers for data transmission feeds. This type of compression achieves very high compression ratios (over 10:1) on financial data feeds such as Nasdaq Quote Dissemination Service Data (NQDS) and SuperMontage Services. The information utilized to develop the methods described herein for Nasdaq has been garnered solely from public knowledge through specifications available from the Nasdaq Trader and Nasdaq websites. The techniques disclosed herein are broadly applicable to all financial data feeds and information or trading services.

Three types of encoding are utilized dependent upon the data fields and packet structure. In the event that a data field is unrecognizable then content independent data compression is preferably used, as previously discussed herein.

Variable Length Encoding

The basic unit of the compression process is the code. Each message field or set of set of fields being compressed together is assigned one or more codes in the range 0 . . . N. The code for a single character field is the ASCII value of the field minus 32 since all characters are in the range 32 to 127.

For various reasons, additional (escape) codes may be added to those for field values. For example, the category field has an escape code to indicate the end of a block and another to allow encoding of messages, which do not match the current format.

A basic technique used is variable rate encoding of symbols. In this approach, different amounts of the output bits are used to transmit the codes within a set. Higher frequency codes use less output bits while lower frequency codes use more output bits. Thus the average number of bits is reduced. Two methods of accomplishing this are used. The

faster method uses a variant of Huffman coding while the slower method uses a form of Arithmetic coding.

In Huffman coding, each code is represent by an integral number of bits. The code sizes are computed using the standard algorithm and then (possibly) adjusted to facilitate table driven decoding (for instance, limiting codes to at most 16 bits). In the table driven decoding method used, there is a 256 element base table and two 256 element forwarding table. At each step, the next 8 bits of the input are used to index into the base table. If the code is represented in no more than 8 bits, it will be found directly. Otherwise, there will be a forwarding entry indicating which forwarding table to use and how many input bits to discard before using the next 8 bits as an index. The entry determining the result also indicates how many bits of the input to discard before processing the next field.

In arithmetic coding, the message is essentially represented as the (approximate) product of fractions with base 16384. The numerators of the fractions are proportional to the frequencies with which the codes appear in the training data. The number of output bits used to represent a code is the base 2 logarithm of the fraction. Thus codes which appear in almost all messages may be represented with fractions of a bit.

Single Character Codes

For arithmetic coding, all single character fields are encoded as the ASCII value−32+the number of escape codes. For Huffman coding, certain single character message fields are encoded in the same way. These include:

MM Trade Desk
Quote Condition
Inside Indicator
Quote Type

Other single character fields, which have a single value that occurs most of the time, are encoded as multiple character fields (see next). In Huffman coding the smallest representation for a code is 1 bit. By combining these fields, we may encode the most common combination of values in 1 bit for the whole set. These include:

Message Category+Message Type
Session Identifier+Originator ID
PMM+Bid Price Denominator+Ask Price Denominator (Quotes)
Inside Status+Inside Type
Inside Bid Denominator+Inside Bid MC
Inside Ask Denominator+Inside Ask MC
UPC Indicator+Short Sale Bid Tick
Market of Origin+Reason

Small Set Multiple Character Codes

Multiple character fields with a small number of common values and certain combinations of single character fields are encoded based on the frequency of the combinations. A list of common combinations is used together with an escape code.

The common combinations are encoded using the corresponding code. All other combinations are encoded by the escape code followed by the (7 bit) ASCII values for the characters in the combination. The fields include the field sets above for Huffman coding as well as the following for both approaches:

Retransmission Requester
MM Location
Currency Code

Large Set Multiple Character Codes

Multiple character alphabetic or alphanumeric fields for which a large number of values are possible (Issue Symbol and MMID/MPID) are encoded as follows. Trailing spaces for Issue Symbols are deleted. Then the result is encoded using:

Variable length codes for a list of the most common values together with escapes for the possible lengths of values not in the list.

A table for the first character of the field.

A table for subsequent characters in the field.

If a value is in the list of most common values, it is encoded with the corresponding code. Otherwise, the value is encoded by sending the escape code corresponding to the (truncated) length of the value, followed by the code for the first character, which is then followed by codes for the remaining characters.

Absolute Numeric Values

Numeric fields are transmitted by sending a variable length code for the number of significant bits of the value followed by the bits of the value other than the most significant bit (which is implicitly **1**). For example, 27 (a 5 bit value) would be represented by the code for a 5 bit value followed by the 4 least significant bits (**11**). These fields include:

Short Bid Price
Long Bid Price
Short Bid Size
Long Bid Size
Short Ask Size
Long Ask Size
Short Inside Bid Size
Long Inside Bid Size
Short Inside Ask Size
Long Inside Ask Size

Relative Numeric Values

Numeric fields expected to be close to the value of numeric values occurring earlier in the message are encoded by encoding the difference between the new value and the base value as follows:

If the difference in non-negative and less than ⅛ of the base value, the difference is encoded by sending a variable length code for the number of significant bits of the difference followed by the bits of the difference other than the most significant bit (which is implicitly **1**). Otherwise, the new value is encoded by sending a variable length code for the number of significant bits of the value followed by the bits of the value other than the most significant bit (which is implicitly **1**). The difference significant bit codes and the value significant bit codes are mutually exclusive. The following fields are encoded using the difference compared to the field in parentheses:

Short Ask Price (Bid Price)
Long Ask Price (Bid Price)
Short Inside Bid Price (Bid Price)
Short Inside Ask Price (Inside Bid Price)
Long Inside Bid Price (Bid Price)
Long Inside Ask Price (Inside Bid Price)

Differences

Both time and Message Sequence Number are encoded as the difference between the new value and a previous value within the compression block. This is transmitted using a code giving the sign of the difference and the number of significant bits in the absolute value of the difference followed by the bits of the absolute value other than the first.

Date

Each message within a compression block is expected to have the same date. The base date is transmitted at the beginning of the block as 7 bits of year, 4 bits of month and 5 bits of day of the month. If the date of a message is

different than that of the block, a special escape code is used in place of the encoding of the sequence number and time. This is followed by the year, month and day as above followed by the time in seconds (17 bits) and the sequence number (24 bits).

Message Sequence Number and Time

Message time is converted to seconds after midnight. For all retransmitted messages (Retransmission Requester not "0"), the time is transmitted as a 17-bit value followed by the Message Sequence Number transmitted as a 24-bit value. If the date is not the same as the block date, a time value of 0x1ffff is used as an escape code.

For the first original transmission message in a block, the Message Sequence Number and time are transmitted in the same way.

For arithmetic coding of all other original transmission messages in a block, the Message Sequence Number is transmitted as the encoded change from the Message Sequence Number of the preceding original transmission message. Similarly, the time of all other original transmission messages is encoded as the difference from the previous original transmission message. An escape code in the Message Sequence Number Difference Table is used to indicate that the date is not the same as the block date.

Since almost all sequence number changes are 1 and almost all time changes are 0, we can save a bit (while Huffman coding) by encoding time and sequence number together.

This is done as follows: The most common values for both time and sequence number changes are 0 and 1 so there are three possibilities for each: 0, 1 and something else. Together this yields nine possibilities. An escape code is added to indicate a date different from the block date. To transmit the sequence number and time, the code corresponding the correct combination is first sent and then, if the time difference is not 0 or 1, the difference code for time followed by the difference code for sequence number (if required) is sent.

Unexpected Message Types

For administrative messages or non-control messages of unexpected category or type, the body of the message (the part after the header) is encoded as a 10-bit length field followed by the characters of the body encoded as 7-bit ASCII. Any Quotation message with an unexpected Inside Indicator value will have the remainder of the message encoded similarly.

Termination Code and Error Detection

Each compression block is terminated by an escape code of the message header category or category-type table. If this code is not found before the end of the block or if it is found too soon in the block, an error is returned. It is highly unlikely that a transmission error in the compressed packet could result in decoding so as to end at the same place as the original. The exception to this would be errors in transmitting bits values such as date, time or sequence number or the least significant bits of encoded values or changes. For additional error detection, a CRC check for the original could be added to compressed block.

Experimental Results

The aforecited Data Acceleration Methods were successfully applied to data captured on NASDAQ's NQDS feed. The data captured was first analyzed to optimize the Data Acceleration Methods. Essentially two distinct data rates were evaluated; one similar to the upcoming NASDAQ SuperMontage rate of 9.0 Megabits/sec and the second being the maximum data rate of the NQDS feed of 221 Kilobits/sec. In addition, two modes of data acceleration were applied—one utilizing Arithmetic and the other utilizing Huffman techniques.

The Arithmetic routines typically use 40% more CPU time than the Huffman routines and achieve approximately 15% better compression. On average the compression ratio for the SuperMontage data rate (9.0 Megabits/sec) utilizing Arithmetic Mode, yielded a value of 9.528 with a latency under 10.0 ms. This effectively says that the NQDS feed operating at a SuperMontage rate could be transmitted over one T1 line! Further overall latency can be reduced from 500 msec to something approaching 10 milliseconds if routing delays are reduced. Since the amount of data is substantially less, it will be easier and much more cost efficient to reduce routing delays. Further, since the quantity of transmitted bits is substantially smaller, the skew amongst transmitted packets will also be proportionately lower.

The average compression ratio for the standard NQDS data rate (221 Kbits/sec) was 9.3925 for the Arithmetic Mode with a latency under 128 ms. The higher latency is due to the time required to accumulated data for blocking Since the present invention allows for very high compression ratios with small blocks of data, the latency can be reduced substantially from 128 msec without a loss in compression ratio. This effectively says that the existing NQDS feed could be transmitted over one-half of a 56 Kilobit/sec modem line. Other advantages of using data acceleration according to the invention is that such methods inherently provide (i) a high level of encryption associated with the Arithmetic Mode (with no subsequent impact on latency) and (ii) error detection capability of the decompression methods at the end user site. The first benefit produces additional levels of security for the transmitted data and the second benefit guarantees that corrupted data will not be displayed at the end user site. Furthermore, the need to dynamically compare the redundant data feeds at the end user site is eliminated.

In yet another embodiment of the present invention the aforecited algorithms and all other data compression/decompression algorithms may be utilized in a data field specific compiler that is utilized to create new data feed and data stream specific compression algorithms.

A data field description language is utilized to define a list of possible data fields and parameters along with associated data compression encoders and parameter lists. In one embodiment of the invention the data fields are defined utilizing the following convention:

```
<start list>
<list file name (optional)>
<data field a descriptor, optional parameters>
[data field a compression algorithm x, optional parameters]
<data field b descriptor, optional parameters>
[data field b compression algorithm y, optional parameters]
...
<data field m descriptor, optional parameters>
[data field m compression algorithm n, optional parameters]
<end list>
```

Thus start list and end list are reserved identifiers however any suitable nomenclature can be utilized.

In this simple embodiment of the present invention the list is then submitted to a data compression compiler that accepts the data field list and creates two output files. The first is a data compression algorithm set comprised of data field specific encoders and the second output file is a data decompression algorithm set comprised of encoded data

field specific decoders. In practice this compiler can be implemented in any high level language, machine code, or any variant in between. In addition the language can be Java, r Visual Basic, or another interpreted language to be dynamically operated over the Internet.

More advanced embodiments of the list can be created where the order of the data fields is important to the selection of encoders. In this case the fields are an ordered vector set and the encoders are also an ordered vector set.

```
<start list>
<list file name (optional)>
<ordered data field list 1, optional parameters>
<data field a, optional parameters; data field b, optional
    parameters; ...; data field n, optional parameters;>
[data field a compression algorithm x, optional parameters;
    data field b compression algorithm y, optional
    parameters; ...;data field m compression algorithm n]
[data field b compression algorithm x, optional parameters;
    data field a compression algorithm y, optional
    parameters; ...;data field m compression algorithm n]
<end list>
```

In this more sophisticated embodiment the encoders are selected based upon the data fields and their specific ordering.

In yet another embodiment of the present invention the sets of ordered data fields can be assigned to sets by set name, giving the ability for nesting of sets to facilitate ease of coding.

In yet another embodiment of the present invention the optional parameters to each encoder are utilized to share parameters amongst the same or different data fields.

Although illustrative embodiments have been described herein with reference to the accompanying drawings, it is to be understood that the present invention is not limited to those precise embodiments, and that various other changes and modifications may be affected therein by one skilled in the art without departing from the scope or spirit of the invention. All such changes and modifications are intended to be included within the scope of the invention as defined by the appended claims.

What is claimed is:

1. A method for compressing data comprising:

analyzing content of a data block to identify a parameter, attribute, or value of the data block that excludes analyzing based solely on reading a descriptor;

selecting an encoder associated with the identified parameter, attribute, or value;

compressing data in the data block with the selected encoder to produce a compressed data block, wherein the compressing includes utilizing a state machine; and

storing the compressed data block;

wherein the time of the compressing the data block and the storing the compressed data block is less than the time of storing the data block in uncompressed form.

2. The method of claim **1**, further comprising transmitting the compressed data block in a data packet to a client, the data packet including both control information and compressed data information.

3. The method of claim **2**, wherein the compressed data block is transmitted utilizing Transmission Control Protocol/Internet Protocol (TCP/IP).

4. The method of claim **3**, wherein the compressed data block is one of a plurality of compressed data blocks transmitted in sequence.

5. The method of claim **2**, wherein the compressed data block is one of a plurality of compressed data blocks transmitted in sequence with a plurality of synchronization points.

6. The method of claim **5**, wherein the plurality of compressed data blocks in sequence is transmitted in User Datagram Protocol (UDP) Packets and wherein at least one synchronization point occurs at the beginning of at least one of the UDP Packets.

7. The method of claim **5**, wherein the plurality of compressed data blocks in sequence is transmitted in User Datagram Protocol (UDP) Packets and wherein at least one synchronization point occurs at the end of at least some of the UDP Packets.

8. The method of claim **5**, wherein the plurality of compressed data blocks in sequence is transmitted in User Datagram Protocol (UDP) Packets and wherein at least one synchronization point occurs at the end of at least one of the UDP Packets.

9. The method of claim **5**, wherein the one or more compressed data blocks in sequence have at least one synchronization point per data block.

10. The method of claim **9**, wherein the at least one synchronization point is a predetermined byte sequence.

11. The method of claim **1**, further comprising transmitting the compressed data block in a packetized data stream having data packets that include control information and compressed data information, and wherein the selected encoder is a packet independent encoder.

12. The method of claim **11**, further comprising resetting the state machine for each data packet.

13. The method of claim **1**, further comprising:

transmitting the compressed data block and a plurality of other compressed data blocks in a stream of Transmission Control Protocol/Internet Protocol (TCP/IP) packets, the TCP/IP data packets including control information and compressed data information, and

resetting the state machine used in the compressing for each TCP/IP packet.

14. The method of claim **1**, wherein the state machine includes one or more global state machines, and further comprising selectively storing data blocks in at least one of the one or more global state machines based on a priori knowledge of data block structure.

15. The method of claim **14**, further comprising:

transmitting the compressed data blocks in a packetized data stream of data packets having control and compressed data information, and

resetting the one or more local state machines at a predetermined point of each data packet in the packetized data stream.

16. The method of claim **1**, wherein the state machine includes one or more local state machines, and further comprising storing the data in the data block in at least one of the one or more local state machines such that the data is available to encode one or more other data blocks.

17. The method of claim **1**, wherein the state machine is a fixed table, and further comprising storing data in the fixed table based on a priori knowledge of data block structure.

18. The method of claim **1**, wherein the state machine is an adaptive table, and further comprising storing data from selected data block in the adaptive table such that the data is available to encode one or more other data blocks.

19. The method of claim **18**, wherein the compressed data block is to be transmitted in a packetized data stream of data packets having control and compressed data information,

and further comprising resetting the adaptive table at a point of each data packet in the packetized data stream.

20. The method of claim **1**, wherein the state machine is an adaptive table and the compressed data block is to be transmitted in a packetized data stream of data packets having control and compressed data information, and further comprising resetting the adaptive table at a point of each data packet in the packetized data stream.

21. The method of claim **1**, wherein the selected encoder is lossless.

22. The method of claim **1**, further comprising compressing the data block with a default lossless encoder when the analyzing of the content of the data block is unable to identify a parameter, attribute, or value of the data block.

23. The method of claim **1**, wherein the storing the compressed data block further comprises storing the compressed data block in a buffer.

24. The method of claim **1**, further comprising transmitting the compressed data block, wherein the time of the compressing the data block, storing the compressed data block, and transmitting the compressed data block is less than the time of transmitting the data block in an uncompressed form.

25. A system for compressing data comprising:

a data server implemented on one or more processors and one or more memory systems and configured to:

analyze content of a data block to identify a parameter, attribute, or value of the data block that excludes analysis based solely on reading a descriptor;

select an encoder associated with the identified parameter, attribute, or value;

compress data in the data block with the selected encoder to produce a compressed data block, wherein the compression utilizes a state machine; and

store the compressed data block;

wherein the time of the compressing the data block and the storing the compressed data block is less than the time of storing the data block in uncompressed form.

26. The system of claim **25**, wherein the data server is further configured to output the compressed data block in a data packet for transmission to a client, the data packet including both control information and compressed data information.

27. The system of claim **26**, wherein the compressed data block is to be transmitted in Transmission Control Protocol/Internet Protocol (TCP/IP) Packets and each (TCP/IP) Packet has at least one synchronization point.

28. The system of claim **27**, wherein the compressed data block is one of a plurality of compressed data blocks to be transmitted in sequence.

29. The system of claim **26**, wherein the compressed data block is one of a plurality of compressed data blocks to be transmitted in sequence with a plurality of synchronization points.

30. The system of claim **29**, wherein the plurality of compressed data blocks in sequence is to be transmitted in User Datagram Protocol (UDP) Packets and wherein at least one synchronization point occurs at the beginning of at least one of the UDP Packets.

31. The system of claim **29**, wherein the plurality of compressed data blocks in sequence is to be transmitted in User Datagram Protocol (UDP) Packets and wherein at least one synchronization point occurs at the end of at least some of the UDP Packets.

32. The system of claim **29**, wherein the plurality of compressed data blocks in sequence is to be transmitted in User Datagram Protocol (UDP) Packets and wherein at least one synchronization point occurs at the end of at least one of the UDP Packets.

33. The system of claim **29**, wherein the one or more compressed data blocks in sequence have at least one synchronization point per data block.

34. The system of claim **25**, wherein the data server is further configured to transmit the data compressed data block in a packetized data stream having data packets that include control information and compressed data information, and wherein the selected encoder is a packet independent encoder.

35. The system of claim **33**, wherein the at least one synchronization point is a predetermined byte sequence.

36. The system of claim **34**, wherein the state machine is reset for each data packet.

37. The system of claim **25**, wherein a plurality of the compressed data blocks are to be transmitted in a stream of Transmission Control Protocol/Internet Protocol (TCP/IP) packets, the TCP/IP data packets including control information and compressed data information, and

wherein the state machine is reset for each TCP/IP packet.

38. The system of claim **25**, wherein the state machine includes one or more global state machines, and the data server is further configured to selectively store data blocks in at least one of the one or more global state machines based on a priori knowledge of data block structure.

39. The system of claim **38**, wherein the compressed data blocks are to be transmitted in a packetized data stream, the packets having control and compressed data information and wherein the one or more local state machines are reset at a predetermined point of each data packet in the packetized data stream.

40. The system of claim **25**, wherein the state machine includes one or more local state machines, and the data server is further configured to store the data in the data block in at least one of the one or more local state machines such that the data is available to encode one or more other data blocks.

41. The system of claim **25**, wherein the state machine is a fixed table, and further comprising storing data in the fixed table based on a priori knowledge of the data block structure.

42. The system of claim **25**, wherein the state machine is an adaptive table, and the data server is further configured to store data from selected data block in the adaptive table such that the data is available to encode one or more other data blocks.

43. The system of claim **42**, wherein the compressed data blocks are to be transmitted in a packetized data stream, the packets having control and compressed data information, and wherein the adaptive table is reset at a point of each data packet in the packetized data stream.

44. The system of claim **25**, wherein the compressed data block is to be transmitted in a packetized data stream, the packets having control and compressed data information and wherein the state machine is an adaptive table reset at a point of each data packet in the packetized data stream.

45. The system of claim **25**, wherein the selected encoder is lossless.

46. The system of claim **25**, wherein the data server is further configured to compress the data block with a default lossless encoder when the analysis of the content of the data block is unable to identify a parameter, attribute, or value of the data block.

47. The system of claim **25**, wherein the data server is further configured to store the compressed data block in a buffer.

48. The system of claim 25, wherein the data server is further configured to transmit the compressed data block, wherein the time of compression of the data block, storage of the compressed data block, and transmission of the compressed data block is less than the time of transmission of the data block in an uncompressed form.

* * * * *

CERTIFICATE OF COMPLIANCE

This brief complies with the type-volume limitation of Federal Circuit Rule 32(a). This brief contains 13,934 words, excluding the parts of the brief exempted under Federal Rule of Appellate Procedure 32(f) and Federal Circuit Rule 32(b).

This brief complies with the typeface requirements of Federal Rule of Appellate Procedure 32(a)(5) and the type-style requirements of Federal Rule of Appellate Procedure 32(a)(6). This brief has been prepared in a proportionally spaced typeface using Microsoft Word in 14-point Times New Roman font.

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CERTIFICATE OF SERVICE

I hereby certify that on December 4, 2019, I electronically filed the foregoing with the Clerk of the Court of the United States Court of Appeals for the Federal Circuit by using the appellate CM/ECF system.

DATED: December 4, 2019

Respectfully submitted,

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