(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 April 2012 (05.04.2012)

PCT

(10) International Publication Number
WO 2012/043883 A1

(51) International Patent Classification:
H04N 7/26 (2006.01)

(21) International Application Number:
PCT/JP2011/073150

(22) International Filing Date:
30 September 2011 (30.09.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
12/895,676 30 September 2010 (30.09.2010) US

(71) Applicant *(for all designated States except US)*: **SHARP KABUSHIKI KAISHA** [JP/JP]; 22-22, Nagaike-cho, Abeno-ku, Osaka-shi, Osaka, 5458522 (JP).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **MISRA, Kiran.** **SEGALL, Christopher A.**.

(74) Agent: **HARAKENZO WORLD PATENT & TRADEMARK**; Daiwa Minamimorimachi Building, 2-6, Tenjinbashi 2-chome Kita, Kita-ku, Osaka-shi, Osaka, 5300041 (JP).

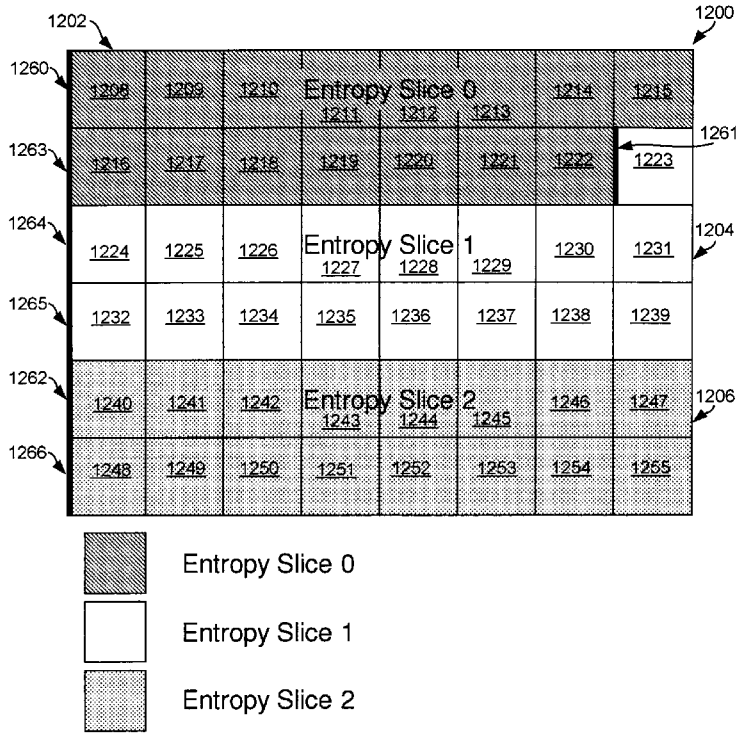
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ,

[Continued on next page]

(54) Title: METHODS AND SYSTEMS FOR CONTEXT INITIALIZATION IN VIDEO CODING AND DECODING

FIG. 34



(57) Abstract: Systems and methods for context model initialization in entropy encoders and decoders are disclosed. In some exemplary embodiments, the context model may be reset when a current macroblock is the first one in a row, the number of bins or bits are processed within the entropy slice.

WO 2012/043883 A1

DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

DESCRIPTION

TITLE OF INVENTION: METHODS AND SYSTEMS FOR CONTEXT INITIALIZATION IN VIDEO CODING AND DECODING

TECHNICAL FIELD

Embodiments of the present invention relate generally to video coding and, in particular, some embodiments of the present invention relate to methods and systems for context initialization in parallel video encoding and parallel video decoding.

BACKGROUND ART

State-of-the-art video-coding methods and standards, for example, H.264/MPEG-4 AVC (H.264/AVC) and JCT-VC Test Model under Consideration (TMuC), may provide higher coding efficiency than older methods and standards at the expense of higher complexity. Increasing quality requirements and resolution requirements on video coding methods and standards may also increase their complexity. Decoders that support parallel decoding may improve decoding speeds and reduce memory requirements. Additionally, advances in multi-core processors may make encoders and decoders that support parallel decoding desirable.

H.264/MPEG-4 AVC [Joint Video Team of ITU-T VCEG and ISO/IEC MPEG, "H.264: Advanced video coding for generic audiovisual services," ITU-T Rec. H.264 and ISO/IEC 14496-10 (MPEG4 - Part 10), November 2007], which is hereby incorporated by reference herein in its entirety, is a video codec (coder/decoder) specification that uses macroblock prediction followed by residual coding to reduce temporal and spatial redundancy in a video sequence for compression efficiency.

Test Model under Consideration (TMuC) [JCT-VC A205, "Test Model under Consideration," June 16, 2010], which is hereby incorporated by reference herein in its entirety, is the initial test model of JCT-VC. TMuC, using a basic coding unit called a coding tree block (CTB) that can have variable sizes, may provide more flexibility than H.264/AVC.

SUMMARY OF INVENTION

Some embodiments of the present invention comprise methods and systems for parallel entropy encoding. Some embodiments of the present invention comprise methods and systems for parallel entropy decoding.

According to a first aspect of the present invention, a plurality of context models used for entropy coding may be initialized, using a context table, at the start of an entropy slice.

According to a second aspect of the present invention, a plurality of context models used for entropy coding may be initialized, using a context table, at a starting elementary unit in a row in an entropy slice.

One embodiment of the present invention discloses a method for decoding a video frame in a video sequence, said method comprising:

in a video decoder, receiving an entropy slice;

identifying a slice-start elementary unit in said entropy slice; and

initializing a context model associated with entropy decoding said slice-start elementary unit to a first context model.

One embodiment of the present invention discloses a method for decoding a video frame in a video sequence, said method comprising:

in a video decoder, receiving an entropy slice;

receiving a context-table-reset flag value for a context-table-reset flag;

identifying a first row-slice elementary unit in said entropy slice; and

when said context-table-reset flag value is a first value, initializing a context model associated with entropy decoding said first row-start elementary unit to a first context model.

One embodiment of the present invention discloses a

method for encoding a video frame of a video sequence, said method comprising:

in an encoder, partitioning a frame of a video sequence into at least one reconstruction slice, thereby producing a first reconstruction slice;

forming a first entropy slice associated with said reconstruction slice;

identifying a first row-start elementary unit associated with said first entropy slice; and

signaling, in a bitstream associated with said video frame, a first context model associated with said first row-start elementary unit.

The foregoing and other objectives, features, and advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a picture showing an H.264/AVC video encoder (prior art);

Fig. 2 is a picture showing an H.264/AVC video decoder (prior art);

Fig. 3 is a picture showing an exemplary slice structure (prior art);

Fig. 4 is a picture showing an exemplary slice group structure (prior art);

Fig. 5 is a picture showing an exemplary slice partition according to embodiments of the present invention, wherein a picture may be partitioned in at least one reconstruction slice and a reconstruction slice may be partitioned into more than one entropy slice;

Fig. 6 is chart showing exemplary embodiments of the present invention comprising an entropy slice;

Fig. 7 is a chart showing exemplary embodiments of the present invention comprising parallel entropy decoding of multiple entropy slices followed by slice reconstruction;

Fig. 8 is a chart showing exemplary embodiments of the present invention comprising prediction data / residual data multiplexing at the picture level for entropy slice construction;

Fig. 9 is a chart showing exemplary embodiments of the present invention comprising color-plane multiplexing at the picture level for entropy slice construction;

Fig. 10 is a chart showing exemplary embodiments of the present invention comprising trans-coding a bitstream by entropy decoding, forming entropy slices and entropy encoding;

Fig. 11 is a chart showing exemplary embodiments of the present invention comprising partitioning a reconstruction

slice into a plurality of entropy slices, wherein the number of bins associated with each entropy slice in the plurality of entropy slices does not exceed a predefined number of bins;

Fig. 12 is a chart showing exemplary embodiments of the present invention comprising partitioning a reconstruction slice into a plurality of entropy slices, wherein bins may be associated with an entropy slice until the number of bins in the entropy slice exceeds a threshold based on a predefined maximum number of bins;

Fig. 13 is a chart showing exemplary embodiments of the present invention comprising partitioning a reconstruction slice into a plurality of entropy slices, wherein the number of bins associated with each entropy slice in the plurality of entropy slices does not exceed a predefined number of bins and each reconstruction slice contains no more than a predefined number of macroblocks;

Fig. 14 is a chart showing exemplary embodiments of the present invention comprising partitioning a reconstruction slice into a plurality of entropy slices, wherein bins may be associated with an entropy slice until the number of bins in the entropy slice exceeds a threshold based on a predefined maximum number of bins and each reconstruction slice contains no more than a predefined number of macroblocks;

Fig. 15 is a chart showing exemplary embodiments of the present invention comprising partitioning a reconstruction

slice into a plurality of entropy slices, wherein the number of bits associated with each entropy slice in the plurality of entropy slices does not exceed a predefined number of bits;

Fig. 16 is a chart showing exemplary embodiments of the present invention comprising partitioning a reconstruction slice into a plurality of entropy slices, wherein bits may be associated with an entropy slice until the number of bits in the entropy slices exceeds a threshold based on a predefined maximum number of bits;

Fig. 17 is a picture depicting exemplary embodiments of the present invention comprising multiple bin coders;

Fig. 18 is a picture depicting exemplary embodiments of the present invention comprising multiple context-adaptation units;

Fig. 19 is a picture depicting exemplary embodiments of the present invention comprising multiple bin coders and multiple context-adaptation units;

Fig. 20 is a chart showing exemplary embodiments of the present invention comprising partitioning a reconstruction slice into a plurality of entropy slices, wherein the size of an entropy slice is restricted to limit the number of bins operated on, in the entropy slice, by each restricted entropy-coder unit;

Fig. 21 is a chart showing exemplary embodiments of the present invention comprising partitioning a reconstruction

slice into a plurality of entropy slices, wherein the size of an entropy slice is restricted to limit the number of bins operated on, in the entropy slice, by each restricted entropy-coder unit;

Fig. 22 is a picture depicting exemplary embodiments of the present invention comprising a plurality of bin decoders;

Fig. 23 is a picture depicting exemplary embodiments of the present invention comprising a plurality of context-adaptation units;

Fig. 24 is a picture depicting exemplary embodiments of the present invention comprising multiple bin decoders and multiple context-adaptation units;

Fig. 25 is a picture showing an exemplary partition of a reconstruction block into a plurality of entropy slices in which the macroblocks within an entropy slice are contiguous;

Fig. 26 is a picture showing an exemplary partition of a reconstruction block into a plurality of entropy slices in which the macroblocks within an entropy slice are not contiguous;

Fig. 27 is a picture illustrating non-contiguous neighboring blocks, used in entropy decoding, for an exemplary partition of a reconstruction block into a plurality of entropy slices in which the macroblocks within an entropy slice are not contiguous;

Fig. 28 is a picture illustrating neighboring blocks used in entropy decoding and reconstruction of a block within an entropy slice for an exemplary partition of a reconstruction block into a plurality of entropy slice in which the macroblocks within an entropy slice are not contiguous;

Fig. 29 is a pictorial representation of an exemplary portion of an exemplary bitstream depicting entropy-slice header location restrictions;

Fig. 30 is a pictorial representation of an exemplary portion of an exemplary bitstream depicting entropy-slice header location restrictions;

Fig. 31 is a chart showing exemplary embodiments of the present invention comprising an entropy decoder processing a restricted portion of a bitstream to identify an entropy-slice header;

Fig. 32 is a chart showing exemplary embodiments of the present invention comprising an entropy decoder processing a restricted portion of a bitstream to identify an entropy-slice header;

Fig. 33 is a chart showing exemplary embodiments of the present invention comprising an entropy decoder processing a restricted portion of a bitstream to identify an entropy-slice header; and

Fig. 34 is a picture illustrating an exemplary context-model-initialization scheme within entropy slices according to

embodiments of the present invention.

DESCRIPTION OF EMBODIMENTS

Embodiments of the present invention will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout. The figures listed above are expressly incorporated as part of this detailed description.

It will be readily understood that the components of the present invention, as generally described and illustrated in the figures herein, could be arranged and designed in a wide variety of different configurations. Thus, the following more detailed description of the embodiments of the methods and systems of the present invention is not intended to limit the scope of the invention, but it is merely representative of the presently preferred embodiments of the invention.

Elements of embodiments of the present invention may be embodied in hardware, firmware and/or software. While exemplary embodiments revealed herein may only describe one of these forms, it is to be understood that one skilled in the art would be able to effectuate these elements in any of these forms while resting within the scope of the present invention.

While any video coder/decoder (codec) that uses entropy encoding/decoding may be accommodated by embodiments of

the present invention, many exemplary embodiments of the present invention will be illustrated in relation to an H.264/AVC encoder and an H.264/AVC decoder. This is intended for illustration of embodiments of the present invention and not as a limitation.

Many exemplary embodiments of the present invention may be described in relation to a macroblock as an elementary unit. This is intended for illustration and not as a limitation.

U.S. Patent Application No. 12/058,301, entitled "Methods and Systems for Parallel Video Encoding and Decoding," filed on March 28, 2008, is hereby incorporated by reference herein, in its entirety. U.S. Patent Application No. 12/579, 236, entitled "Methods and Systems for Parallel Video Encoding and Decoding," filed on October 14, 2009, is hereby incorporated by reference herein, in its entirety.

State-of-the-art video-coding methods and standards, for example, H.264/AVC and TMuC, may provide higher coding efficiency than older methods and standards at the expense of higher complexity. Increasing quality requirements and resolution requirements on video coding methods and standards may also increase their complexity. Decoders that support parallel decoding may improve decoding speeds and reduce memory requirements. Additionally, advances in multi-core processors may make encoders and decoders that

support parallel decoding desirable.

H.264/AVC, and many other video coding standards and methods, are based on a block-based hybrid video-coding approach, wherein the source-coding algorithm is a hybrid of inter-picture, also considered inter-frame, prediction, intra-picture, also considered intra-frame, prediction and transform coding of a prediction residual. Inter-frame prediction may exploit temporal redundancies, and intra-frame and transform coding of the prediction residual may exploit spatial redundancies.

Figure 1 shows a block diagram of an exemplary H.264/AVC video encoder **2**. An input picture **4**, also considered a frame, may be presented for encoding. A predicted signal **6** and a residual signal **8** may be produced, wherein the predicted signal **6** may be based on either an inter-frame prediction **10** or an intra-frame prediction **12**. The inter-frame prediction **10** may be determined by motion compensation section **14** using a stored, reference picture **16**, also considered reference frame, and motion information **19** determined by a motion estimation section **18** process between the input frame **4** and the reference frame **16**. The intra-frame prediction **12** may be determined by an intra-frame prediction section **20** using a decoded signal **22**. The residual signal **8** may be determined by subtracting the input **4** from the prediction **6**. The residual signal **8** is transformed,

scaled and quantized by a transforming/scaling/quantizing section **24**, thereby producing quantized, transform coefficients **26**. The decoded signal **22** may be generated by adding the predicted signal **6** to a signal **28** generated by an inverse (transforming/scaling/quantizing) section **30** using the quantized, transform coefficients **26**. The motion information **19** and the quantized, transform coefficients **26** may be entropy coded by an entropy coding section **32** and written to the compressed-video bitstream **34**. An output image region **38**, for example a portion of the reference frame, may be generated at the encoder **2** by a de-blocking filter **36** using the reconstructed, pre-filtered signal **22**.

Figure 2 shows a block diagram of an exemplary H.264/AVC video decoder **50**. An input signal **52**, also considered a bitstream, may be presented for decoding. Received symbols may be entropy decoded by an entropy decoding section **54**, thereby producing motion information **56** and quantized, scaled, transform coefficients **58**. The motion information **56** may be combined by a motion compensation section **60** with a portion of a reference frame **84** which may reside in frame memory **64**, and an inter-frame prediction **68** may be generated. The quantized, scaled, transform coefficients **58** may be inverse quantized, scaled and inverse transformed by an inverse (transforming/scaling /quantizing) section **62**, thereby producing a decoded residual

signal **70**. The residual signal **70** may be added to a prediction signal **78**: either the inter-frame prediction signal **68** or an intra-frame prediction signal **76**. The intra-frame prediction signal **76** may be predicted by an intra-frame prediction section **74** from previously decoded information in the current frame **72**. The combined signal **72** may be filtered by a de-blocking filter **80** and the filtered signal **82** may be written to frame memory **64**.

In H.264/AVC, an input picture is partitioned into fixed-size macroblocks, wherein each macroblock covers a rectangular picture area of 16x16 samples of the luma component and 8x8 samples of each of the two chroma components. In other codecs and standards, an elementary unit, or basic coding unit, different than a macroblock, for example, a coding tree block, may be used. The decoding process of the H.264/AVC standard is specified for processing units which are macroblocks. The entropy decoder **54** parses the syntax elements of the compressed-video bitstream **52** and de-multiplexes them. H.264/AVC specifies two alternative methods of entropy decoding: a low-complexity technique that is based on the usage of context-adaptively switched sets of variable length codes, referred to as CAVLC, and the computationally more demanding algorithm of context-based adaptively binary arithmetic coding, referred to as CABAC. In both entropy decoding methods, decoding of a

current symbol may rely on previously, correctly decoded symbols and adaptively updated context models. In addition, different data information, for example, prediction data information, residual data information and different color planes, may be multiplexed together. De-multiplexing may not be done until elements are entropy decoded.

After entropy decoding, a macroblock may be reconstructed by obtaining: the residual signal through inverse quantization and the inverse transform, and the prediction signal, either the intra-frame prediction signal or the inter-frame prediction signal. Blocking distortion may be reduced by applying a de-blocking filter to every decoded macroblock. No processing may begin until the input signal is entropy decoded, thereby making entropy decoding a potential bottleneck in decoding.

Similarly, in codecs in which alternative prediction mechanisms may be allowed, for example, inter-layer prediction in H.264/AVC or inter-layer prediction in other scalable codecs, entropy decoding may be requisite prior to all processing at the decoder, thereby making entropy decoding a potential bottleneck.

In H.264/AVC, an input picture comprising a plurality of macroblocks may be partitioned into one or several slices. The values of the samples in the area of the picture that a slice represents may be correctly decoded without the use of

data from other slices provided that the reference pictures used at the encoder and the decoder are identical. Therefore, entropy decoding and macroblock reconstruction for a slice do not depend on other slices. In particular, the entropy coding state is reset at the start of each slice. The data in other slices are marked as unavailable when defining neighborhood availability for both entropy decoding and reconstruction. In H.264/AVC, slices may be entropy decoded and reconstructed in parallel. No intra prediction and motion-vector prediction are allowed across the slice boundary. De-blocking filtering may use information across slice boundaries.

Figure 3 shows an exemplary video picture **90** comprising eleven macroblocks in the horizontal direction and nine macroblocks in the vertical direction (nine exemplary macroblocks labeled **91**-**99**). Figure 3 shows three exemplary slices: a first slice denoted "SLICE #0" **100**, a second slice denoted "SLICE #1" **101** and a third slice denoted "SLICE #2" **102**. An H.264/AVC decoder may decode and reconstruct the three slices **100**, **101**, **102** in parallel. At the beginning of the decoding/reconstruction process for each slice, context models are initialized or reset and macroblocks in other slices are marked as unavailable for both entropy decoding and macroblock reconstruction. Thus, for a macroblock, for example, the macroblock labeled **93**, in "SLICE #1," macroblocks (for example, macroblocks labeled **91** and **92**) in

"SLICE #0" may not be used for context model selection or reconstruction. Whereas, for a macroblock, for example, the macroblock labeled **95**, in "SLICE #1," other macroblocks (for example, macroblocks labeled **93** and **94**) in "SLICE #1" may be used for context model selection or reconstruction. Therefore, entropy decoding and macroblock reconstruction must proceed serially within a slice. Unless slices are defined using flexible macroblock ordering (FMO), macroblocks within a slice are processed in the order of a raster scan.

Flexible macroblock ordering defines a slice group to modify how a picture is partitioned into slices. The macroblocks in a slice group are defined by a macroblock-to-slice-group map, which is signaled by the content of the picture parameter set and additional information in the slice headers. The macroblock-to-slice-group map consists of a slice-group identification number for each macroblock in the picture. The slice-group identification number specifies to which slice group the associated macroblock belongs. Each slice group may be partitioned into one or more slices, wherein a slice is a sequence of macroblocks within the same slice group that is processed in the order of a raster scan within the set of macroblocks of a particular slice group. Entropy decoding and macroblock reconstruction must proceed serially within a slice.

Figure 4 depicts an exemplary macroblock allocation into three slice groups: a first slice group denoted "SLICE GROUP #0" **103**, a second slice group denoted "SLICE GROUP #1" **104** and a third slice group denoted "SLICE GROUP #2" **105**. These slice groups **103**, **104**, **105** may be associated with two foreground regions and a background region, respectively, in the picture **90**.

Some embodiments of the present invention may comprise partitioning a picture into one or more reconstruction slices, wherein a reconstruction slice may be self-contained in the respect that values of the samples in the area of the picture that the reconstruction slice represents may be correctly reconstructed without use of data from other reconstruction slices, provided that the references pictures used are identical at the encoder and the decoder. All reconstructed macroblocks within a reconstruction slice may be available in the neighborhood definition for reconstruction.

Some embodiments of the present invention may comprise partitioning a reconstruction slice into more than one entropy slice, wherein an entropy slice may be self-contained in the respect that symbol values in the area of the picture that the entropy slice represents may be correctly entropy decoded without the use of data from other entropy slices. In some embodiments of the present invention, the entropy coding state may be reset at the decoding start of

each entropy slice. In some embodiments of the present invention, the data in other entropy slices may be marked as unavailable when defining neighborhood availability for entropy decoding. In some embodiments of the present invention, macroblocks in other entropy slices may not be used in a current block's context model selection. In some embodiments of the present invention, the context models may be updated only within an entropy slice. In these embodiments of the present invention, each entropy decoder associated with an entropy slice may maintain its own set of context models.

ITU Telecommunication Standardization Sector, Study Group 16 – Contribution 405 entitled "Entropy slices for parallel entropy decoding," April 2008, is hereby incorporated by reference herein in its entirety.

Some embodiments of the present invention may comprise CABAC encoding/decoding. The CABAC encoding process includes the following four elementary steps: binarization; context model selection; binary arithmetic coding; and probability update.

Binarization: A non-binary-valued symbol (for example, a transform coefficient, a motion vector, or other coding data) is converted into a binary code, also referred to as a bin string or a binarized symbol. When a binary-valued syntax element is given, the initial step of binarization may be

bypassed. A binary-valued syntax element or an element of a binarized symbol may be referred to as a bin.

For each bin, the following may be performed:

Context Model Selection: A context model is a probability model for one or more bins. The context model comprises, for each bin, the probability of the bin being a "1" or a "0." The model may be chosen for a selection of available models depending on the statistics of recently coded data symbols, usually based on the left and above neighboring symbols, if available.

Binary Arithmetic Coding: An arithmetic coder encodes each bin according to the selected probability model and is based on recursive interval subdivision.

Probability Update: The selected context model is updated based on the actual coded value.

Context adaptation may refer to the process of selecting, based on neighboring symbol values, a context model state, also referred to as a state, associated with a bin and updating a model probability distribution assigned to the given symbols. The location of the neighboring symbols may be defined according to a context template.

In some embodiments of the present invention comprising CABAC encoding/decoding, at the decoding start of an entropy slice, all of the context models may be initialized or reset to predefined models.

Some embodiments of the present invention may be understood in relation to Figure 5. Figure 5 shows an exemplary video frame **110** comprising eleven macroblocks in the horizontal direction and nine macroblocks in the vertical direction (nine exemplary macroblocks labeled **115-123**). Figure 5 shows three exemplary reconstruction slices: a first reconstruction slice denoted "R_SLICE #0" **111,** a second reconstruction slice denoted "R_SLICE #1" **112** and a third reconstruction slice denoted "R_SLICE #2" **113**. Figure 5 further shows a partitioning of the second reconstruction slice "R_SLICE #1" **112** into three entropy slices: a first entropy slice denoted "E_SLICE #0" shown in cross-hatch **114**, a second entropy slice denoted "E_SLICE #1" shown in vertical-hatch **115** and a third entropy slice denoted "E_SLICE #2" shown in angle-hatch **116**. Each entropy slice **114**, **115**, **116** may be entropy decoded in parallel.

In some embodiments of the present invention, only data from macroblocks within an entropy slice may be available for context model selection during entropy decoding of the entropy slice. All other macroblocks may be marked as unavailable. For this exemplary partitioning, macroblocks labeled **117** and **118** are unavailable for context model selection when decoding symbols corresponding to the area of macroblock labeled **119** because macroblocks labeled **117** and **118** are outside of the entropy slice containing macroblock

119. However, these macroblocks **117**, **118** are available when macroblock **119** is reconstructed.

In some embodiments of the present invention, an encoder may determine whether or not to partition a reconstruction slice into entropy slices, and the encoder may signal the decision in the bitstream. In some embodiments of the present invention, the signal may comprise an entropy-slice flag, which may be denoted "entropy_slice_flag" in some embodiments of the present invention.

Some decoder embodiments of the present invention may be described in relation to Figure 6. In these embodiments, an entropy-slice flag may be examined **130**, and if the entropy-slice flag indicates that there are no **132** entropy slices associated with a picture, or a reconstruction slice, then the header may be parsed **134** as a regular slice header. The entropy decoder state may be reset **136**, and the neighbor information for the entropy decoding and the reconstruction may be defined **138**. The slice data may then be entropy decoded **140**, and the slice may be reconstructed **142**. If the entropy-slice flag indicates there are **146** entropy slices associated with a picture, or a reconstruction slice, then the header may be parsed **148** as an entropy-slice header. The entropy decoder state may be reset **150**, the neighbor information for entropy decoding may be defined **152** and the entropy-slice data may be entropy decoded **154**. The neighbor

information for reconstruction may then be defined **156**, and the slice may be reconstructed **142**. After slice reconstruction **142**, the next slice, or picture, may be examined **158**.

Some alternative decoder embodiments of the present invention may be described in relation to Figure 7. In these embodiments, the decoder may be capable of parallel decoding and may define its own degree of parallelism, for example, consider a decoder comprising the capability of decoding *N* entropy slices in parallel. The decoder may identify **170** *N* entropy slices. In some embodiments of the present invention, if fewer than *N* entropy slices are available in the current picture, or reconstruction slice, the decoder may decode entropy slices from subsequent pictures, or reconstruction slices, if they are available. In alternative embodiments, the decoder may wait until the current picture, or reconstruction slice, is completely processed before decoding portions of a subsequent picture, or reconstruction slice. After identifying **170** up to *N* entropy slices, each of the identified entropy slices may be independently entropy decoded. A first entropy slice may be decoded **172-176**. The decoding **172-176** of the first entropy slice may comprise resetting the decoder state **172**. In some embodiments comprising CABAC entropy decoding, the CABAC state may be reset. The neighbor information for the entropy decoding of the first entropy slice

may be defined **174**, and the first entropy slice data may be decoded **176**. For each of the up to *N* entropy slices, these steps may be performed (**178-182** for the *N*th entropy slice). In some embodiments of the present invention, the decoder may reconstruct **184** the entropy slices when all of the entropy slices are entropy decoded. In alternative embodiments of the present invention, the decoder may begin reconstruction **184** after one or more entropy slices are decoded.

In some embodiments of the present invention, when there are more than *N* entropy slices, a decode thread may begin entropy decoding a next entropy slice upon the completion of entropy decoding of an entropy slice. Thus when a thread finishes entropy decoding a low complexity entropy slice, the thread may commence decoding additional entropy slices without waiting for other threads to finish their decoding.

In some embodiments of the present invention which may accommodate an existing standard or method, an entropy slice may share most of the slice attributes of a regular slice according to the standard or method. Therefore, an entropy slice may require a small header. In some embodiments of the present invention, the entropy slice header may allow a decoder to identify the start of an entropy slice and start entropy decoding. In some embodiments, at the start of a

picture, or a reconstruction slice, the entropy slice header may be the regular header, or a reconstruction slice header.

In some embodiments of the present invention comprising an H.264/AVC codec, an entropy slice may be signaled by adding a new bit, "entropy_slice_flag" to the existing slice header. Table 1 lists the syntax for an entropy slice header according to embodiments of the present invention, wherein C indicates Category and Descriptor u(1), ue(v) indicate some fixed length or variable length coding methods. Embodiments of the present invention comprising an "entropy_slice_flag" may realize improved coding efficiency.

"**first_mb_in_slice**" specifies the address of the first macroblock in the entropy slice associated with the entropy-slice header. In some embodiments, the entropy slice may comprise a sequence of macroblocks.

"**cabac_init_idc**" specifies the index for determining the initialization table used in the initialization process for the context mode.

slice_header() {	C	Descriptor
entropy_slice_flag	2	u(1)
if (entropy_slice_flag) {		
first_mb_in_slice	2	ue(v)
if (entropy_coding_mode_flag && slice_type != I && slice_type != SI)		
cabac_init_idc	2	ue(v)
}		
}		
else {		
a regular slice header ...		

}		
}		

Table 1: Exemplary Syntax Table for Entropy Slice Header

In some embodiments of the present invention, an entropy slice may be assigned a different network abstraction layer (NAL) unit type from the regular slices. In these embodiments, a decoder may distinguish between regular slices and entropy slices based on the NAL unit type. In these embodiments, the bit field "entropy_slice_flag" is not required.

In some embodiments of the present invention, the bit field "entropy_slice_flag" may not be transmitted in all profiles. In some embodiments of the present invention, the bit field "entropy_slice_flag" may not be transmitted in a baseline profile, but the bit field "entropy_slice_flag" may be transmitted in higher profiles such as a main, an extended or a professional profile. In some embodiments of the present invention, the bit field "entropy_slice_flag" may only be transmitted in bitstreams associated with characteristics greater than a fixed characteristic value. Exemplary characteristics may include spatial resolution, frame rate, bit depth, bit rate and other bitstream characteristics. In some embodiments of the present invention, the bit field "entropy_slice_flag" may only be transmitted in bitstreams associated with spatial resolutions greater than 1920x1080

interlaced. In some embodiments of the present invention, the bit field "entropy_slice_flag" may only be transmitted in bitstreams associated with spatial resolutions greater than 1920x1080 progressive. In some embodiments of the present invention, if the bit field "entropy_slice_flag" is not transmitted, a default value may be used.

In some embodiments of the present invention, an entropy slice may be constructed by altering the data multiplexing. In some embodiments of the present invention, the group of symbols contained in an entropy slice may be multiplexed at the macroblock level. In alternative embodiments of the present invention, the group of symbols contained in an entropy slice may be multiplexed at the picture level. In other alternative embodiments of the present invention, the group of symbols contained in an entropy slice may be multiplexed by data type. In yet alternative embodiments of the present invention, the group of symbols contained in an entropy slice may be multiplexed in a combination of the above.

Some embodiments of the present invention comprising entropy slice construction based on picture level multiplexing may be understood in relation to Figure 8 and Figure 9. In some embodiments of the present invention shown in Figure 8, prediction data **190** and residual data **192** may be entropy encoded by a prediction encoder **194**, and a residual encoder

196 separately and the encoded prediction data and the encoded residual data may be multiplexed by a picture-level multiplexer **198** at the picture level. In some embodiments of the present invention, the prediction data for a picture **190** may be associated with a first entropy slice, and the residual data for a picture **192** may be associated with a second entropy slice. The encoded prediction data and the encoded entropy data may be decoded in parallel. In some embodiments of the present invention, each partition comprising prediction data or residual data may be partitioned into entropy slices which may be decoded in parallel.

In some embodiments of the present invention shown in Figure 9, the residual of each color plane, for example, the luma residual **200** and the two chroma residuals **202**, **204**, may be entropy encoded by a Y encoder **206**, a U encoder **208**, and a V encoder **210** separately and the entropy encoded residuals may be multiplexed by a picture-level multiplexer **212** at the picture level. In some embodiments of the present invention, the luma residual for a picture **200** may be associated with a first entropy slice, the first chroma residual for a picture **202** may be associated with a second entropy slice, and the second residual for a picture **204** may be associated with a third entropy slice. The encoded residual data for the three color planes may be decoded in parallel. In

some embodiments of the present invention, each partition comprising color-plane residual data may be partitioned into entropy slices which may be decoded in parallel. In some embodiments of the present invention, the luma residual **200** may have relatively more entropy slices compared to the chroma residuals **202**, **204**.

In some embodiments of the present invention, an compressed-video bitstream may be trans-coded to comprise entropy slices, thereby allowing for parallel entropy decoding as accommodated by embodiments of the present invention described above. Some embodiments of the present invention may be described in relation to Figure 10. An input bitstream without entropy slices may be processed picture-by-picture according to Figure 10. In these embodiments of the present invention, a picture from the input bitstream may be entropy decoded **220**. The data which had been coded, for example, mode data, motion information, residual information and other data, may be obtained. Entropy slices may be constructed **222** one at a time from the data. An entropy-slice header corresponding to an entropy slice may be inserted **224** in a new bitstream. The encoder state may be reset and the neighbor information defined **226**. The entropy slice may be entropy encoded **228** and written to the new bitstream. If there is picture data that has not been consumed **232** by the constructed entropy slices, then

another entropy slice may be constructed **222**, and the process **224-230** may continue until all of the picture data has been consumed **234** by the constructed entropy slices, and then the next picture may be processed.

In some embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality of entropy slices wherein the size of each entropy slice may be less than, or may not exceed, a fixed number of bins. In some embodiments wherein the encoder may restrict the size of each entropy slice, the maximum number of bins may be signaled in the bitstream. In alternative embodiments wherein the encoder may restrict the size of each entropy slice, the maximum number of bins may be defined by the profile and level conformance point of the encoder. For example, Annex A of the H.264/AVC video coding specification may be extended to comprise a definition of the maximum number of bins allowed in an entropy slice.

In some embodiments of the present invention, the maximum number of bins allowed in an entropy slice may be indicated for each level conformance point of the encoder according to a table, for example, as shown in Table 2, where $M_{m.n}$ denotes the maximum number of bins allowed in an entropy slice for a level $m.n$ conformance point.

Level	Maximum Number of Bins per Entropy Slice

1.1	$M_{1.1}$
1.2	$M_{1.2}$
:	:
m.n	$M_{m.n}$
:	:
5.1	$M_{5.1}$

Table 2: Maximum Number of Bins per Entropy Slice for Each Level

Exemplary maximum number of bins allowed in an entropy slice are $M_{1.1}=1{,}000$ bins, $M_{1.2}=2{,}000$ bins, ..., and $M_{5.1}=40{,}000$ bins. Other exemplary maximum number of bins allowed in an entropy slice are $M_{1.1}=2{,}500$ bins, $M_{1.2}=4{,}200$ bins, ..., and $M_{5.1}=150{,}000$ bins.

In some embodiments, a set of maximum number of bins allowed in an entropy slice may be determined for all levels based on bit rate, image size, number of macroblocks and other encoding parameters. In some embodiments of the present invention the maximum number of bins allowed in an entropy slice may be the set to the same number for all levels. Exemplary values are 38,000 bins and 120,000 bins.

In some embodiments of the present invention, an encoder may determine a worst case number of bins associated with a macroblock, and the encoder may write the bins associated with:

$$\frac{ESLICE_MaxNumberBins}{BinsPerMB},$$

macroblocks to each entropy slice, where *ESLICE_MaxNumberBins* may denote the maximum number of bins allowed in an entropy slice and *BinsPerMB* may denote the worst case number of bins associated with a macroblock. In some embodiments, the macroblocks may be selected in raster-scan order. In alternative embodiments, the macroblocks may be selected in another, predefined order. In some embodiments, the worst case number of bins associated with a macroblock may be a fixed number. In alternative embodiments, the encoder may update the worst case number based on measurements of the sizes of previously processed macroblocks.

Some embodiments of the present invention may be described in relation to Figure 11. In these embodiments, an encoder may, for a reconstruction slice, partition the reconstruction slice into a plurality of entropy slices wherein no entropy slice may be larger in size than a predetermined number of bins. The encoder may initialize **240** to zero a counter associated with the number of bins in a current entropy slice. The counter value may be denoted *A* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 11. The syntax elements for a next macroblock may be obtained **242**. The next macroblock may

be determined according to a predefined macroblock processing order. In some embodiments, the macroblock processing order may correspond to a raster-scan ordering. Non-binary syntax elements in the macroblock may be converted **244** to a string of bins. Binary syntax elements may not require conversion. The number of bins associated with the macroblock may be determined **246**. The number of bins associated with the macroblock may include the bins in the strings of bins associated with the non-binary syntax elements in addition to the binary syntax elements, and the number of bins associated with the macroblock may be denoted *num* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 11.

If the number of bins associated with the macroblock may be added **248** to the number of already accumulated bins associated with the current entropy slice without **249** exceeding a maximum number of bins allowed for an entropy slice, then the number of accumulated bins associated with the current entropy slice may be updated **250** to include the bins associated with the macroblock, and the bins associated with the macroblock may be written **252**, by the entropy encoder, to the bitstream and associated with the current entropy slice. The syntax elements for the next macroblock may be obtained **242**, and the partitioning process may

continue.

If **248** the sum of the number of bins associated with the macroblock and the number of already accumulated bins associated with the current entropy slice exceeds **253** the maximum number of bins allowed for an entropy slice, then the encoder may start **254** a new entropy slice associated with the current reconstruction slice and may terminate the current entropy slice. Then the counter associated with the number of bins in the new, now current, entropy slice may be initialized **256** to zero. The number of accumulated bins associated with the current entropy slice may be updated **250** to include the bins associated with the macroblock, and the bins associated with the macroblock may be written **252**, by the entropy encoder, to the bitstream and associated with the current entropy slice. The syntax elements for the next macroblock may be obtained **242**, and the partitioning process may continue.

Some embodiments of the present invention may be described in relation to Figure 12. In these embodiments, an encoder may, for a reconstruction slice, partition the reconstruction slice into a plurality of entropy slices wherein no entropy slice may be larger in size than a predetermined maximum number of bins. In these embodiments, the encoder may associate macroblock syntax elements with an entropy slice until the size of the entropy slice reaches a

threshold associated with the predetermined maximum number of bins allowed in an entropy slice. In some embodiments, the threshold may be a percentage of the maximum number of bins allowed in an entropy slice. In one exemplary embodiment, the threshold may be 90% of the maximum number of bins allowed in an entropy slice, supposing that the greatest number of bins expected in a macroblock is less than 10% of the maximum number of bins. In another exemplary embodiment, the threshold may be a percentage of the maximum number of bins allowed in an entropy slice wherein the percentage may be based on the greatest number of bins expected in a macroblock. In these embodiments, once the size of an entropy slice exceeds a threshold size, then another entropy slice may be created. The threshold size may be selected to ensure that the entropy slice does not exceed the maximum number of bins allowed in an entropy slice. In some embodiments, the threshold size may be a function of the maximum number of bins allowed in an entropy slice and an estimate of the maximum number of bins expected for a macroblock.

The encoder may initialize **270** to zero a counter associated with the number of bins in a current entropy slice. The counter value may be denoted *A* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 12. The

syntax elements for a next macroblock may be obtained **272**. The next macroblock may be determined according to a predefined macroblock processing order. In some embodiments, the macroblock processing order may correspond to a raster-scan ordering. Non-binary syntax elements in the macroblock may be converted **274** to a string of bins. Binary syntax elements may not require conversion. The bins associated with the macroblock may be written **276**, by the entropy encoder, to the bitstream and associated with the current entropy slice. The number of bins associated with the macroblock may be determined **278**, and the number of accumulated bins associated with the current entropy slice may be updated **280** to include the bins associated with the macroblock. If **282** the number of accumulated bins associated with the current entropy slice is greater **284** than a threshold, which may be denoted $TH(MaxNumBins)$, based on the maximum number of bins allowed in an entropy slice, then the encoder may start **286** a new entropy slice and may terminate the current entropy slice. Then the encoder may initialize **288** to zero the counter associated with the number of bins in the new, now current, entropy slice. The syntax elements for the next macroblock may be obtained **272**, and the partitioning process may continue. If the number of accumulated bins associated with the current entropy slice is not greater **283** than the threshold based on the maximum

number of bins allowed in an entropy slice, then the syntax elements for the next macroblock may be obtained **272**, and the partitioning process may continue.

In some embodiments of the present invention, an encoder may terminate the current reconstruction slice and start a new reconstruction slice when a predetermined number of macroblocks have been assigned to the current reconstruction slice.

Some embodiments of the present invention may be described in relation to Figure 13. In these embodiments, an encoder may terminate the current reconstruction slice and start a new reconstruction slice when a predetermined number of macroblocks have been assigned to the current reconstruction slice. The encoder may initialize **300** to zero a counter associated with the number of macroblocks in a current reconstruction slice. The counter value may be denoted *AMB* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 13. The encoder may initialize **310** to zero a counter associated with the number of bins in a current entropy slice. The counter value may be denoted *ABin* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 13. If **312** the counter value of the counter associated with the number of macroblocks in the current

reconstruction slice is not less **331** than a predetermined maximum number of macroblocks allowed in a reconstruction slice, then a new entropy slice may be started **332** and a new reconstruction slice may be started **334**, terminating the current reconstruction slice and current entropy slice. The maximum number of macroblocks allowed in a reconstruction slice may be denoted *MaxMBperRSlice* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 13.

If the counter value of the counter associated with the number of macroblocks in the current reconstruction slice is less **313** than the predetermined maximum number of macroblocks allowed in a reconstruction slice, then the syntax elements for a next macroblock may be obtained **314**. The next macroblock may be determined according to a predefined macroblock processing order. In some embodiments, the macroblock processing order may correspond to a raster-scan ordering. Non-binary syntax elements in the macroblock may be converted **316** to a string of bins. Binary syntax elements may not require conversion. The number of bins associated with the macroblock may be determined **318**. The number of bins associated with the macroblock may include the bins in the strings of bins associated with the non-binary syntax elements in addition to the binary syntax elements, and the number of bins

associated with the macroblock may be denoted *num* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 13.

If the number of bins associated with the macroblock may be added **320** to the number of already accumulated bins associated with the current entropy slice without **321** exceeding a maximum number of bins allowed for an entropy slice, then the number of accumulated bins associated with the current entropy slice may be updated **322** to include the bins associated with the macroblock, the bins associated with the macroblock may be written **324**, by the entropy encoder, to the bitstream and associated with the current entropy slice, and the number of macroblocks associated with the current reconstruction slice may be incremented **326**. The number of macroblocks associated with the current reconstruction slice may be compared **312** to the predetermined maximum number of macroblocks allowed in a reconstruction slice, and the partitioning process may continue.

If **320** the sum of the number of bins associated with the macroblock and the number of already accumulated bins associated with the current entropy slice exceeds **327** the maximum number of bins allowed for an entropy slice, then the encoder may start **328** a new, now current, entropy slice associated with the current reconstruction slice, and the

counter associated with the number of bins in the current entropy slice may be initialized **330** to zero. The number of accumulated bins associated with the current entropy slice may be updated **322** to include the bins associated with the macroblock, the bins associated with the macroblock may be written **324**, by the entropy encoder, to the bitstream and associated with the current entropy slice, and the number of macroblocks associated with the current reconstruction slice may be incremented **326**. The number of macroblocks associated with the current reconstruction slice may be compared **312** to the predetermined maximum number of macroblocks allowed in a reconstruction slice, and the partitioning process may continue.

Some embodiments of the present invention may be described in relation to Figure 14. In these embodiments, an encoder may start a new reconstruction slice when a predetermined number of macroblocks have been assigned to the current reconstruction slice. In these embodiments, the encoder may associate macroblock syntax elements with an entropy slice until the size of the entropy slice reaches a threshold associated with the predetermined maximum number of bins allowed in an entropy slice. In some embodiments, the threshold may be a percentage of the maximum number of bins allowed in an entropy slice. In one exemplary embodiment, the threshold may be 90% of the

maximum number of bins allowed in an entropy slice, supposing that the greatest number of bins expected in a macroblock is less than 10% of the maximum number of bins. In another exemplary embodiment, the threshold may be a percentage of the maximum number of bins allowed in an entropy slice wherein the percentage may be based on the greatest number of bins expected in a macroblock. In these embodiments, once the size of an entropy slice exceeds a threshold size, then another entropy slice may be created. The threshold size may be selected to ensure that the entropy slice does not exceed the maximum number of bins allowed in an entropy slice. In some embodiments, the threshold size may be a function of the maximum number of bins allowed in an entropy slice and an estimate of the maximum number of bins expected for a macroblock.

The encoder may initialize **350** to zero a counter associated with the number of macroblocks in a current reconstruction slice. The counter value may be denoted *AMB* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 14. The encoder may initialize **352** to zero a counter associated with the number of bins in a current entropy slice. The counter value may be denoted *ABin* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in

relation to Figure 14. If **354** the counter value of the counter associated with the number of macroblocks in the current reconstruction slice is not less **373** than a predetermined maximum number of macroblocks allowed in a reconstruction slice, then a new entropy slice may be started **374**, and a new reconstruction slice may be started **376**. The maximum number of macroblocks allowed in a reconstruction slice may be denoted *MaxMBperRSlice* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 14.

If the counter value of the counter associated with the number of macroblocks in the current reconstruction slice is less **355** than the predetermined maximum number of macroblocks allowed in a reconstruction slice, then the syntax elements for a next macroblock may be obtained **356**. The next macroblock may be determined according to a predefined macroblock processing order. In some embodiments, the macroblock processing order may correspond to a raster-scan ordering. Non-binary syntax elements in the macroblock may be converted **358** to a string of bins. Binary syntax elements may not require conversion. The bins associated with the macroblock may be written **360**, by the entropy encoder, to the bitstream and associated with the current entropy slice. The number of bins associated with the macroblock may be determined **362**, and the number of

accumulated bins associated with the current entropy slice may be updated **364** to include the bins associated with the macroblock. If **366** the number of accumulated bins associated with the current entropy slice is greater **369** than a threshold, which may be denoted $TH(MaxNumBins)$, based on the maximum number of bins allowed in an entropy slice, then the encoder may start **370** a new entropy slice, and initialize **372** to zero the counter associated with the number of bins in a current entropy slice. The number of macroblocks associated with the current reconstruction slice may be incremented **368**. The number of macroblocks associated with the current reconstruction slice may be compared **354** to the predetermined maximum number of macroblocks allowed in a reconstruction slice, and the partitioning process may continue. If the number of accumulated bins associated with the current entropy slice is not greater **367** than the threshold based on the maximum number of bins allowed in an entropy slice, then the number of macroblocks associated with the current reconstruction slice may be incremented **368,** and the number of macroblocks associated with the current reconstruction slice may be compared **354** to the predetermined maximum number of macroblocks allowed in a reconstruction slice, and the partitioning process may continue.

In alternative embodiments of the present invention, an

encoder may partition a reconstruction slice into a plurality of entropy slices, wherein each entropy slice may be associated with no more than a predefined number of bits.

Some embodiments of the present invention may be described in relation to Figure 15. In these embodiments, an encoder may, for a reconstruction slice, partition the reconstruction slice into a plurality of entropy slices wherein no entropy slice may be larger in size than a predetermined number of bits. The encoder may initialize **400** to zero a counter associated with the number of bits in a current entropy slice. The counter value may be denoted A for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 15. The syntax elements for a next macroblock may be obtained **402**. The next macroblock may be determined according to a predefined macroblock processing order. In some embodiments, the macroblock processing order may correspond to a raster-scan ordering. Non-binary syntax elements in the macroblock may be converted **404** to a string of bins. Binary syntax elements may not require conversion. The bins, converted non-binary elements and binary elements, associated with the macroblock may be presented to the entropy encoder, and the bins may be entropy encoded **406**. The number of bits associated with the macroblock may be determined **408**. The

number of bits associated with the macroblock may be denoted *num* for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 15.

If the number of bits associated with the macroblock may be added **410** to the number of already accumulated bits associated with the current entropy slice without **411** exceeding a maximum number of bits allowed for an entropy slice, then the number of accumulated bits associated with the current entropy slice may be updated **412** to include the bits associated with the macroblock, and the bits associated with the macroblock may be written **414** to the bitstream and associated with the current entropy slice. The syntax elements for the next macroblock may be obtained **402**, and the partitioning process may continue.

If **410** the sum of the number of bits associated with the macroblock and the number of already accumulated bits associated with the current entropy slice exceeds **415** the maximum number of bits allowed for an entropy slice, then the encoder may start **416** a new entropy slice associated with the current reconstruction slice, and the counter associated with the number of bits in the current entropy slice may be initialized **418** to zero. The number of accumulated bits associated with the current entropy slice may be updated **412** to include the bits associated with the macroblock, and the

bits associated with the macroblock may be written **414** to the bitstream and associated with the current entropy slice. The syntax elements for the next macroblock may be obtained **402**, and the partitioning process may continue.

Some embodiments of the present invention may be described in relation to Figure 16. In these embodiments, an encoder may, for a reconstruction slice, partition the reconstruction slice into a plurality of entropy slices wherein no entropy slice may be larger in size than a predetermined maximum number of bits. In these embodiments, the encoder may associate macroblock syntax elements with an entropy slice until the size of the entropy slice reaches a threshold associated with the predetermined maximum number of bits allowed in an entropy slice. In some embodiments, the threshold may be a percentage of the maximum number of bits allowed in an entropy slice. In one exemplary embodiment, the threshold may be 90% of the maximum number of bits allowed in an entropy slice, supposing that the greatest number of bits expected in a macroblock is less than 10% of the maximum number of bits. In another exemplary embodiment, the threshold may be a percentage of the maximum number of bits allowed in an entropy slice wherein the percentage may be based on the greatest number of bits expected in a macroblock. In these embodiments, once the size of an entropy slice exceeds a threshold size, then another

entropy slice may be created. The threshold size may be selected to ensure that the entropy slice does not exceed the maximum number of bits allowed in an entropy slice. In some embodiments, the threshold size may be a function of the maximum number of bits allowed in an entropy slice and an estimate of the maximum number of bits expected for a macroblock.

The encoder may initialize **440** to zero a counter associated with the number of bits in a current entropy slice. The counter value may be denoted A for illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 16. The syntax elements for a next macroblock may be obtained **442**. The next macroblock may be determined according to a predefined macroblock processing order. In some embodiments, the macroblock processing order may correspond to a raster-scan ordering. Non-binary syntax elements in the macroblock may be converted **444** to a string of bins. Binary syntax elements may not require conversion. The bins associated with the macroblock may be entropy encoded **446**, and the number of bins associated with the macroblock may be determined **448**. The number of accumulated bits associated with the current entropy slice may be updated **450** to include the bins associated with the macroblock, and the entropy encoded bins associated with the

macroblock may be written **452** to the bitstream. If **454** the number of accumulated bits associated with the current entropy slice is greater **456** than a threshold based on the maximum number of bits allowed in an entropy slice, then the encoder may start **458** a new entropy slice, and initialize **460** to zero the counter associated with the number of bits in a current entropy slice. The syntax elements for the next macroblock may be obtained **442**, and the partitioning process may continue. If the number of accumulated bits associated with the current entropy slice is not greater **455** than a threshold based on the maximum number of bits allowed in an entropy slice, then the syntax elements for the next macroblock may be obtained **442**, and the partitioning process may continue.

In alternative embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality of entropy slices, wherein each entropy slice may be associated with no more than a predefined number of macroblocks.

In some embodiments of the present invention, a restriction on the maximum number of macroblocks in a reconstruction slice may be imposed in addition to a restriction on the size of an entropy slice.

In some embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality

of entropy slices, wherein the size of each entropy slice may be restricted to less than a predefined number of macroblocks and to less than a predefined number of bins.

In some embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality of entropy slices, wherein the size of each entropy slice may be restricted to less than a predefined number of macroblocks and to less than a predefined number of bits.

In some embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality of entropy slices, wherein the size of each entropy slice may be restricted to less than a predefined number of macroblocks, to less than a predefined number of bins and to less than a predefined number of bits.

In some embodiments of the present invention, bin coding within an entropy coder may be parallelized allowing parallel encoding of more than one bin, which may reduce encoding time. These embodiments of the present invention may be understood in relation to an exemplary entropy coder depicted in Figure 17. In these embodiments, the entropy coder **480** may comprise a context-adaptation unit **482**, a state-based, bin-coder selector **484** and a plurality of bin coders, also considered bin-coder units, (three shown) **486**, **488**, **500** that may operate in parallel. Bins **502** may be made available to the entropy coder **480** from a binarizer **504**

that may generate the bins **502** from input symbols **506**. The bins **502** may be made available to the context-adaptation unit **482** and the state-based, bin-coder selector **484**. The context-adaptation unit **482** may perform context adaptation and generate a model state, also referred to as a state, **508** that may be used to select a bin coder to which a bin **502** may be directed among the bin coders **486**, **488**, **500**. The state-based, bin-coder selector **484** may select the bin coder associated with the generated model state **508** among the bin coders **486**, **488**, **500** to encode the bin **502**. In some embodiments (not shown), the generated state **508** may be made available to the selected bin coder. Output bits **510**, **512**, **514** may be generated by the bin coders **486**, **488**, **500**, and the output bits **510**, **512**, **514** may be incorporated into a bitstream. In some embodiments of the present invention, the output bits **510**, **512**, **514** may be buffered and incorporated into the bitstream by concatenation. In alternative embodiments, the output bits **510**, **512**, **514** may be buffered and incorporated into the bitstream according to an interleaving scheme.

According to embodiments of the present invention described in relation to Figure 17, a first bin may be sent to a first bin coder in response to a first model state generated in relation to the first bin. The context-adaptation unit **482**, upon completion of processing the first bin, may begin

processing of a second bin, sending the second bin to a second bin coder in response to a second model state generated in relation to the second bin, thereby allowing substantially parallel processing of more than one bin.

In alternative embodiments of the present invention, an entropy coder may comprise a plurality of context-adaptation units that may operate in parallel and a single bin coder. In systems wherein the context-adaptation units require longer processing time than the bin coder, a plurality of context-adaptation units operating in parallel may reduce encoding time. Some of these embodiments of the present invention may be understood in relation to an exemplary entropy coder depicted in Figure 18. In these embodiments, the entropy coder **530** may comprise a plurality of context-adaptation units (three shown) **532**, **534**, **536**, a context-adaptation-unit selector **538**, a state selector **540** and a bin coder **542**. Bins **544** may be made available to the entropy coder **530** from a binarizer **546** that may generate the bins **544** from input symbols **548**. The bins **544** may be made available to the context-adaptation-unit selector **538**, the state selector **540** and the bin coder **542**. The context-adaptation-unit selector **538** may be used to select, or to schedule, a context-adaptation unit **532**, **534**, **536** to which a bin **544** may be directed and from which a state value **550**, **552**, **554** may be generated. In some exemplary embodiments, the context-

adaptation-unit selector **538** may select a context-adaptation unit among the context-adaptation units **532**, **534**, **536** based on the syntax associated with the bin, for example a context-adaptation unit identifier may be associated with a bin identifying the context-adaptation unit to which the bin may be directed for processing. In alternative exemplary embodiments, the context-adaptation-unit selector **538** may select a context-adaptation unit among the context-adaptation units **532**, **534**, **536** based on a scheduling protocol or load-balancing constraint associated with the context-adaptation units **532**, **534**, **536**. In some embodiments, the generated state value may be selected by the state selector **540**, according to the criterion used at the context-adaptation unit selector **538**, at the appropriate timing to be passed to the bin coder **542**. The bin coder **542** may use the state value **556** passed by the state selector **540** in coding the bin **544**. In alternative embodiments of the present invention (not shown), the state value may not be required by the bin coder and, therefore, not made available to the bin coder. Output bits **558** may be generated by the bin coder **542**, and the output bits **558** may be incorporated into a bitstream. In some embodiments of the present invention, the output bits **558** may be buffered and incorporated into the bitstream by concatenation. In alternative embodiments, the output bits **558** may be buffered

and incorporated into the bitstream according to an interleaving scheme.

In yet alternative embodiments of the present invention, an entropy coder may comprise a plurality of context-adaptation units that may operate in parallel and a plurality of bin coders that may operate in parallel. These embodiments of the present invention may be understood in relation to an exemplary entropy coder depicted in Figure 19. In these embodiments, the entropy coder **570** may comprise a plurality of context-adaptation units (three shown) **572**, **574**, **576**, a context-adaptation-unit selector **578**, a state selector **580**, a state-based, bin-coder selector **582** and a plurality of bin coders (three shown) **584**, **586**, **588**. Bins **590** may be made available to the entropy coder **570** from a binarizer **592** that may generate the bins **590** from input symbols **594**. The bins **590** may be made available to the context-adaptation-unit selector **578**, the state selector **580** and the bin-coder selector **582**. The context-adaptation-unit selector **578** may be used to select, or to schedule, a context-adaptation unit **572**, **574**, **576** to which a bin **590** may be directed and from which a state value **596**, **598**, **600** may be generated. The generated state value may be selected by the state selector **580** at the appropriate timing to be passed to the state-based, bin-coder selector **582**. The state-based, bin-coder selector **582** may use the state value **602** passed by the state selector

580 to select a bin coder among the bin coders **584**, **586**, **588** to which a bin **590** may be directed. In alternative embodiments (not shown), the state value **602** may be made available to the selected bin coder. The selected bin coder may use the state value **602** in coding the bin **590**. In alternative embodiments of the present invention (not shown), the state value may not be required by the bin coder and, therefore, not made available to the bin coder. Output bits **604**, **606**, **608** may be generated by the bin coders **584**, **586**, **588** and the output bits **604**, **606**, **608** may be incorporated into a bitstream. In some embodiments of the present invention, the output bits **604**, **606**, **608** may be buffered and incorporated into the bitstream by concatenation. In alternative embodiments, the output bits **604**, **606**, **608** may be buffered and incorporated into the bitstream according to an interleaving scheme

An exemplary embodiment of the present invention may comprise a plurality of variable length coding codecs that may operate in parallel.

In one exemplary embodiment of the present invention, a bin coder may comprise binary arithmetic coding. In another exemplary embodiment of the present invention, a bin coder may comprise variable length coding. In yet another exemplary embodiment of the present invention, a bin coder may comprise fixed length coding.

In general, an entropy coder may comprise N_{ca} context-adaptation units and N_{bc} bin-coder units, where N_{ca} is an integer greater than, or equal to, one and N_{bc} is an integer greater than, or equal to, one.

In some embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality of entropy slices, wherein the size of each entropy slice may be restricted such that one, or more, of N_{ca} context-adaptation units and N_{bc} bin-coder units may each operate on no more than a limited number of bins during the processing of the entropy slice. Context-adaptation units and bin-coder units with such a restriction may be referred to as restricted entropy-coder units.

In some embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality of entropy slices, wherein the size of each entropy slice may be restricted such that none of the N_{ca} context-adaptation units may operate on more than B_{ca} bins during the processing of an entropy slice. In some embodiments of the present invention, the value of B_{ca} may be signaled, for example, in a bitstream, profile constraint, level constraint or other normative mechanism.

In alternative embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality of entropy slices, wherein the size of each entropy slice may

be restricted such that none of the N_{bc} bin-coder units may operate on more than B_{bc} bins during the processing of an entropy slice. In some embodiments of the present invention, the value of B_{bc} may be signaled, for example, in a bitstream, profile constraint, level constraint or other normative mechanism.

In yet alternative embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality of entropy slices, wherein the size of each entropy slice may be restricted such that none of the N_{ca} context-adaptation units may operate on more than B_{ca} bins and none of the N_{bc} bin-coder units may operate on more than B_{bc} bins during the processing of an entropy slice. In some embodiments of the present invention, the value of B_{bc} and the value of B_{ca} may be signaled, for example, in a bitstream, profile constraint, level constraint or other normative mechanism.

In still alternative embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality of entropy slices, wherein the size of each entropy slice may be restricted such that the ith N_{ca} context-adaptation unit, denoted $N_{ca}(i)$, for $i=1,...,N_{ca}$, may operate on no more than $B_{ca}(i)$ bins and the ith N_{bc} bin-coder unit, $N_{bc}(i)$, for $i=1,...,N_{bc}$, may operate on no more than $B_{bc}(i)$ bins during the processing of an entropy slice. In some embodiments of

the present invention, the values of the $B_{bc}(i)$ and the values of the $B_{ca}(i)$ may be signaled, for example, in a bitstream, profile constraint, level constraint or other normative mechanism.

Some exemplary embodiments of the present invention may be described in relation to Figure 20. In these embodiments, an encoder may, for a reconstruction slice, partition the reconstruction slice into a plurality of entropy slices, wherein the size of each entropy slice may be restricted such that one, or more, of N_{ca} context-adaptation units and N_{bc} bin-coder units may operate on no more than a limited number of bins. The encoder may initialize **650** to zero a counter, for each restricted entropy-coder unit, associated with the number of bins processed in a current entropy slice. For illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 20, the counter value may be denoted **A**, where **A** represents a vector with each entry in the vector corresponding to the accumulated number of processed bins, for the current entropy slice, by a restricted entropy-coder unit. The syntax elements for a next macroblock may be obtained **652**. The next macroblock may be determined according to a predefined macroblock processing order. In some embodiments, the macroblock processing order may correspond to a raster-scan ordering. Non-binary syntax

elements in the macroblock may be converted **654** to a string of bins. Binary syntax elements may not require conversion. The number of bins, associated with the macroblock, processed by each restricted entropy-coder unit may be determined **656**. The number of bins associated with the macroblock may include the bins in the strings of bins associated with the non-binary syntax elements in addition to the binary syntax elements. For illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 20, the number of bins, associated with the macroblock, processed by each restricted entropy-coder unit may be denoted num, where num represents a vector with each entry in the vector corresponding to the number of processed bins, for the current macroblock, by a restricted entropy-coder unit.

If the number of bins associated with the macroblock for each restricted entropy-coder unit may be added **658** to the number of already accumulated bins, associated with the current entropy slice, for each restricted entropy-coder unit, without **659** exceeding a maximum number of bins allowed for any restricted entropy-coder unit, then the number of accumulated bins associated with the current entropy slice may be updated **660** to include the bins associated with the macroblock, and the bins associated with the macroblock may be written **662**, by the entropy encoder, to the bitstream and

associated with the current entropy slice. The syntax elements for the next macroblock may be obtained **652**, and the partitioning process may continue.

If **658** the sum of the number of bins associated with the macroblock and the number of already accumulated bins associated with the current entropy slice exceeds **663** the maximum number of bins allowed for any restricted entropy-coder unit, then the encoder may start **664** a new entropy slice associated with the current reconstruction slice, and the counter associated with the number of bins in the current entropy slice may be initialized **666** to zero. The number of accumulated bins associated with the current entropy slice may be updated **660** to include the bins associated with the macroblock, and the bins associated with the macroblock may be written **662**, by the entropy encoder, to the bitstream and associated with the current entropy slice. The syntax elements for the next macroblock may be obtained **652**, and the partitioning process may continue.

Some embodiments of the present invention may be described in relation to Figure 21. In these embodiments, an encoder may, for a reconstruction slice, partition the reconstruction slice into a plurality of entropy slices, wherein the size of each entropy slice may be restricted such that one, or more, of N_{ca} context-adaptation units and N_{bc} bin-coder units may operate on no more than a limited number of bins.

The encoder may initialize **700** to zero a counter, for each restricted entropy-coder unit, associated with the number of bins processed in a current entropy slice by the restricted entropy-coder unit. For illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 21, the counter value may be denoted A, where Arepresents a vector with each entry in the vector corresponding to the accumulated number of processed bins, for the current entropy slice, by a restricted entropy-coder unit. In these embodiments, the encoder may associate macroblock syntax elements with an entropy slice until the number of bins processed by a restricted entropy-coder unit reaches a threshold associated with the predetermined maximum number of bins allowed to be processed, in an entropy slice, by the restricted entropy-coder unit. In some embodiments, the threshold may be a percentage of the maximum number of bins allowed to be processed, in an entropy slice, by the restricted entropy-coder unit. In one exemplary embodiment, the threshold may be 90% of the maximum number of bins allowed to be processed, in an entropy slice, by the restricted entropy-coder unit, supposing that the greatest number of bins expected in a macroblock to be processed by the restricted entropy-coder unit is less than 10% of the maximum number of bins allowed to be processed, in an

entropy slice, by the restricted entropy-coder unit. In another exemplary embodiment, the threshold may be a percentage of the maximum number of bins allowed to be processed, in an entropy slice, by a restricted entropy-coder unit wherein the percentage may be based on the greatest number of bins expected in a macroblock to be processed by the restricted entropy-coder unit. In these embodiments, once the size of an entropy slice exceeds a threshold size, then another entropy slice may be created. The threshold size may be selected to ensure that the entropy slice does not exceed the maximum number of bins allowed to be processed by any one restricted entropy-coder unit in an entropy slice. In some embodiments, the threshold size may be a function of the maximum number of bins allowed in an entropy slice and an estimate of the maximum number of bins expected for a macroblock.

The syntax elements for a next macroblock may be obtained **702**. The next macroblock may be determined according to a predefined macroblock processing order. In some embodiments, the macroblock processing order may correspond to a raster-scan ordering. Non-binary syntax elements in the macroblock may be converted **704** to a string of bins. Binary syntax elements may not require conversion. The bins associated with the macroblock may be written **706**, by the entropy encoder, to the bitstream and associated with

the current entropy slice. The number of bins, associated with the macroblock, processed by each restricted entropy-coder unit may be determined **708**. The number of bins associated with the macroblock may include the bins in the strings of bins associated with the non-binary syntax elements in addition to the binary syntax elements. For illustrative purposes in the remainder of the description of the embodiments of the present invention described in relation to Figure 21, the number of bins, associated with the macroblock, processed by each restricted entropy-coder unit may be denoted num, where num represents a vector with each entry in the vector corresponding to the number of processed bins, for the current macroblock, by a corresponding restricted entropy-coder unit. The number of accumulated bins, associated with the current entropy slice, processed by each restricted entropy-coder unit may be updated **710** to include the bins associated with the macroblock. If **712** the number of accumulated bins, associated with the current entropy slice, processed by a restricted entropy-coder unit is greater **714** than a threshold, which may be denoted $TH(MaxNumBins)(i)$ for restricted entropy-coder unit i, then the encoder may start **716** a new entropy slice, and initialize **718** to zero the counter associated with the number of bins processed by each restricted entropy-coder unit in a current entropy slice. The syntax elements for the next macroblock

may be obtained **702**, and the partitioning process may continue. If the number of accumulated bins, associated with the current entropy slice, processed by a restricted entropy-coder unit is not greater **713** than the threshold, then the syntax elements for the next macroblock may be obtained **702**, and the partitioning process may continue.

Some embodiments of the present invention may comprise a combination of the above-described criteria for entropy slice partitioning.

It is to be understood that while some embodiments of the present invention may restrict the size of an entropy slice to be less than a first predefined size, that the size of the entropy slice may be equivalently restricted to not exceed a second predefined size. The embodiments described herein are exemplary embodiments of the present invention, and a person of ordinary skill in the art will appreciate that there are equivalent embodiments of the present invention for restricting the size of an entropy slice.

In some embodiments of the present invention, starting a new entropy slice may comprise terminating the current slice and considering the new entropy slice the current entropy slice.

In some embodiments of the present invention, the decoding of a plurality of bits within an entropy slice may be parallelized within an entropy decoder comprising a plurality

of bin decoders, which may reduce decoding time. Exemplary embodiments of the present invention may be understood in relation to an exemplary entropy decoder **750**, depicted in Figure 22, comprising a plurality (three shown) of bin decoders **762**, **764**, **766**. Bits **752** within an entropy slice and previously decoded symbols **754** may be made available to an entropy decoder **750**. The bits **752** may be made available to a bin-decoder selector **756** which may select a bin decoder, based on a context state **758** generated from a context-adaptation unit **760**, among the bin decoders **762**, **764**, **766**. The context-adaptation unit **760** may generate the context state **758** based on the previously decoded symbols **754** made available to the context-adaptation unit **760**. The bin-decoder selector **756** may assign a bin-decoder **762**, **764**, **766** based on the context state **758**. The bit to be decoded **752** may be passed by the bin-decoder selector **756** to the selected bin decoder. The bin decoders **762**, **764**, **766** may generate decoded bins **768**, **770**, **772** which may be multiplexed by a multiplexer **774** and the multiplexed bins **776** may be sent to a symbolizer **778** which may generate the symbols **754** associated with the bins **776**.

In some embodiments of the present invention, decoding of a plurality of bits within an entropy slice may be parallelized within an entropy decoder comprising a plurality of context-adaptation units, which may reduce decoding time.

Exemplary embodiments of the present invention may be understood in relation to an exemplary entropy decoder **800**, depicted in Figure 23, comprising a plurality (three shown) of context-adaptation units **814**, **816**, **818**. Bits **802** within an entropy slice and previously decoded symbols **810** may be made available to an entropy decoder **800**. The bits **802** may be made available to a context-adaptation unit selector **812** that may select from a plurality of context-adaptation units **814**, **816**, **818** a context-adaptation unit for the decoding process of an input bit. In some embodiments of the present invention, the context-adaptation unit selector **812** may select the Nth context-adaptation unit when receiving every Nth bit. The selected context-adaptation unit may generate a context state **820**, **822**, **824** based on the previously decoded symbols **810** made available to the selected context-adaptation unit. A state selector **826**, at the appropriate timing, may select the generated context state in associated with an input bit. In some embodiments of the present invention, state selector **826** may select the Nth context-adaptation unit when receiving every Nth bit according to the same procedure as the context-adaptation unit selector **812**. The selected state **828** may be made available to the bin decoder **804**. The bin decoder **804** may decode the bit **802** and send the decoded bin **806** to a symbolizer **808** which may generate a symbol **810** associated

with the decoded bin **806**.

In some embodiments of the present invention, decoding of a plurality of bits within an entropy slice may be parallelized within an entropy decoder comprising a plurality of context-adaptation units and a plurality of bin decoders, which may reduce decoding time. Exemplary embodiments of the present invention may be understood in relation to an exemplary entropy decoder **850**, depicted in Figure 24, comprising a plurality (three shown) of context-adaptation units **852**, **854**, **856** and a plurality (three shown) of bin decoders **858**, **860**, **862**. Bits **864** within an entropy slice and previously decoded symbols **866** may be made available to an entropy decoder **850**. The bits **864** may be made available to a context-adaptation unit selector **868** that may select from the plurality of context-adaptation units **852**, **854**, **856** a context-adaptation unit for the decoding process of an input bit. In some embodiments of the present invention, the context-adaptation unit selector **868** may select the Nth context-adaptation unit when receiving every Nth bit. The selected context-adaptation unit may generate a context state **870**, **872**, **874** based on the previously decoded symbols **866** made available to the selected context-adaptation unit. A state selector **876**, at the appropriate timing, may select the generated context state in associated with an input bit. In some embodiments of the present invention, state selector

876 may select the Nth context-adaptation unit when receiving every Nth bit according to the same procedure as the context-adaptation unit selector **868**. The selected state **878** may be made available to a bin-decoder selector **880**, which may select, based on the selected context state **878**, a bin decoder **858**, **860**, **862**. The bin-decoder selector **880** may assign a bin-decoder **858**, **860**, **862** based on the context state **878**. The bit to be decoded **864** may be passed by the bin-decoder selector **880** to the selected bin decoder. The bin decoders **858**, **860**, **862** may generate decoded bins **882**, **884**, **886** which may be multiplexed by a multiplexer **888** and the multiplexed bins **890** may be sent to a symbolizer **892** which may generate the symbols **866** associated with the bins **890**.

In some embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality of entropy slices, wherein the macroblocks within an entropy slice are contiguous. Figure 25 depicts an exemplary reconstruction slice **950** partitioned into three entropy slices: entropy slice 0 shown in cross-hatch **952**, entropy slice 1 shown in white **954** and entropy slice 2 shown in dot-hatch **956**. The macroblocks within each entropy slice **952**, **954**, **956**, in this exemplary reconstruction slice **950**, are contiguous.

In alternative embodiments of the present invention, an encoder may partition a reconstruction slice into a plurality

of entropy slices, wherein the macroblocks within an entropy slice may not be contiguous. Figure 26 depicts an exemplary reconstruction slice **960** partitioned into three entropy slices: entropy slice 0 shown in cross-hatch **962**, entropy slice 1 shown in white **964** and entropy slice 2 shown in dot-hatch **966**. The macroblocks within each entropy slice **962**, **964**, **966**, in this exemplary reconstruction slice **960**, are not contiguous. A partition of a reconstruction slice in which the macroblocks within an entropy slice are not contiguous may be referred to as an interleaved partition.

In some embodiments of the present invention, during the entropy decoding of a current block within an entropy slice, the decoder may use other blocks from the same entropy slice to predict information related to the entropy decoding of the current block. In some embodiments of the present invention, during reconstruction of a current block within a reconstruction slice, other blocks from the same reconstruction slice may be used to predict information related to the reconstruction of the current block.

In some embodiments of the present invention in which a reconstruction slice comprises an interleaved partition, neighboring blocks within an entropy slice used in the decoding of a current block within the entropy slice may not be directly neighboring, or contiguous. Figure 27 illustrates this situation for the exemplary interleaved partition depicted

in Figure 26.

In Figure 27, for a current block **970** within an entropy slice **964**, the left-neighbor block used for entropy decoding of the current block **970** is the contiguous, left-neighbor block **972** within the entropy slice **964**. The upper-neighbor block used for entropy decoding of the current block **970** is the non-contiguous, upper-neighbor block **974** within the same entropy slice **964**. For reconstruction of the current block **970**, the left-neighbor block is the contiguous, left-neighbor block **972** within the reconstruction slice **960**, and the upper-neighbor block is the contiguous, upper-neighbor block **976** within the reconstruction slice **960**.

In some embodiments of the present invention in which a reconstruction slice comprises an interleaved partition, there may be no appropriate neighboring block within an entropy slice to be used in the decoding of a current block within the entropy slice. Figure 28 illustrates this situation for the exemplary interleaved partition depicted in Figure 26.

In Figure 28, for a current block **980** within an entropy slice **964**, there is no left-neighbor block within the entropy slice **964** to be used for entropy decoding of the current block **980**. The upper-neighbor block used for entropy decoding of the current block **980** is the non-contiguous, upper-neighbor block **982** within the same entropy slice **964**. For reconstruction of the current block **980**, the left-neighbor

block is the contiguous, left-neighbor block **984** within the reconstruction slice **960**, and the upper-neighbor block is the contiguous, upper-neighbor block **986** within the reconstruction slice **960**.

In some embodiments of the present invention, a decoder may pre-process a complete incoming bitstream to identify the locations of the entropy slices. In some embodiments of the present invention, a decoder may pre-process an entire reconstruction slice to identify the locations of the entropy slices within the reconstruction slice. In some embodiments, the locations of the entropy slices may be determined by identifying the locations of the entropy-slice headers. In these embodiments, the decoder may read the bits in the bitstream and pre-defined start-code values may be identified.

In alternative embodiments, entropy-slice headers may be constrained to a range of bits located at pre-defined positions within an incoming bitstream. In alternative embodiments, entropy-slice headers may be constrained to a range of bytes located at pre-defined positions within an incoming bitstream. In these embodiments, either bit aligned or byte aligned, a decoder need not pre-process significantly large portions of the incoming bitstream to locate the entropy slices.

In some embodiments of the present invention, an encoder may signal, in the bitstream, entropy-slice-location

information, also referred to as entropy-slice-location parameters, for example, offset and range information, that may constrain the locations of the entropy-slice headers. In alternative embodiments, entropy-slice-location information may not be signaled in the bitstream, but may be determined from entropy-slice parameters, for example, a fixed number of bins allowed in any given entropy slice, a fixed number of bits allowed in any given entropy slice and other entropy-slice parameters. In still alternative embodiments of the present invention, entropy-slice-location information may be defined by other normative means, for example, the information may be specified in a profile constraint, a level constraint, an application constraint, or other constraint, or the information may be signaled as supplemental information or signaled by other out-of-bound means.

In some embodiments of the present invention, one set of entropy-slice-location parameter values may be used for all entropy slices within a bitstream. In alternative embodiments, entropy-slice-location parameter values may be defined for a group of pixels represented by a portion of a sequence. In alternative embodiments, entropy-slice-location parameter values may be defined for each picture within a bitstream and may be used for all entropy slices within the associated picture. In alternative embodiments, entropy-slice-location parameter values may be defined for each reconstruction slice

within a bitstream and may be used for all entropy slices within the associated reconstruction slice. In yet alternative embodiments, multiple sets of entropy-slice-location parameter values may be used by the decoder. In still alternative embodiments, entropy-slice-location parameter values may be assigned to entropy-slice identifiers, for example, a first entropy-slice header may use a first set of entropy-slice-location parameter values, a second entropy-slice header may use a second set of entropy-slice-location parameter values and, in general, an Nth entropy-slice header may use an Nth set of entropy-slice-location parameter values. In some embodiments of the present invention, entropy-slice-parameter values may be assigned to frame identifiers. In one exemplary embodiment, a first picture may use a first set of entropy-slice-parameter values, a second picture may use a second set of entropy-slice-parameter values and, in general, an Nth picture may use an Nth set of entropy-slice-location parameter values. In another exemplary embodiment, a picture of a first type may use a first set of entropy-slice-location parameter values and a picture of a second type may use a second set of entropy-slice-location parameter values. Exemplary types of pictures are intra pictures, predicted pictures and other types of pictures.

In some embodiments of the present invention comprising an H.264/AVC codec, an entropy-slice offset and

an entropy-slice range may be signaled in a sequence parameter set Raw Byte Sequence Payload (RBSP) by adding an "entropy_slice_offset" parameter and an "entropy_slice_range" to the sequence parameter set. Table 3 lists exemplary sequence parameter set RBSP syntax according to embodiments of the present invention.

In some embodiments of the present invention comprising an H.264/AVC codec, an entropy-slice offset and an entropy-slice range may be signaled in a picture parameter set Raw Byte Sequence Payload (RBSP) by adding an "entropy_slice_offset" parameter and an "entropy_slice_range" to the picture parameter set. Table 4 lists exemplary picture parameter set RBSP syntax according to embodiments of the present invention.

In some embodiments of the present invention comprising an H.264/AVC codec, an entropy-slice offset and an entropy-slice range may be signaled in a slice header by adding an "entropy_slice_offset" parameter and an "entropy_slice_range" to the slice header. Table 5 lists exemplary slice header syntax according to embodiments of the present invention.

In some embodiments of the present invention, an entropy-slice offset and an entropy-slice range may be indicated for each level conformance point of the encoder according to a table, for example, as shown in Table 6, where

$O_{m.n}$ denotes the entropy-slice offset for a level $m.n$ conformance point and $R_{m.n}$ denotes the entropy-slice range for a $m.n$ conformance point.

seq_parameter_set_rbsp( ) {	C	Descriptor
profile_idc	0	u(8)
reserved_zero_8bits /* equal to 0 */	0	u(8)
level_idc	0	u(8)
seq_parameter_set_id	0	ue(v)
bit_depth_luma_minus8	0	ue(v)
bit_depth_chroma_minus8	0	ue(v)
increased_bit_depth_luma	0	ue(v)
increased_bit_depth_chroma	0	ue(v)
log2_max_frame_num_minus4	0	ue(v)
log2_max_pic_order_cnt_lsb_minus4	0	ue(v)
max_num_ref_frames	0	ue(v)
gaps_in_frame_num_value_allowed_flag	0	u(1)
log2_min_coding_unit_size_minus3	0	ue(v)
max_coding_unit_hierarchy_depth	0	ue(v)
log2_min_transform_unit_size_minus2	0	ue(v)
max_transform_unit_hierarchy_depth	0	ue(v)
pic_width_in_luma_samples	0	u(16)
pic_height_in_luma_samples	0	u(16)
entropy_slice_offset	0	ue(v)
entropy_slice_range	0	ue(v)
rbsp_trailing_bits( )	0	
}		

Table 3: Exemplary Sequence Parameter Set RBSP Syntax Table

pic_parameter_set_rbsp( ) {	C	Descriptor
pic_parameter_set_id	1	ue(v)
seq_parameter_set_id	1	ue(v)
entropy_coding_mode_flag	1	u(1)
num_ref_idx_l0_default_active_minus1	1	ue(v)
num_ref_idx_l1_default_active_minus1	1	ue(v)
pic_init_qp_minus26 /* relative to 26 */	1	se(v)
constrained_intra_pred_flag	1	u(1)

entropy_slice_offset	0	ue(v)
entropy_slice_range	0	ue(v)
rbsp_trailing_bits( )	1	
}		

Table 4: Exemplary Picture Parameter Set RBSP Syntax

Table

slice_header( ) {	C	Descriptor
first_lctb_in_slice	2	ue(v)
entropy_slice_flag		u(1)
if (!entropy_slice_flag){		
slice_type	2	ue(v)
pic_parameter_set_id	2	ue(v)
frame_num	2	u(v)
if(IdrPicFlag)		
idr_pic_id	2	ue(v)
pic_order_cnt_lsb	2	u(v)
if(slice_type = = P | | slice_type = = B) {		
num_ref_idx_active_override_flag	2	u(1)
if(num_ref_idx_active_override_flag) {		
num_ref_idx_l0_active_minus1	2	ue(v)
if(slice_type = = B)		
num_ref_idx_l1_active_minus1	2	ue(v)
}		
}		
if(nal_ref_idc != 0)		
dec_ref_pic_marking( )	2	
if(entropy_coding_mode_flag && slice_type != I)		
cabac_init_idc	2	ue(v)
slice_qp_delta	2	se(v)
alf_param()		
if(slice_type = = P | | slice_type = = B) {		
mc_interpolation_idc	2	ue(v)
mv_competition_flag	2	u(1)
if (mv_competition_flag) {		
mv_competition_temporal_flag	2	u(1)
}		
}		

if (slice_type = = B && mv_competition_flag)		
collocated_from_l0_flag	2	u(1)
} else		
if (entropy_coding_mode_flag && slice_type != I)		
cabac_init_idc		ue(v)
entropy_slice_offset	0	ue(v)
entropy_slice_range	0	ue(v)
}		

Table 5: Exemplary Syntax Table for Slice Header

Level	Entropy Slice Offset	Entropy Slice Range
1.1	$O_{1.1}$	$R_{1.1}$
1.2	$O_{1.2}$	$R_{1.2}$
:	:	:
m.n	$O_{m.n}$	$R_{m.n}$
:	:	:
5.1	$O_{5.1}$	$R_{5.1}$

Table 6: Exemplary Entropy-Slice Offset and Entropy-Slice Range for Each Level

In some embodiments, entropy-slice-location information may comprise information that may constrain the locations of the entropy-slice headers. In one example, entropy-slice-location information may comprise an offset, also referred to as a period or base offset, value and a range, also referred to as a deviation or offset for a period, value. An entropy-slice-header location may be constrained based on the offset value and the range value.

In some embodiments of the present invention, an offset value and a range value may be defined explicitly. In alternative embodiments of the present invention, an offset value and a range value may be implicitly defined as a minimum offset value and a maximum offset value. In still alternative embodiments of the present invention, an offset value and a range value may be implicitly defined as a maximum offset value and the difference between the maximum offset value and a minimum offset value. In yet alternative embodiments of the present invention, an offset value and a range value may be implicitly defined as a minimum offset value and the difference between the minimum offset value and a maximum offset value. In alternative embodiments, an offset value and a range value may be implicitly defined as a third value and the difference between the third value and a maximum offset value and a minimum offset value. In still alternative embodiments, an offset value and a range value may be defined through an index into a look-up table that contains the corresponding minimum and maximum bit-values. In some embodiments, an offset value and a range value may be defined using an offset based look-up tree. In some embodiments, an offset value and a range value may be defined using cost-minimizing indexing. A person having ordinary skill in the art will recognize that there are many methods known in the art for

implicitly defining a range value and an offset value and for assuring that an encoder and a decoder operate with the same value for the pre-defined offset and range values.

In some embodiments of the present invention, signaling a range value may be optional. In some embodiments, when a range value is not signaled, then the range value may be set to a pre-defined value. In an exemplary embodiment, the pre-defined value may be zero. In another exemplary embodiment, the pre-defined value may be a non-zero integer value.

In an exemplary embodiment described in relation to Figure 29, the entropy-slice header associated with an entropy slice, slice number N within a reconstruction slice, may be constrained to start after $Nk-p$ bits from the start of, or other fixed location within, the reconstruction-slice header, where k denotes the offset value and p denotes the range. The location from which the $Nk-p$ bits may be measured may be referred to as the reference location. In alternative embodiments, a reference location may not be associated with a particular reconstruction slice and may be the same fixed location within a bitstream for all entropy slices. In alternative embodiments, the entropy-slice header may be byte aligned, and the constraint may be associated with a number of bytes. While the example illustrated in relation to Figure 29 is described in terms of bits, a person having ordinary skill in the art may appreciate the alternative byte-

aligned embodiments.

Figure 29 is a pictorial representation of an exemplary portion **1000** of an exemplary bitstream. The bitstream portion **1000** comprises a reconstruction-slice header **1002**, represented by a solid black rectangle, four entropy-slice headers (the entropy-slice header corresponding to the zeroth entropy slice **1003**, referred to as the zeroth entropy-slice header, the entropy-slice header corresponding to the first entropy slice **1004**, referred to as the first entropy-slice header, the entropy-slice header corresponding to the second entropy slice **1005**, referred to as the second entropy-slice header, the entropy-slice header corresponding to the third entropy slice **1006**, referred to as the third entropy-slice header), represented by solid gray rectangles, and remaining portions of the entropy slices, represented by thin, black-and-white stripes. In this example, the reference location may be the start **1001** of the reconstruction-slice header **1002.** In some embodiments of the present invention, the entropy-slice header corresponding to the zeroth entropy slice **1003** may be constrained to be located immediately after the reconstruction-slice header **1002**. In some embodiments of the present invention, the entropy-slice header corresponding to the zeroth entropy slice may be a part of the reconstruction-slice header. That is to say, the reconstruction-slice header can also serve as the entropy-

slice header corresponding to the zeroth entropy slice. In these embodiments, the reconstruction-slice header may comprise a reconstruction portion and an entropy portion. In some embodiments of the present invention depicted in Figure 29, the first entropy-slice header **1004** may be constrained to be located after $k-p$ bits **1007** from the reference location **1001**, the second entropy-slice header **1005** may be constrained to be located after $2k-p$ bits **1008** from the reference location **1001**, the second entropy-slice header **1006** may be constrained to be located after $3k-p$ bits **1009** from the reference location **1001**. In these embodiments, an entropy decoder assigned to decode entropy slice N may begin searching for the corresponding entropy-slice header after $Nk-p$ bits from the reference location **1001**.

In alternative embodiments of the present invention, the entropy-slice-location information may not comprise a range parameter. In these embodiments, an entropy decoder may begin searching for the Nth entropy-slice header after Nk bits from a reference location.

In another exemplary embodiment described in relation to Figure 30, the entropy-slice header associated with entropy slice, slice number N within a reconstruction slice, may be constrained to start after $Nk-p$ bits from the start of, or other fixed location within, the reconstruction-slice header, where k denotes the offset value and p denotes the range, and

the entropy-slice header may further be constrained to be within a $2p$ range of bits from the constrained starting location. The location from which the $Nk-p$ bits may be measured may be referred to as the reference location. In alternative embodiments, a reference location may not be associated with a particular reconstruction slice and may be the same fixed location within a bitstream for all entropy slices. In alternative embodiments, the entropy-slice header may be byte aligned, and the constraint may be associated with a number of bytes. While the example illustrated in relation to Figure 30 is described in terms of bits, a person having ordinary skill in the art may appreciate the alternative byte-aligned embodiments.

Figure 30 is a pictorial representation of an exemplary portion **1020** of an exemplary bitstream. The bitstream portion **1020** comprises a reconstruction-slice header **1022**, represented by a solid black rectangle, four entropy-slice headers (the entropy-slice header corresponding to the zeroth entropy slice **1023**, referred to as the zeroth entropy-slice header, the entropy-slice header corresponding to the first entropy slice **1024**, referred to as the first entropy-slice header, the entropy-slice header corresponding to the second entropy slice **1025**, referred to as the second entropy-slice header, the entropy-slice header corresponding to the third entropy slice **1026**, referred to as the third entropy-slice

header), represented by solid gray rectangles, and remaining portions of the entropy slices, represented by thin, black-and-white stripes. In this example, the reference location may be the start **1021** of the reconstruction-slice header **1022.** In some embodiments of the present invention, the entropy-slice header corresponding to the zeroth entropy slice **1023** may be constrained to be located immediately after the reconstruction-slice header **1022**. In some embodiments of the present invention, the entropy-slice header corresponding to the zeroth entropy slice may be a part of the reconstruction-slice header. In these embodiments, the reconstruction-slice header may comprise a reconstruction portion and an entropy portion. In some embodiments of the present invention depicted in Figure 30, the first entropy-slice header **1024** may be constrained to be located within $2p$ bits **1031** after $k-p$ bits **1027** from the reference location **1021**, the second entropy-slice header **1025** may be constrained to be located within $2p$ bits **1032** after $2k-p$ bits **1028** from the reference location **1021**, the second entropy-slice header **1026** may be constrained to be located within $2p$ bits **1033** after $3k-p$ bits **1029** from the reference location **1021**. In these embodiments, an entropy decoder assigned to decode entropy slice N may begin searching for the corresponding entropy-slice header after $Nk-p$ bits from the reference location and may terminate the search after

identifying the entropy-slice header or after searching 2^p bits .

Some embodiments of the present invention may be described in relation to Figure 31. In these embodiments, an entropy decoder may receive **1050** an entropy-slice number indicating the number of the entropy slice in the current reconstruction block to entropy decode. The entropy decoder may determine **1052** the entropy-slice-location information. In some embodiments of the present invention, the entropy-slice-location information, also referred to as entropy-slice-location parameters, may be signaled in the bitstream, and the decoder may determine **1052** the entropy-slice information by examining the bitstream. In alternative embodiments, the entropy-slice-location information may not be signaled in the bitstream, but may be determined **1052**, by the decoder, from entropy-slice parameters, for example, a fixed number of bins allowed in any given entropy slice, a fixed number of bits allowed in any given entropy slice and other entropy-slice parameters. In still alternative embodiments of the present invention, the entropy-slice-location information may be defined and determined **1052** by other normative means, for example, the information may be specified in a profile constraint, a level constraint, an application constraint, or other constraint, or the information may be signaled as supplemental information or signaled by

other out-of-bound means.

The entropy decoder may calculate **1054** an entropy-slice-search start location at before which, in the bitstream, the entropy-slice header is restricted from having been written by the encoder. In some embodiments of the present invention, the entropy-slice-search start location may be calculated **1054** using an offset value and a range value determined from the entropy-slice-location information. In alternative embodiments of the present invention, the entropy-slice-search start location may be calculated **1054** using an offset value determined from the entropy-slice-location information. The entropy decoder may advance **1056**, in the bitstream, to the entropy-slice-search start location, and may examine **1058** the bitstream for an entropy-slice header. In some embodiments of the present invention, an entropy-slice header may be indicated by a start code.

Some embodiments of the present invention may be described in relation to Figure 32. In these embodiments, an entropy decoder may receive **1070** an entropy-slice number indicating the number of the entropy slice in the current reconstruction block to entropy decode. The entropy decoder may determine **1072** the entropy-slice-location information. In some embodiments of the present invention, the entropy-slice-location information, also referred to as entropy-slice-location parameters, may be signaled in the bitstream, and

the decoder may determine **1072** the entropy-slice information by examining the bitstream. In alternative embodiments, the entropy-slice-location information may not be signaled in the bitstream, but may be determined **1072**, by the decoder, from entropy-slice parameters, for example, a fixed number of bins allowed in any given entropy slice, a fixed number of bits allowed in any given entropy slice and other entropy-slice parameters. In still alternative embodiments of the present invention, the entropy-slice-location information may be defined and determined **1072** by other normative means, for example, the information may be specified in a profile constraint, a level constraint, an application constraint, or other constraint, or the information may be signaled as supplemental information or signaled by other out-of-bound means.

The entropy decoder may calculate **1074** an entropy-slice-search start location before which, in the bitstream, the entropy-slice header is restricted from having been written by the encoder. In some embodiments of the present invention, the entropy-slice-search start location may be calculated **1074** using an offset value and a range value determined from the entropy-slice-location information. In alternative embodiments of the present invention, the entropy-slice-search start location may be calculated **1074** using an offset value determined from the entropy-slice-location information.

The entropy decoder may advance **1076**, in the bitstream, to the entropy-slice-search start location and may examine **1078** the bitstream for an entropy-slice header. In some embodiments of the present invention, an entropy-slice header may be indicated by a start code.

The bits, in the bitstream, may be examined **1078** in sequence starting at said entropy-slice-search start location. If **1080** an entropy-slice header is identified **1081**, then the entropy decoder may entropy decode **1082** the entropy slice associated with the identified entropy-slice header. If **1080** an entropy-slice header is not identified **1083**, then the entropy decoder may terminate **1084** the search. In some embodiments, the entropy decoder may indicate an error when no entropy-slice header is identified **1083**.

Some embodiments of the present invention may be described in relation to Figure 33. In these embodiments, an entropy decoder may receive **1100** an entropy-slice number indicating the number of the entropy slice, in the current reconstruction, block to entropy decode. The entropy decoder may determine **1102** the entropy-slice-location information. In some embodiments of the present invention, the entropy-slice-location information, also referred to as entropy-slice-location parameters, may be signaled in the bitstream, and the decoder may determine **1102** the entropy-slice information by examining the bitstream. In alternative

embodiments, the entropy-slice-location information may not be signaled in the bitstream, but may be determined **1102**, by the decoder, from entropy-slice parameters, for example, a fixed number of bins allowed in any given entropy slice, a fixed number of bits allowed in any given entropy slice and other entropy-slice parameters. In still alternative embodiments of the present invention, the entropy-slice-location information may be defined and determined **1102** by other normative means, for example, the information may be specified in a profile constraint, a level constraint, an application constraint, or other constraint, or the information may be signaled as supplemental information or signaled by other out-of-bound means.

The entropy decoder may calculate **1104** an entropy-slice-search start location before which, in the bitstream, the entropy-slice header is restricted from having been written by the encoder. In some embodiments of the present invention, the entropy-slice-search start location may be calculated **1104** using an offset value and a range value determined from the entropy-slice-location information. In alternative embodiments of the present invention, the entropy-slice-search start location may be calculated **1104** using an offset value determined from the entropy-slice-location information. The entropy decoder may advance **1106**, in the bitstream, to the entropy-slice-search start location and may examine **1108**

the bitstream for an entropy-slice header. In some embodiments of the present invention, an entropy-slice header may be indicated by a start code.

The bits, in the bitstream, may be examined **1108** in sequence starting at said entropy-slice-search start location. If **1110** an entropy-slice header is identified **1111**, then the entropy decoder may entropy decoder **1112** the entropy slice associated with the identified entropy-slice header. If **1110** an entropy-slice header is not identified **1113**, then if **1114** a search criterion is satisfied **1115**, the entropy decoder may terminate **1116**. The search criterion may provide a standard by which a determination may be made as to whether, or not, valid locations for the start of entropy-slice header remain to be searched. In some embodiments (not shown), a search criterion may be satisfied if valid locations remain to be examined. In alternative embodiments, a search criterion may be satisfied if there are no valid locations remaining to be examined **1115**, and the search may terminate **1116**. In some embodiments, the entropy decoder may indicate an error when no entropy-slice header is identified **1115**. If **1114** the search criterion is not satisfied **1117**, the examination **1108** of the bitstream may continue after advancing **1118**, in the bitstream to the next search location.

In some embodiments of the present invention, the search criterion may be related to a range value, for example,

the location of the start of an entropy-slice header may be restricted to a range of $2p$ bits centered at Nk, where k denotes the offset value, p denotes the range value and N is the entropy slice number within a reconstruction slice. In these embodiments, the location of the start of the entropy-slice header associated with entropy slice N may be restricted to the range $Nk-p$ to $Nk+p$. In some embodiments, the search criterion may be related to a restriction, or restrictions, on the size of an entropy slice. In some embodiments, the search criterion may be related to a combination of restrictions.

In some embodiments of the present invention, an encoder may pad an entropy slice in order to meet a restriction on the location of the next entropy-slice header.

In some embodiments of the present invention, an encoder may terminate an entropy slice prior to other entropy-slice size restrictions being met in order to meet a restriction on the location of the next entropy-slice header.

In some embodiments of the present invention, when the last entropy slice within a reconstruction slice does not contain the number of bits (or bytes, in a byte-aligned embodiment) necessary to satisfy the constraint on the location of the next entropy-slice header, an encoder may pad the last entropy slice within the reconstruction slice to satisfy the constraint on the location of the next entropy-slice header.

In alternative embodiments, an entropy-slice header may comprise a last-entropy-slice flag, wherein the value of the last-entropy-slice flag may indicate whether or not the entropy slice associated with the entropy-slice header is the last entropy slice in a reconstruction slice. In some embodiments, a last-entropy-slice flag value of zero may be associated with the last entropy slice. In alternative embodiments, a last-entropy-slice flag value of one may be associated with the last entropy slice. In some embodiments, when the value of the last-entropy-slice flag indicates that the entropy slice is the last entropy slice in a reconstruction slice, then the subsequent entropy-slice header may be located immediately following the current entropy slice without padding.

Table 7 shows exemplary syntax and semantics for signaling a last-entropy-slice flag, referred to as a "next_entropy_slice_flag." In an exemplary embodiment comprising the exemplary syntax and semantics shown in Table 7, the "next_entropy_slice_flag" flag signals if there are additional entropy slices for a current reconstruction slice. If the "next_entropy_slice_flag" flag indicates that there are no additional entropy slices for the current reconstruction slice, then the location of the next entropy-slice header in the bitstream may not be constrained by the entropy-slice-location parameters.

In some embodiments of the present invention, the location of entropy-slice headers may be organized in a tree format with the root node pointing to an entropy-slice header location. In some embodiments, the entropy-slice header location pointed to by the root node may be relative. In alternative embodiments, the entropy-slice header location pointed to by the root node may be absolute. The remaining nodes of the tree may contain offset distances with respect to their parent node. The tree may be designed according to a design constraint, for example, to reduce an average time for determining entropy-slice header location, to bound a worst-case time required for determining entropy-slice header location, to signal a preferred order of entropy slice decoding, to minimize a storage cost for the tree and other design constraints. In some embodiments, the number of children of each node in the tree may be controlled based on a desired level of parallelism in entropy-slice header location determination.

slice_header( ) {	C	Descriptor
entropy_slice_flag	2	u(1)
next_entropy _slice_flag	2	ue(v)
if (entropy_slice_flag) {		
first_mb_in_slice	2	ue(v)
if(entropy_coding_mode_flag && slice_type != I && slice_type != SI)		
cabac_init_idc	2	ue(v)
}		
}		

else {		
a regular slice header		
}		
}		

Table 7: Exemplary Syntax Table for Last-Entropy-Slice Flag

In some embodiments of the present invention, the context models may be reset within an entropy slice whenever a context-model-reset condition is met. In some of these embodiments, the values to which the context models may be reset may be based on the context model of a neighboring elementary unit within the entropy slice, and if the neighboring elementary unit is not within the entropy slice, then default values may be used. In alternative embodiments, the context models may be reset to default values. In yet alternative embodiments, the context models may be reset based on a context model whose identifier may be signaled within the bitstream, said identifier indicating one of a plurality of predefined context models. A predefined context model may depend on one, or more, parameters in the bitstream. In exemplary embodiments, the context models may be reset based on a signaled "cabac_init_idc" value, within the bitstream, indicating one of a plurality of predefined context models.

In some embodiments, a context table may be used to initialize a plurality of context models, wherein a context

table refers to a set of context models. In some embodiments, the set of context models in a context table may undergo adaptation based on one, or more, parameters in the bitstream, for example, a quantization parameter, a slice type parameter or other parameter.

In one exemplary embodiment illustrated in Figure 34, the context models may be reset, within an entropy slice, when a current macroblock is the first macroblock in a row, in addition to being reset at the starting macroblock in an entropy slice. Figure 34 depicts an exemplary reconstruction slice **1200** containing 48 macroblocks **1208**-**1255** partitioned into three entropy slices: entropy slice "0" (shown in cross-hatch) **1202**, entropy slice "1" (shown in white) **1204** and entropy slice "2" (shown in dot-hatch) **1206**. Entropy slice "0" **1202** contains 15 macroblocks **1208**-**1222**. Entropy slice "1" **1204** contains 17 macroblocks **1223**-**1239**, and entropy slice "2" **1206** contains 16 macroblocks **1240**-**1255**. The macroblocks at which the context models may be reset are indicated with a thick black edge **1260**-**1266** and are those macroblocks **1208**, **1223**, **1240** at the start of each entropy slice and the first macroblock in each row **1216**, **1224**, **1232**, **1240**, **1248**.

The elementary unit, for example, the macroblock, at the start of an entropy slice may be referred to as the slice-start elementary unit. For example, for the entropy slices **1202**,

1204, **1206** in the exemplary reconstruction slice **1200** in Figure 34, the respective slice-start elementary units are **1208**, **1223** and **1240**. An elementary unit that is the first elementary unit in a row in an entropy slice may be referred to as a row-start elementary unit, for example, macroblocks **1208**, **1216**, **1224**, **1232**, **1240** and **1248** in Figure 34.

In some embodiments, the context models may be reset based on the context models of a neighboring macroblock if the neighboring macroblock is within the entropy slice and default values if the neighboring macroblock is not within the entropy slice. For example, the context models may be reset based on the context models of the macroblock above the current macroblock if the macroblock above the current macroblock is in the same entropy slice, but set to default values if the macroblock above the current macroblock is not in the same entropy slice.

In another exemplary embodiment, the context models may be reset, within an entropy slice, when a current elementary unit is the first elementary unit in a row. In alternative embodiments, the context-model-reset condition may be based on other criteria, for example, the number of bins processed within the entropy slice, the number of bits processed within the slice, the spatial location of the current elementary unit and other criterion.

In some embodiments of the present invention, a

context-model-reset flag may be used to indicate whether or not the context models may be reset within an entropy slice whenever a context-model-reset condition is met. In some embodiments, the context-model-reset flag may be in the entropy-slice header. In alternative embodiments, the context-model-reset flag may be in the reconstruction-slice header. In some embodiments, the context-model-reset flag may be a binary flag, and the context-model-reset condition may be a default condition. In alternative embodiments, the context-model-reset flag may by a multi-valued flag further indicating the context-model-reset condition.

In one exemplary embodiment comprising context-adaptive coding, for example, CABAC coding, CAV2V coding and other context-adaptive coding, an "lcu_row_cabac_init_flag" flag may signal if entropy decoding may be initialized at the start of the largest coding unit (LCU) row. In some embodiments, an LCU is a generalization of the macroblock concept used in H.264 to high efficiency video coding (HEVC), and a picture is divided into slices, wherein a slice is made up of a sequence of LCUs. In alternative embodiments, an LCU is the largest block of pixel value locations that may be represented with a single, transmitted mode value. In alternative embodiments, an LCU is the largest block of pixel value locations that may be represented with a single, transmitted prediction mode value. In some

embodiments of the present invention, an "lcu_row_cabac_init_flag" flag value of "1" may signal that the entropy coding context is reset. An entropy coding context may represent the set of all context models associated with an entropy coder. In some embodiments of the present invention, an "lcu_row_cabac_init_flag" flag value of "1" may signal that the entropy coding context is reset and the adaptive scanning is reset. Adaptive scanning may refer to a process in which a codec adapts a scan ordering of transform coefficients based on previously transmitted transform coefficient values. In one embodiment, the scan ordering is determined by generating a coefficient significance map, and the transform coefficient values corresponding to coefficient significance values larger than a pre-determined value may be transmitted prior to the transform coefficient values corresponding to coefficient significance values less than or equal to the pre-determined value. In one embodiment, the coefficient significance values that correspond to transform coefficient values that are greater than a pre-determined value may subsequently be increased. In an alternative embodiment, the coefficient significance values that correspond to transform coefficient values that are less than or equal to a pre-determined value may subsequently be decreased. The adaptive scanning process may be reset by setting the coefficient significant map to a pre-defined value. In some embodiments, the default

value, assumed when the flag is not sent, for the "lcu_row_cabac_init_flag" flag may be "0." An "lcu_row_cabac_init_idc_flag" flag may signal if cabac_init_idc values will be transmitted at the start of each LCU row. In some embodiments, when the value of the "lcu_row_cabac_init_idc_flag" flag is "1" values will be transmitted at the start of each LCU row. In some embodiments, the default value, assumed when the flag is not sent, for the "lcu_row_cabac_init_idc_flag" flag may be "0." In some embodiments, a "cabac_init_idc_present_flag" flag may signal if a cabac_init_idc value is transmitted for the LCU. In some embodiments, when a cabac_init_idc value is not transmitted for the LCU then the entropy coding context is reset using the preceding value for cabac_init_idc in the bit-stream. In some embodiments of the present invention, "lcu_row_cabac_init_flag" and "lcu_row_cabac_init_idc_flag" may be signaled in a regular slice header, for example, when the value of "entropy_slice_flag" is "0". Table 8 and Table 9 show exemplary syntax for these embodiments. In some embodiments of the present invention, "lcu_row_cabac_init_flag" and "lcu_row_cabac_init_idc_flag" may be signaled in a entropy-slice header, for example, when the value of "entropy_slice_flag" is "1". Table 8 shows exemplary slice header syntax, and Table 9 shows exemplary slice data syntax (coding_unit).

slice_header( ) {	C	Descriptor
entropy_slice_flag	2	u(1)
if (entropy_slice_flag) {		
first_lcu_in_slice	2	ue(v)
if (entropy_coding_mode_flag) {		
lcu_row_cabac_init_flag	1	u(1)
if(lcu_row_cabac_init_flag){		
lcu_row_cabac_init_idc_flag	1	u(1)
}		
}		
if(entropy_coding_mode_flag && slice_type != I) {		
cabac_init_idc	2	ue(v)
}		
}		
else {		
lcu_row_cabac_init_flag	1	u(1)
if(lcu_row_cabac_init_flag){		
lcu_row_cabac_init_idc_flag	1	u(1)
}		
a regular slice header		
}		
}		

Table 8: Exemplary Syntax Table for Signaling the Initialization of Entropy Coding at the Start of the LCU Row

coding_unit(x0, y0, currCodingUnitSize) {	C	Descriptor
if (x0==0 && currCodingUnitSize==MaxCodingUnitSize && lcu_row_cabac_init_idc_flag==true && lcu_id!=first_lcu_in_slice) {		
cabac_init_idc_present_flag	1	u(1)
if(cabac_init_idc_present_flag)		
cabac_init_idc	2	ue(v)
}		
a regular coding unit ...		
}		

Table 9: Exemplary Syntax Table for Signaling the Initial Context for the LCU

In another exemplary embodiment comprising context-adaptive coding, for example, CABAC coding, CAV2V coding and other context-adaptive coding, an "mb_row_cabac_init_flag" flag may signal if entropy decoding may be initialized at the first macroblock in a row. In some embodiments of the present invention, an "mb_row_cabac_init_flag" flag value of "1" may signal that the entropy coding context is reset at the start of each macroblock row. In alternative embodiments of the present invention, an "mb_row_cabac_init_flag" flag value of "1" may signal that the entropy coding context is reset and the adaptive scanning is reset at the start of each macroblock row. In some embodiments, the default value, assumed when the flag is not sent, for the "mb_row_cabac_init_flag" flag may be "0." An "mb_row_cabac_init_idc_flag" flag may signal if

cabac_init_idc values will be transmitted at the start of each macroblock row. In some embodiments, when the value of the "mb_row_cabac_init_idc_flag" flag is "1" values will be transmitted at the start of each macroblock row. In some embodiments, the default value, assumed when the flag is not sent, for the "mb_row_cabac_init_idc_flag" flag may be "0." In some embodiments, a "cabac_init_idc_present_flag" flag may signal if a cabac_init_idc value is transmitted for the macroblock. In some embodiments, when a cabac_init_idc value is not transmitted for the macroblock, then the entropy coding context is reset using the preceding value for cabac_init_idc in the bit-stream. In some embodiments of the present invention, the "mb_row_cabac_init_flag" flag and the "mb_row_cabac_init_idc_flag" flag may be signaled in a regular slice header, for example, when the value of "entropy_slice_flag" is "0". In some embodiments of the present invention, the "mb_row_cabac_init_flag" flag and the "mb_row_cabac_init_idc_flag" flag may be signaled in a entropy-slice header, for example, when the value of "entropy_slice_flag" is "1". Table 10 and Table 11 show exemplary syntax for these embodiments. Table 10 shows exemplary slice header syntax, and Table 11 shows exemplary slice data syntax (coding_unit).

slice_header( ) {	C	Descriptor
entropy_slice_flag	2	u(1)
if (entropy_slice_flag) {		
first_mb_in_slice	2	ue(v)
if (entropy_coding_mode_flag) {		
mb_row_cabac_init_flag	1	u(1)
if(mb_row_cabac_init_flag){		
mb_row_cabac_init_idc_flag	1	u(1)
}		
}		
if(entropy_coding_mode_flag && slice_type != I) {		
cabac_init_idc	2	ue(v)
}		
}		
else {		
mb_row_cabac_init_flag	1	u(1)
if(mb_row_cabac_init_flag){		
mb_row_cabac_init_idc_flag	1	u(1)
}		
a regular slice header		
}		
}		

Table 10: Exemplary Syntax Table for Signaling the Initialization of Entropy Coding at the Start of the Macroblock Row

coding_unit(x0, y0, currCodingUnitSize) {	C	Descriptor
if (x0==0 && currCodingUnitSize==MaxCodingUnitSize && mb_row_cabac_init_idc_flag==true && mb_id!=first_mb_in_slice) {		
cabac_init_idc_present_flag	1	u(1)
if(cabac_init_idc_present_flag)		
cabac_init_idc	2	ue(v)
}		
a regular coding unit ...		
}		

Table 11: Exemplary Syntax Table for Signaling the Initial Context for the Macroblock

In some embodiments of the present invention, the locations, in a bitstream, of the entropy slices may be signaled in the bitstream. In some embodiments, a flag may be used to signal that the locations, in the bitstream, of the entropy slices are going to be signaled in the bitstream. Some exemplary embodiments may comprise an "entropy_slice_locations_flag" that if "true" may indicate that the locations, in the bitstream, of the entropy-slice headers are going to be signaled in the bitstream. In some embodiments, the location data may be differentially encoded. In some embodiments, the location data may be sent in each reconstruction slice. In alternative embodiments, the location data may be sent once per picture.

In some embodiments of the present invention, the

locations, in a bitstream, of the LCU rows may be signaled in the bitstream. In some embodiments, a flag may be used to signal that the location, in the bitstream, of the first LCU in each row is going to be signaled in the bitstream. Some exemplary embodiments may comprise an "lcu_row_location_flag" that if "true" may indicate that the location, in the bitstream, of the first LCU in each row is going to be signaled in the bitstream. In some embodiments, the location data may be differentially encoded. In some embodiments, the location data may be sent in each entropy slice. In alternative embodiments, the location data may be sent once per reconstruction slice.

Table 12 shows exemplary syntax for signaling the locations, in the bitstream, of the LCU rows and the entropy slices. For this exemplary syntax, the semantics are:

- "entropy_slice_locations_flag" signals if entropy slice header location is transmitted. If the value of "entropy_slice_locations_flag" is set to "1", then the entropy slice header location is transmitted, otherwise it is not transmitted. The default value for the "entropy_slice_locations_flag" is "0".

- "num_of_entropy_slice_minus1" signals the number of entropy slices in the reconstruction slice minus 1.

- "entropy_slice_offset [i]" indicates the offset of the i^{th} entropy slice from the previous entropy slice.

- "lcu_row_locations_flag" signals if LCU row location information is being transmitted or not. If the value of "lcu_row_locations_flag" is "1", then the LCU row location information is transmitted, otherwise it is not transmitted. The default value for "lcu_row_locations_flag" is "0".
- "num_of_lcu_rows_minus1" signals the number of LCU rows in the entropy slice minus 1.
- "lcu_row_offset [i]" indicates the offset of the i^{th} LCU row from the previous LCU row.

In some embodiments of the present invention, "lcu" in Table 12 may be replaced by "macroblock". For example, "first_lcu_in_slice", "lcu_row_cabac_init_flag", "lcu_row_cabac_init_idc_flag", "lcu_row_locations_flag", "lcu_row_locations ()", "num_of_lcu_rows_minus1", and "lcu_row_offset[i]" in Table 12 may be replaced by "first_mb_in_slice", "mb_row_cabac_init_flag", "mb_row_cabac_init_idc_flag", "mb_row_locations_flag", "mb_row_locations ()", "num_of_mb_rows_minus1", and "mb_row_offset[i]", respectively.

slice_header( ) {	C	Descriptor
entropy_slice_flag	2	u(1)
if (entropy_slice_flag) {		
first_lcu_in_slice	2	ue(v)
if (entropy_coding_mode_flag) {		
lcu_row_cabac_init_flag	1	u(1)
if(lcu_row_cabac_init_flag){		
lcu_row_cabac_init_idc_flag	1	u(1)
lcu_row_locations_flag	1	u(1)
if (lcu_row_locations_flag) {		
lcu_row_locations ()		
}		
}		
}		
if(entropy_coding_mode_flag && slice_type != I) {		
cabac_init_idc	2	ue(v)
}		
}		
else {		
entropy_slice_locations_flag	1	u(1)
if (entropy_slice_locations_flag) {		
entropy_slice_locations()		
}		
if (entropy_coding_mode_flag) {		
lcu_row_cabac_init_flag	1	u(1)
if(lcu_row_cabac_init_flag){		
lcu_row_cabac_init_idc_flag	1	u(1)
lcu_row_locations_flag	1	u(1)
if (lcu_row_locations_flag) {		
lcu_row_ locations ()		
}		
}		
}		
a regular slice header		
}		
}		

entropy_slice_ locations()	C	Descriptor
{		
num_entropy_slices_minus1	2	ue(v)
for (i=0; i<num_of_entropy_slices_minus1; i++)		
entropy_slice_offset[i]	2	ue(v)
}		

lcu_row_ locations()	C	Descriptor
{		
num_of_lcu_rows_minus1	2	ue(v)
for (i=0; i<num_of_lcu_rows_minus1_slice; i++) {		
lcu_row_offset[i]	2	ue(v)
}		
}		

Table 12: Exemplary Syntax Table for Signaling the Locations, in the Bitstream, of the First LCU in a Row

Table 13 shows a comparison of rate distortion performance for all-intra coding. The first comparison, shown in the two sub-columns of column three, is a comparison, using the H.264/AVC Joint Model (JM) software, version 13.0, between encoding using multiple slices, wherein entropy decoding and macroblock reconstruction for a slice does not depend on other slices, and encoding using no slices. On average, for the same bit rate, the quality is degraded by -0.3380 dB encoding using multiple slices over using no slices. On average, for the same quality level, the bit rate is increased by 7% by encoding using multiple slices over using no slices.

The second comparison, shown in the two sub-columns

of column four, is a comparison between encoding using one reconstruction slice partitioned, according to embodiments of the present invention, into multiple entropy slices (two rows of macroblocks per entropy slice) and encoding using JM 13.0 with no slices. On average, for the same bit rate, the quality is degraded by -0.0860 dB using one reconstruction slice with multiple entropy slices over encoding using no slices. On average, for the same quality level, the bit rate is increased by 1.83% by encoding using one reconstruction slice with multiple entropy slices over encoding using no slices.

All Intra Coding					
Sequence	**Resolution**	**JM 13.0 slices compared to JM 13.0 no slices**		**One reconstruction slice with multiple entropy slices compared to JM 13.0 no slices**	
		BD SNR [dB]	**BD Bit rate [%]**	**BD SNR [dB]**	**BD Bit rate [%]**
BigShip	720p	-0.22	4.54	-0.08	1.61
City	720p	-0.28	4.03	-0.06	0.84
Crew	720p	-0.42	11.67	-0.11	2.98
Night	720p	-0.38	5.64	-0.06	0.91
ShuttleStart	720p	-0.39	9.12	-0.12	2.81
AVERAGE		**-0.3380**	**7.00**	**-0.0860**	**1.83**

Table 13: Comparison of rate distortion performance – all-intra encoding

Table 14 shows a comparison of rate distortion performance for IBBP coding. The first comparison, shown in

the two sub-columns of column three, is a comparison, using the H.264/AVC Joint Model (JM) software, version 13.0, between encoding using multiple slices, wherein entropy decoding and macroblock reconstruction for a slice does not depend on other slices, and encoding using no slices. On average, for the same bit rate, the quality is degraded by -0.5460 dB encoding using multiple slices. On average, for the same quality level, the bit rate is increased by 21.41% by encoding using multiple slices over using no slices.

The second comparison, shown in the two sub-columns of column four, is a comparison between encoding using one reconstruction slice partitioned, according to embodiments of the present invention, into multiple entropy slices (two rows of macroblocks per entropy slice) and encoding using JM 13.0 with no slices. On average, for the same bit rate, the quality is degraded by -0.31 dB using one reconstruction slice with multiple entropy slices over encoding using no slices. On average, for the same quality level, the bit rate is increased by 11.45% by encoding using one reconstruction slice with multiple entropy slices over encoding using no slices.

IBBP Coding					
Sequence	**Resolution**	**JM 13.0 slices compared to JM 13.0 no slices**		**One reconstruction slice with multiple entropy slices compared to JM 13.0 no slices**	
		BD SNR [dB]	**BD Bit rate [%]**	**BD SNR [dB]**	**BD Bit rate [%]**
BigShip	720p	-0.45	19.34	-0.26	10.68
City	720p	-0.48	17.83	-0.22	7.24
Crew	720p	-0.62	30.10	-0.33	14.93
Night	720p	-0.36	11.11	-0.19	5.5
ShuttleStart	720p	-0.82	28.69	-0.55	18.89
AVERAGE		**-0.5460**	**21.41**	**-0.31**	**11.45**

Table 14: Comparison of rate distortion performance – IBBP encoding

Comparing the results, encoding using multiple entropy slices in one reconstruction slice provides a bit rate savings of 5.17% and 9.96% for all-intra and IBBP coding, respectively, over encoding using slices, wherein entropy decoding and macroblock reconstruction for a slice does not depend on other slices, although both allow for parallel decoding.

Table 15 shows a comparison of rate distortion performance for all-intra and IBBP coding. In this table, the comparison is a comparison between encoding using no slices and encoding using one reconstruction slice partitioned into entropy slices, according to embodiments of the present invention, of maximum size 26k bins per entropy slice. The

first comparison, shown in the two sub-columns of column two, is a comparison using all-intra coding. On average, for the same bit rate, the quality is degraded by -0.062 dB by encoding using a reconstruction slice with multiple entropy slices. On average, for the same quality level, the bit rate is increased by 1.86% by encoding using a reconstruction slice with multiple entropy slices. Thus, for all-intra coding using entropy slices of maximum size 26k bins per entropy slice, there is an average bit rate savings of approximately 0.64 % over that of fixed entropy slice sizes of two rows of macroblocks.

The second comparison, shown in the two sub-columns of column three, is a comparison using IBBP coding. On average, for the same bit rate, the quality is degraded by -0.022 dB using one reconstruction slice with multiple entropy slices over encoding using no slices. On average, for the same quality level, the bit rate is increased by 0.787% by encoding using one reconstruction slice with multiple entropy slices over encoding using no slices. Thus, for IBBP coding using entropy slices of maximum size 26k bins per entropy slice, there is an average bit rate savings of approximately 10.66 % over that of fixed entropy slice sizes of two rows of macroblocks.

Entropy Slice Compared to JM 15.1 No Slice. Experiment (1): 26k bins maximum per entropy slice				
Sequence (720p)	All Intra Coding		IBBP Coding	
	BD SNR [dB]	BD Bit rate [%]	BD SNR [dB]	BD Bit rate [%]
BigShip	-0.07	1.40	-0.02	0.70
City	-0.07	1.02	-0.02	0.51
Crew	-0.05	1.31	-0.03	1.25
Night	-0.07	1.00	-0.02	0.66
ShuttleStart	-0.05	1.20	-0.03	-0.82
AVERAGE	**-0.062**	**1.187**	**-0.022**	**0.787**

Table 15: Comparison of rate distortion performance – all-intra and IBBP encoding using entropy slices with less than 26k bins per entropy slice

The use of entropy slices allows for parallel decoding, and encoder partitioning of a reconstruction slice into entropy slices, wherein each entropy slice is less than a maximum number of bins may provide considerable bit rate savings over entropy slices of a fixed number of macroblocks.

Although the charts and diagrams in the figures may show a specific order of execution, it is understood that the order of execution may differ from that which is depicted. For example, the order of execution of the blocks may be changed relative to the shown order. Also, as a further example, two or more blocks shown in succession in a figure may be executed concurrently, or with partial concurrence. It is understood by those with ordinary skill in the art that

software, hardware and/or firmware may be created by one of ordinary skill in the art to carry out the various logical functions described herein.

Some embodiments of the present invention may comprise a computer program product comprising a computer-readable storage medium having instructions stored thereon/in which may be used to program a computing system to perform any of the features and methods described herein. Exemplary computer-readable storage media may include, but are not limited to, flash memory devices, disk storage media, for example, floppy disks, optical disks, magneto-optical disks, Digital Versatile Discs (DVDs), Compact Discs (CDs), micro-drives and other disk storage media, Read-Only Memory (ROMs), Programmable Read-Only Memory (PROMs), Erasable Programmable Read-Only Memory (EPROMS), Electrically Erasable Programmable Read-Only Memory (EEPROMs), Random-Access Memory (RAMS), Video Random-Access Memory (VRAMs), Dynamic Random-Access Memory (DRAMs) and any type of media or device suitable for storing instructions and/or data.

The terms and expressions which have been employed in the foregoing specification are used therein as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding equivalence of the features shown and described or portions

thereof, it being recognized that the scope of the invention is defined and limited only by the claims which follow.

CLAIMS

1. A method for decoding a video frame in a video sequence, said method comprising:

in a video decoder, receiving an entropy slice;

identifying a slice-start elementary unit in said entropy slice; and

initializing a context model associated with entropy decoding said slice-start elementary unit to a first context model.

2. The method as described in claim 1, further comprising:

identifying a first row-start elementary unit in said entropy slice; and

initializing a context model associated with entropy decoding said first row-start elementary unit to a second context model.

3. The method as described in claim 2, wherein said first row-start elementary unit is a macroblock.

4. The method as described in claim 2, wherein said second context model is signaled in a bitstream associated with said entropy slice.

5. The method as described in claim 4, wherein said second context model is one of a plurality of context models associated with said bitstream.

6. The method as described in claim 2, wherein said second context model is determined from a neighboring context model associated with a neighboring elementary unit in said entropy slice to said first row-start elementary unit.

7. The method as described in claim 2, wherein said second context state is a default context model.

8. The method as described in claim 2 further comprising:

identifying a second row-start elementary unit in said entropy slice; and

initializing a context model associated with entropy decoding said second row-start elementary unit to a third context model.

9. The method as described in claim 1, wherein said start-slice elementary unit is a macroblock.

10. A method for decoding a video frame in a video sequence, said method comprising:

in a video decoder, receiving an entropy slice;

receiving a context-table-reset flag value for a context-table-reset flag;

identifying a first row-slice elementary unit in said entropy slice; and

when said context-table-reset flag value is a first value, initializing a context model associated with entropy decoding said first row-start elementary unit to a first context model.

11. The method as described in claim 10, further comprising:

identifying a slice-start elementary unit in said entropy slice; and

initializing a context model associated with entropy decoding said slice-start elementary unit to a second context model.

12. The method as described in claim 10 wherein said first row-start elementary unit is a macroblock.

13. The method as described in claim 10, wherein said first context model is signaled in a bitstream associated with said entropy slice.

14. The method as described in claim 13, wherein said

first context model is one of a plurality of context models associated with said bitstream.

15. The method as described in claim 10, wherein said first context model is determined from a neighboring context model associated with a neighboring elementary unit in said entropy slice to said first row-start elementary unit.

16. The method as described in claim 10, wherein said first context model is a default context model.

17. The method as described in claim 10 further comprising:

identifying a second row-start elementary unit in said entropy slice; and

when said context-table-reset flag value is said first value, initializing a context model associated with entropy decoding said second row-start elementary unit to a second context model .

18. A method for encoding a video frame of a video sequence, said method comprising:

in an encoder, partitioning a frame of a video sequence into at least one reconstruction slice, thereby producing a first reconstruction slice;

forming a first entropy slice associated with said reconstruction slice;

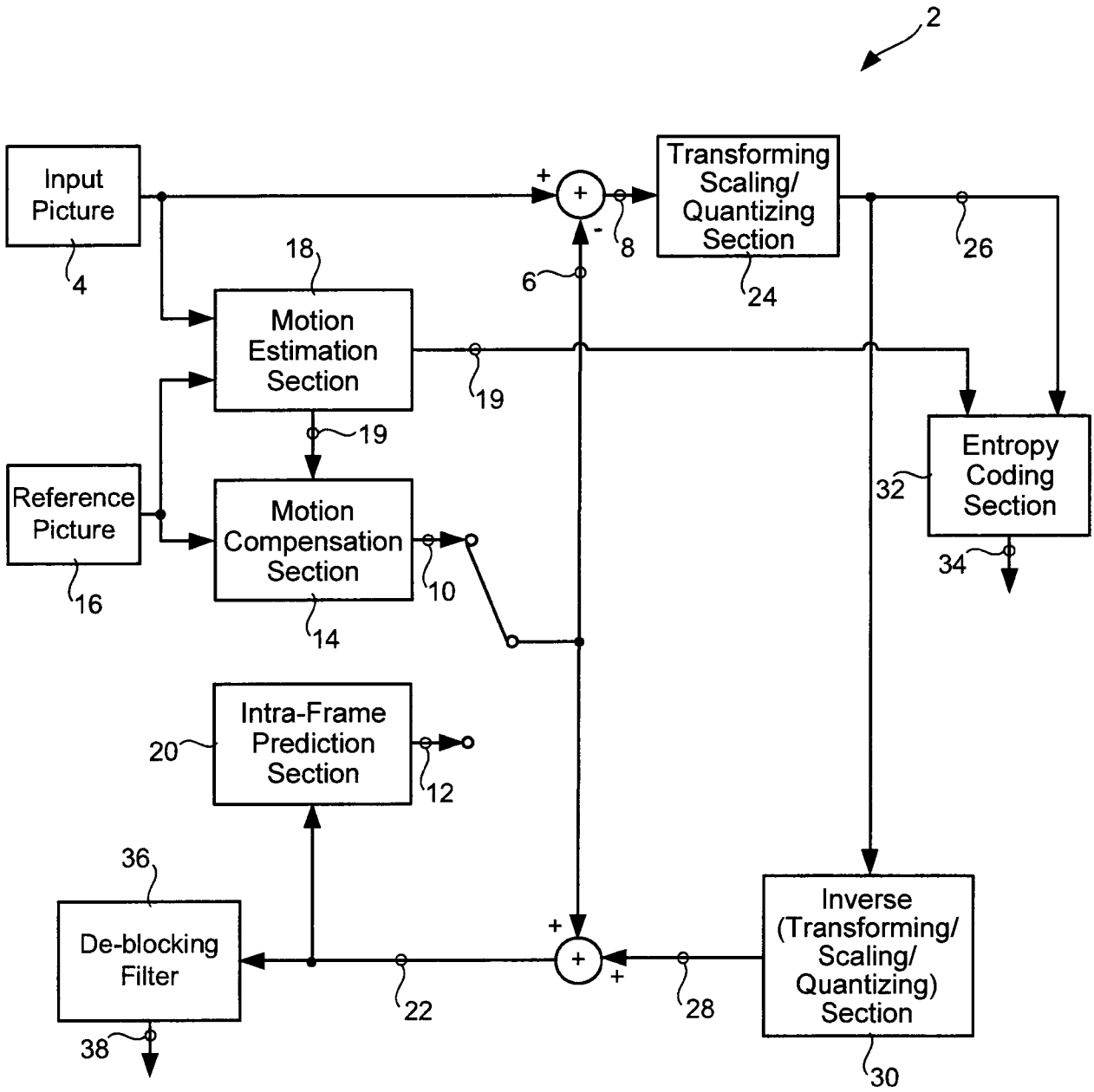
identifying a first row-start elementary unit associated with said first entropy slice; and

signaling, in a bitstream associated with said video frame, a first context model associated with said first row-start elementary unit.

19. The method as described in claim 18, wherein said first context model is one of a plurality of context models associated with said bitstream.

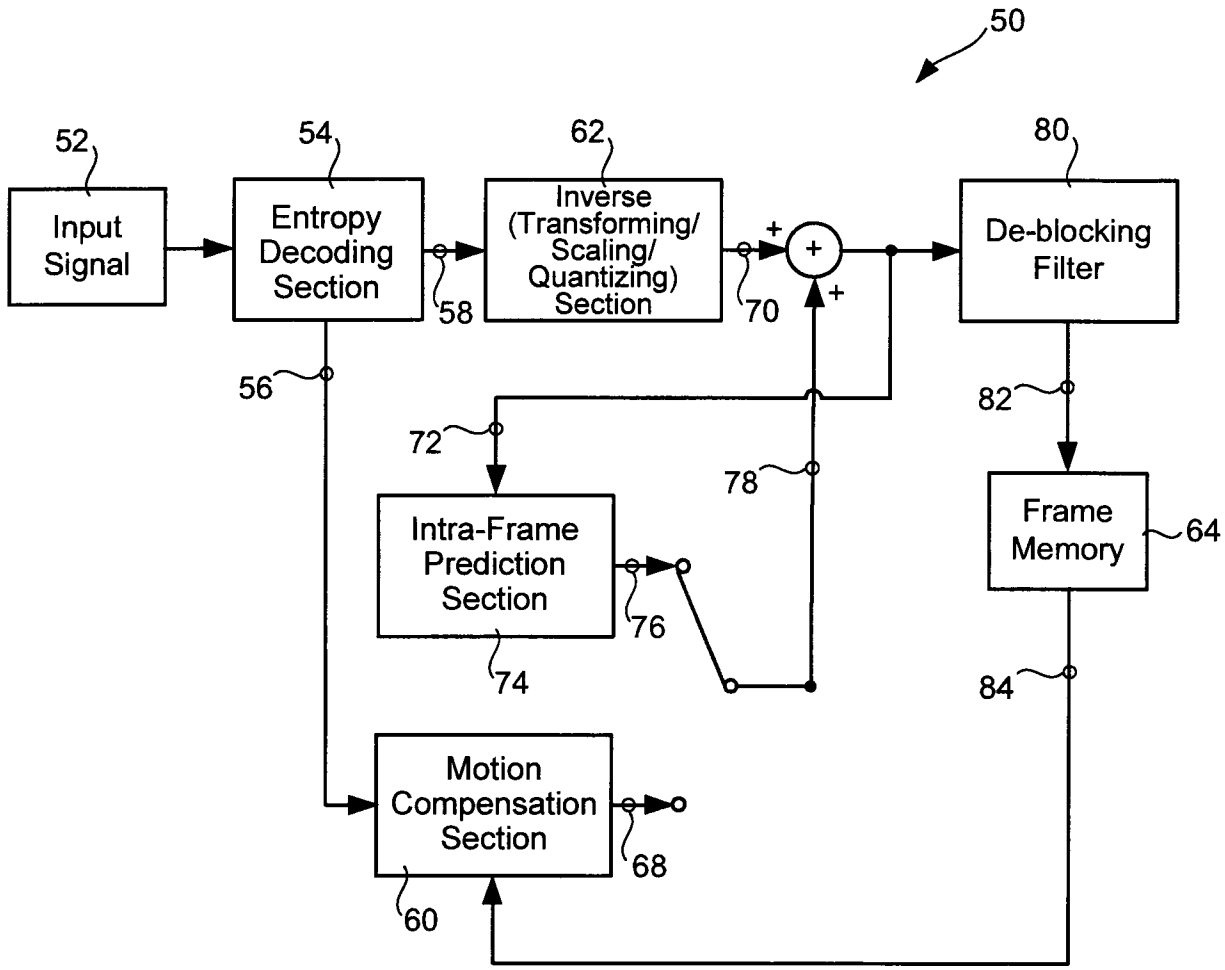
20. The method as described in claim 18 further comprising signaling a context-model-reset flag value for a context-model-reset flag in said bitstream.

FIG. 1



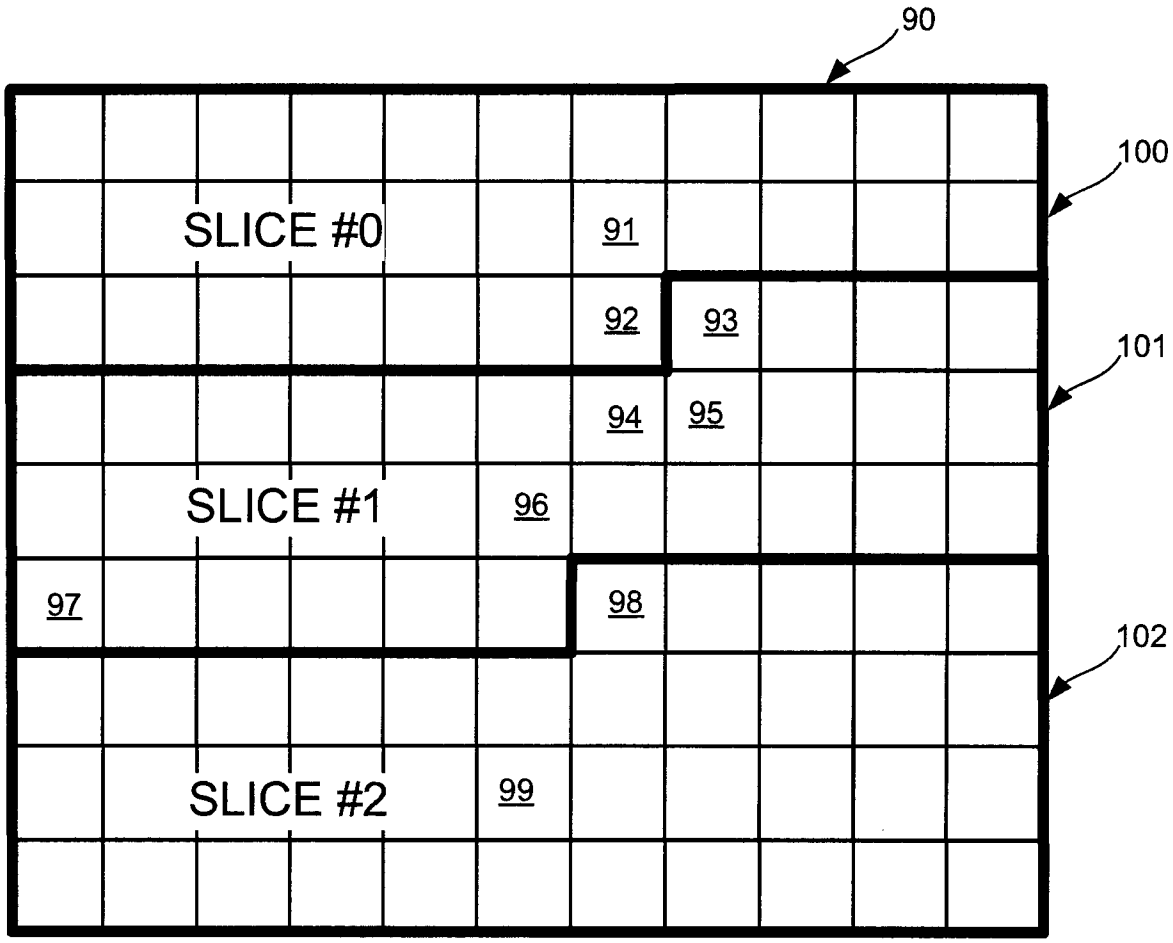
PRIOR ART

FIG. 2



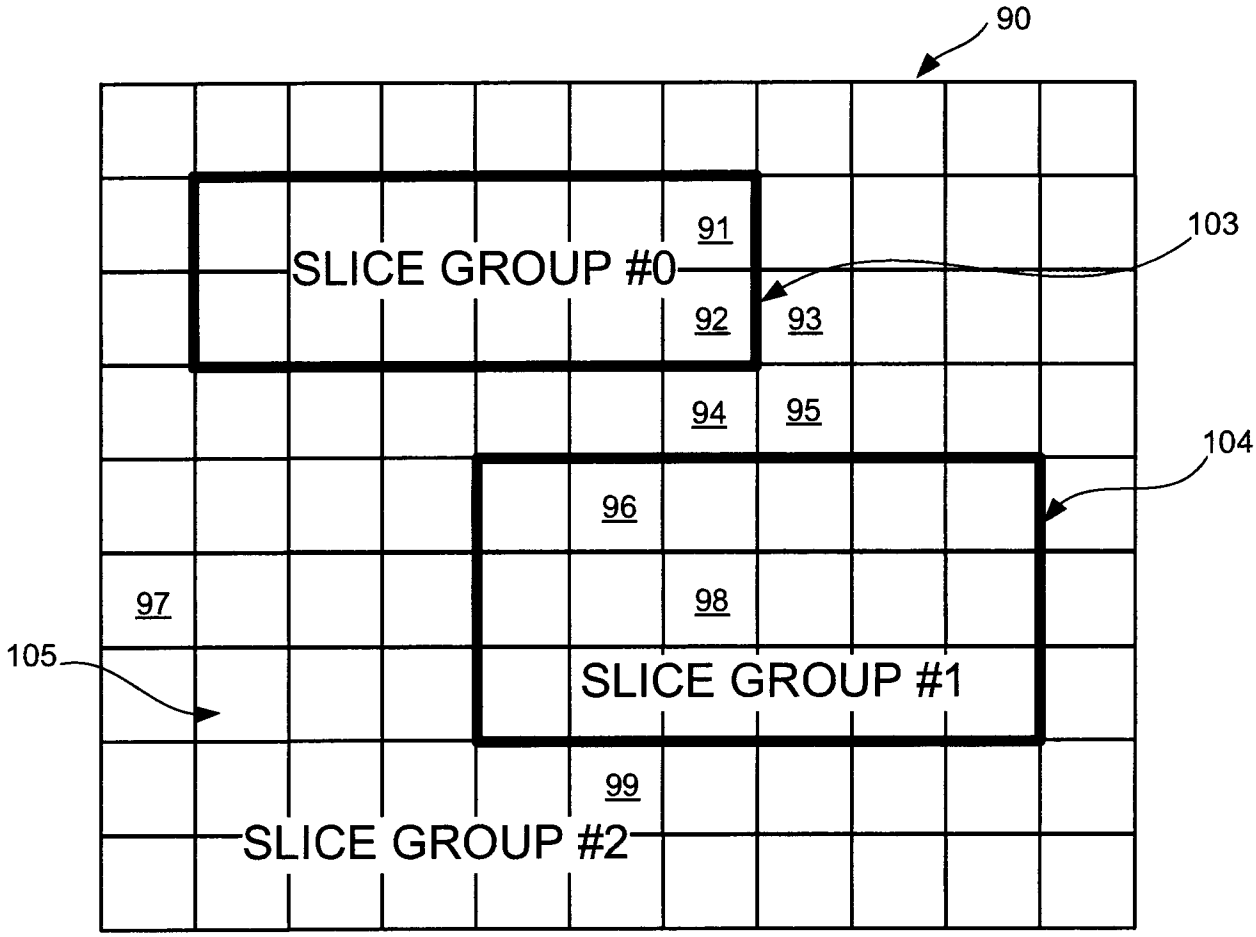
PRIOR ART

FIG. 3



PRIOR ART

FIG. 4



PRIOR ART

FIG. 5

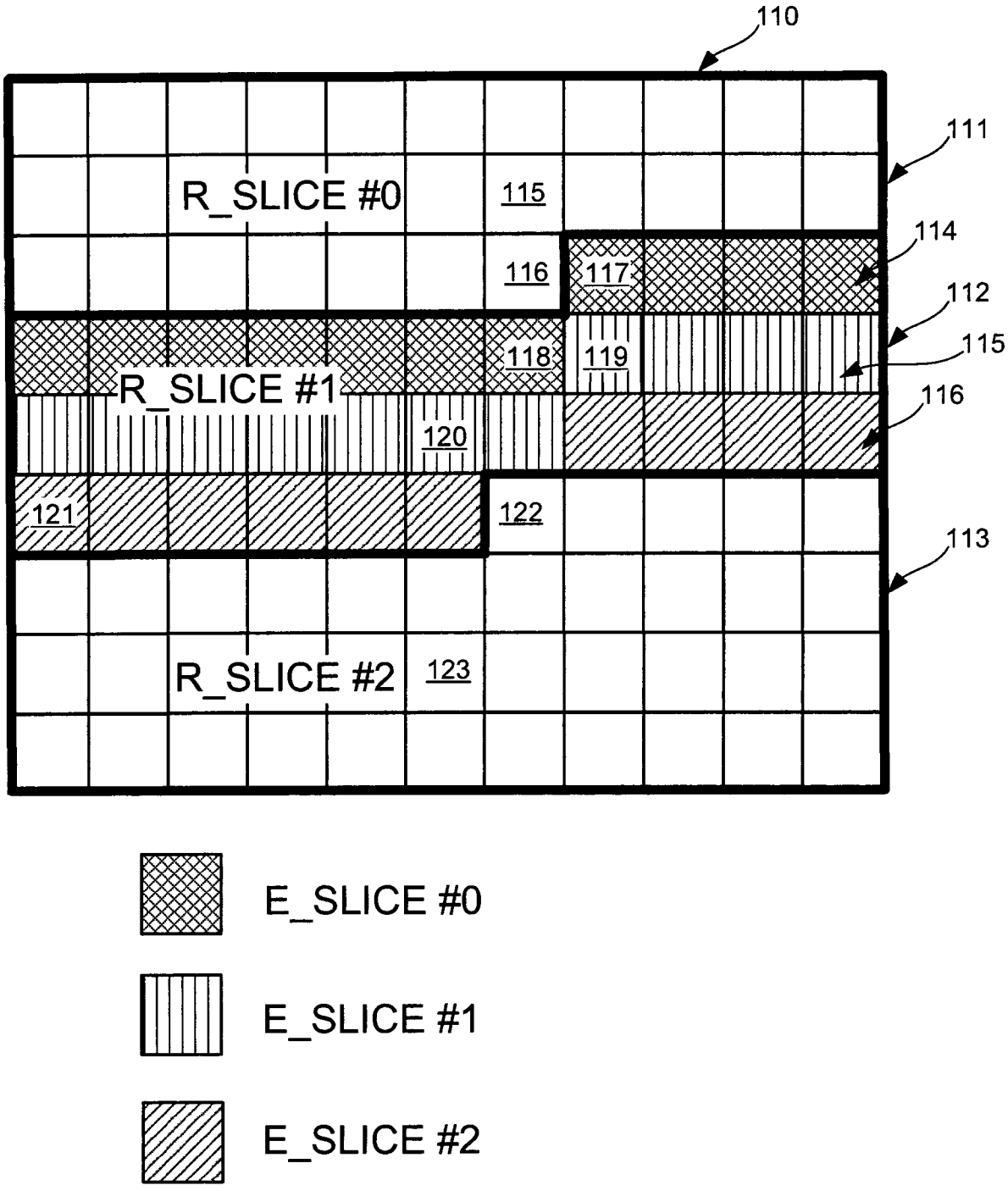

110
111
R_SLICE #0
115
116
117
114
112
118
119
115
R_SLICE #1
116
120
121
122
113
R_SLICE #2
123
E_SLICE #0
E_SLICE #1
E_SLICE #2

FIG. 6

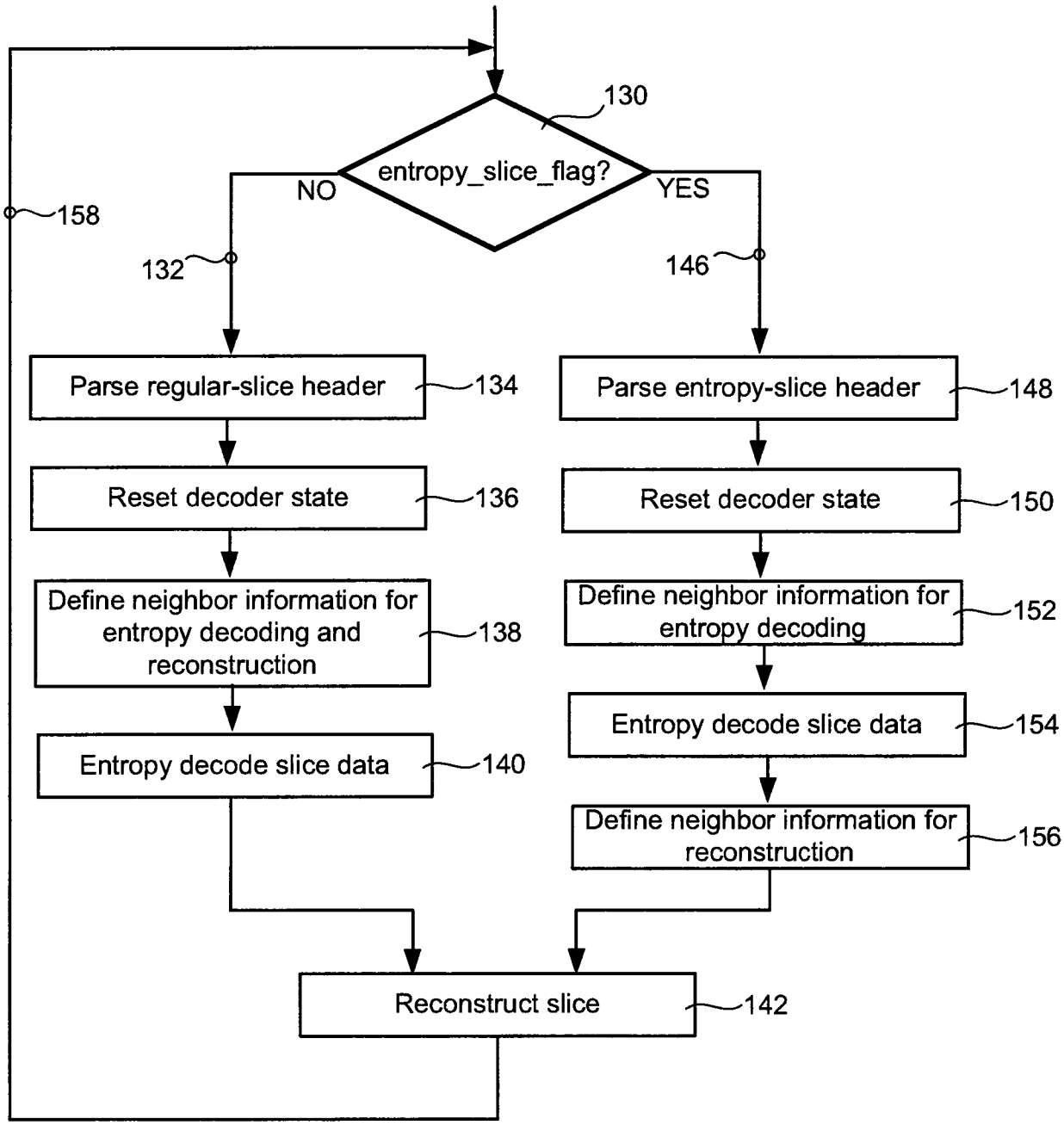

130
entropy_slice_flag?
NO
YES
158
132
146
Parse regular-slice header
134
Parse entropy-slice header
148
Reset decoder state
136
Reset decoder state
150
Define neighbor information for entropy decoding and reconstruction
138
Define neighbor information for entropy decoding
152
Entropy decode slice data
140
Entropy decode slice data
154
Define neighbor information for reconstruction
156
Reconstruct slice
142

FIG. 7

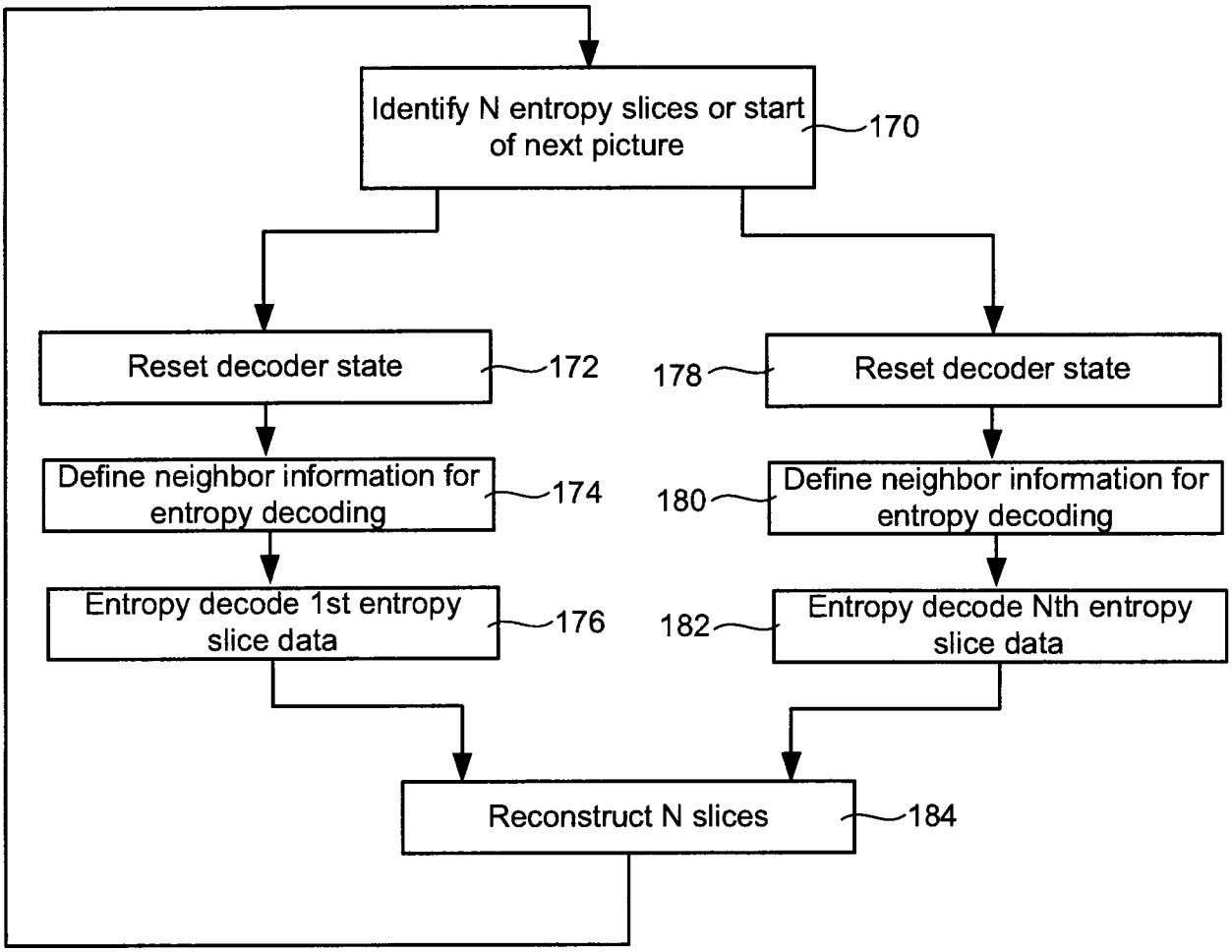

Identify N entropy slices or start of next picture
170
Reset decoder state
172
Define neighbor information for entropy decoding
174
Entropy decode 1st entropy slice data
176
178
Reset decoder state
180
Define neighbor information for entropy decoding
182
Entropy decode Nth entropy slice data
Reconstruct N slices
184

FIG. 8

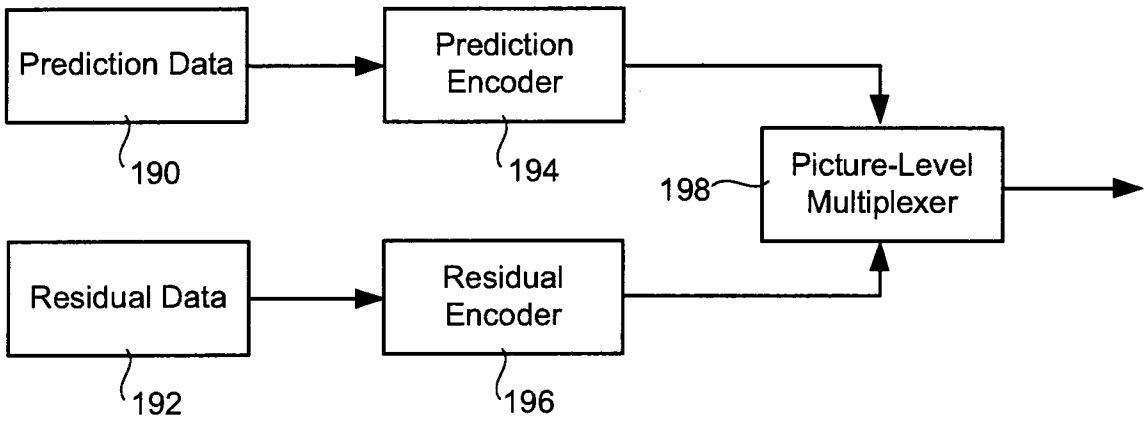

Prediction Data
190
Prediction Encoder
194
198
Picture-Level Multiplexer
Residual Data
192
Residual Encoder
196

FIG. 9

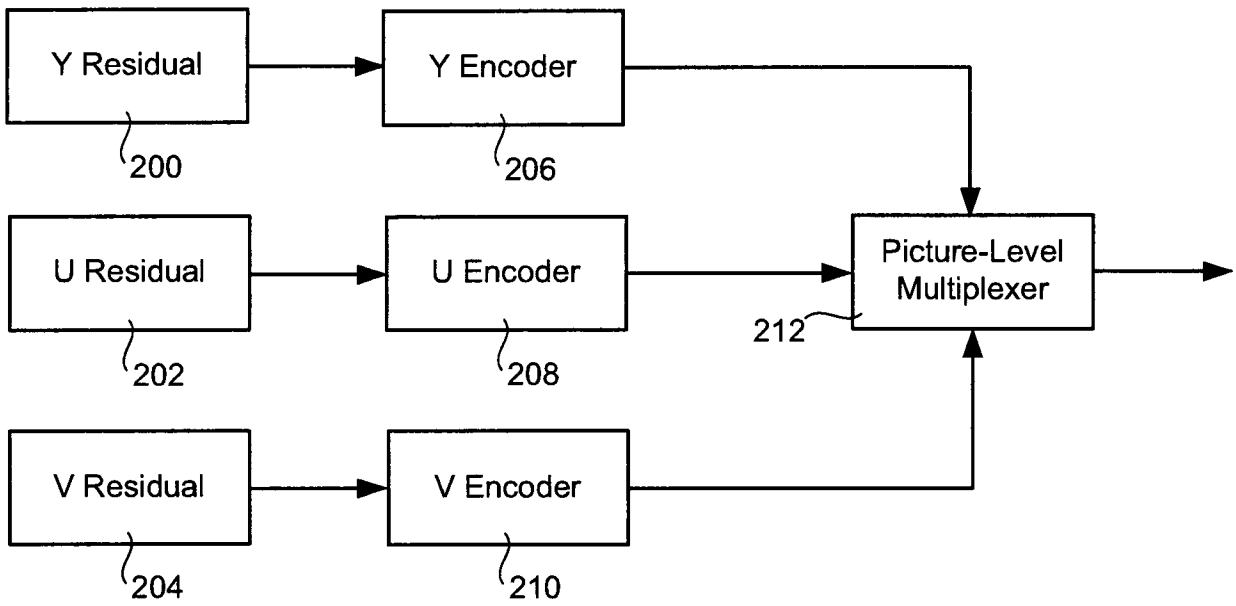

Y Residual
200
Y Encoder
206
U Residual
202
U Encoder
208
V Residual
204
V Encoder
210
Picture-Level Multiplexer
212

FIG. 10

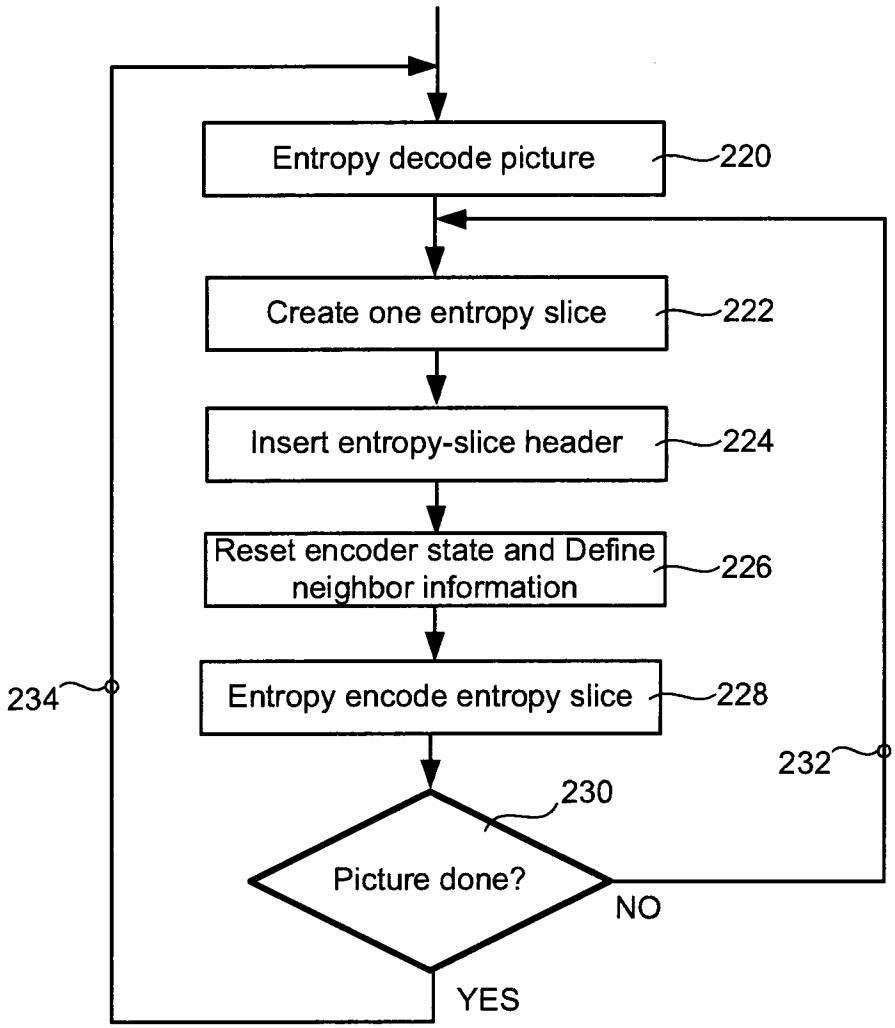

Entropy decode picture
220
Create one entropy slice
222
Insert entropy-slice header
224
Reset encoder state and Define neighbor information
226
Entropy encode entropy slice
228
230
Picture done?
NO
YES
232
234

FIG. 11

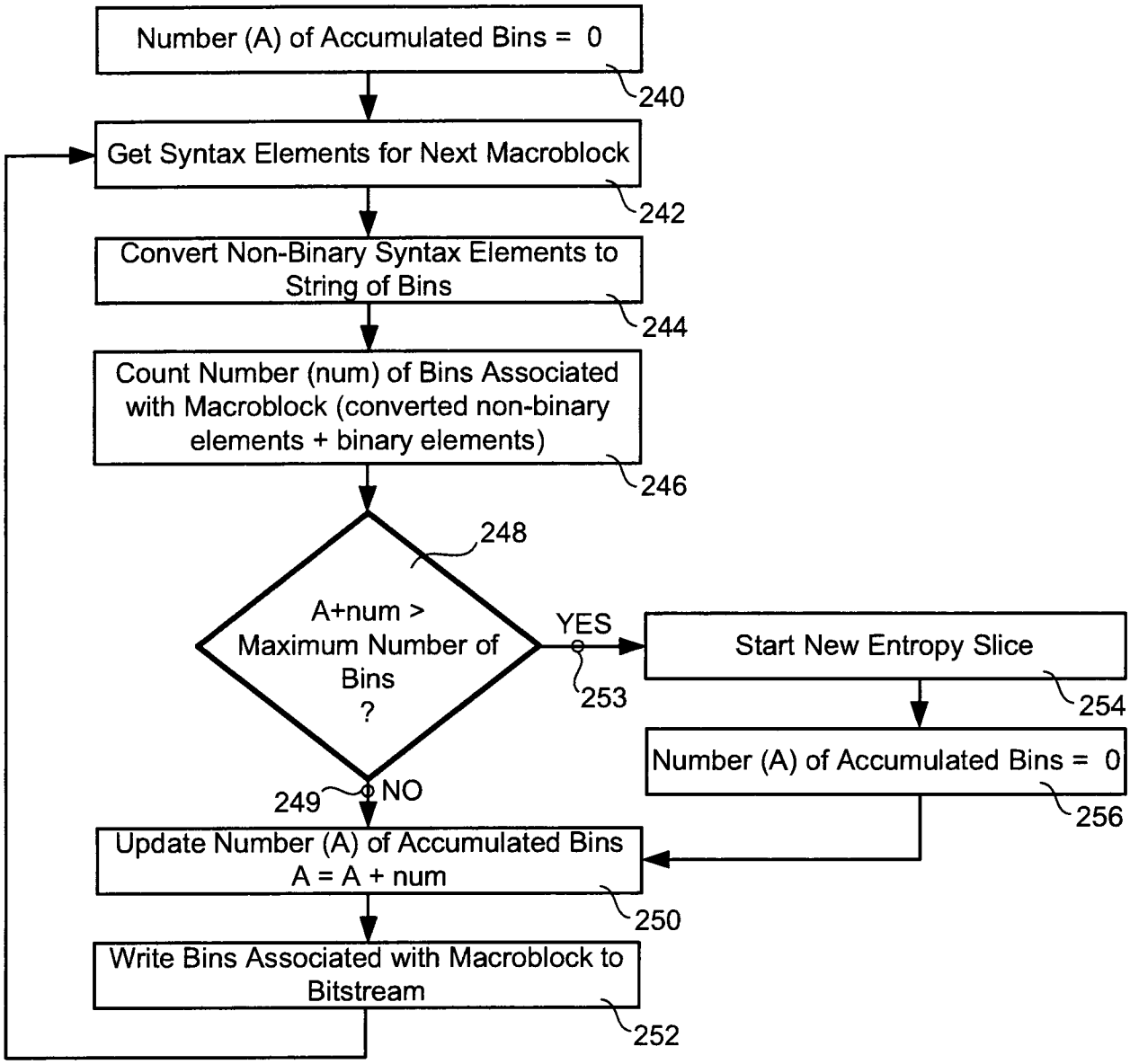

Number (A) of Accumulated Bins = 0
240
Get Syntax Elements for Next Macroblock
242
Convert Non-Binary Syntax Elements to String of Bins
244
Count Number (num) of Bins Associated with Macroblock (converted non-binary elements + binary elements)
246
248
A+num > Maximum Number of Bins ?
YES
253
Start New Entropy Slice
254
Number (A) of Accumulated Bins = 0
256
249
NO
Update Number (A) of Accumulated Bins A = A + num
250
Write Bins Associated with Macroblock to Bitstream
252

FIG. 12

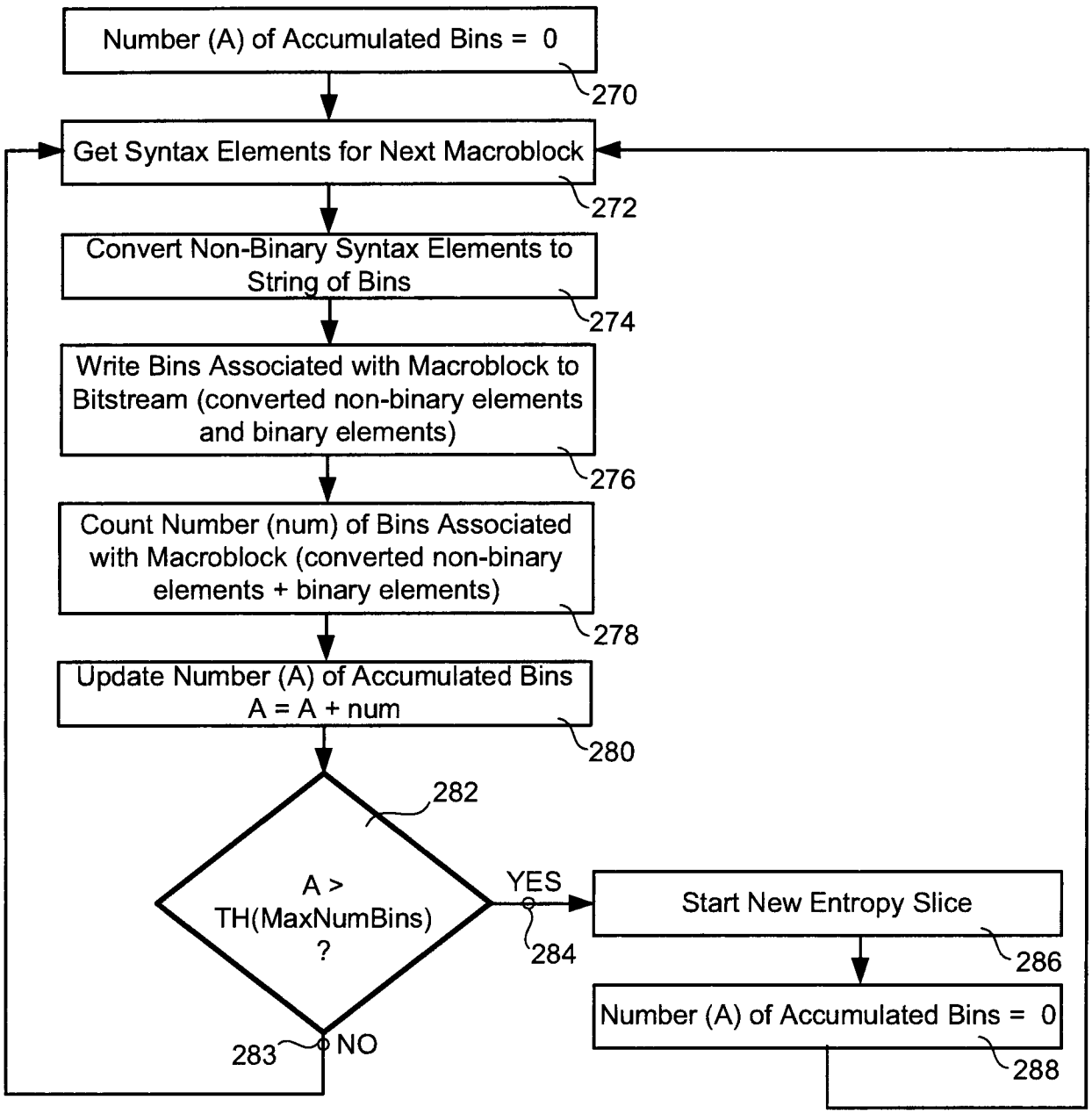

Number (A) of Accumulated Bins = 0
270
Get Syntax Elements for Next Macroblock
272
Convert Non-Binary Syntax Elements to String of Bins
274
Write Bins Associated with Macroblock to Bitstream (converted non-binary elements and binary elements)
276
Count Number (num) of Bins Associated with Macroblock (converted non-binary elements + binary elements)
278
Update Number (A) of Accumulated Bins A = A + num
280
282
A > TH(MaxNumBins) ?
YES
284
Start New Entropy Slice
286
Number (A) of Accumulated Bins = 0
288
283
NO

FIG. 13

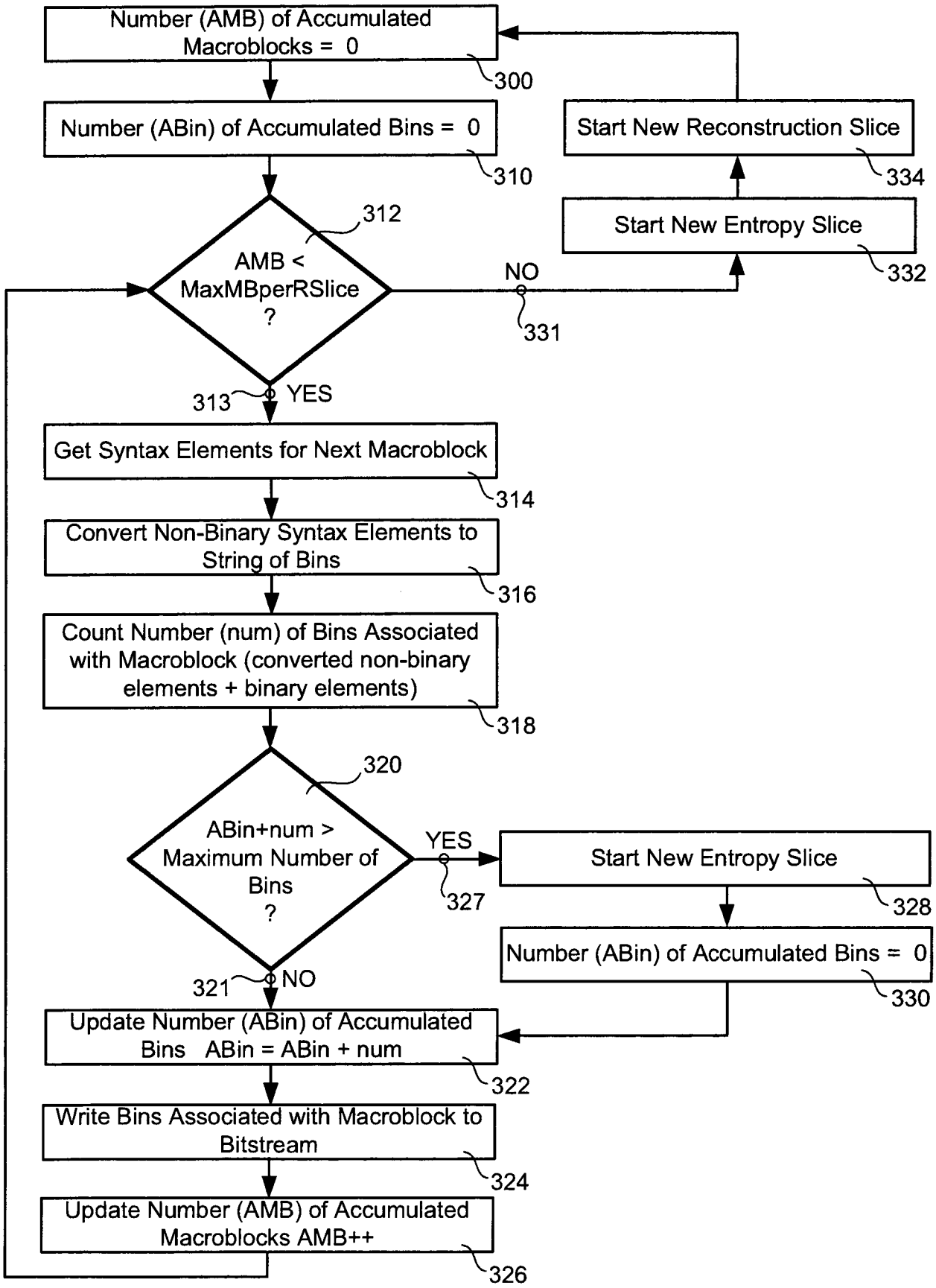

Number (AMB) of Accumulated Macroblocks = 0
300
Number (ABin) of Accumulated Bins = 0
310
312
AMB < MaxMBperRSlice ?
NO
331
Start New Entropy Slice
332
Start New Reconstruction Slice
334
313
YES
Get Syntax Elements for Next Macroblock
314
Convert Non-Binary Syntax Elements to String of Bins
316
Count Number (num) of Bins Associated with Macroblock (converted non-binary elements + binary elements)
318
320
ABin+num > Maximum Number of Bins ?
YES
327
Start New Entropy Slice
328
Number (ABin) of Accumulated Bins = 0
330
321
NO
Update Number (ABin) of Accumulated Bins ABin = ABin + num
322
Write Bins Associated with Macroblock to Bitstream
324
Update Number (AMB) of Accumulated Macroblocks AMB++
326

FIG. 14

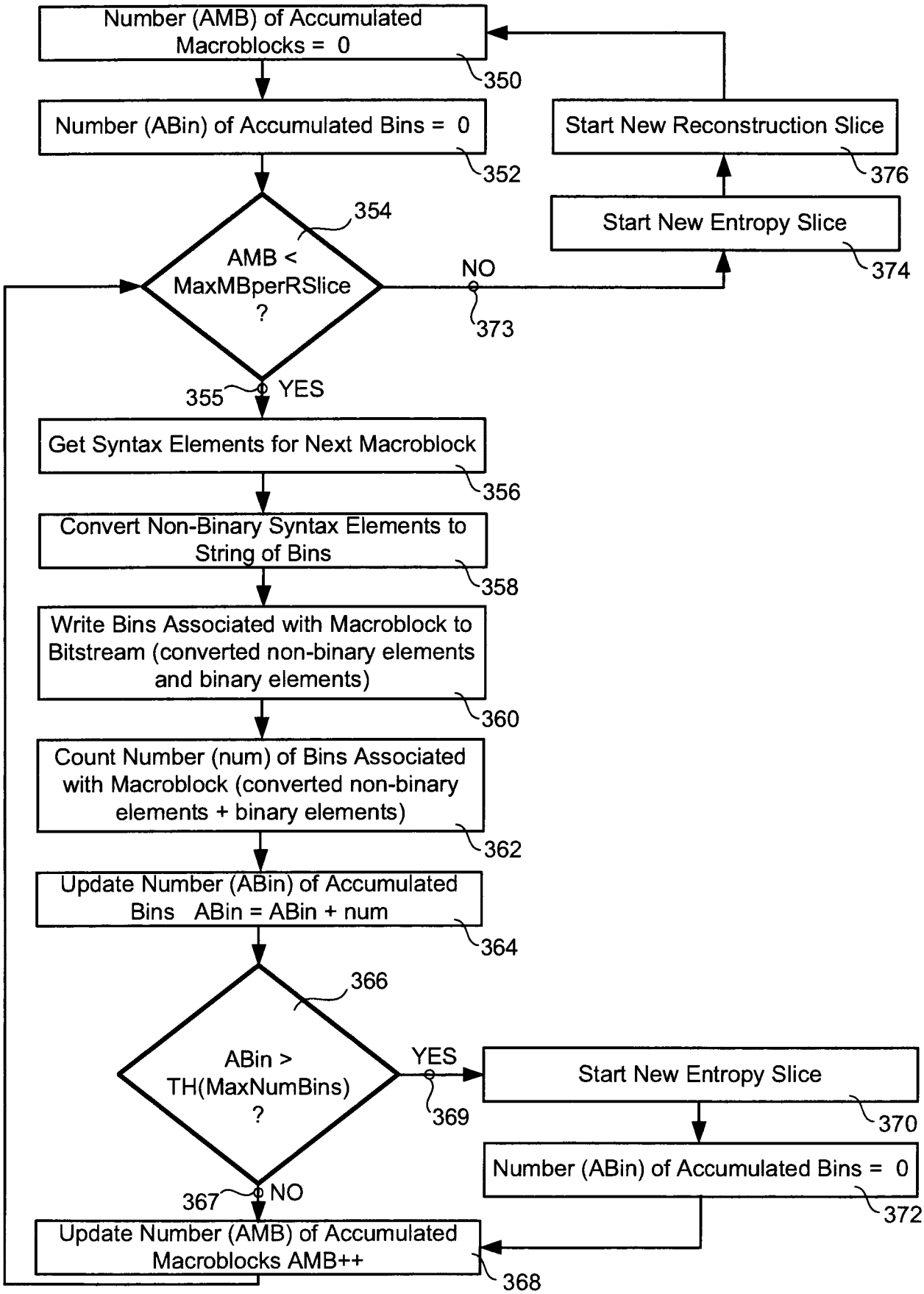

Number (AMB) of Accumulated Macroblocks = 0
350
Number (ABin) of Accumulated Bins = 0
352
354
AMB < MaxMBperRSlice ?
NO
373
Start New Entropy Slice
374
Start New Reconstruction Slice
376
355
YES
Get Syntax Elements for Next Macroblock
356
Convert Non-Binary Syntax Elements to String of Bins
358
Write Bins Associated with Macroblock to Bitstream (converted non-binary elements and binary elements)
360
Count Number (num) of Bins Associated with Macroblock (converted non-binary elements + binary elements)
362
Update Number (ABin) of Accumulated Bins ABin = ABin + num
364
366
ABin > TH(MaxNumBins) ?
YES
369
Start New Entropy Slice
370
Number (ABin) of Accumulated Bins = 0
372
367
NO
Update Number (AMB) of Accumulated Macroblocks AMB++
368

FIG. 15

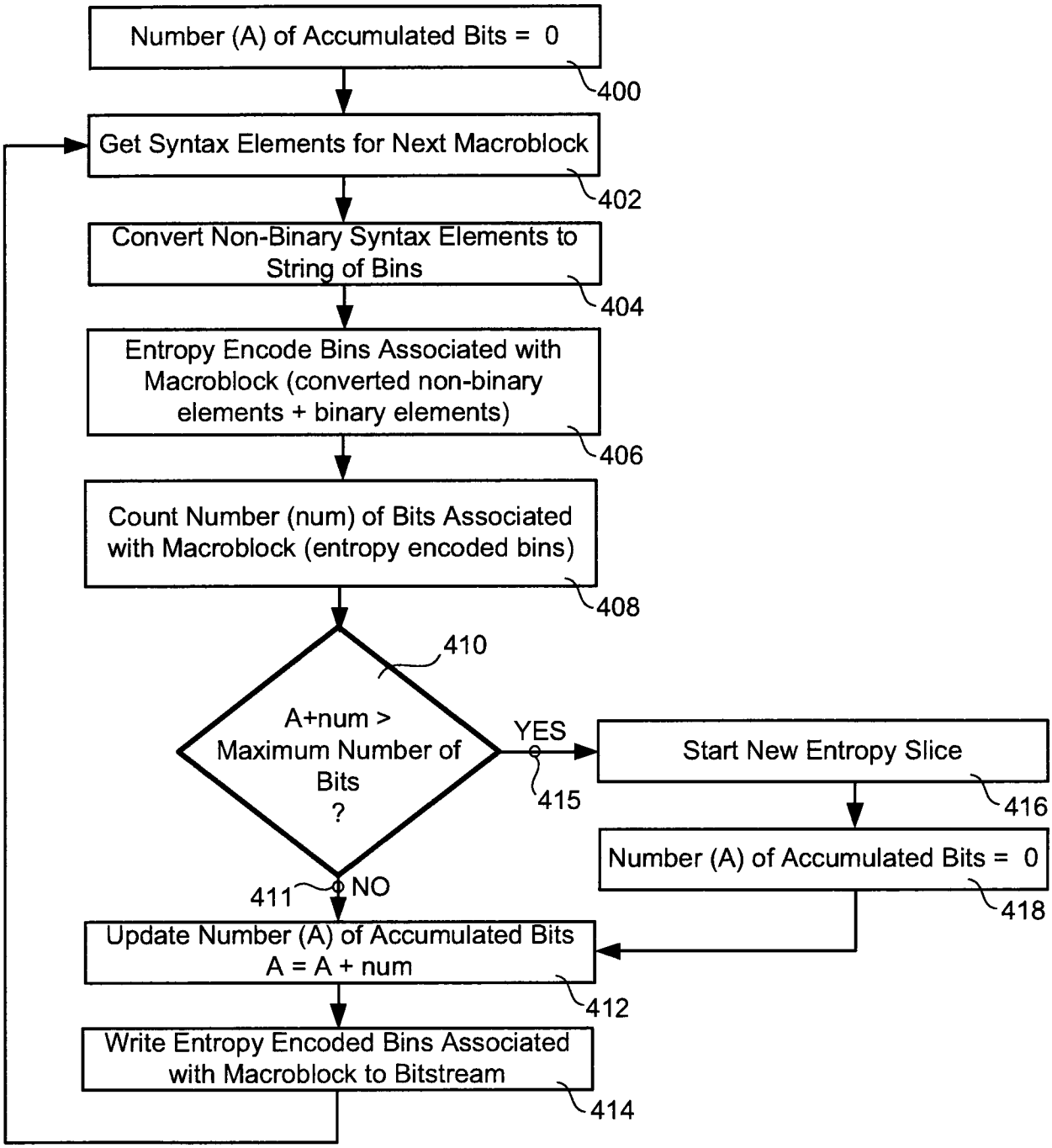

Number (A) of Accumulated Bits = 0
400
Get Syntax Elements for Next Macroblock
402
Convert Non-Binary Syntax Elements to String of Bins
404
Entropy Encode Bins Associated with Macroblock (converted non-binary elements + binary elements)
406
Count Number (num) of Bits Associated with Macroblock (entropy encoded bins)
408
410
A+num > Maximum Number of Bits ?
YES
415
Start New Entropy Slice
416
Number (A) of Accumulated Bits = 0
418
411
NO
Update Number (A) of Accumulated Bits A = A + num
412
Write Entropy Encoded Bins Associated with Macroblock to Bitstream
414

FIG. 16

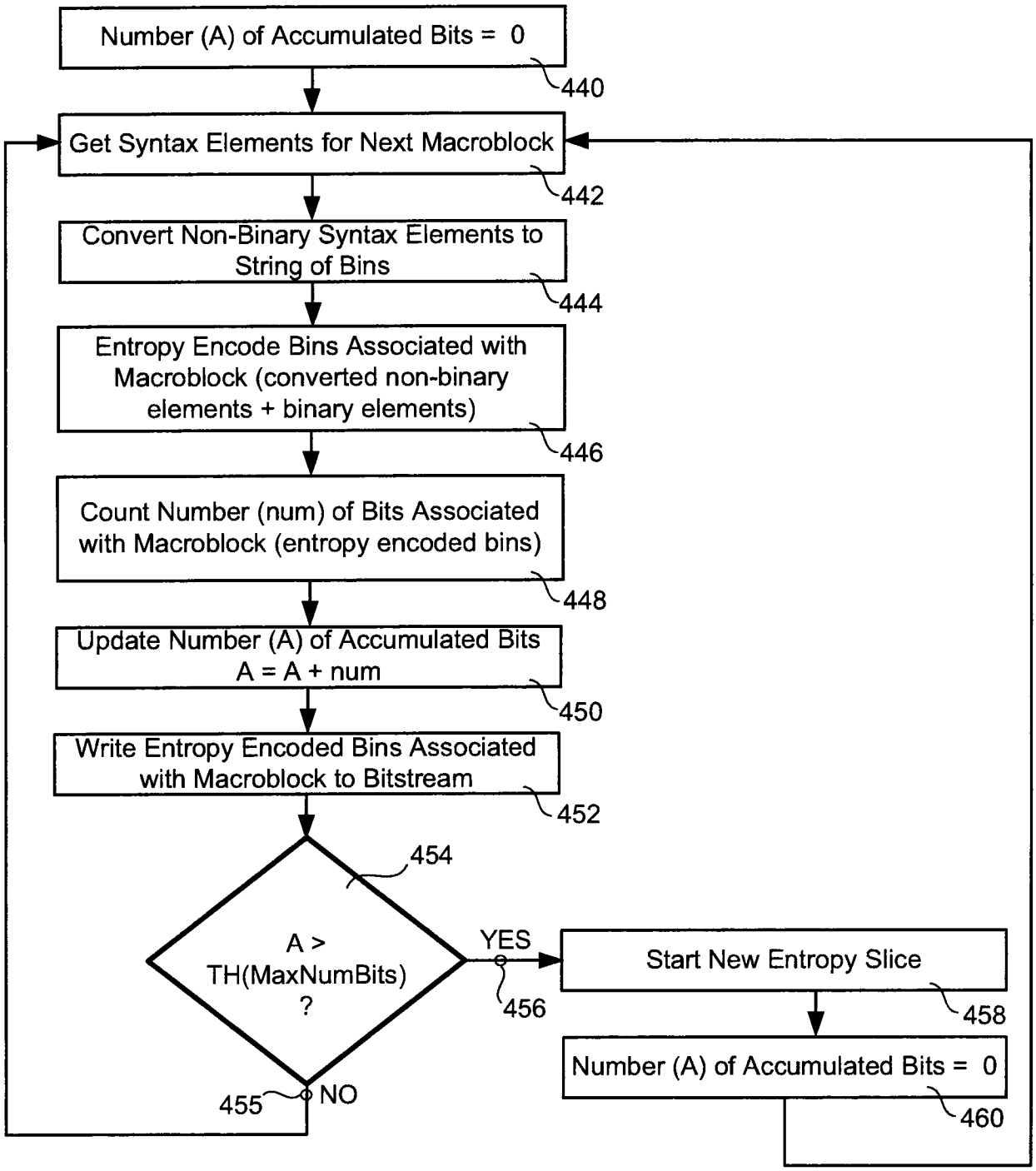

Number (A) of Accumulated Bits = 0
440
Get Syntax Elements for Next Macroblock
442
Convert Non-Binary Syntax Elements to String of Bins
444
Entropy Encode Bins Associated with Macroblock (converted non-binary elements + binary elements)
446
Count Number (num) of Bits Associated with Macroblock (entropy encoded bins)
448
Update Number (A) of Accumulated Bits A = A + num
450
Write Entropy Encoded Bins Associated with Macroblock to Bitstream
452
454
A > TH(MaxNumBits) ?
YES
456
Start New Entropy Slice
458
Number (A) of Accumulated Bits = 0
460
455
NO

FIG. 17

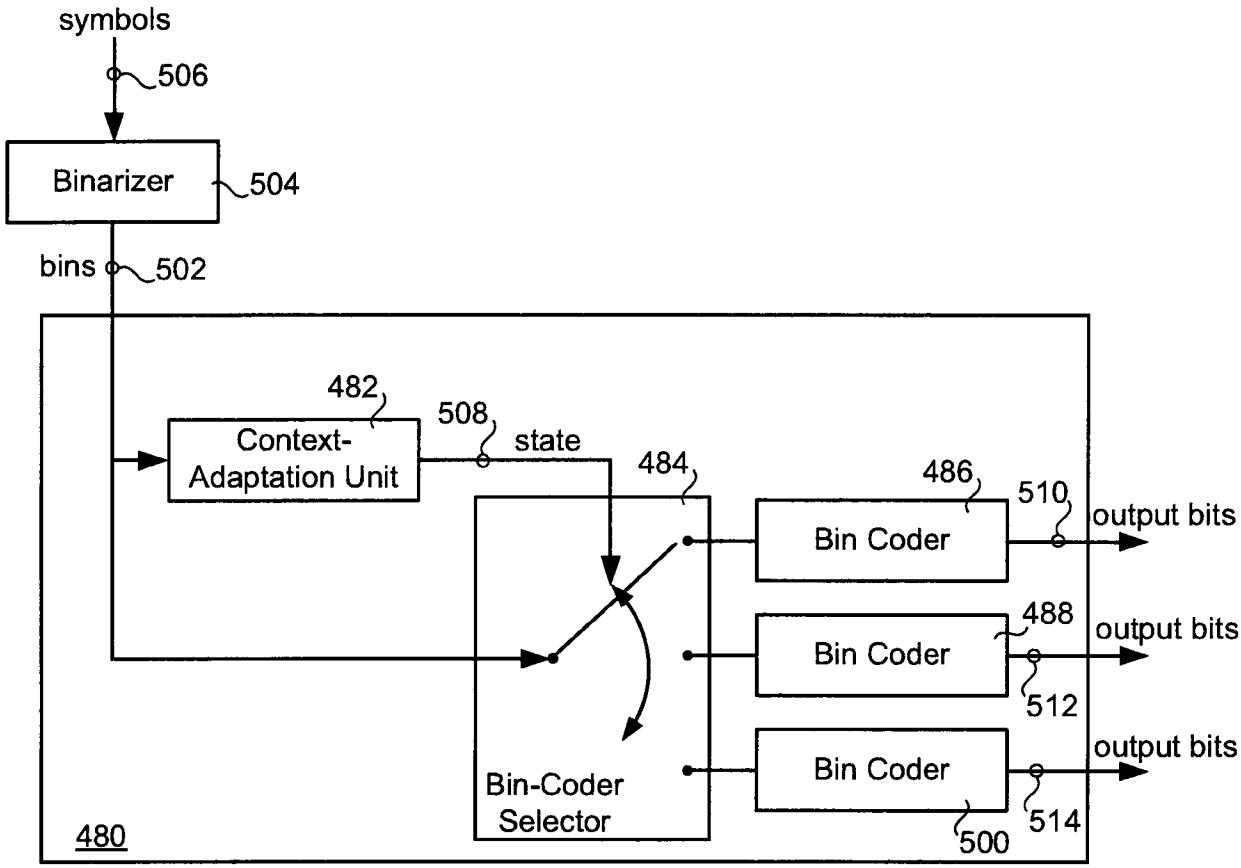

symbols
506
Binarizer
504
bins
502
482
Context-
Adaptation Unit
508
state
484
486
510
output bits
Bin Coder
488
output bits
Bin Coder
512
output bits
Bin Coder
514
Bin-Coder
Selector
480
500

FIG. 18

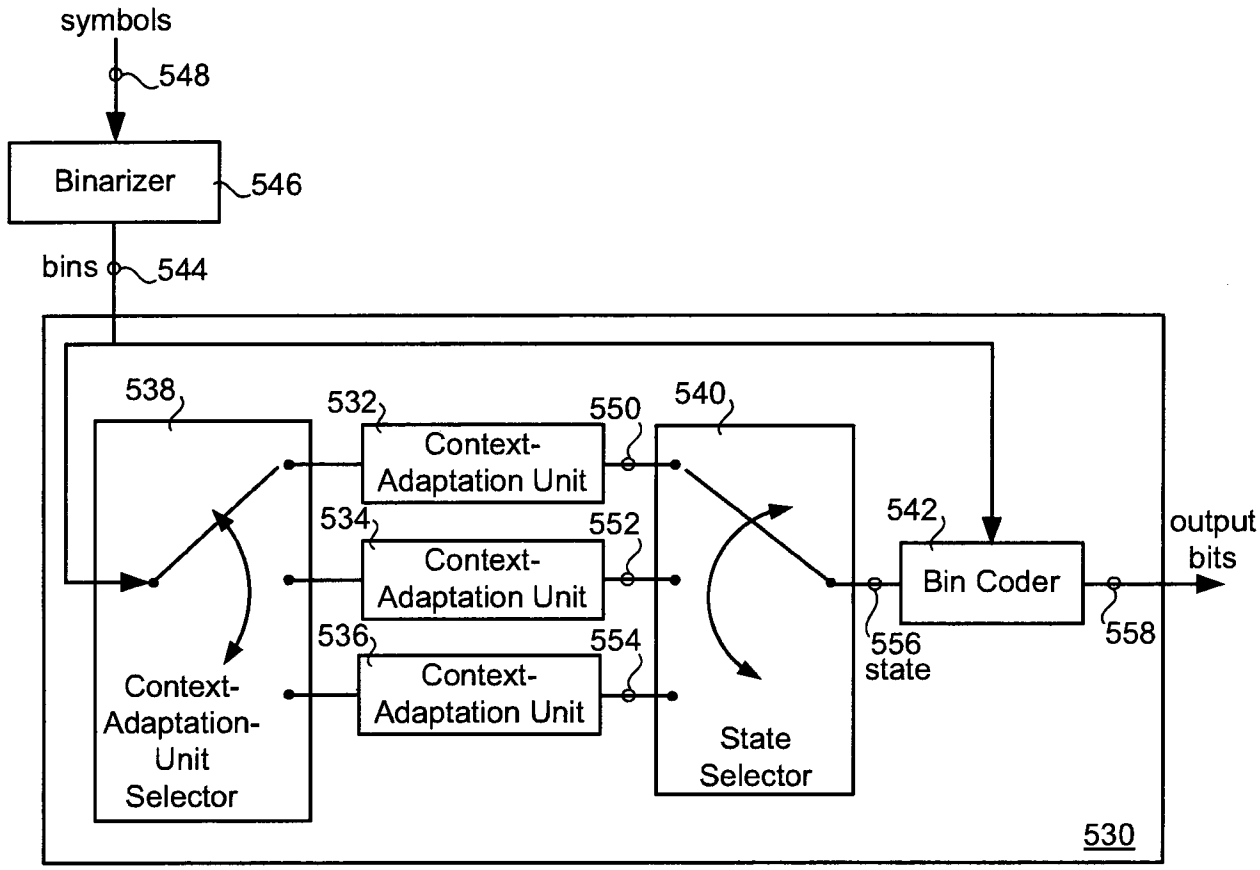

symbols
548
Binarizer
546
bins
544
538
532
Context-
Adaptation Unit
550
540
534
Context-
Adaptation Unit
552
542
Bin Coder
output
bits
536
Context-
Adaptation Unit
554
556
state
558
Context-
Adaptation-
Unit
Selector
State
Selector
530

FIG. 19

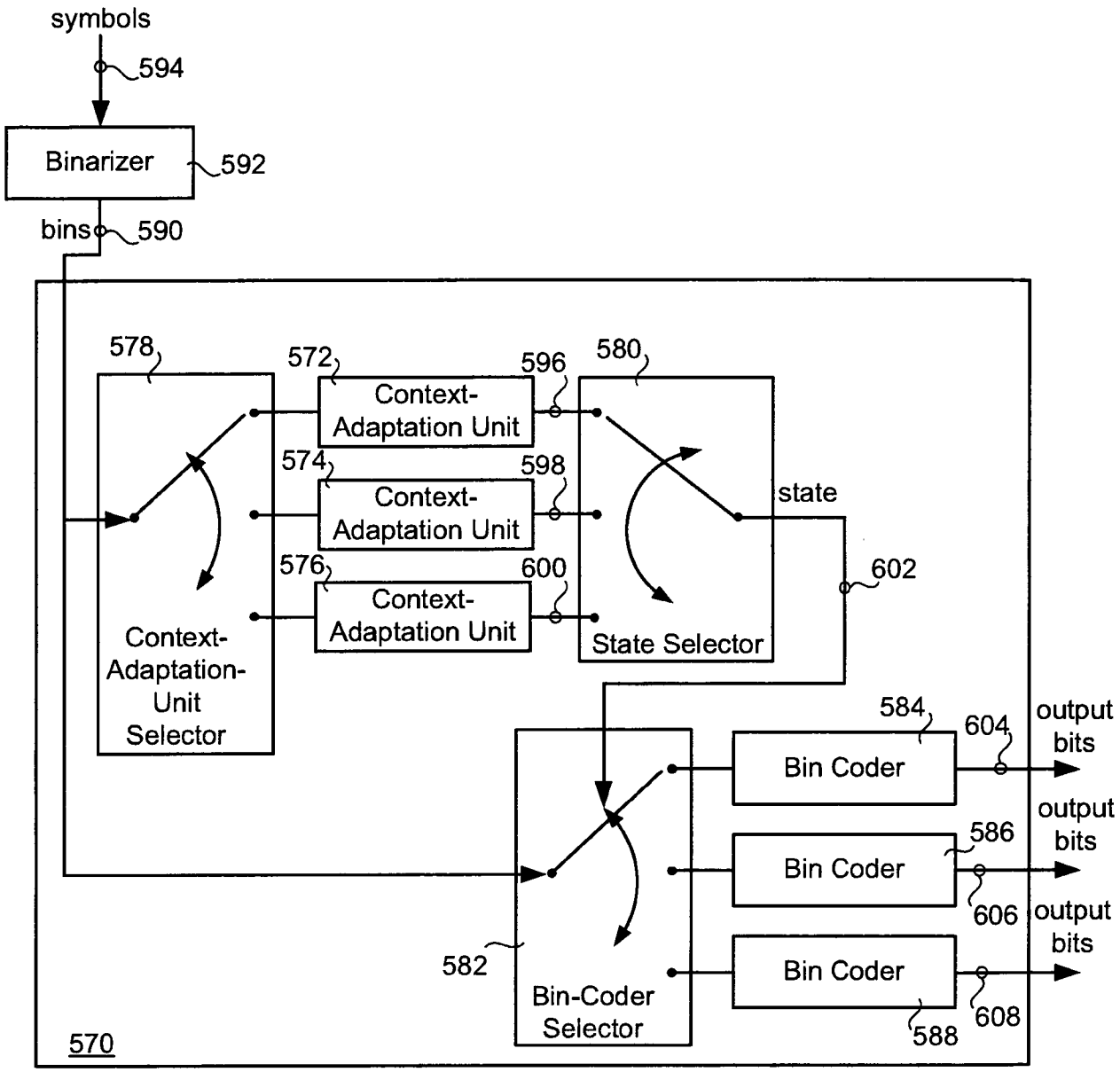

symbols
594
Binarizer
592
bins
590
578
572
Context-
Adaptation Unit
596
580
574
Context-
Adaptation Unit
598
state
576
Context-
Adaptation Unit
600
602
Context-
Adaptation-
Unit
Selector
State Selector
584
604
output
bits
Bin Coder
586
output
bits
Bin Coder
606
output
bits
582
Bin Coder
608
Bin-Coder
Selector
588
570

FIG. 20

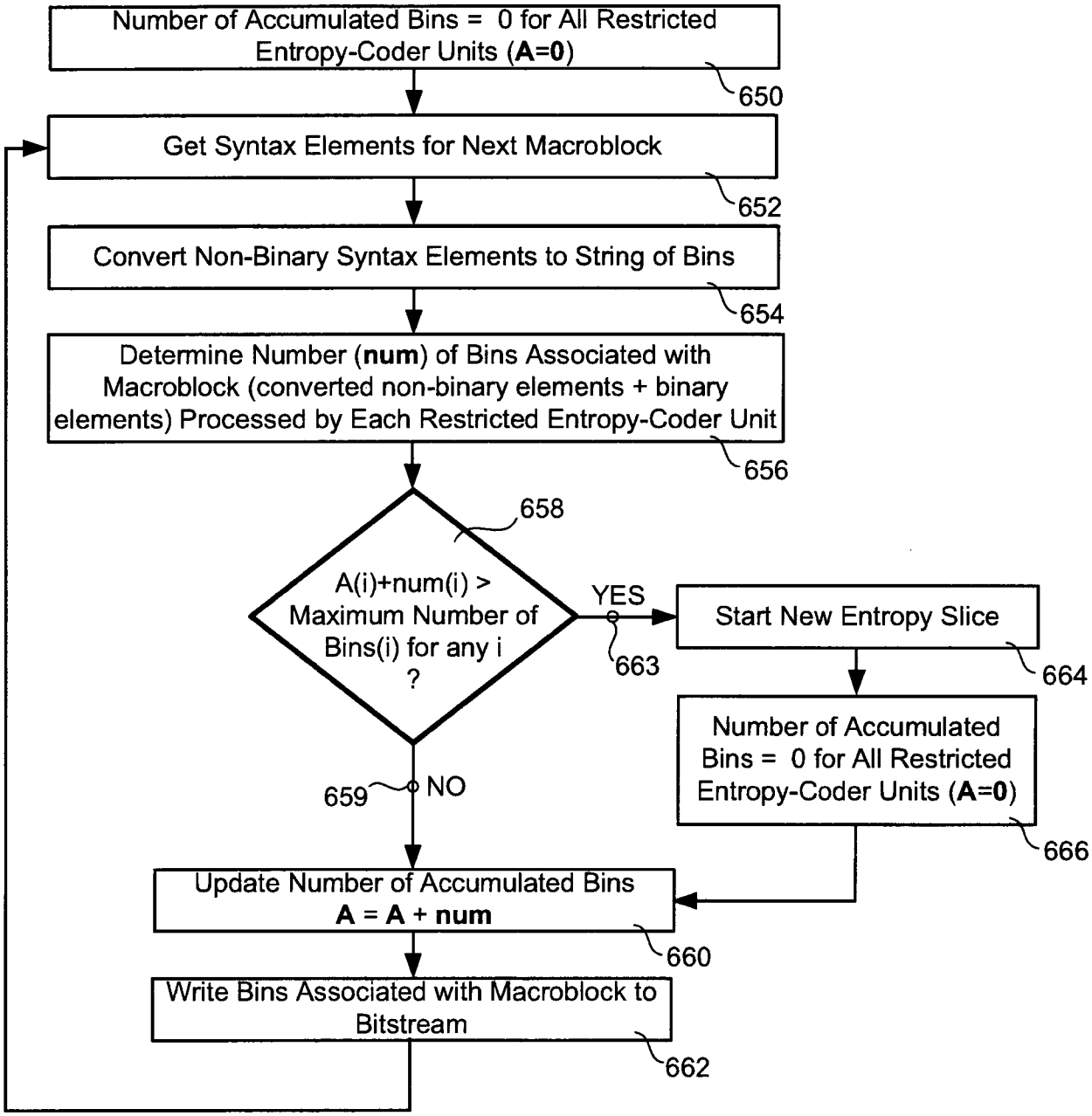

Number of Accumulated Bins = 0 for All Restricted Entropy-Coder Units (A=0)
650
Get Syntax Elements for Next Macroblock
652
Convert Non-Binary Syntax Elements to String of Bins
654
Determine Number (num) of Bins Associated with Macroblock (converted non-binary elements + binary elements) Processed by Each Restricted Entropy-Coder Unit
656
658
A(i)+num(i) > Maximum Number of Bins(i) for any i ?
YES
663
Start New Entropy Slice
664
Number of Accumulated Bins = 0 for All Restricted Entropy-Coder Units (A=0)
666
659
NO
Update Number of Accumulated Bins A = A + num
660
Write Bins Associated with Macroblock to Bitstream
662

FIG. 21

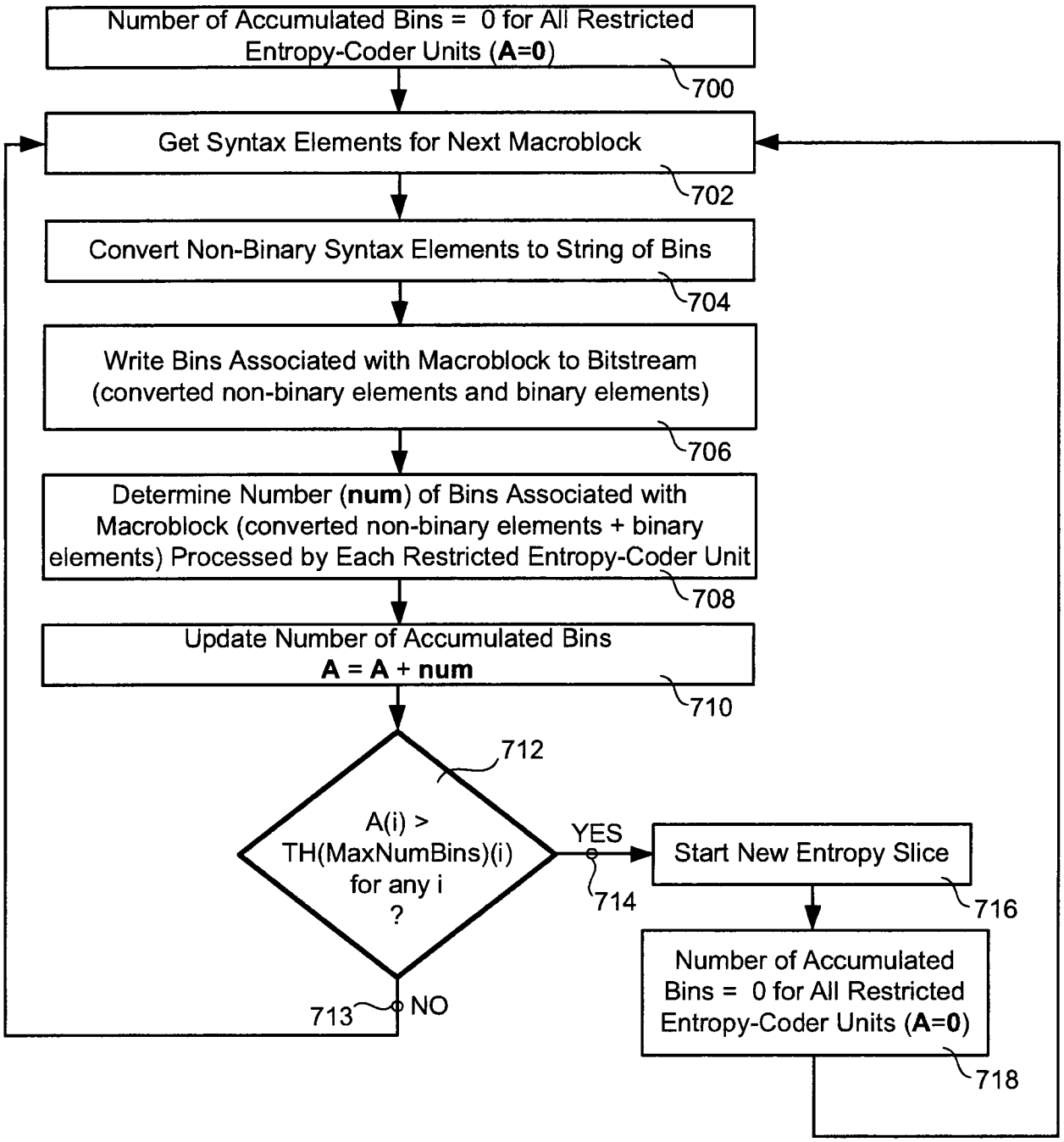

Number of Accumulated Bins = 0 for All Restricted Entropy-Coder Units (A=0)
700
Get Syntax Elements for Next Macroblock
702
Convert Non-Binary Syntax Elements to String of Bins
704
Write Bins Associated with Macroblock to Bitstream (converted non-binary elements and binary elements)
706
Determine Number (num) of Bins Associated with Macroblock (converted non-binary elements + binary elements) Processed by Each Restricted Entropy-Coder Unit
708
Update Number of Accumulated Bins
A = A + num
710
712
A(i) > TH(MaxNumBins)(i) for any i ?
YES
714
Start New Entropy Slice
716
Number of Accumulated Bins = 0 for All Restricted Entropy-Coder Units (A=0)
718
713
NO

FIG. 22

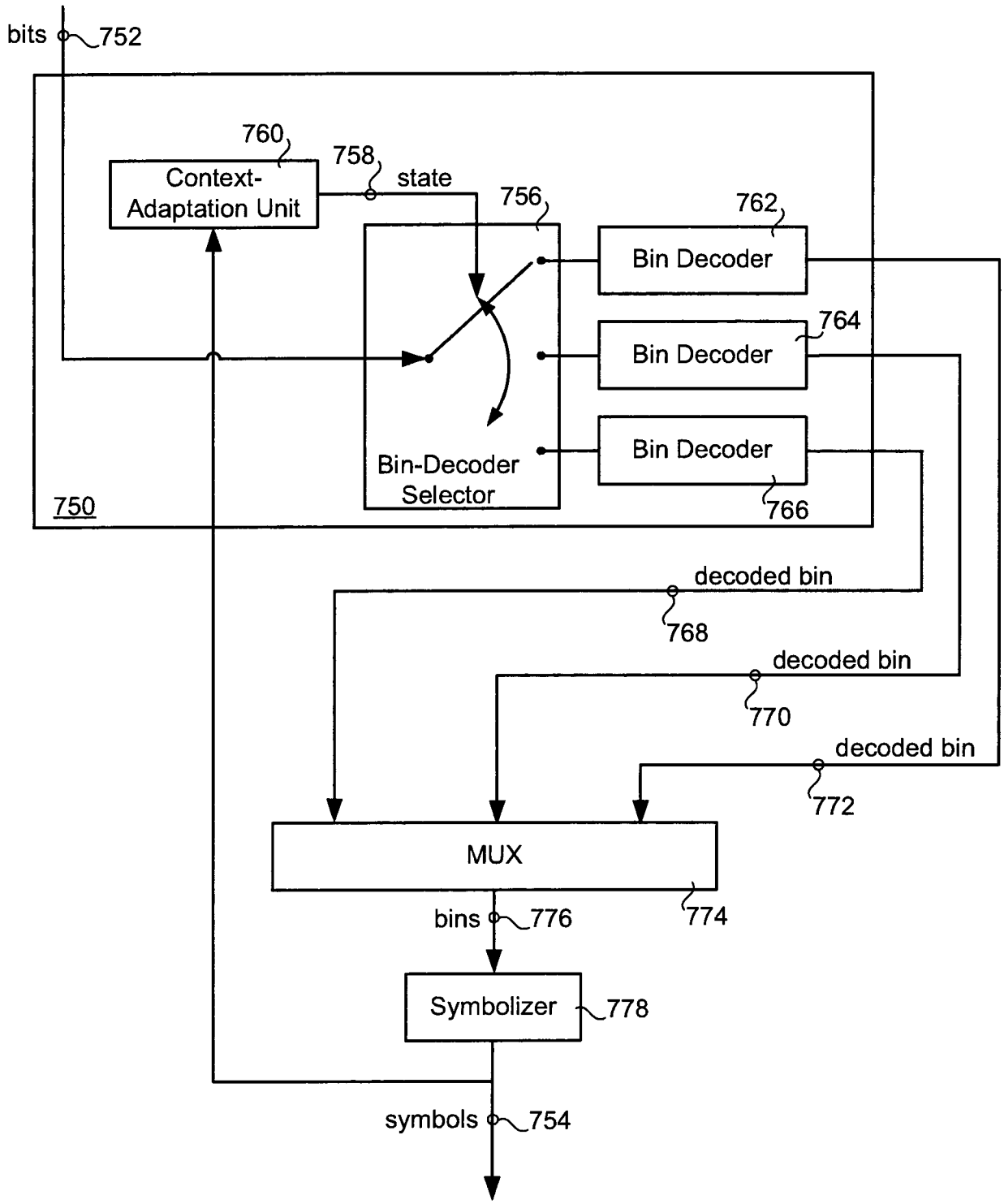

bits
752
760
Context-
Adaptation Unit
758
state
756
762
Bin Decoder
764
Bin Decoder
Bin Decoder
Bin-Decoder
Selector
766
750
decoded bin
768
decoded bin
770
decoded bin
772
MUX
774
bins
776
Symbolizer
778
symbols
754

FIG. 23

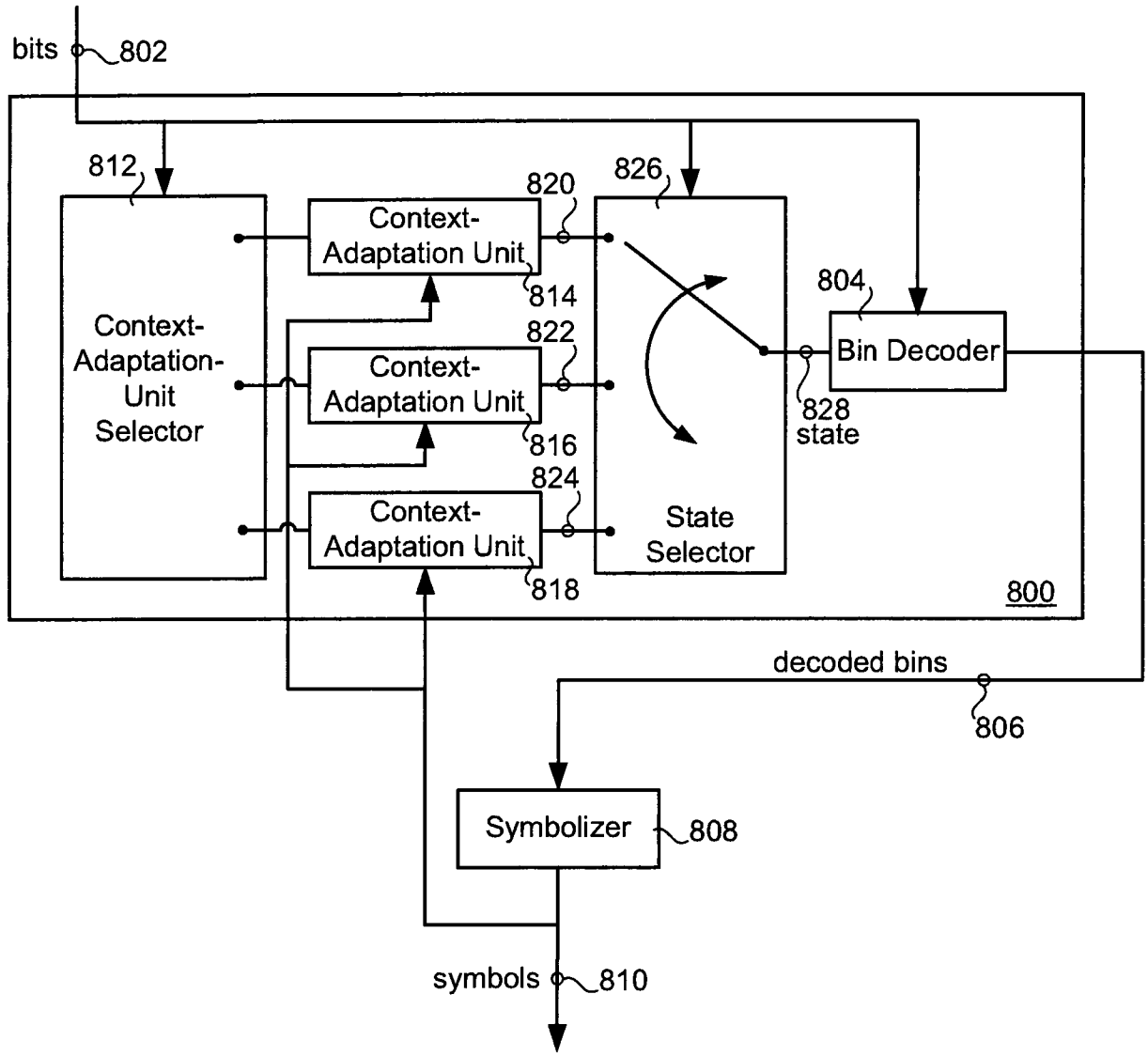

bits
802
812
Context-
Adaptation-
Unit
Selector
820
Context-
Adaptation Unit
814
822
Context-
Adaptation Unit
816
824
Context-
Adaptation Unit
818
826
State
Selector
804
Bin Decoder
828
state
800
decoded bins
806
Symbolizer
808
symbols
810

FIG. 24

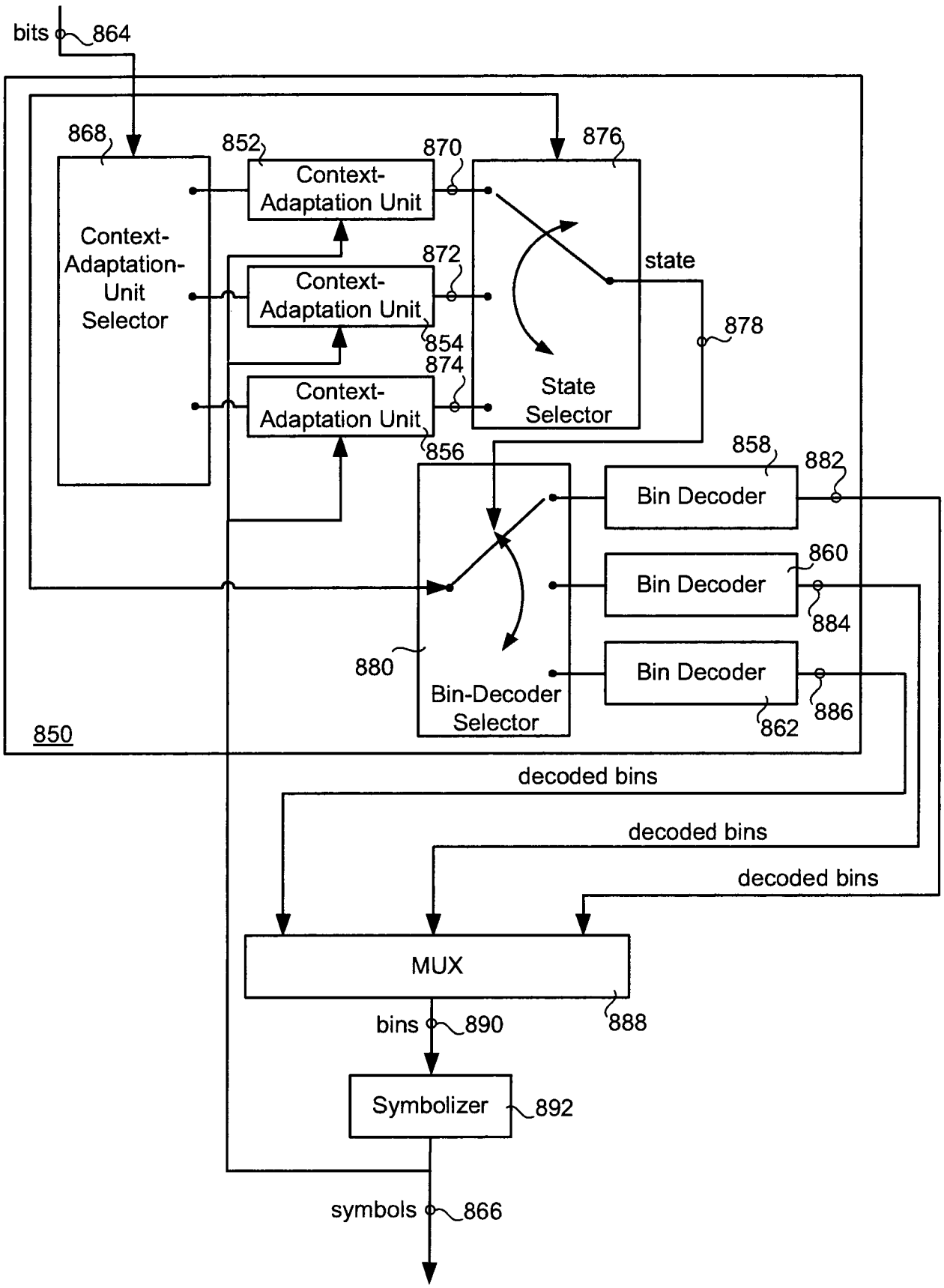

bits
864
868
852
870
876
Context-Adaptation Unit
Context-Adaptation-Unit Selector
872
Context-Adaptation Unit
state
878
854
874
Context-Adaptation Unit
State Selector
856
858
882
Bin Decoder
860
Bin Decoder
884
880
Bin Decoder
Bin-Decoder Selector
886
862
850
decoded bins
decoded bins
decoded bins
MUX
888
bins
890
Symbolizer
892
symbols
866

FIG. 25

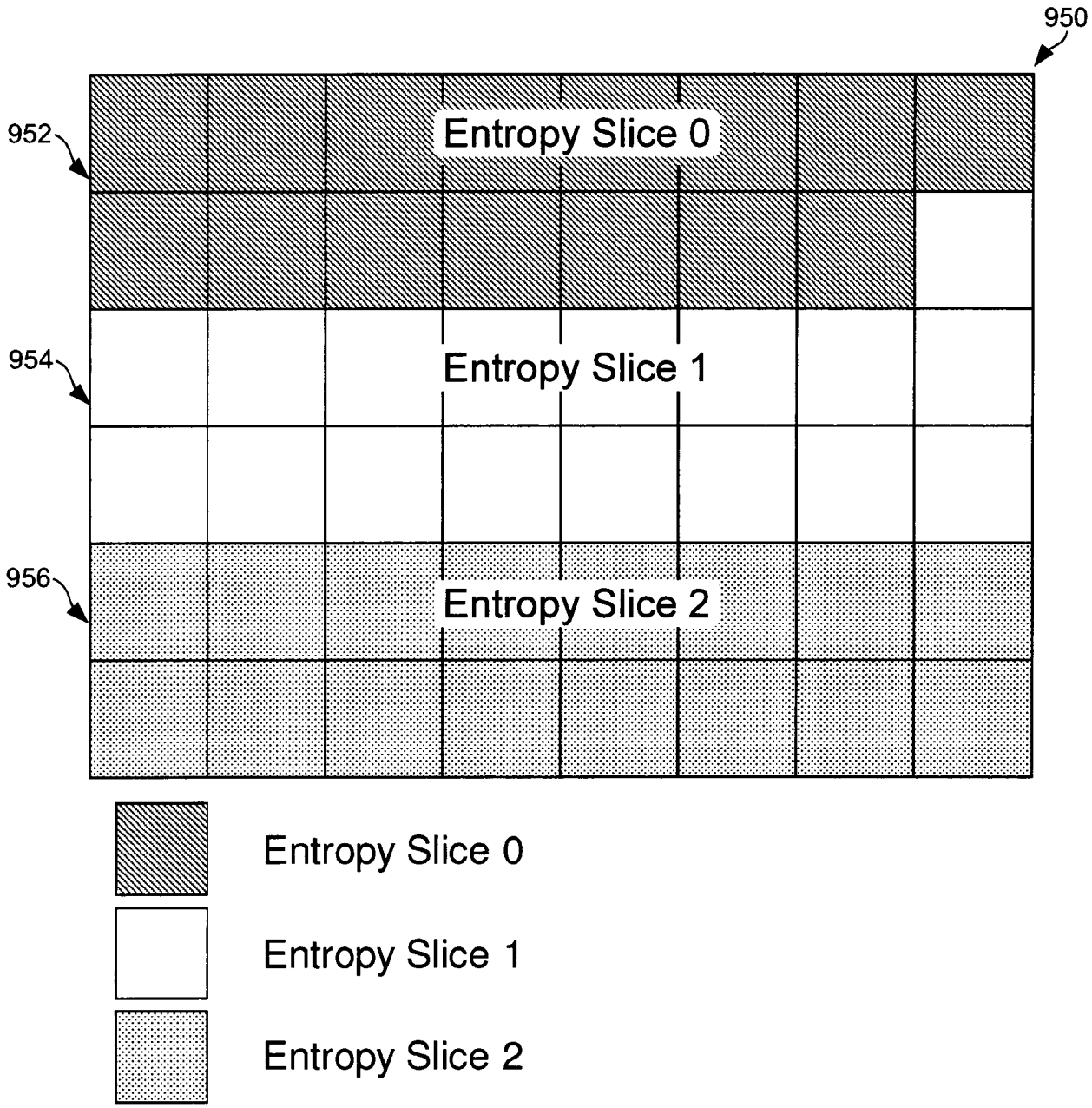

950
952
Entropy Slice 0
954
Entropy Slice 1
956
Entropy Slice 2
Entropy Slice 0
Entropy Slice 1
Entropy Slice 2

FIG. 26

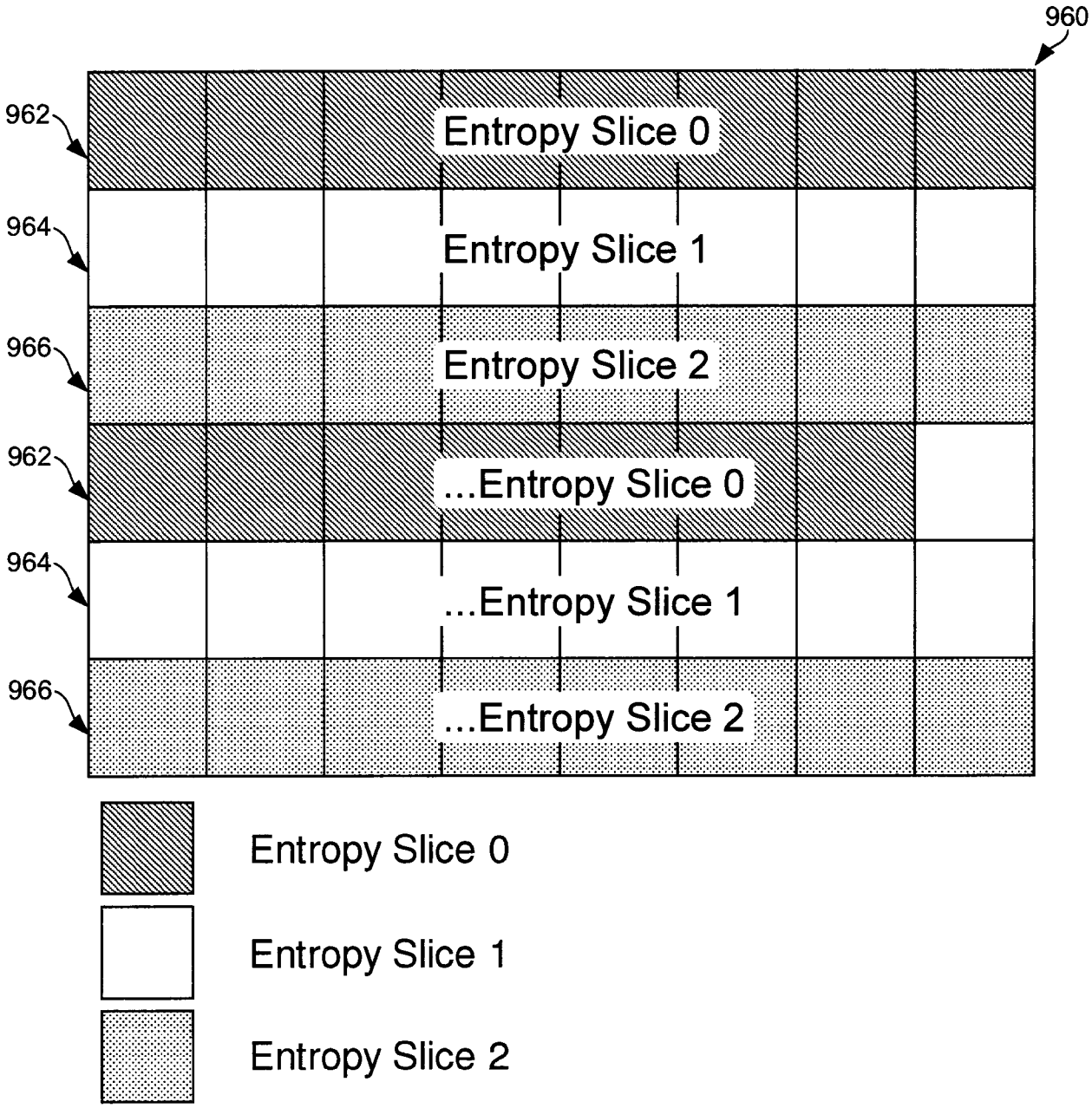

960
962
964
966
962
964
966
Entropy Slice 0
Entropy Slice 1
Entropy Slice 2
...Entropy Slice 0
...Entropy Slice 1
...Entropy Slice 2
Entropy Slice 0
Entropy Slice 1
Entropy Slice 2

FIG. 27

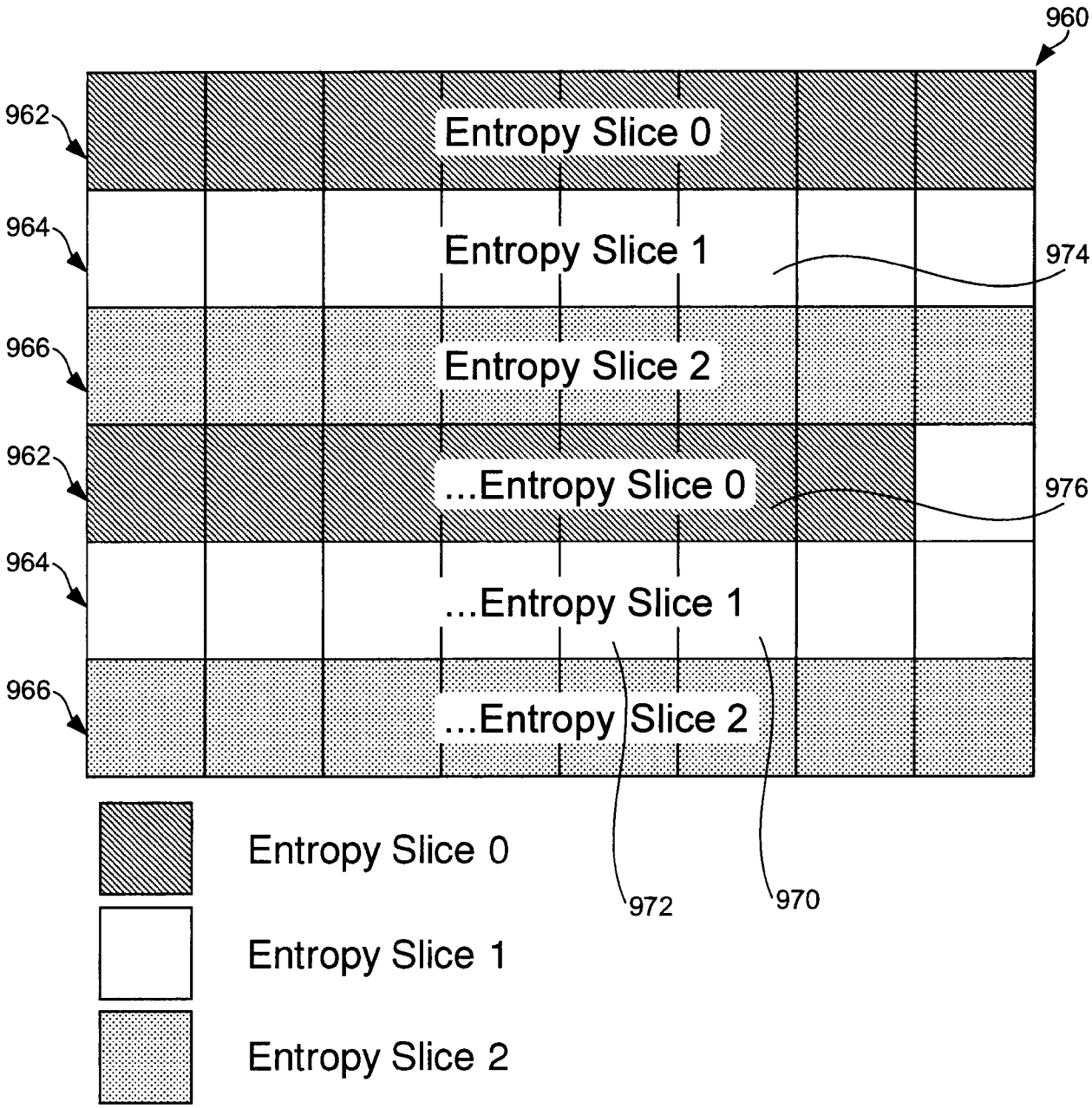

960
962
964
966
962
964
966
Entropy Slice 0
Entropy Slice 1
Entropy Slice 2
...Entropy Slice 0
...Entropy Slice 1
...Entropy Slice 2
974
976
972
970
Entropy Slice 0
Entropy Slice 1
Entropy Slice 2

FIG. 28

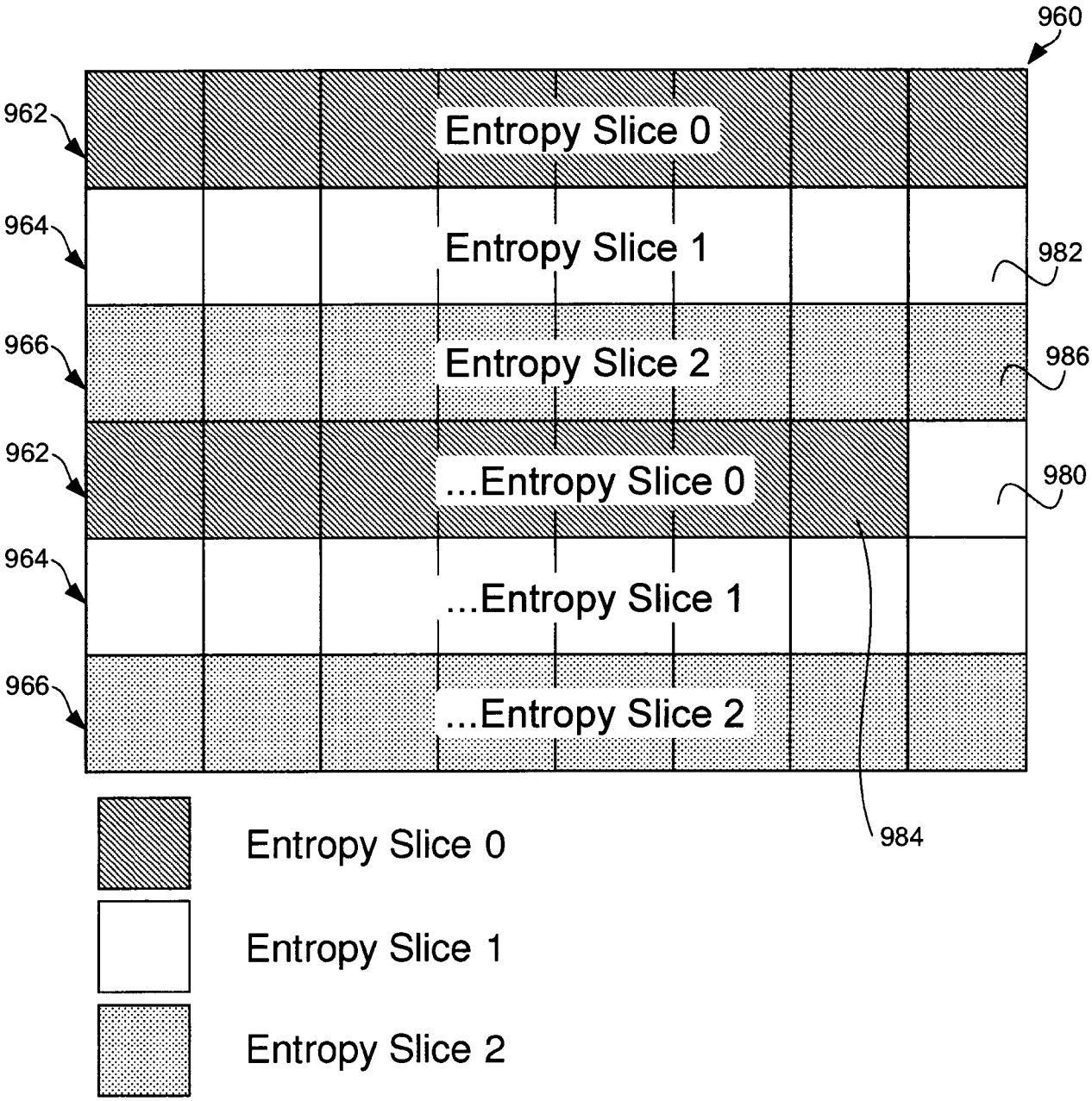

960
962
964
966
962
964
966
Entropy Slice 0
Entropy Slice 1
Entropy Slice 2
...Entropy Slice 0
...Entropy Slice 1
...Entropy Slice 2
982
986
980
984
Entropy Slice 0
Entropy Slice 1
Entropy Slice 2

FIG. 29

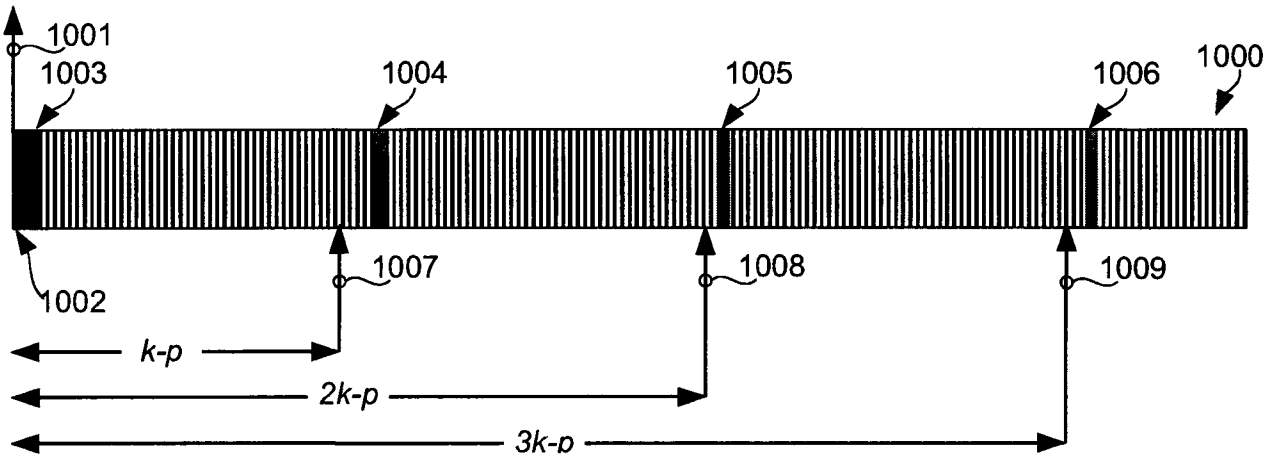


FIG. 30

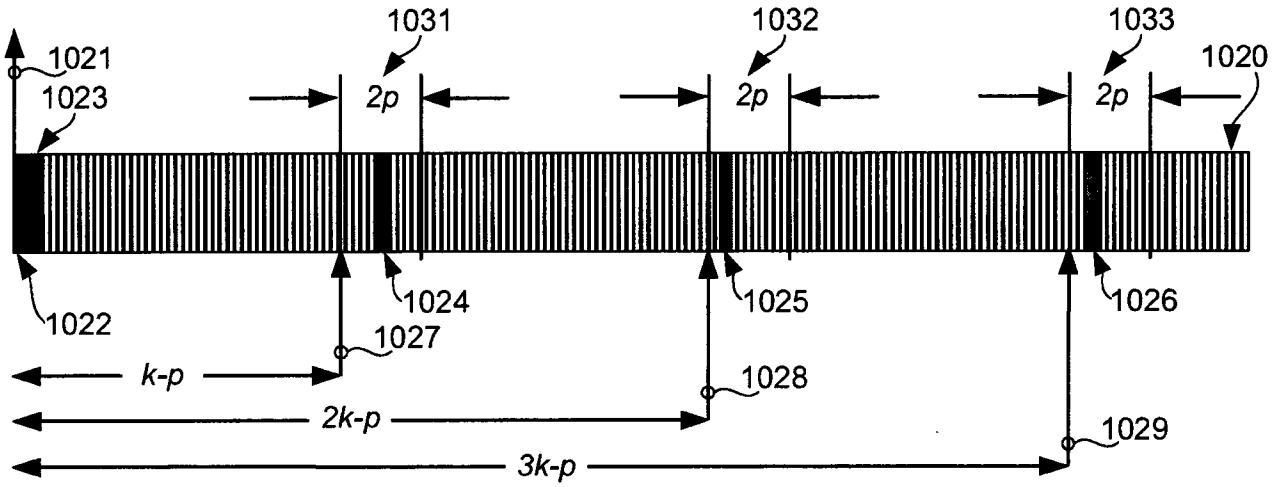

1021
1023
1031
1032
1033
1020
2p
2p
2p
1022
1024
1025
1026
1027
k-p
1028
2k-p
1029
3k-p

FIG. 31

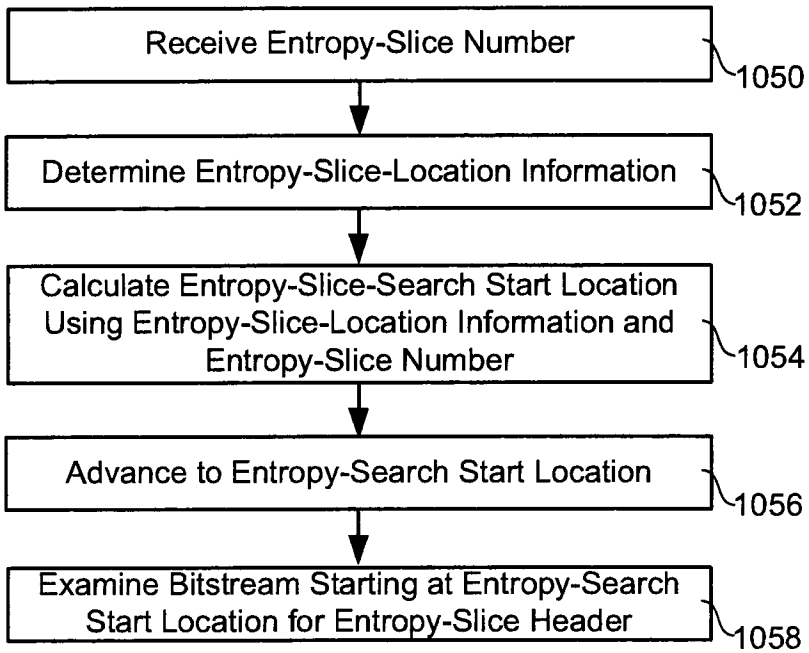

Receive Entropy-Slice Number
1050
Determine Entropy-Slice-Location Information
1052
Calculate Entropy-Slice-Search Start Location Using Entropy-Slice-Location Information and Entropy-Slice Number
1054
Advance to Entropy-Search Start Location
1056
Examine Bitstream Starting at Entropy-Search Start Location for Entropy-Slice Header
1058

FIG. 32

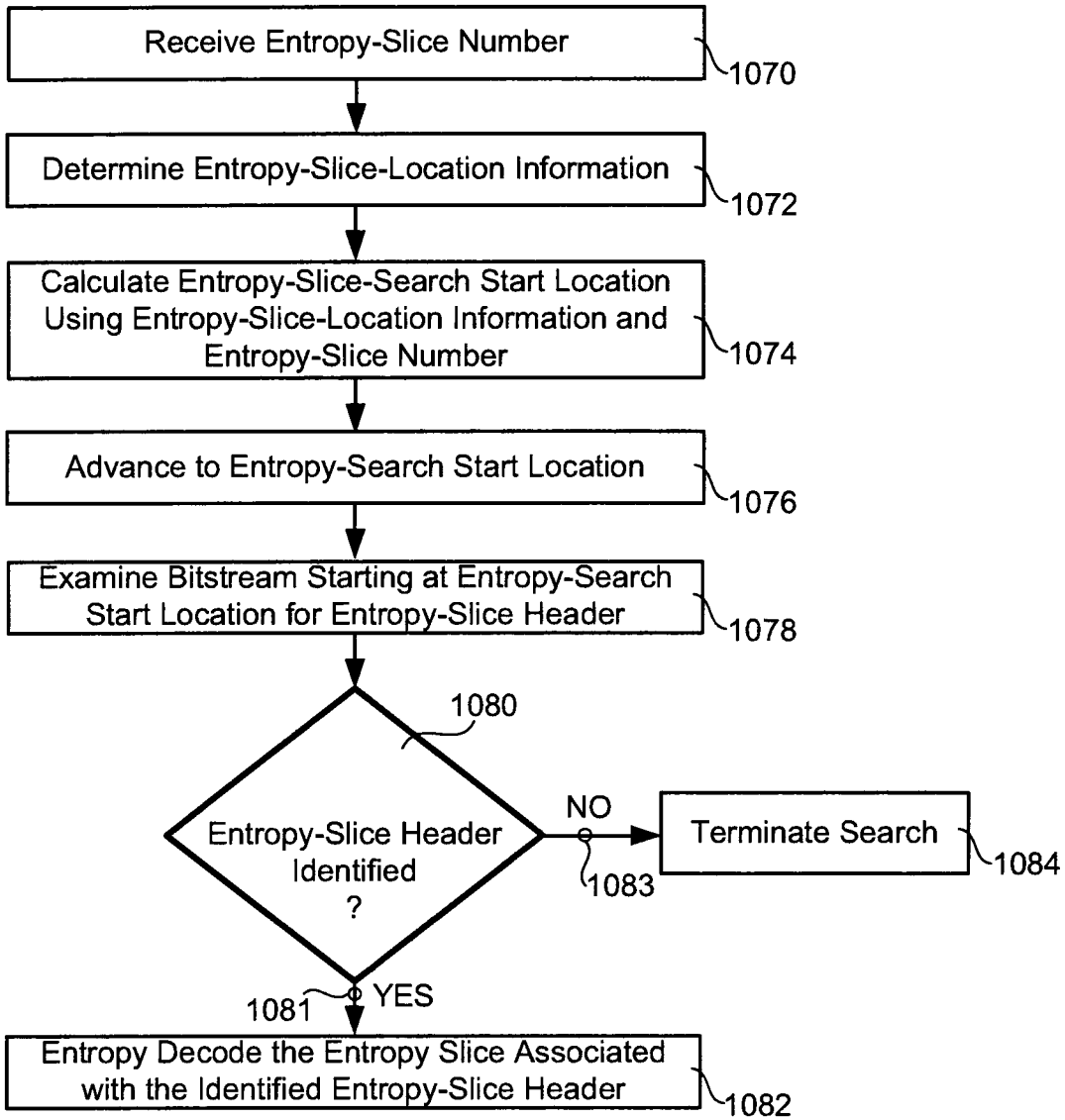

Receive Entropy-Slice Number
1070
Determine Entropy-Slice-Location Information
1072
Calculate Entropy-Slice-Search Start Location Using Entropy-Slice-Location Information and Entropy-Slice Number
1074
Advance to Entropy-Search Start Location
1076
Examine Bitstream Starting at Entropy-Search Start Location for Entropy-Slice Header
1078
1080
Entropy-Slice Header Identified ?
NO
1083
Terminate Search
1084
1081
YES
Entropy Decode the Entropy Slice Associated with the Identified Entropy-Slice Header
1082

FIG. 33

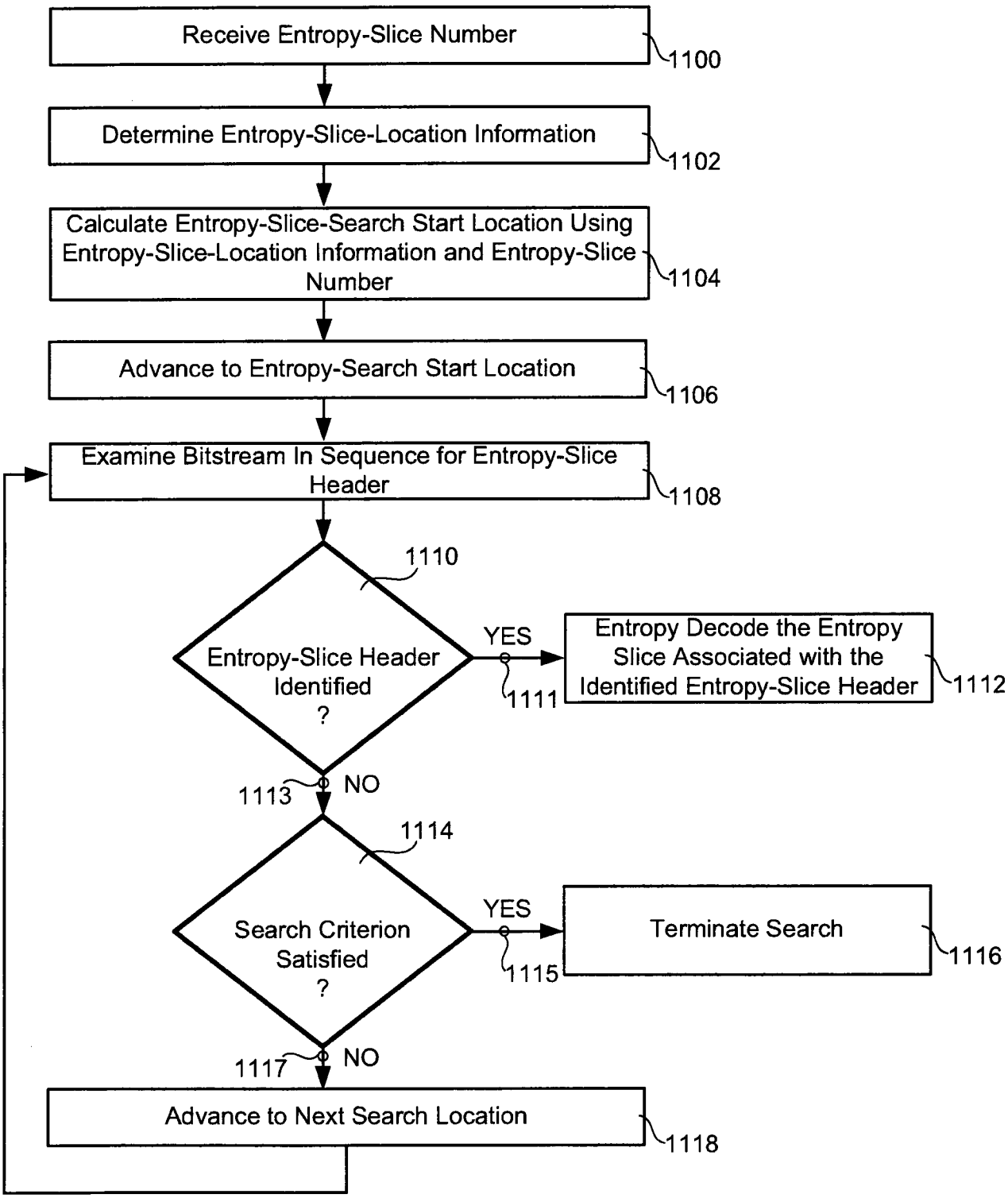
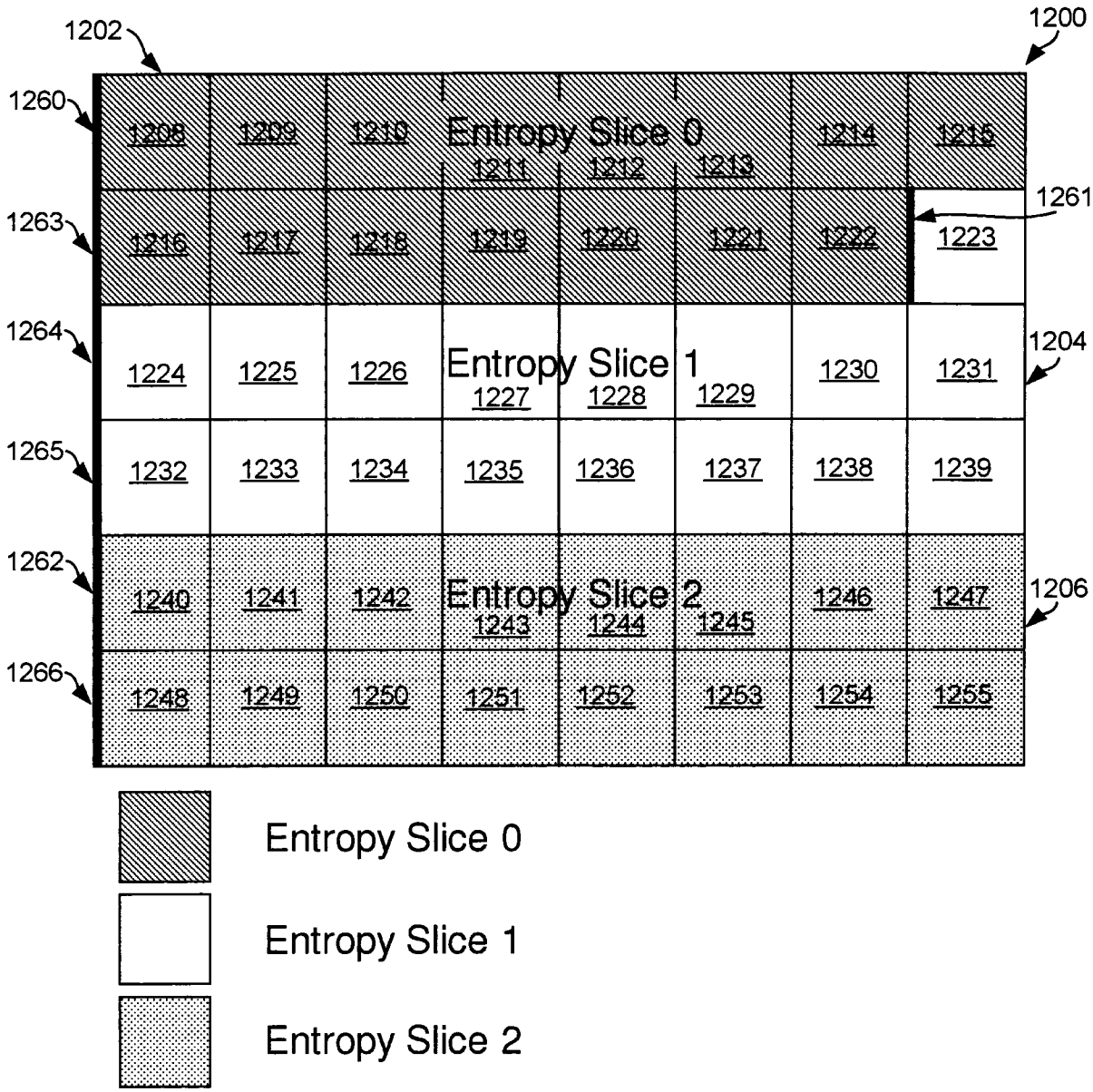

Receive Entropy-Slice Number
1100
Determine Entropy-Slice-Location Information
1102
Calculate Entropy-Slice-Search Start Location Using Entropy-Slice-Location Information and Entropy-Slice Number
1104
Advance to Entropy-Search Start Location
1106
Examine Bitstream In Sequence for Entropy-Slice Header
1108
1110
Entropy-Slice Header Identified ?
YES
1111
Entropy Decode the Entropy Slice Associated with the Identified Entropy-Slice Header
1112
1113
NO
1114
Search Criterion Satisfied ?
YES
1115
Terminate Search
1116
1117
NO
Advance to Next Search Location
1118

FIG. 34


1202
1200
1260
1263
1264
1265
1262
1266
1261
1204
1206
1208
1209
1210
Entropy Slice 0
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
Entropy Slice 1
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
Entropy Slice 2
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
Entropy Slice 0
Entropy Slice 1
Entropy Slice 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/073150

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H04N7/26(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. H04N7/26-50,H03M7/40

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2011
Registered utility model specifications of Japan 1996-2011
Published registered utility model applications of Japan 1994-2011

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Misra,K.,et al, Entropy Slices for Parallel Entropy Coding, Joint Collaborative Team on Video	1
A	Coding (JCT-VC)of ITU-T SG16 WP3 and ISO/IEC JTC1/SC29/WG11 JCTVC-B111, 2010.07.21	2-20
A	WO 2009/119888 A1 (SHARP KABUSHIKI KAISHA) 2009.10.01, line 2,Page 15 to line 21,Page23,line 7,Page 25 to line 5,Page 26,Figs.5-7,10 & JP 2011-515880 A & US 2009/0245349 A1 & EP2266319 A & CN 101981934 A	1-20

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20.12.2011	27.12.2011

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Hiroshi Kawasaki 5C 8944 Telephone No. +81-3-3581-1101 Ext. 3541