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(54) VIDEO CODING WITH NEURAL NETWORK (NN)-ARCHITECTURE FOR IN-LOOP FILTERING AND SUPER RESOLUTION

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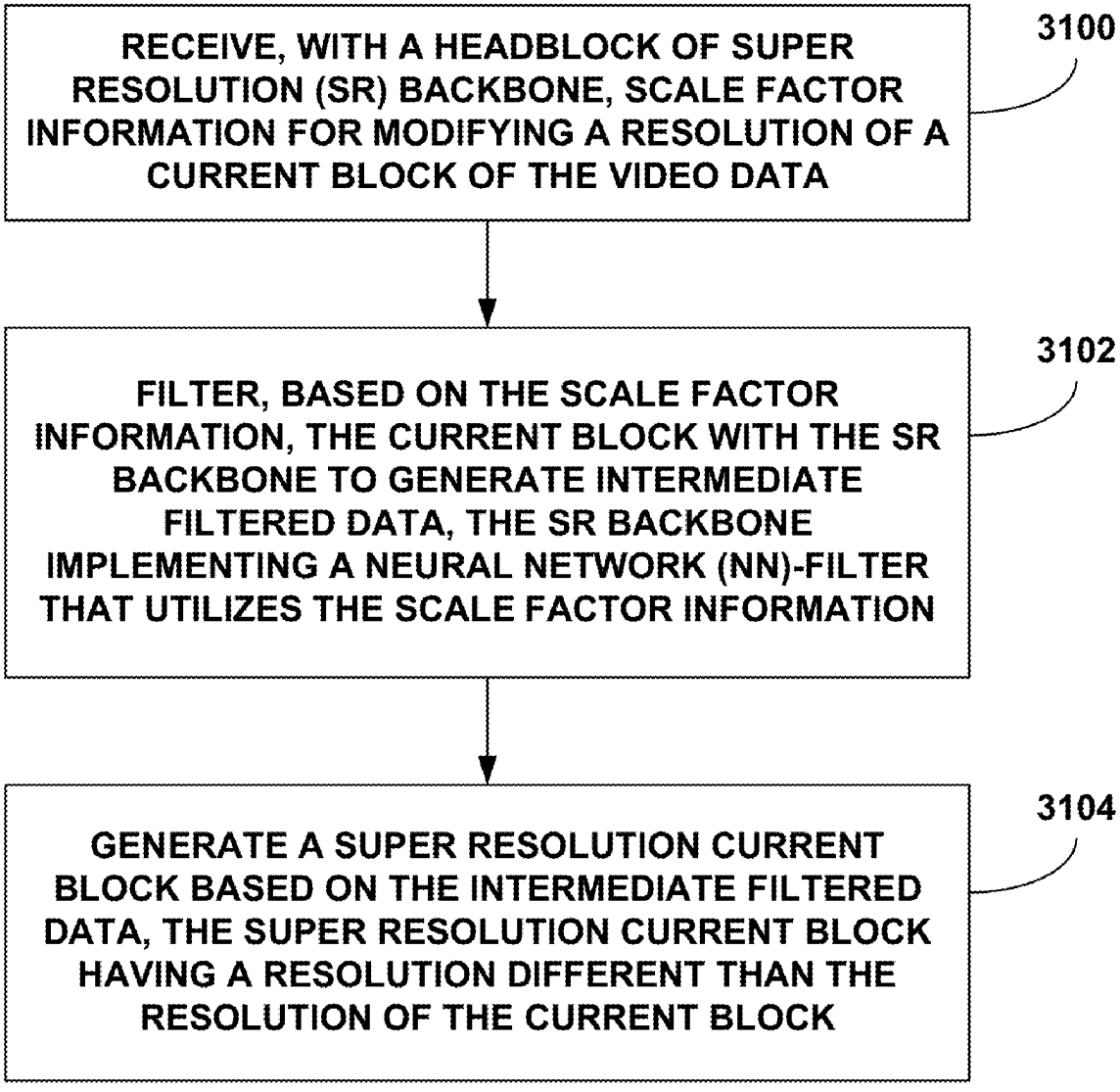
G06T 3/4046 (2024.01)

(52) **U.S. Cl.**
CPC ***G06T 3/4053*** (2013.01); ***G06T 3/4046*** (2013.01)

(57) **ABSTRACT**

A method of processing video data includes receiving, with a headblock of a super resolution (SR) backbone, scale factor information for modifying a resolution of a current block of the video data; filtering, based on the scale factor information, the current block with the SR backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that utilizes the scale factor information; and generating a super resolution current block based on the intermediate filtered data, the super resolution current block having a resolution different than the resolution of the current block.



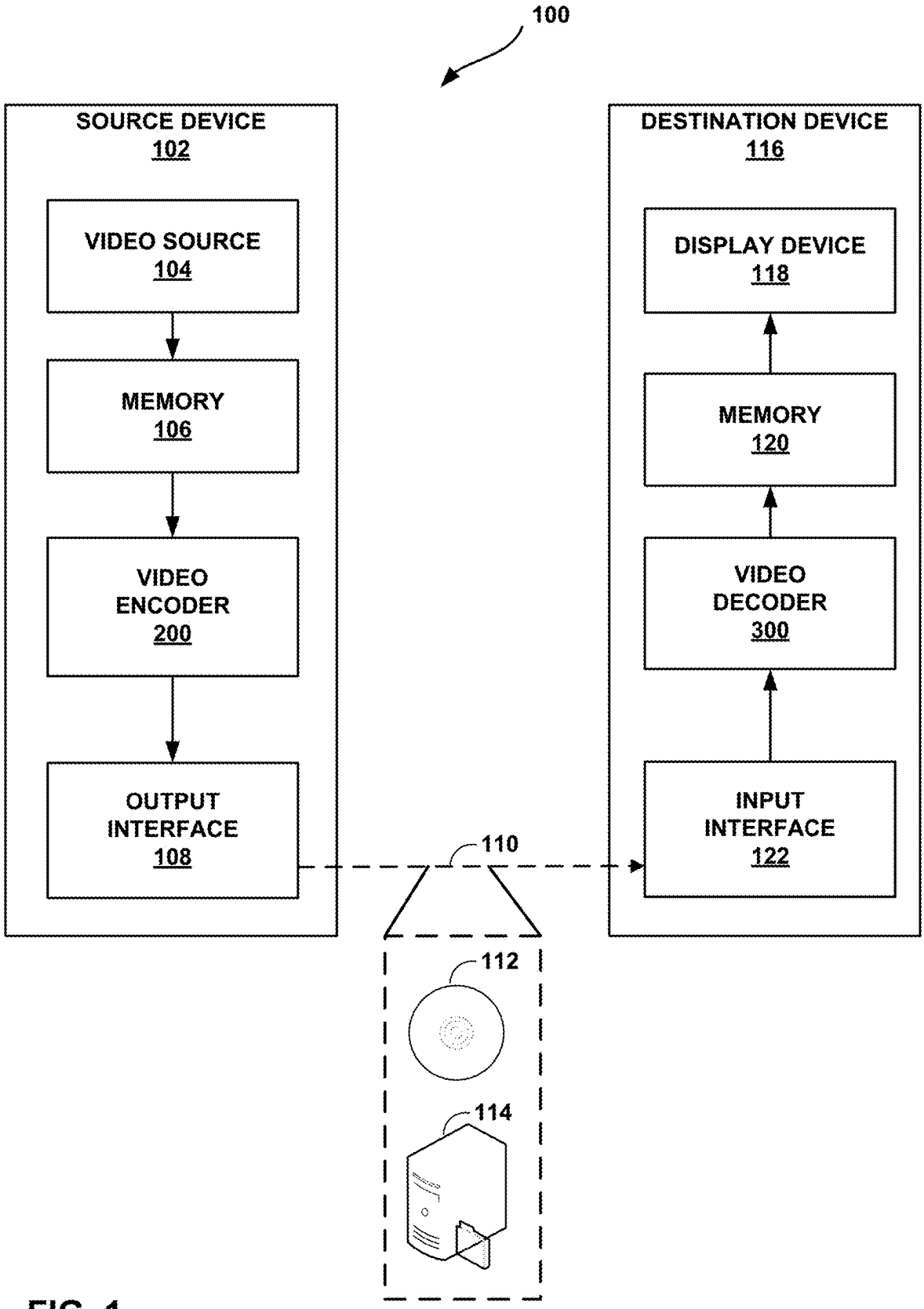

100
SOURCE DEVICE
102
VIDEO SOURCE
104
MEMORY
106
VIDEO
ENCODER
200
OUTPUT
INTERFACE
108
DESTINATION DEVICE
116
DISPLAY DEVICE
118
MEMORY
120
VIDEO
DECODER
300
INPUT
INTERFACE
122
110
112
114

FIG. 1

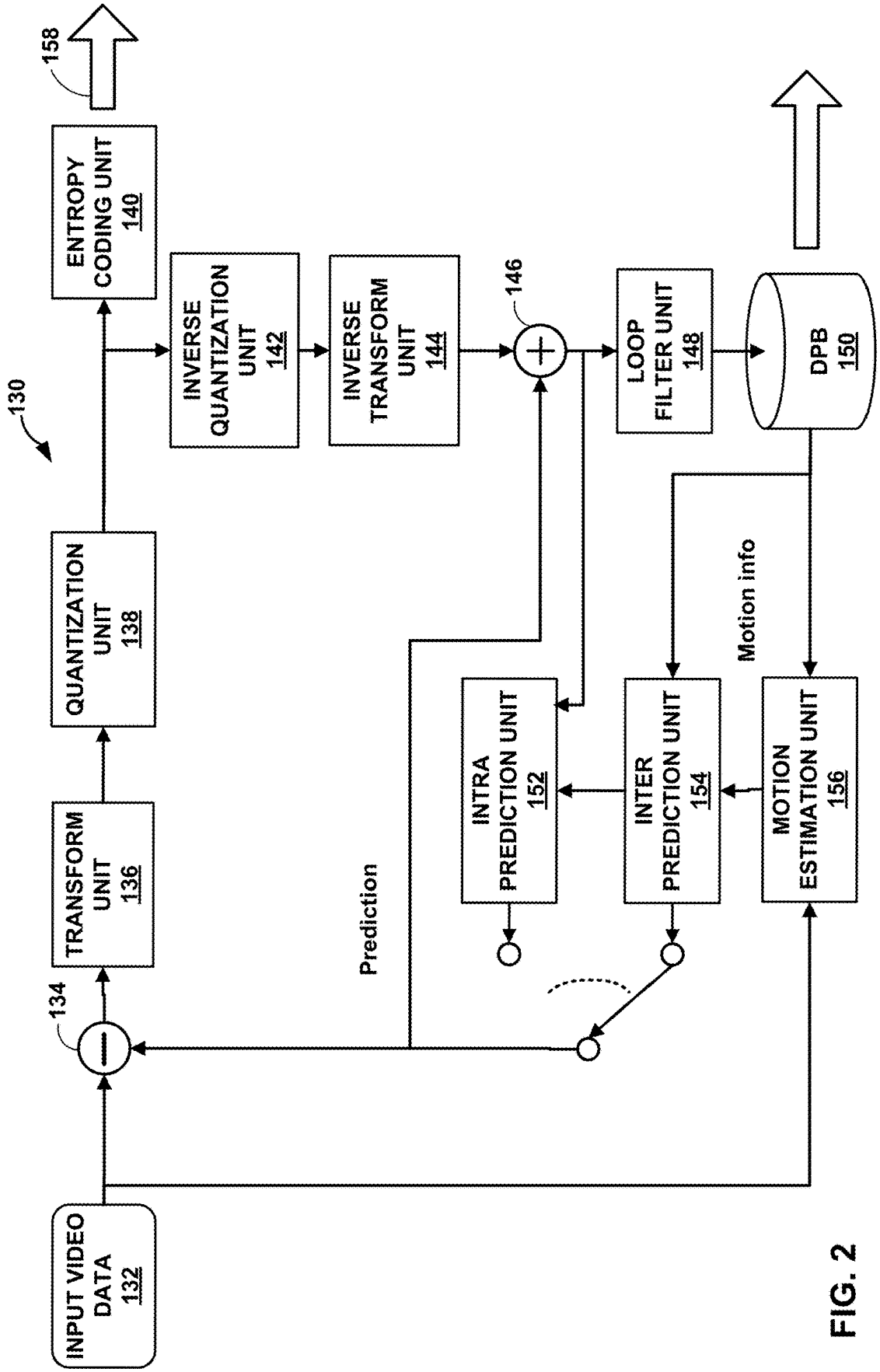

158
ENTROPY CODING UNIT 140
INVERSE QUANTIZATION UNIT 142
INVERSE TRANSFORM UNIT 144
146
LOOP FILTER UNIT 148
DPB 150
130
QUANTIZATION UNIT 138
Motion info
INTRA PREDICTION UNIT 152
INTER PREDICTION UNIT 154
MOTION ESTIMATION UNIT 156
TRANSFORM UNIT 136
Prediction
134
INPUT VIDEO DATA 132

FIG. 2

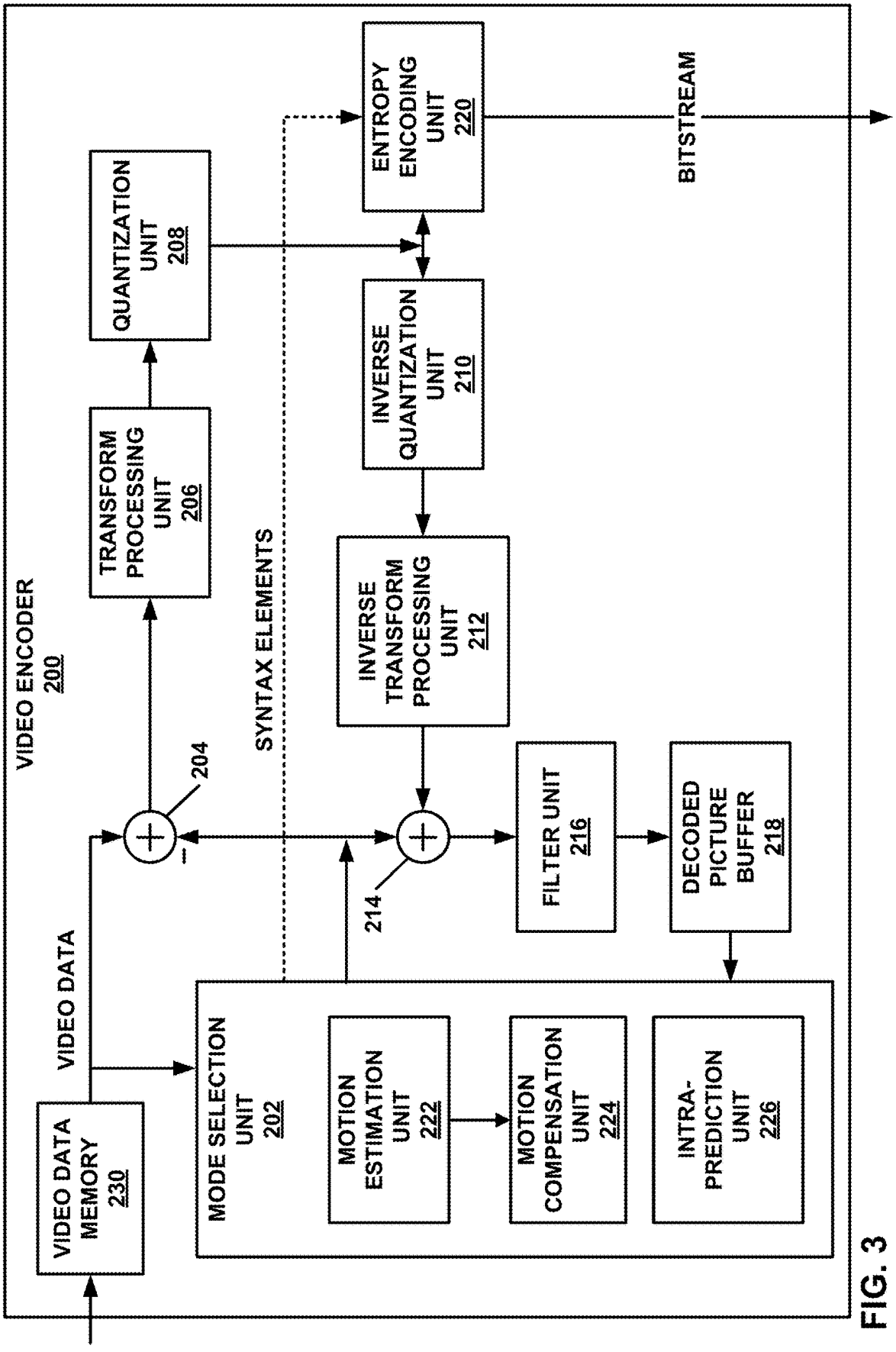

VIDEO ENCODER
200
VIDEO DATA MEMORY
230
VIDEO DATA
MODE SELECTION UNIT
202
MOTION ESTIMATION UNIT
222
MOTION COMPENSATION UNIT
224
INTRA-PREDICTION UNIT
226
204
214
SYNTAX ELEMENTS
TRANSFORM PROCESSING UNIT
206
QUANTIZATION UNIT
208
INVERSE QUANTIZATION UNIT
210
INVERSE TRANSFORM PROCESSING UNIT
212
FILTER UNIT
216
DECODED PICTURE BUFFER
218
ENTROPY ENCODING UNIT
220
BITSTREAM

FIG. 3

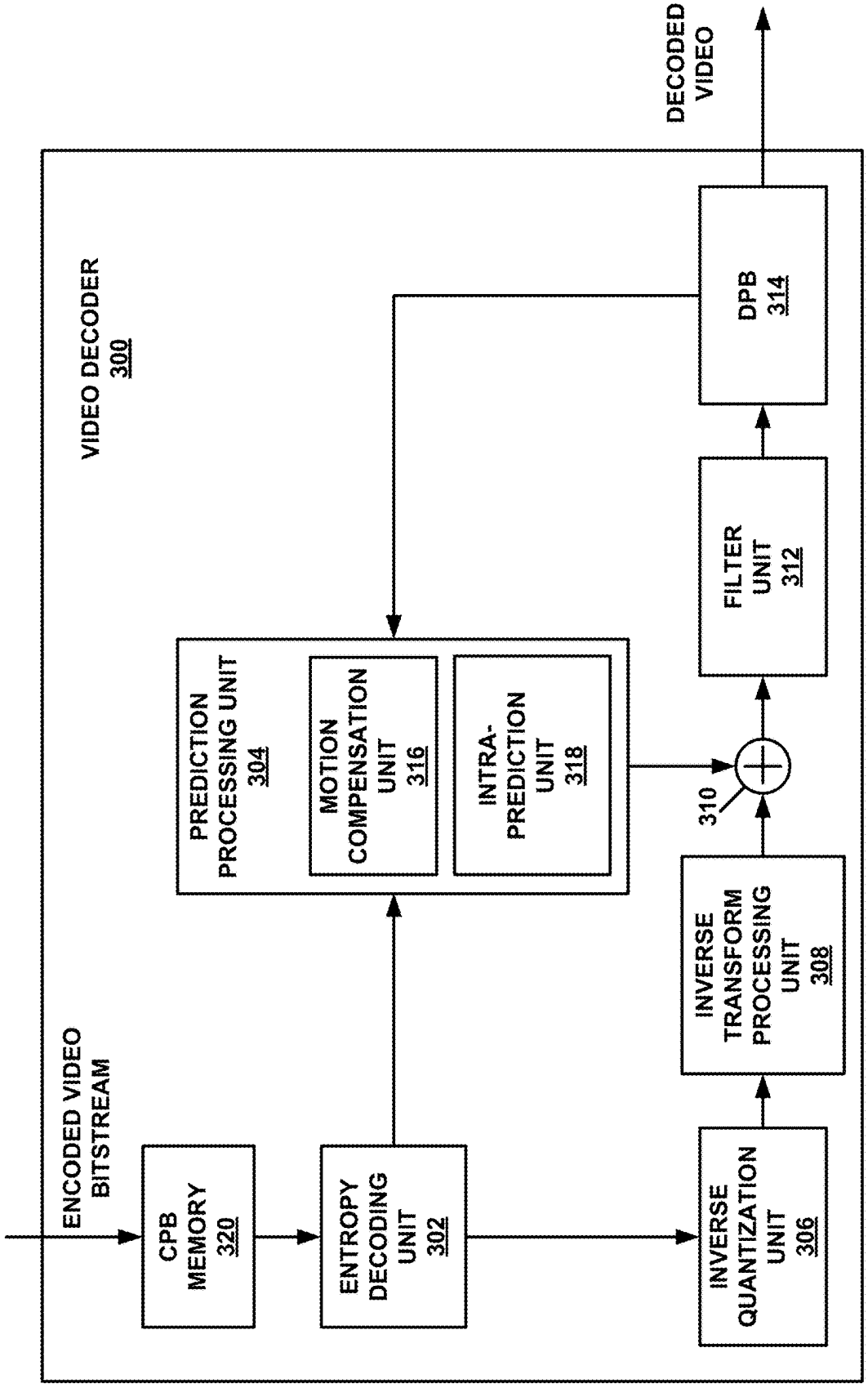

ENCODED VIDEO BITSTREAM
CPB MEMORY 320
ENTROPY DECODING UNIT 302
INVERSE QUANTIZATION UNIT 306
INVERSE TRANSFORM PROCESSING UNIT 308
310
PREDICTION PROCESSING UNIT 304
MOTION COMPENSATION UNIT 316
INTRA-PREDICTION UNIT 318
FILTER UNIT 312
DPB 314
VIDEO DECODER 300
DECODED VIDEO

FIG. 4

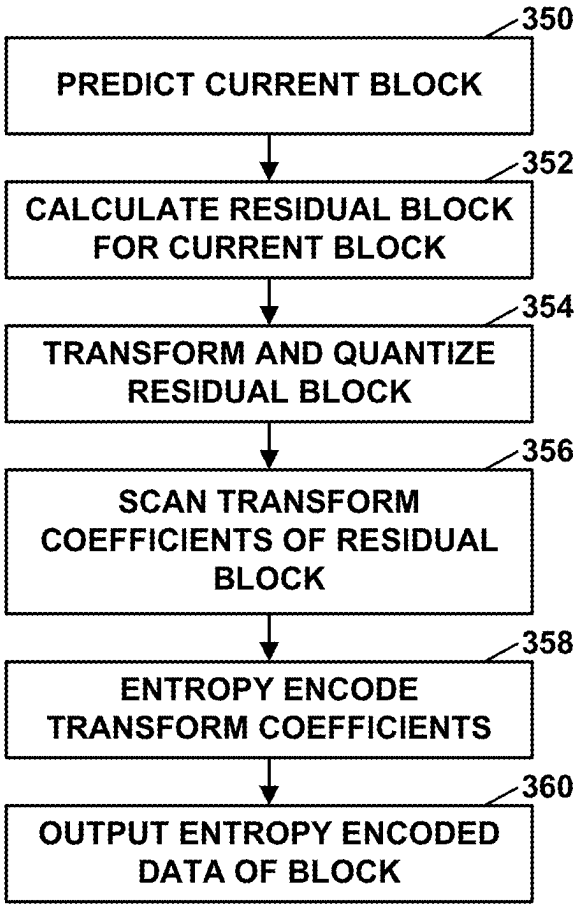

350
PREDICT CURRENT BLOCK
352
CALCULATE RESIDUAL BLOCK FOR CURRENT BLOCK
354
TRANSFORM AND QUANTIZE RESIDUAL BLOCK
356
SCAN TRANSFORM COEFFICIENTS OF RESIDUAL BLOCK
358
ENTROPY ENCODE TRANSFORM COEFFICIENTS
360
OUTPUT ENTROPY ENCODED DATA OF BLOCK

FIG. 5

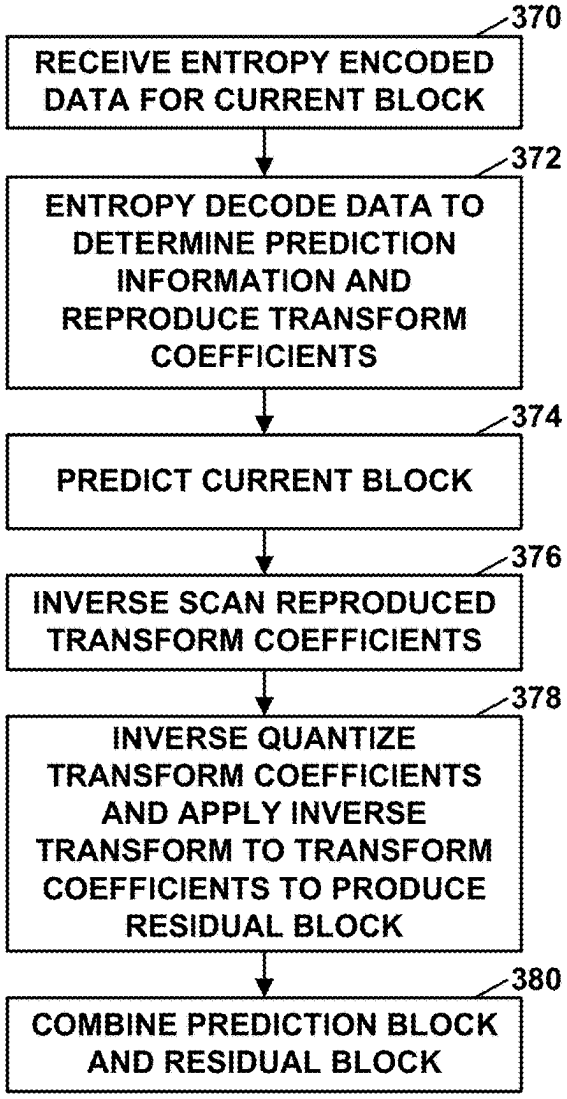

370
RECEIVE ENTROPY ENCODED DATA FOR CURRENT BLOCK
372
ENTROPY DECODE DATA TO DETERMINE PREDICTION INFORMATION AND REPRODUCE TRANSFORM COEFFICIENTS
374
PREDICT CURRENT BLOCK
376
INVERSE SCAN REPRODUCED TRANSFORM COEFFICIENTS
378
INVERSE QUANTIZE TRANSFORM COEFFICIENTS AND APPLY INVERSE TRANSFORM TO TRANSFORM COEFFICIENTS TO PRODUCE RESIDUAL BLOCK
380
COMBINE PREDICTION BLOCK AND RESIDUAL BLOCK

FIG. 6

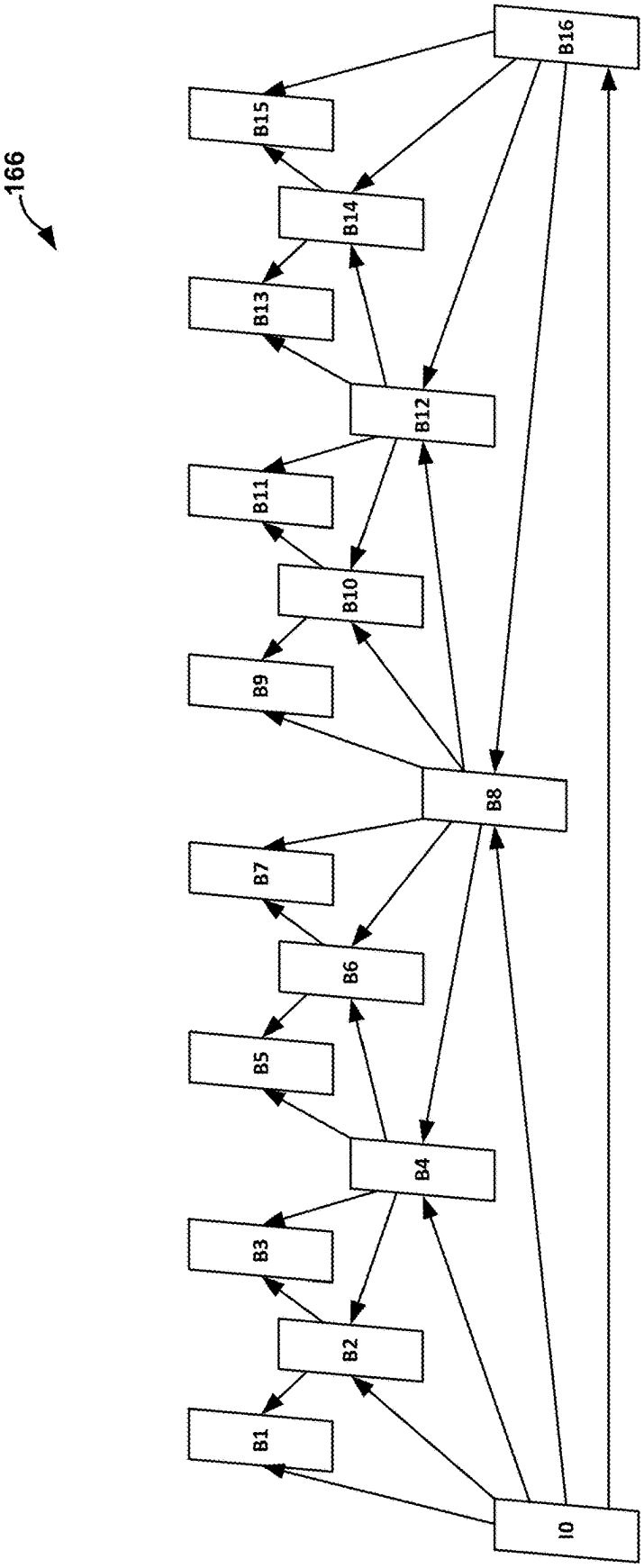


FIG. 7

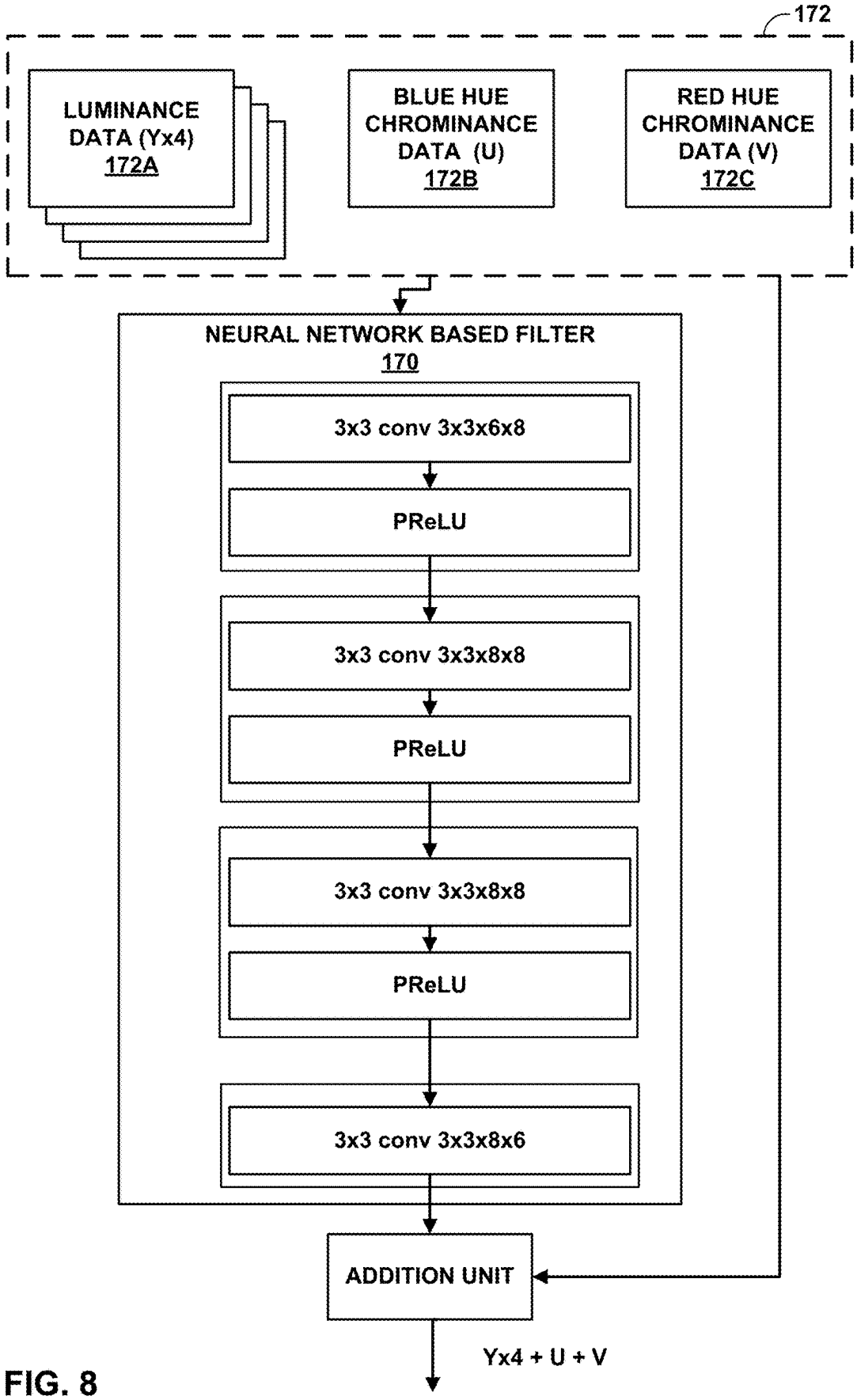

172
LUMINANCE DATA (Yx4) 172A
BLUE HUE CHROMINANCE DATA (U) 172B
RED HUE CHROMINANCE DATA (V) 172C
NEURAL NETWORK BASED FILTER 170
3x3 conv 3x3x6x8
PReLU
3x3 conv 3x3x8x8
PReLU
3x3 conv 3x3x8x8
PReLU
3x3 conv 3x3x8x6
ADDITION UNIT
Yx4 + U + V

FIG. 8

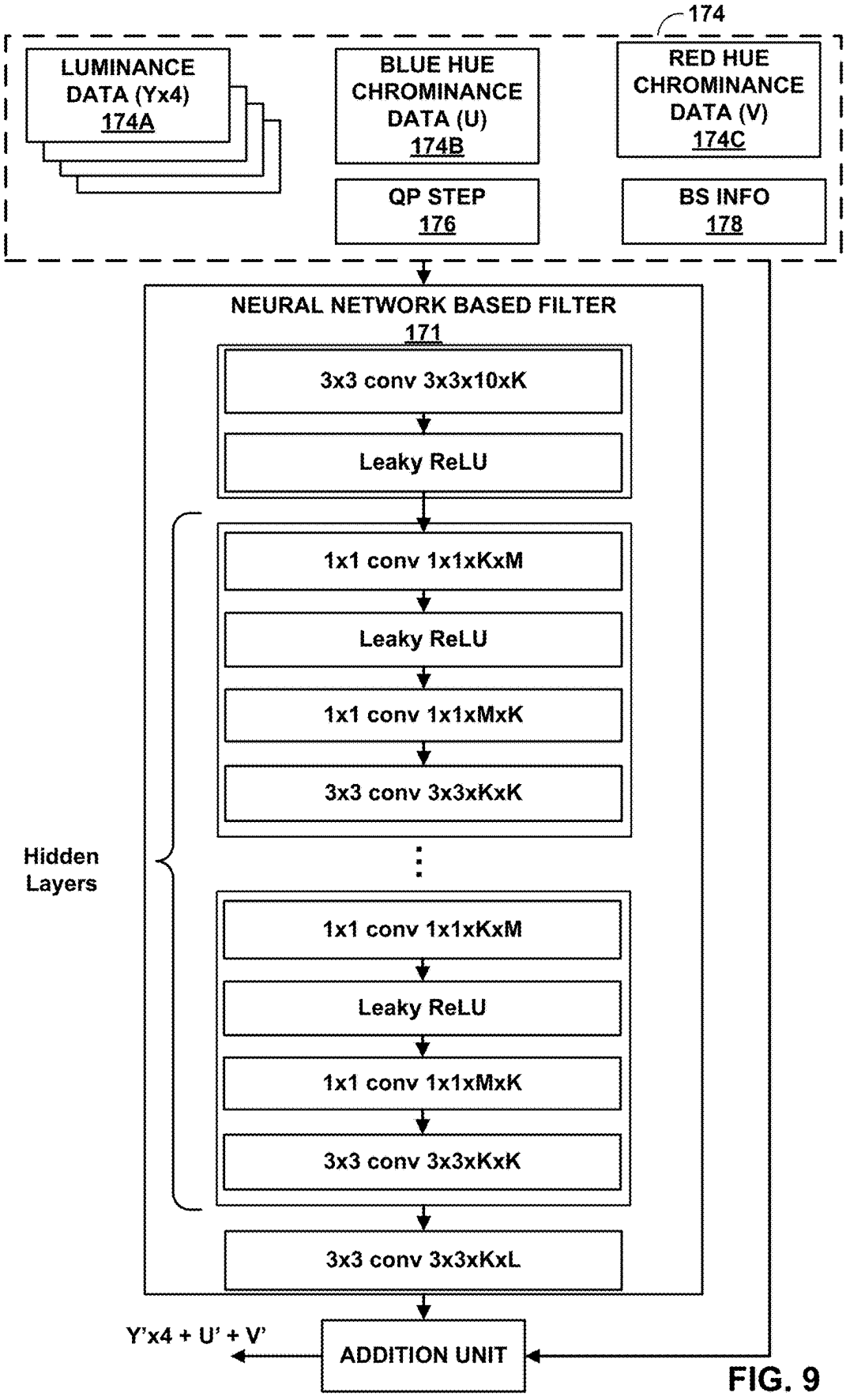

174
LUMINANCE DATA (Yx4) 174A
BLUE HUE CHROMINANCE DATA (U) 174B
RED HUE CHROMINANCE DATA (V) 174C
QP STEP 176
BS INFO 178
NEURAL NETWORK BASED FILTER 171
3x3 conv 3x3x10xK
Leaky ReLU
1x1 conv 1x1xKxM
Leaky ReLU
1x1 conv 1x1xMxK
3x3 conv 3x3xKxK
Hidden Layers
1x1 conv 1x1xKxM
Leaky ReLU
1x1 conv 1x1xMxK
3x3 conv 3x3xKxK
3x3 conv 3x3xKxL
Y'x4 + U' + V'
ADDITION UNIT

FIG. 9

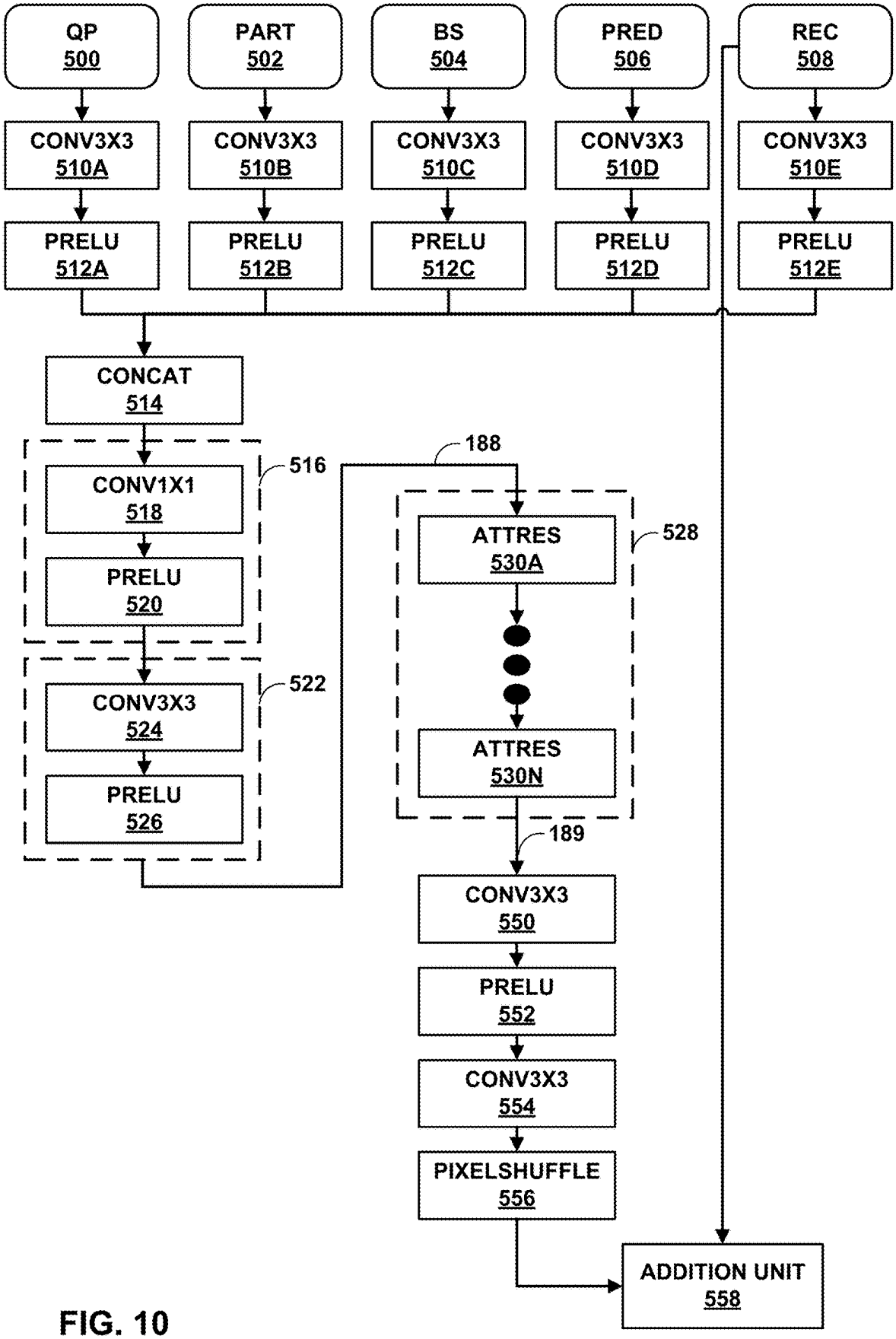

QP
500
PART
502
BS
504
PRED
506
REC
508
CONV3X3
510A
CONV3X3
510B
CONV3X3
510C
CONV3X3
510D
CONV3X3
510E
PRELU
512A
PRELU
512B
PRELU
512C
PRELU
512D
PRELU
512E
CONCAT
514
516
CONV1X1
518
PRELU
520
522
CONV3X3
524
PRELU
526
188
528
ATTRES
530A
ATTRES
530N
189
CONV3X3
550
PRELU
552
CONV3X3
554
PIXELSHUFFLE
556
ADDITION UNIT
558

FIG. 10

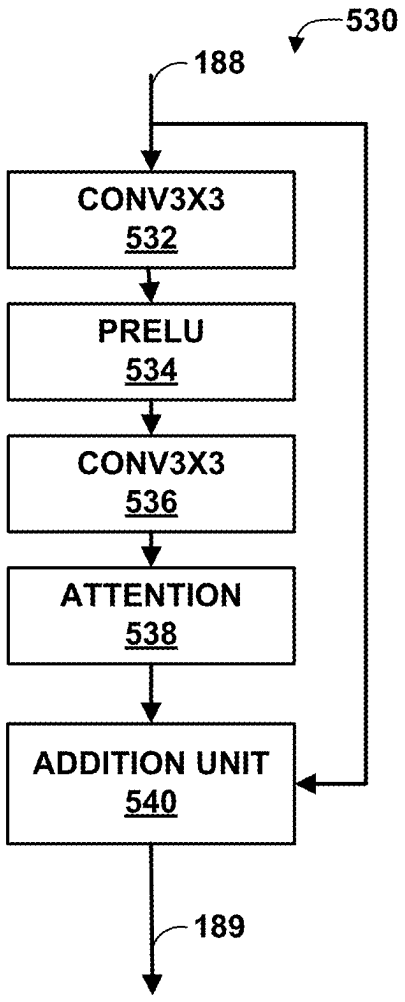

530
188
CONV3X3
532
PRELU
534
CONV3X3
536
ATTENTION
538
ADDITION UNIT
540
189

FIG. 11

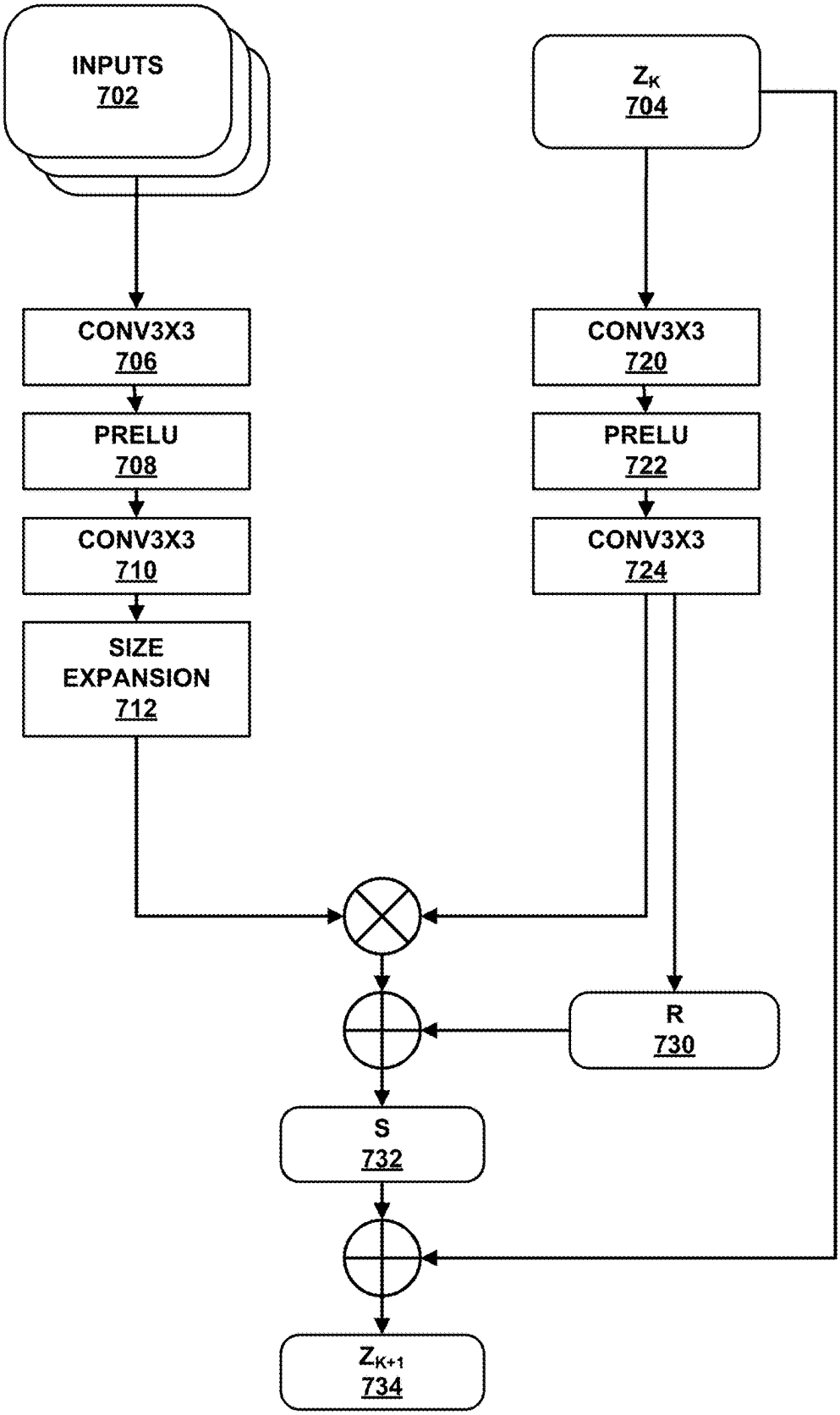

INPUTS
702
Z_K
704
CONV3X3
706
CONV3X3
720
PRELU
708
PRELU
722
CONV3X3
710
CONV3X3
724
SIZE
EXPANSION
712
R
730
S
732
Z_{K+1}
734

FIG. 12

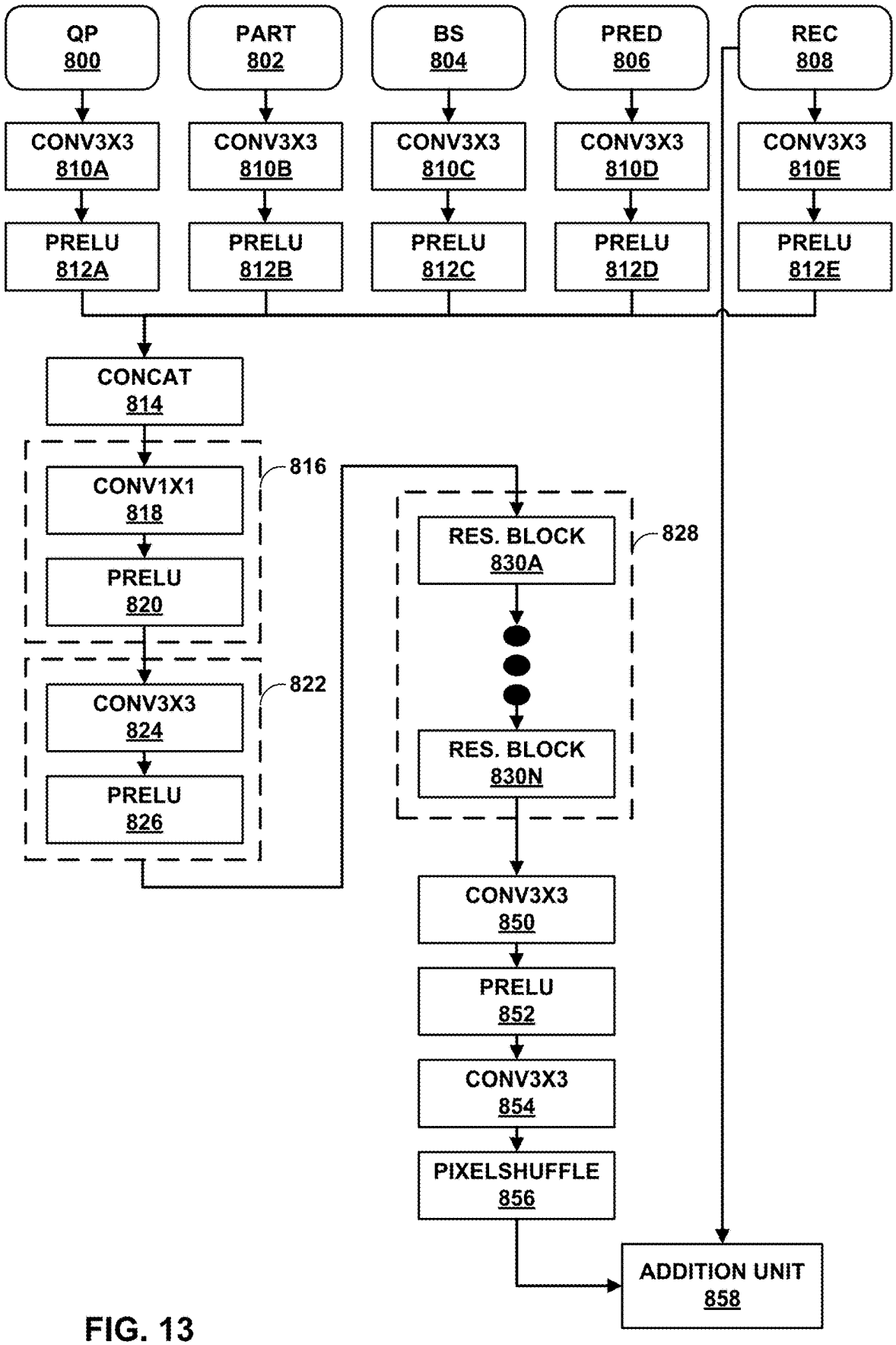

QP
800
PART
802
BS
804
PRED
806
REC
808
CONV3X3
810A
CONV3X3
810B
CONV3X3
810C
CONV3X3
810D
CONV3X3
810E
PRELU
812A
PRELU
812B
PRELU
812C
PRELU
812D
PRELU
812E
CONCAT
814
816
CONV1X1
818
PRELU
820
822
CONV3X3
824
PRELU
826
RES. BLOCK
830A
828
RES. BLOCK
830N
CONV3X3
850
PRELU
852
CONV3X3
854
PIXELSHUFFLE
856
ADDITION UNIT
858

FIG. 13

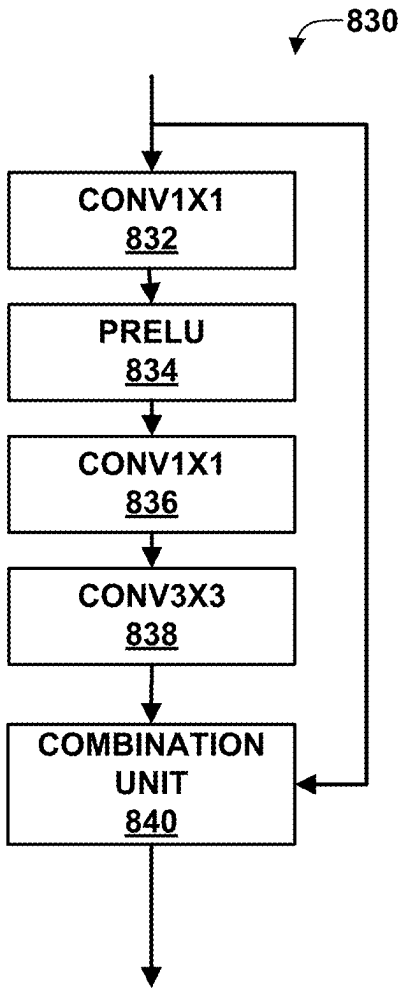

830
CONV1X1
832
PRELU
834
CONV1X1
836
CONV3X3
838
COMBINATION
UNIT
840

FIG. 14

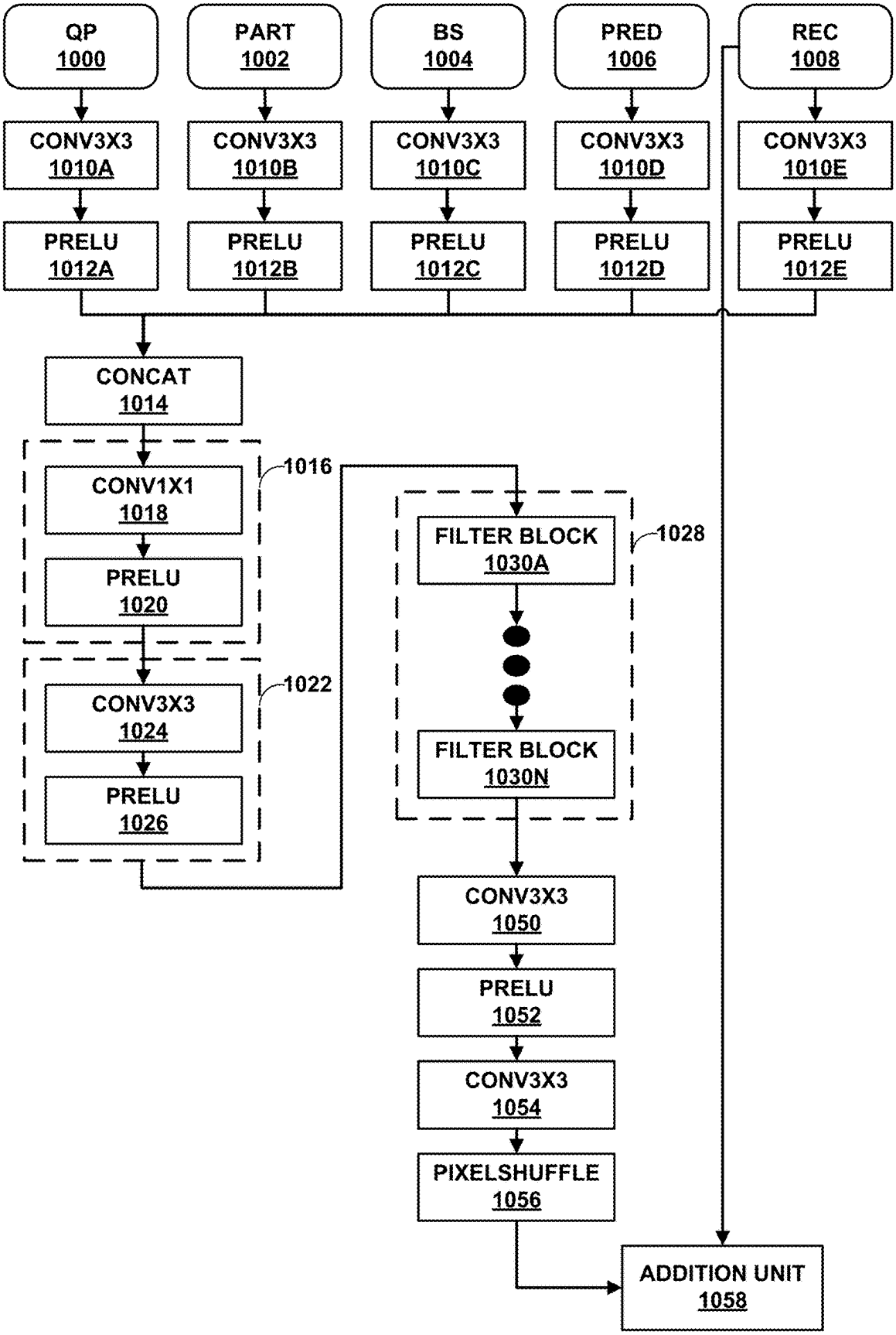

QP
1000
PART
1002
BS
1004
PRED
1006
REC
1008
CONV3X3
1010A
CONV3X3
1010B
CONV3X3
1010C
CONV3X3
1010D
CONV3X3
1010E
PRELU
1012A
PRELU
1012B
PRELU
1012C
PRELU
1012D
PRELU
1012E
CONCAT
1014
1016
CONV1X1
1018
PRELU
1020
1022
CONV3X3
1024
PRELU
1026
FILTER BLOCK
1030A
1028
FILTER BLOCK
1030N
CONV3X3
1050
PRELU
1052
CONV3X3
1054
PIXELSHUFFLE
1056
ADDITION UNIT
1058

FIG. 15

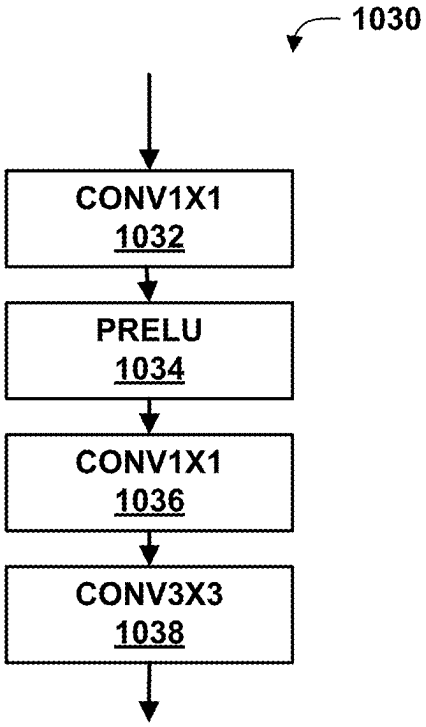


FIG. 16

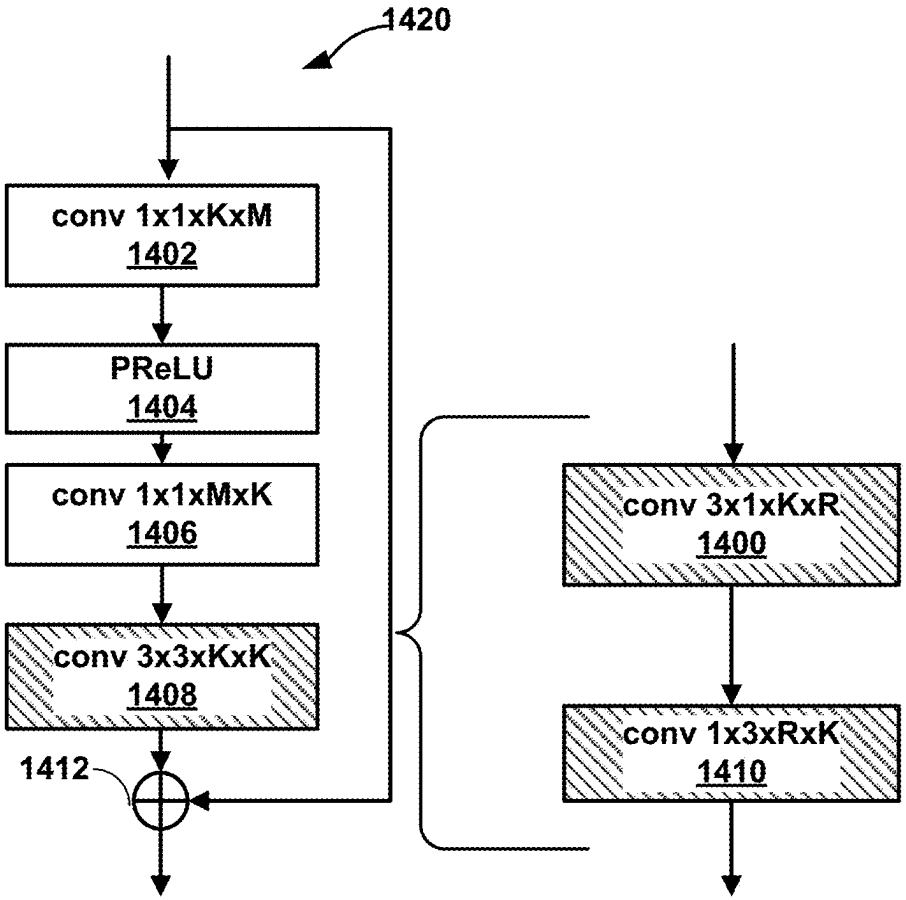

1420
conv 1x1xKxM
1402
PReLU
1404
conv 1x1xMxK
1406
conv 3x3xKxK
1408
1412
conv 3x1xKxR
1400
conv 1x3xRxK
1410

FIG. 17

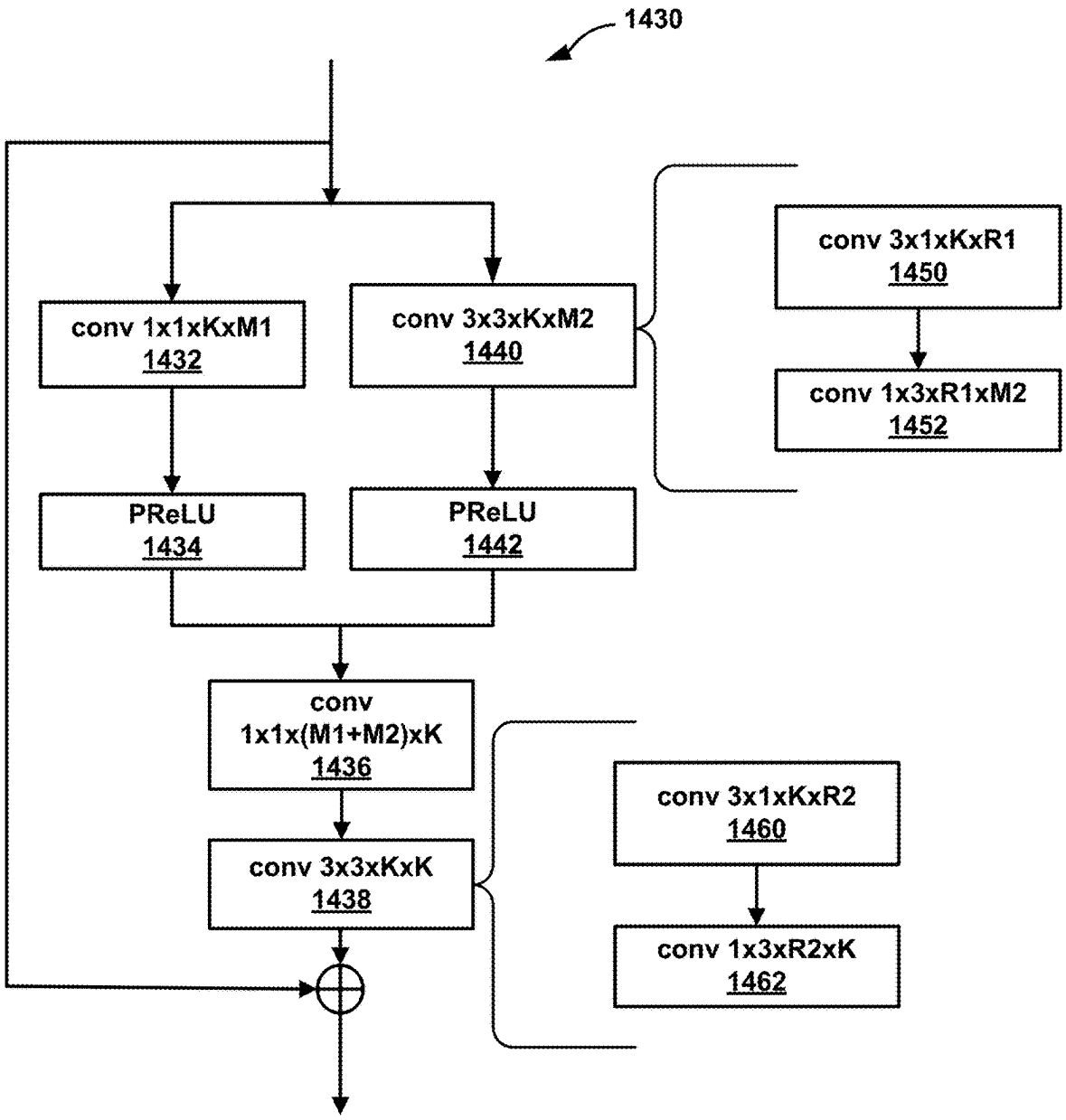

1430
conv 1x1xKxM1
1432
conv 3x3xKxM2
1440
conv 3x1xKxR1
1450
conv 1x3xR1xM2
1452
PReLU
1434
PReLU
1442
conv
1x1x(M1+M2)xK
1436
conv 3x3xKxK
1438
conv 3x1xKxR2
1460
conv 1x3xR2xK
1462

FIG. 18

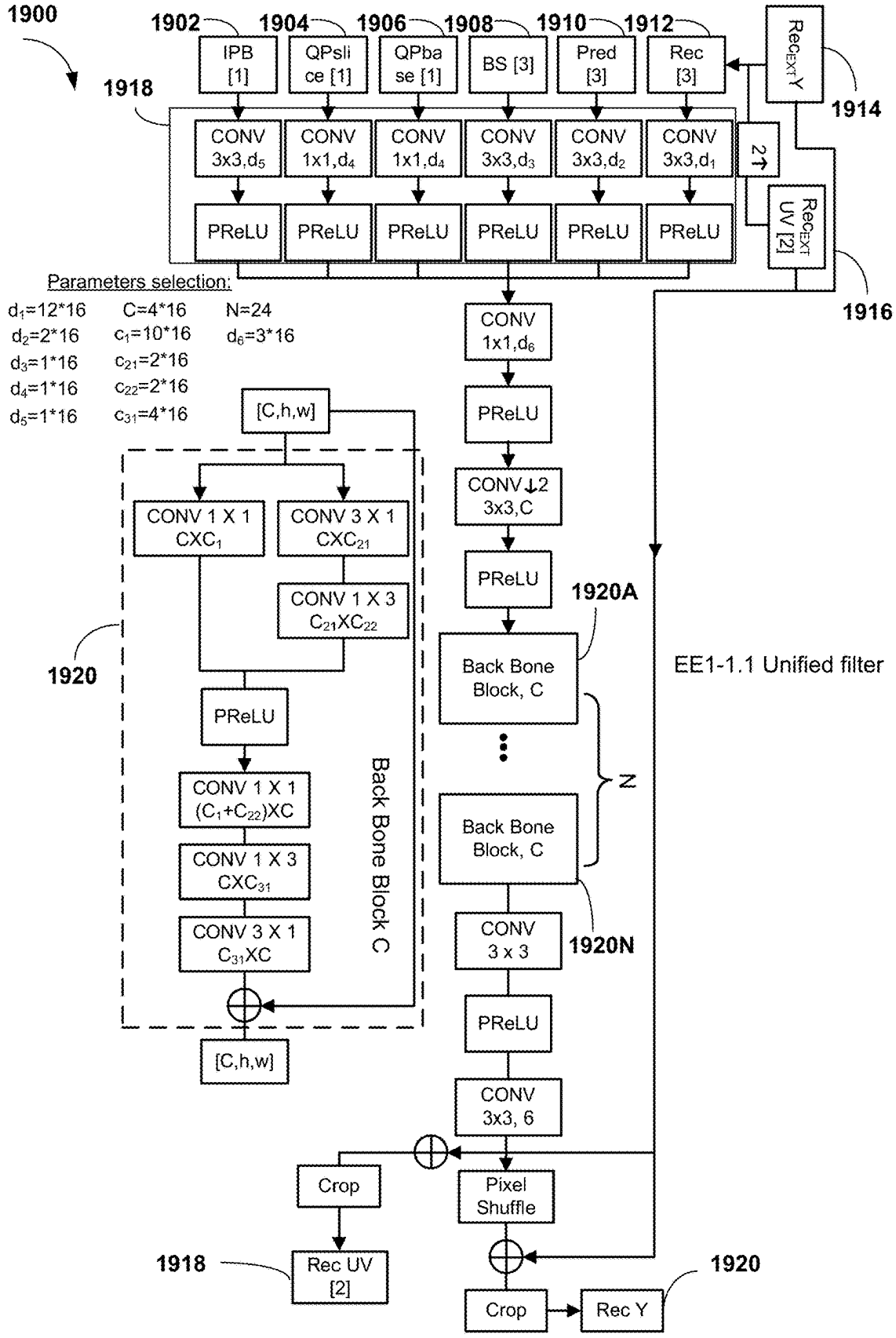

1900
1902
1904
1906
1908
1910
1912
IPB [1]
QPslice [1]
QPbase [1]
BS [3]
Pred [3]
Rec [3]
RecEXT Y
1914
1918
CONV 3x3,d5
CONV 1x1,d4
CONV 1x1,d4
CONV 3x3,d3
CONV 3x3,d2
CONV 3x3,d1
2↑
PReLU
RecEXT UV [2]
1916
Parameters selection:
d1=12*16 C=4*16 N=24
d2=2*16 c1=10*16 d6=3*16
d3=1*16 c21=2*16
d4=1*16 c22=2*16
d5=1*16 c31=4*16
CONV 1x1,d6
[C,h,w]
CONV 1 X 1 CXC1
CONV 3 X 1 CXC21
CONV 1 X 3 C21XC22
1920
CONV↓2 3x3,C
1920A
Back Bone Block, C
EE1-1.1 Unified filter
N
Back Bone Block C
CONV 1 X 1 (C1+C22)XC
CONV 1 X 3 CXC31
CONV 3 X 1 C31XC
1920N
CONV 3 x 3
CONV 3x3, 6
Crop
Pixel Shuffle
1918
Rec UV [2]
1920
Crop
Rec Y

FIG. 19

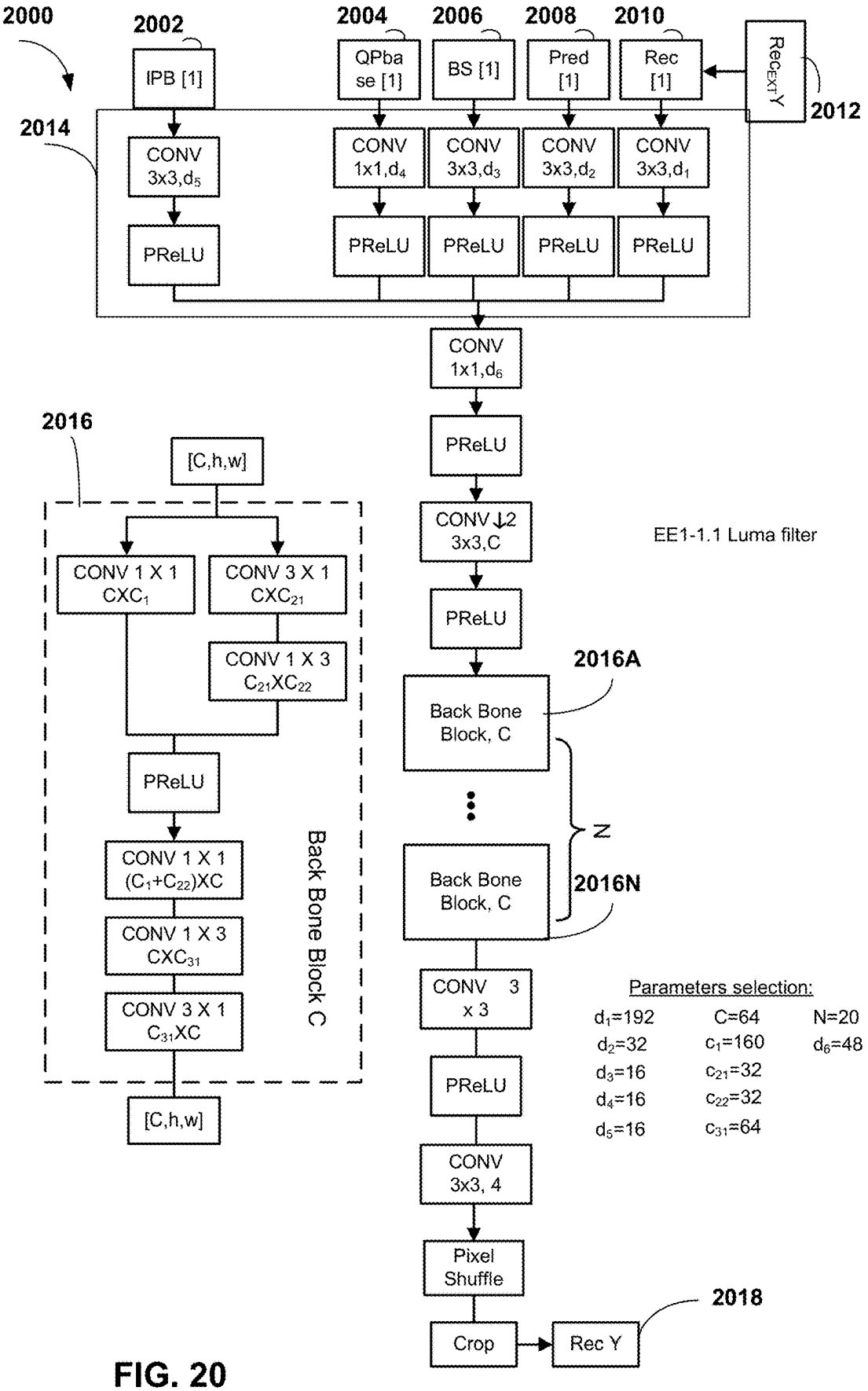

2000
2002
IPB [1]
2004
QPbase [1]
2006
BS [1]
2008
Pred [1]
2010
Rec [1]
Rec EXT Y
2012
2014
CONV 3x3,d5
PReLU
CONV 1x1,d4
CONV 3x3,d3
CONV 3x3,d2
CONV 3x3,d1
PReLU
PReLU
PReLU
PReLU
CONV 1x1,d6
PReLU
CONV ↓2 3x3,C
PReLU
2016
[C,h,w]
CONV 1 X 1 CXC1
CONV 3 X 1 CXC21
CONV 1 X 3 C21XC22
PReLU
CONV 1 X 1 (C1+C22)XC
CONV 1 X 3 CXC31
CONV 3 X 1 C31XC
[C,h,w]
Back Bone Block C
EE1-1.1 Luma filter
2016A
Back Bone Block, C
N
Back Bone Block, C
2016N
CONV 3 x 3
PReLU
CONV 3x3, 4
Pixel Shuffle
2018
Crop
Rec Y
Parameters selection:
d1=192 C=64 N=20
d2=32 c1=160 d6=48
d3=16 c21=32
d4=16 c22=32
d5=16 c31=64

FIG. 20

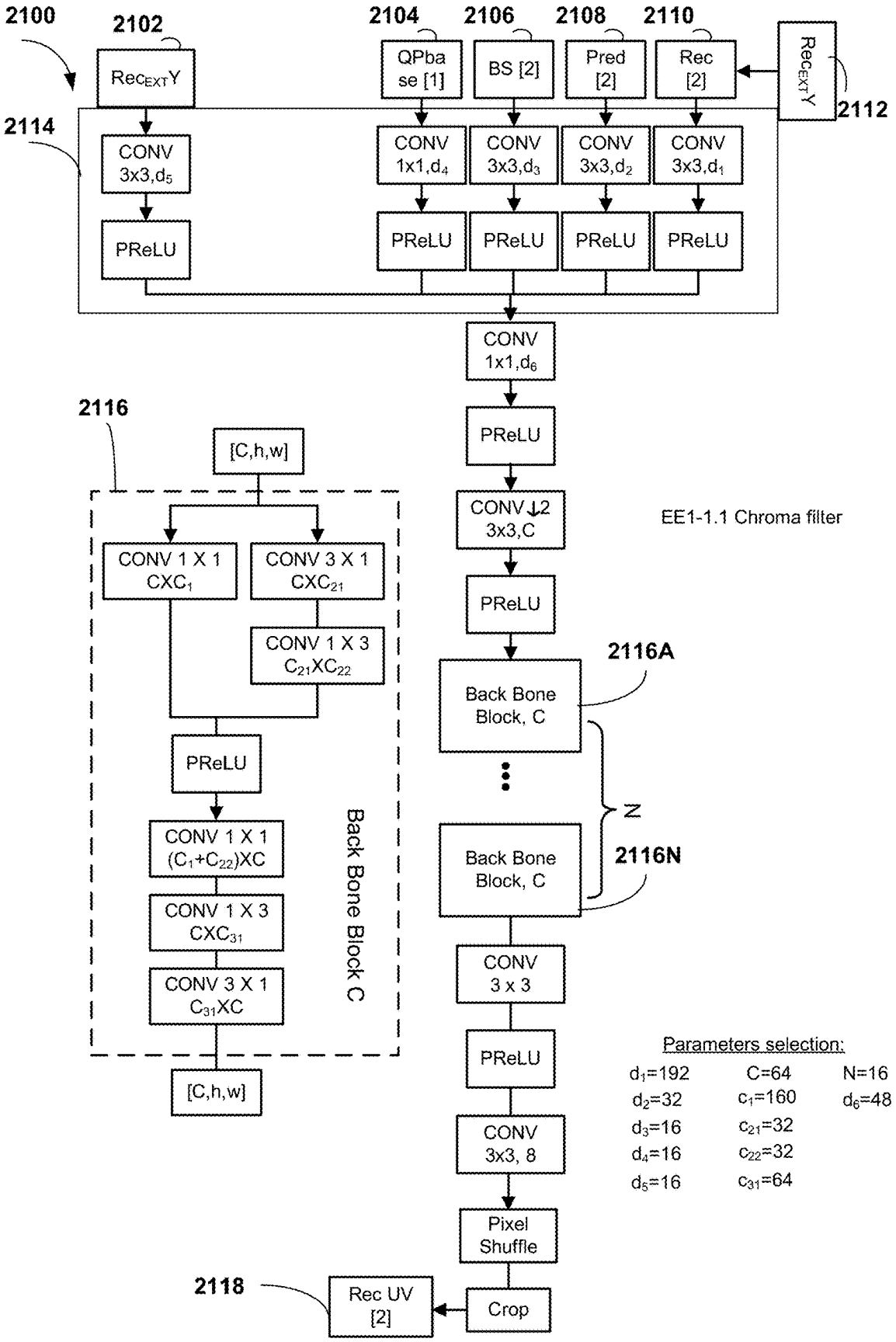

2100
2102
$Rec_{EXT}Y$
2104
QPbase [1]
2106
BS [2]
2108
Pred [2]
2110
Rec [2]
$Rec_{EXT}Y$
2112
2114
CONV 3x3,d_5
PReLU
CONV 1x1,d_4
CONV 3x3,d_3
CONV 3x3,d_2
CONV 3x3,d_1
PReLU
PReLU
PReLU
PReLU
CONV 1x1,d_6
PReLU
CONV↓2 3x3,C
PReLU
2116
[C,h,w]
CONV 1 X 1 CXC1
CONV 3 X 1 CXC21
CONV 1 X 3 C21XC22
PReLU
CONV 1 X 1 (C1+C22)XC
CONV 1 X 3 CXC31
CONV 3 X 1 C31XC
[C,h,w]
Back Bone Block C
2116A
Back Bone Block, C
N
Back Bone Block, C
2116N
EE1-1.1 Chroma filter
CONV 3 x 3
PReLU
CONV 3x3, 8
Pixel Shuffle
2118
Rec UV [2]
Crop
Parameters selection:
d1=192 C=64 N=16
d2=32 c1=160 d6=48
d3=16 c21=32
d4=16 c22=32
d5=16 c31=64

FIG. 21

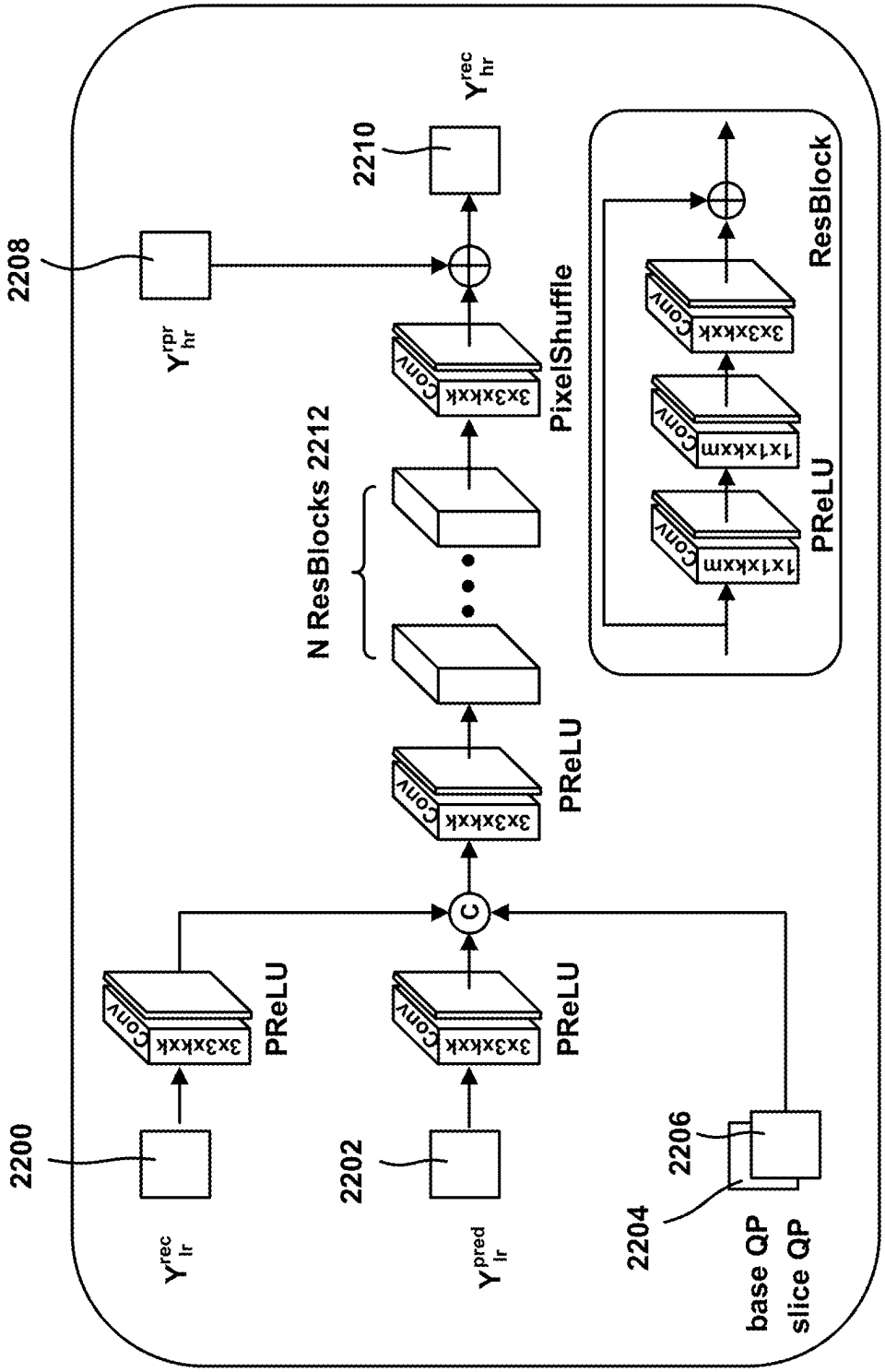

2200
Y_{lr}^{rec}
3x3xkxk
PReLU
2202
Y_{lr}^{pred}
3x3xkxk
PReLU
2206
2204
base QP
slice QP
C
3x3xkxk
PReLU
N ResBlocks 2212
3x3xkxk
PixelShuffle
2208
Y_{hr}^{rpr}
2210
Y_{hr}^{rec}
ResBlock
1x1xkxm
PReLU
1x1xkxm
3x3xkxk

FIG. 22

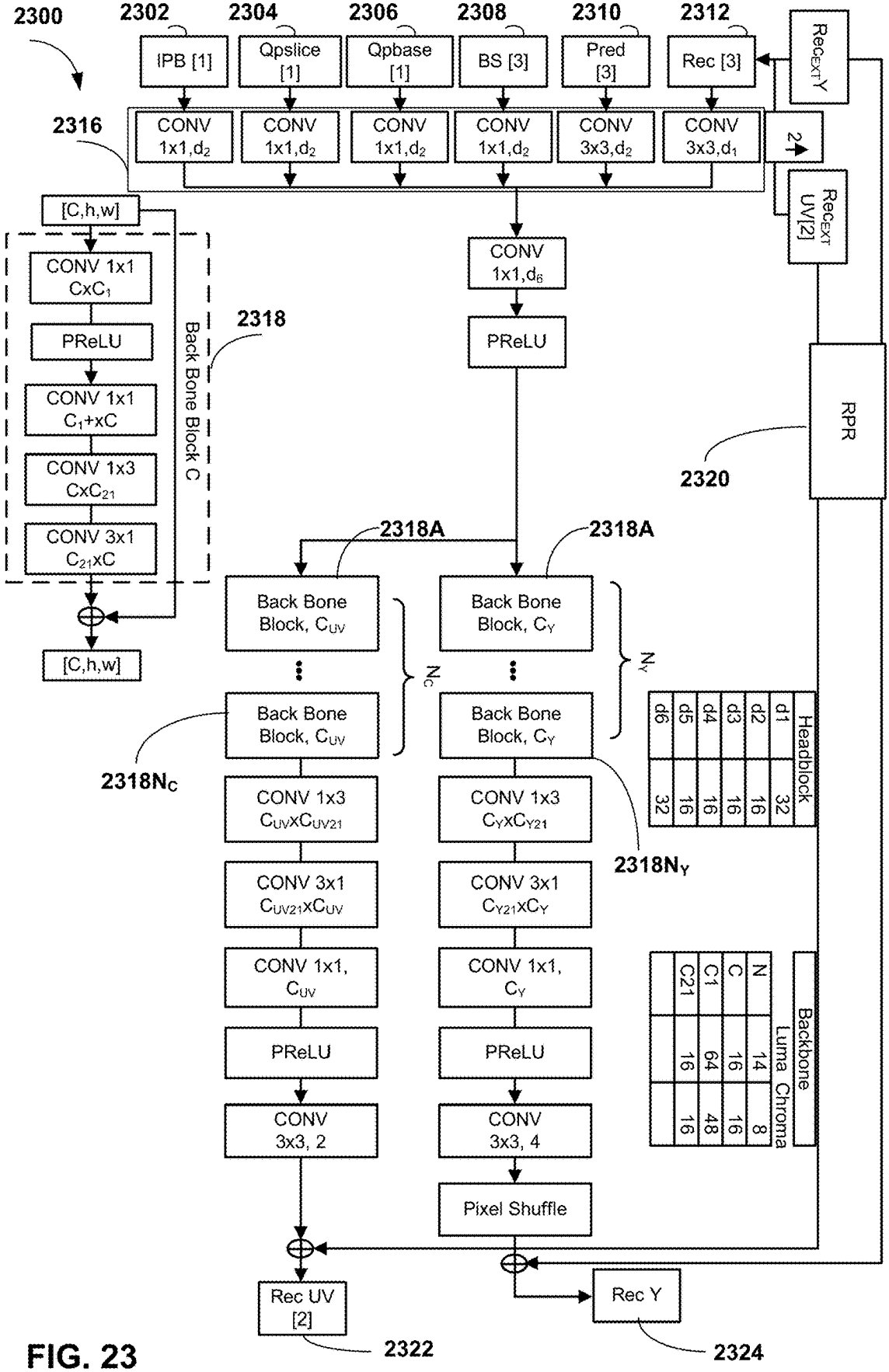

2300
2302
2304
2306
2308
2310
2312
IPB [1]
Qpslice [1]
Qpbase [1]
BS [3]
Pred [3]
Rec [3]
RecEXTY
2316
CONV 1x1,d2
CONV 1x1,d2
CONV 1x1,d2
CONV 1x1,d2
CONV 3x3,d2
CONV 3x3,d1
2
RecEXT UV[2]
[C,h,w]
CONV 1x1 CxC1
PReLU
CONV 1x1 C1+xC
CONV 1x3 CxC21
CONV 3x1 C21xC
2318
Back Bone Block C
[C,h,w]
CONV 1x1,d6
PReLU
RPR
2320
2318A
2318A
Back Bone Block, CUV
Back Bone Block, CY
NC
NY
Back Bone Block, CUV
Back Bone Block, CY
2318NC
2318NY
CONV 1x3 CUVxCUV21
CONV 1x3 CYxCY21
CONV 3x1 CUV21xCUV
CONV 3x1 CY21xCY
CONV 1x1, CUV
CONV 1x1, CY
PReLU
PReLU
CONV 3x3, 2
CONV 3x3, 4
Pixel Shuffle
Rec UV [2]
Rec Y
2322
2324
Headblock
d1 d2 d3 d4 d5 d6
32 16 16 16 16 32
Backbone
Luma Chroma
N C C1 C21
14 16 64 16
8 16 48 16

FIG. 23

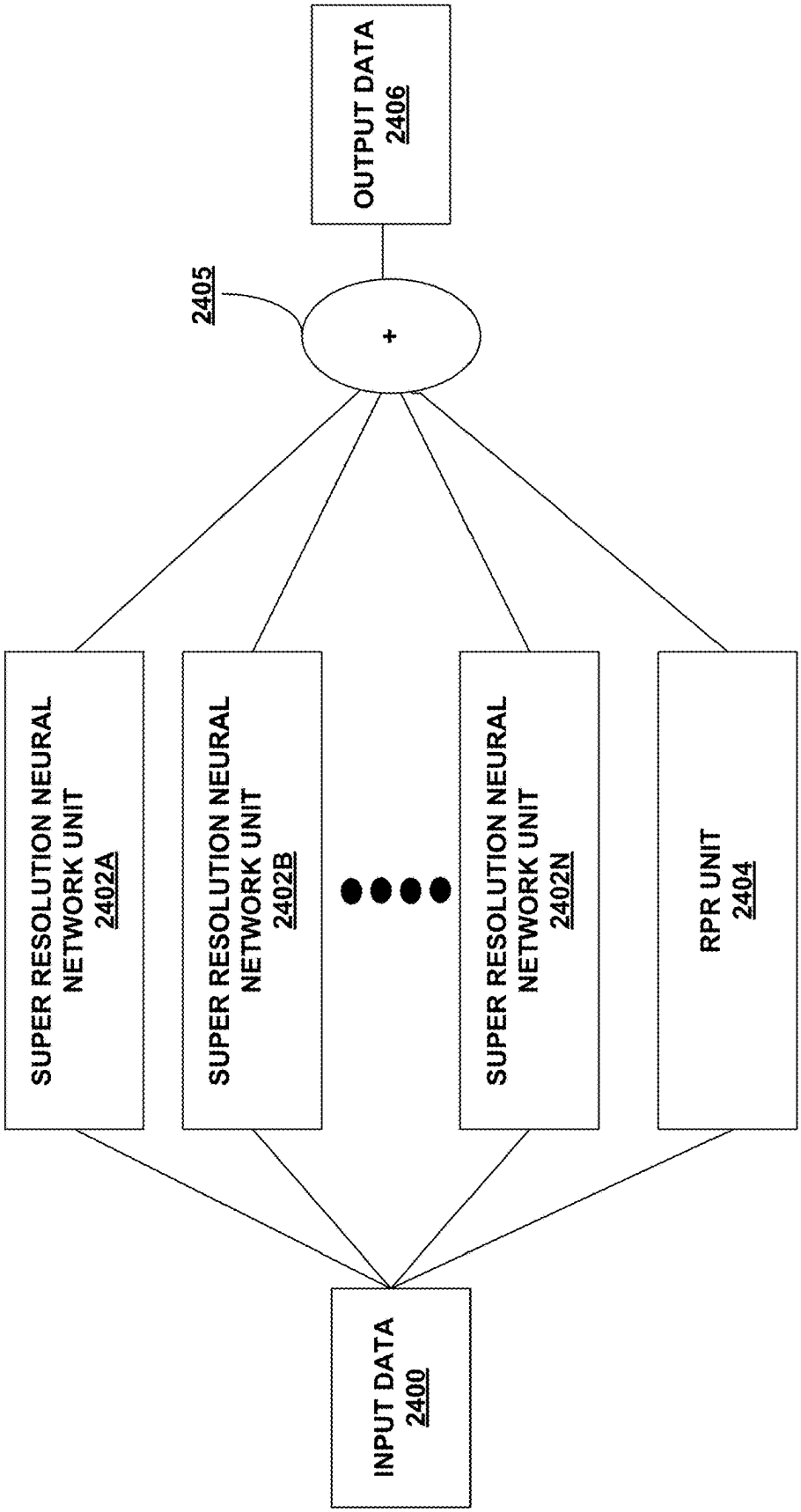

OUTPUT DATA
2406
2405
+
SUPER RESOLUTION NEURAL NETWORK UNIT
2402A
SUPER RESOLUTION NEURAL NETWORK UNIT
2402B
SUPER RESOLUTION NEURAL NETWORK UNIT
2402N
RPR UNIT
2404
INPUT DATA
2400

FIG. 24

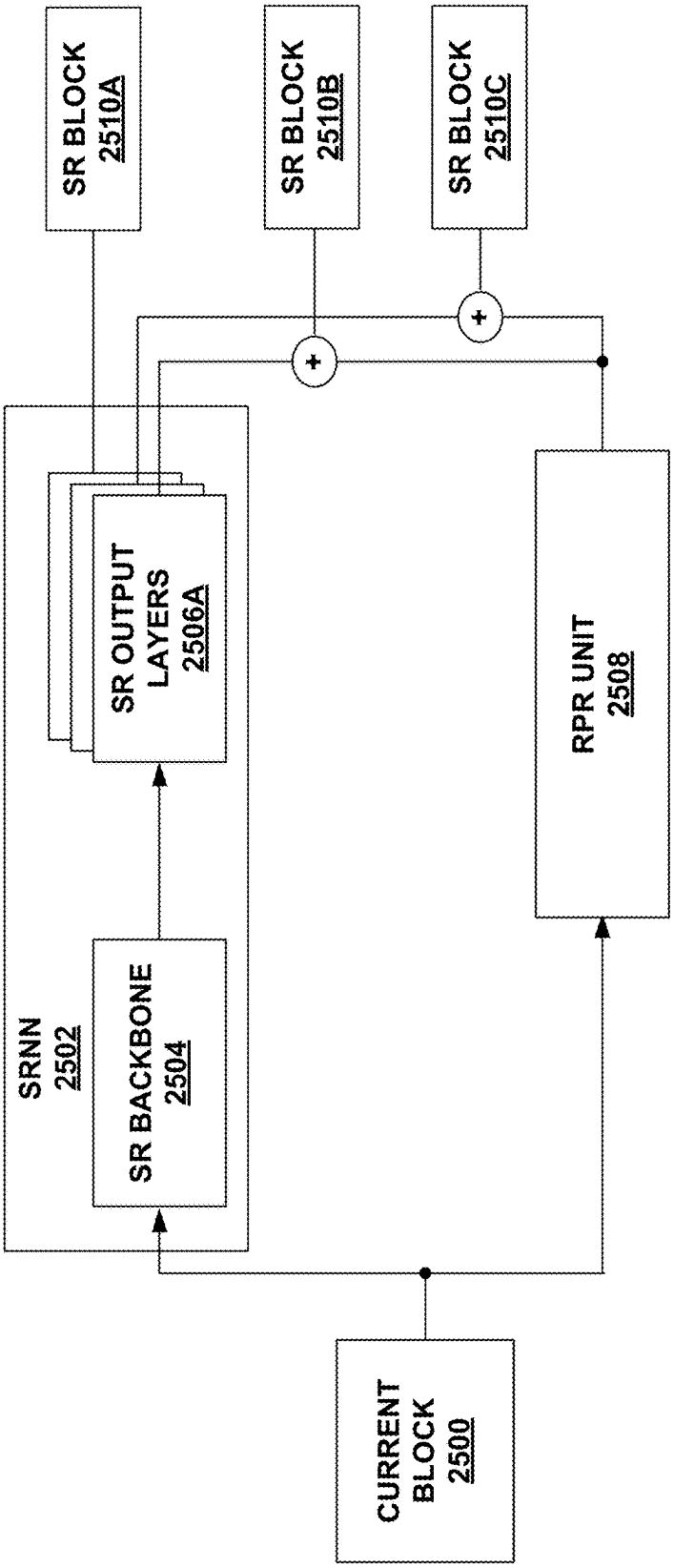

SR BLOCK 2510A
SR BLOCK 2510B
SR BLOCK 2510C
+
+
SR OUTPUT LAYERS 2506A
RPR UNIT 2508
SRNN 2502
SR BACKBONE 2504
CURRENT BLOCK 2500

FIG. 25

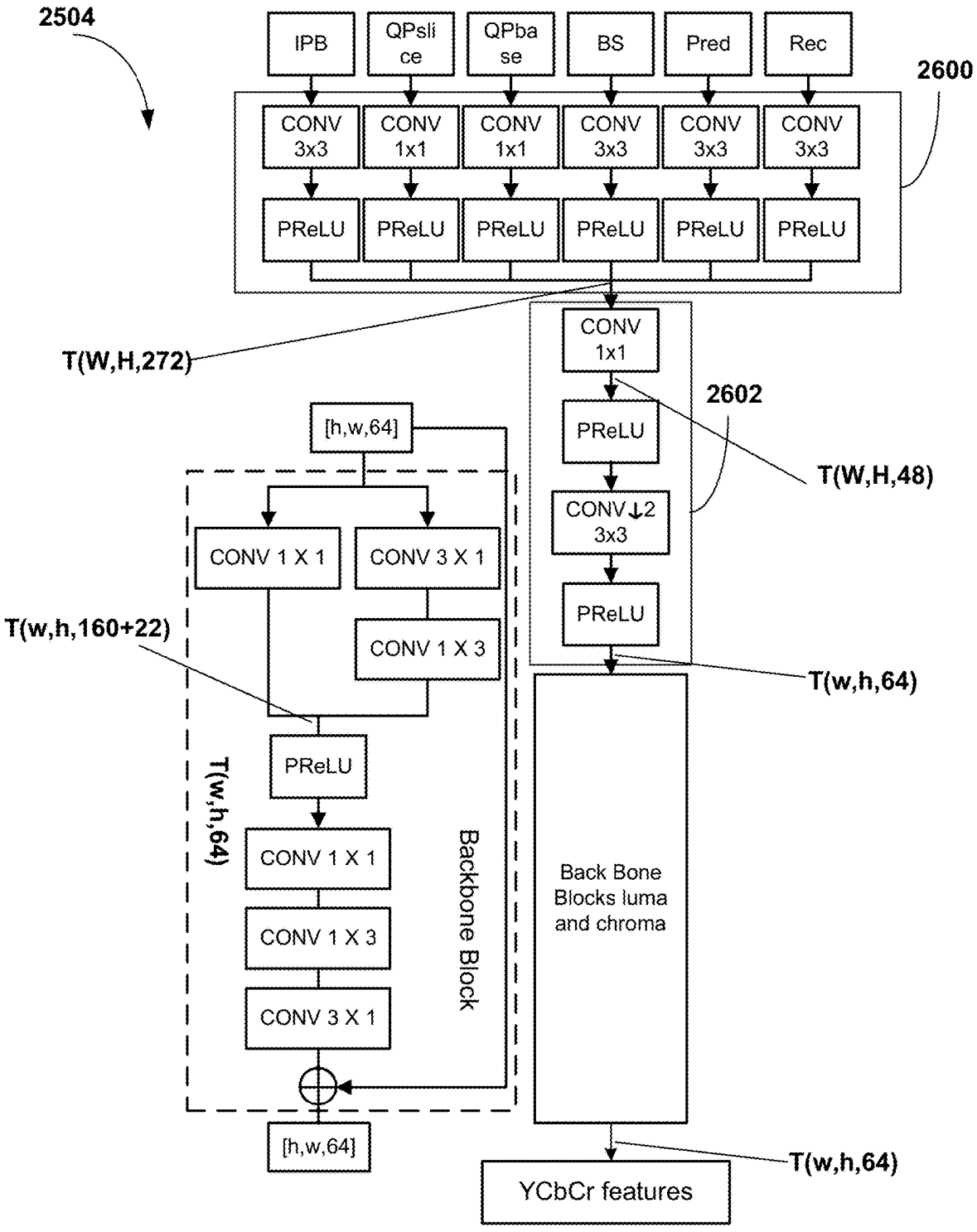

2504
IPB
QPslice
QPbase
BS
Pred
Rec
2600
CONV 3x3
CONV 1x1
CONV 1x1
CONV 3x3
CONV 3x3
CONV 3x3
PReLU
PReLU
PReLU
PReLU
PReLU
PReLU
T(W,H,272)
CONV 1x1
2602
PReLU
T(W,H,48)
CONV↓2 3x3
PReLU
T(w,h,64)
[h,w,64]
CONV 1 X 1
CONV 3 X 1
CONV 1 X 3
T(w,h,160+22)
PReLU
T(w,h,64)
CONV 1 X 1
CONV 1 X 3
CONV 3 X 1
Backbone Block
Back Bone Blocks luma and chroma
[h,w,64]
T(w,h,64)
YCbCr features

FIG. 26

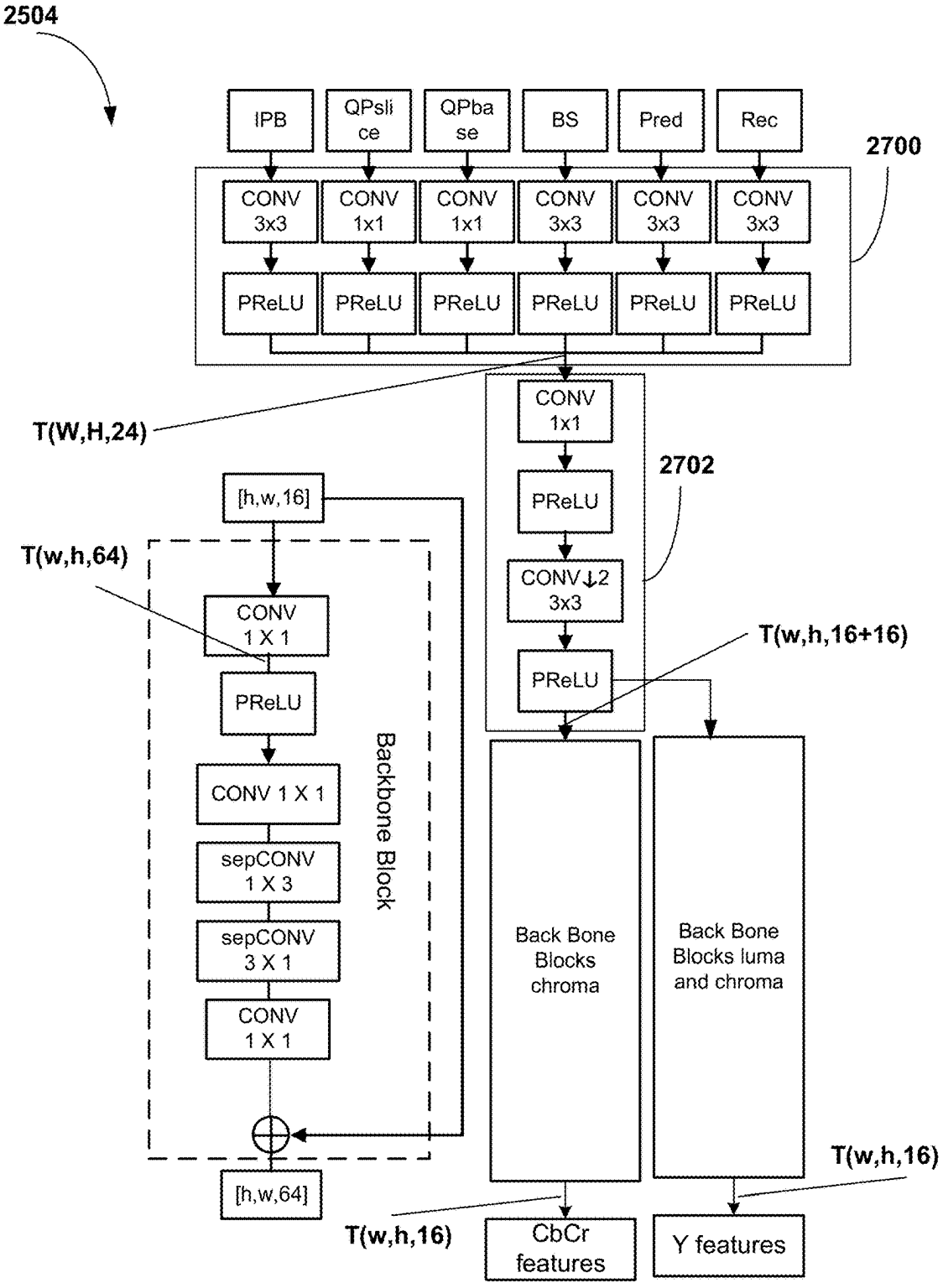

2504
IPB
QPslice
QPbase
BS
Pred
Rec
2700
CONV 3x3
CONV 1x1
CONV 1x1
CONV 3x3
CONV 3x3
CONV 3x3
PReLU
PReLU
PReLU
PReLU
PReLU
PReLU
T(W,H,24)
CONV 1x1
2702
PReLU
CONV↓2 3x3
PReLU
T(w,h,16+16)
[h,w,16]
T(w,h,64)
CONV 1 X 1
PReLU
CONV 1 X 1
sepCONV 1 X 3
sepCONV 3 X 1
CONV 1 X 1
Backbone Block
[h,w,64]
Back Bone Blocks chroma
Back Bone Blocks luma and chroma
T(w,h,16)
T(w,h,16)
CbCr features
Y features

FIG. 27

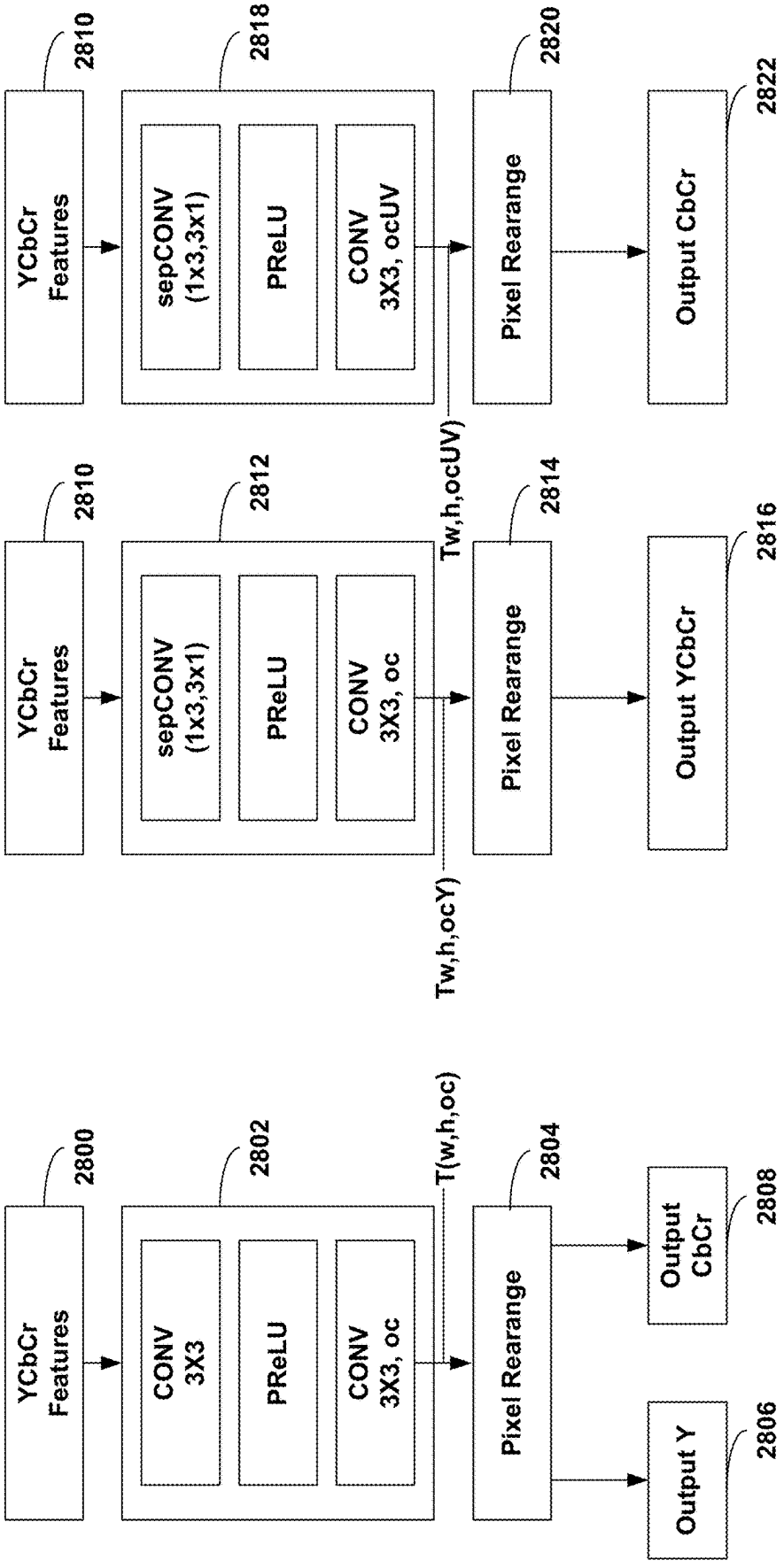


FIG. 28A

FIG. 28B

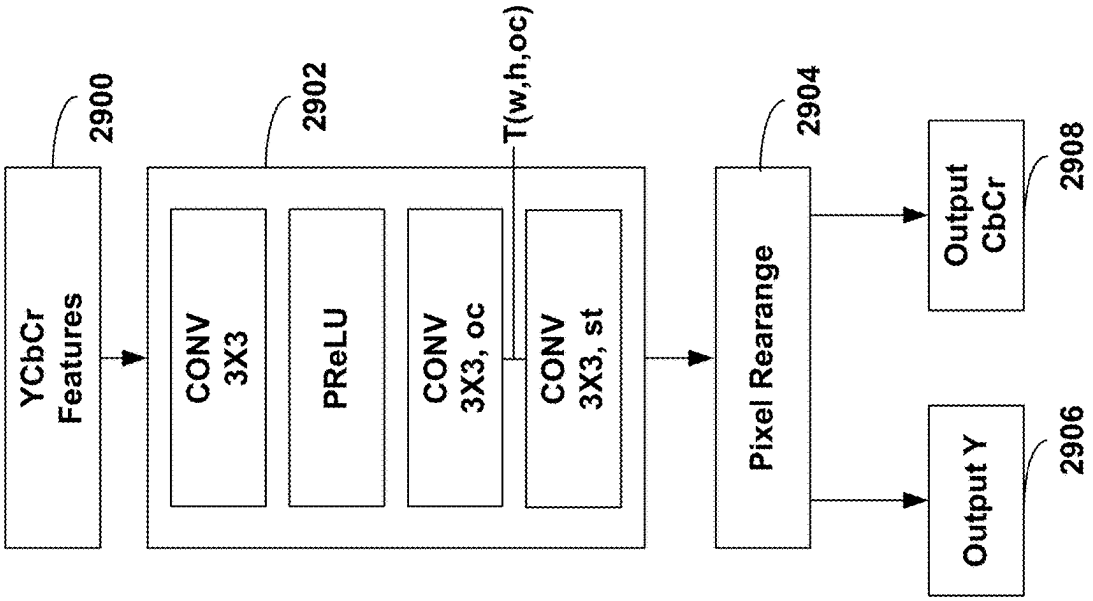

YCbCr Features
2900
CONV 3X3
PReLU
CONV 3X3, oc
CONV 3X3, st
2902
T(w,h,oc)
Pixel Rearange
2904
Output CbCr
2908
Output Y
2906

FIG. 29

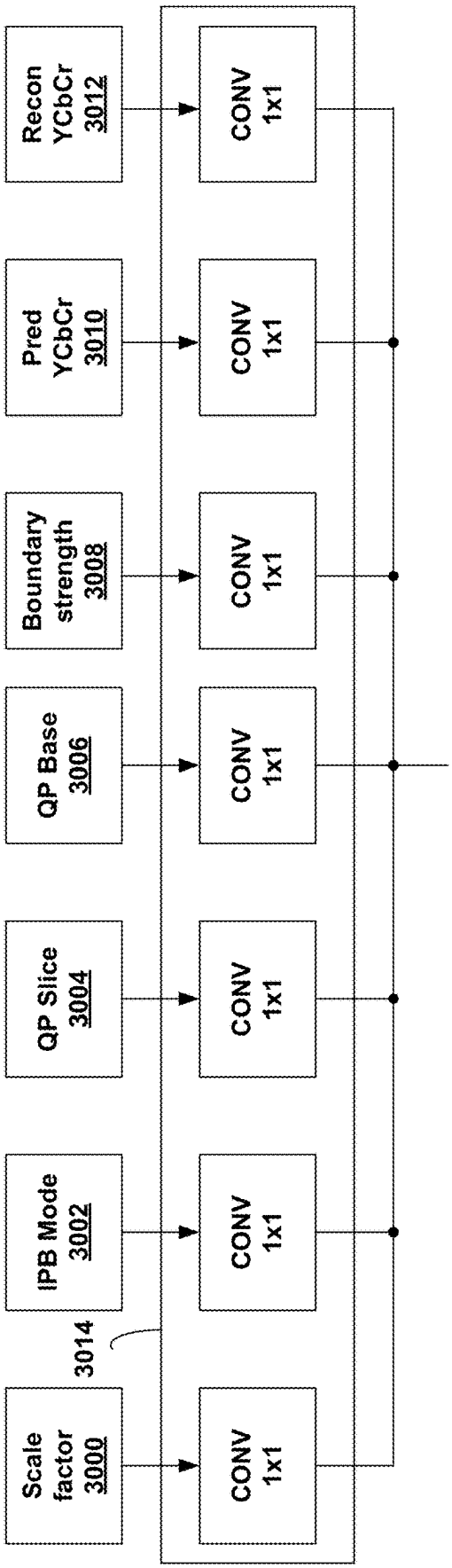

Recon YCbCr 3012
Pred YCbCr 3010
Boundary strength 3008
QP Base 3006
QP Slice 3004
IPB Mode 3002
3014
Scale factor 3000
CONV 1x1
CONV 1x1
CONV 1x1
CONV 1x1
CONV 1x1
CONV 1x1
CONV 1x1

FIG. 30

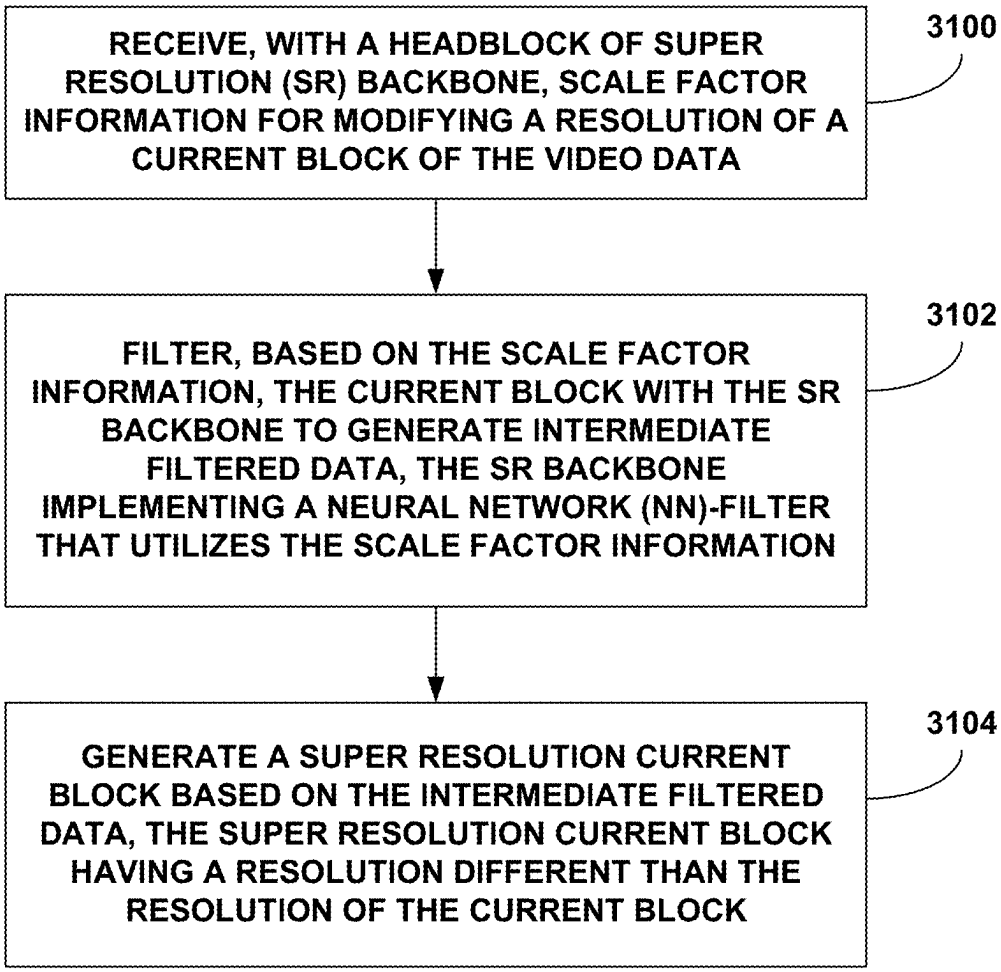

RECEIVE, WITH A HEADBLOCK OF SUPER RESOLUTION (SR) BACKBONE, SCALE FACTOR INFORMATION FOR MODIFYING A RESOLUTION OF A CURRENT BLOCK OF THE VIDEO DATA
3100
FILTER, BASED ON THE SCALE FACTOR INFORMATION, THE CURRENT BLOCK WITH THE SR BACKBONE TO GENERATE INTERMEDIATE FILTERED DATA, THE SR BACKBONE IMPLEMENTING A NEURAL NETWORK (NN)-FILTER THAT UTILIZES THE SCALE FACTOR INFORMATION
3102
GENERATE A SUPER RESOLUTION CURRENT BLOCK BASED ON THE INTERMEDIATE FILTERED DATA, THE SUPER RESOLUTION CURRENT BLOCK HAVING A RESOLUTION DIFFERENT THAN THE RESOLUTION OF THE CURRENT BLOCK
3104

FIG. 31

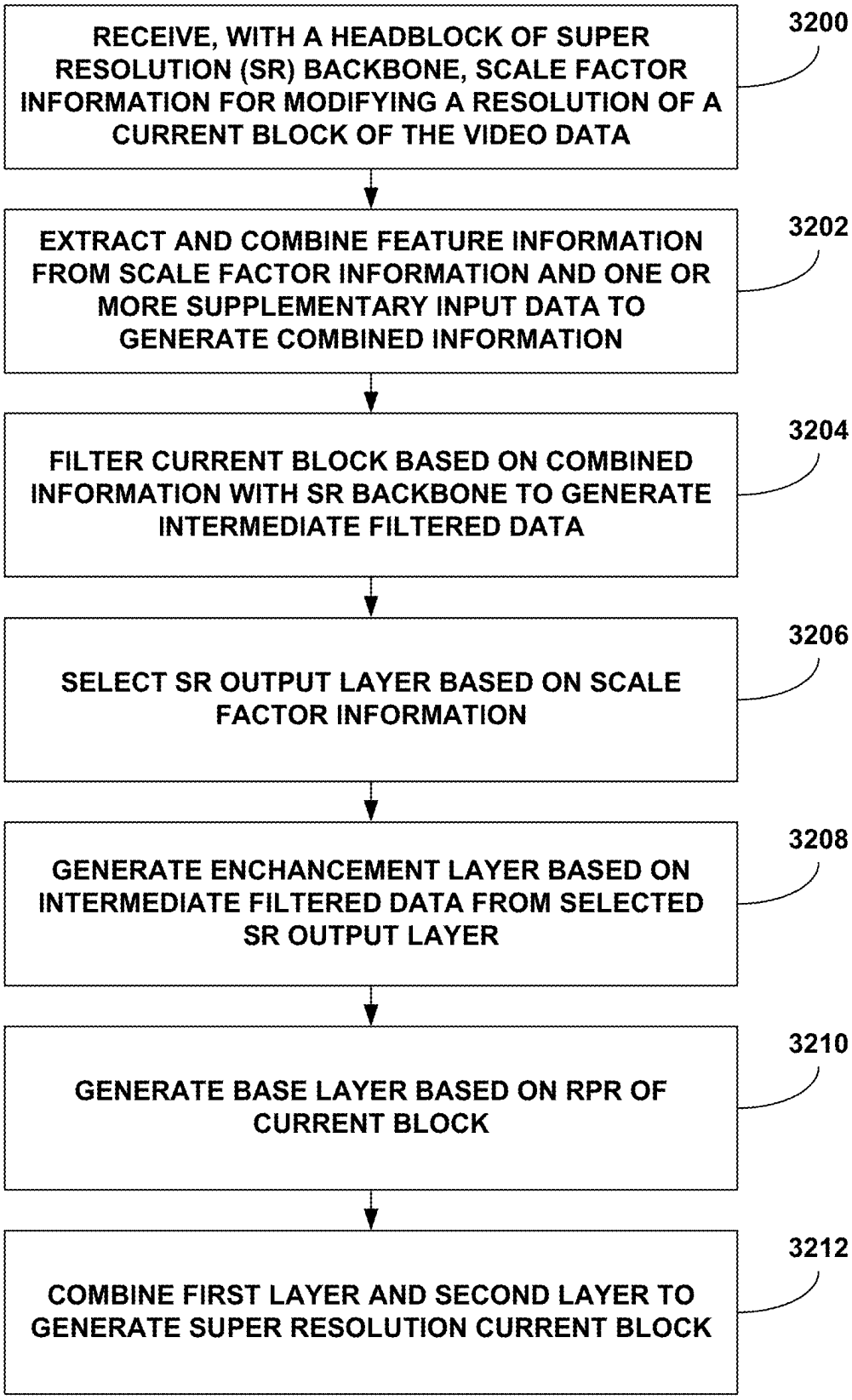

RECEIVE, WITH A HEADBLOCK OF SUPER RESOLUTION (SR) BACKBONE, SCALE FACTOR INFORMATION FOR MODIFYING A RESOLUTION OF A CURRENT BLOCK OF THE VIDEO DATA
3200
EXTRACT AND COMBINE FEATURE INFORMATION FROM SCALE FACTOR INFORMATION AND ONE OR MORE SUPPLEMENTARY INPUT DATA TO GENERATE COMBINED INFORMATION
3202
FILTER CURRENT BLOCK BASED ON COMBINED INFORMATION WITH SR BACKBONE TO GENERATE INTERMEDIATE FILTERED DATA
3204
SELECT SR OUTPUT LAYER BASED ON SCALE FACTOR INFORMATION
3206
GENERATE ENCHANCEMENT LAYER BASED ON INTERMEDIATE FILTERED DATA FROM SELECTED SR OUTPUT LAYER
3208
GENERATE BASE LAYER BASED ON RPR OF CURRENT BLOCK
3210
COMBINE FIRST LAYER AND SECOND LAYER TO GENERATE SUPER RESOLUTION CURRENT BLOCK
3212

FIG. 32

VIDEO CODING WITH NEURAL NETWORK (NN)-ARCHITECTURE FOR IN-LOOP FILTERING AND SUPER RESOLUTION

[0001] This application claims the benefit of U.S. Provisional Patent Application 63/551,464, filed Feb. 8, 2024, the entire content of which is incorporated by reference.

TECHNICAL FIELD

[0002] This disclosure relates to video encoding and video decoding.

BACKGROUND

[0003] Digital video capabilities can be incorporated into a wide range of devices, including digital televisions, digital direct broadcast systems, wireless broadcast systems, personal digital assistants (PDAs), laptop or desktop computers, tablet computers, e-book readers, digital cameras, digital recording devices, digital media players, video gaming devices, video game consoles, cellular or satellite radio telephones, so-called "smart phones," video teleconferencing devices, video streaming devices, and the like. Digital video devices implement video coding techniques, such as those described in the standards defined by MPEG-2, MPEG-4, ITU-T H.263, ITU-T H.264/MPEG-4, Part 10, Advanced Video Coding (AVC), ITU-T H.265/High Efficiency Video Coding (HEVC), and extensions of such standards. The video devices may transmit, receive, encode, decode, and/or store digital video information more efficiently by implementing such video coding techniques.

[0004] Video coding techniques include spatial (intra-picture) prediction and/or temporal (inter-picture) prediction to reduce or remove redundancy inherent in video sequences. For block-based video coding, a video slice (e.g., a video picture or a portion of a video picture) may be partitioned into video blocks, which may also be referred to as coding tree units (CTUs), coding units (CUs) and/or coding nodes. Video blocks in an intra-coded (I) slice of a picture are encoded using spatial prediction with respect to reference samples in neighboring blocks in the same picture. Video blocks in an inter-coded (P or B) slice of a picture may use spatial prediction with respect to reference samples in neighboring blocks in the same picture or temporal prediction with respect to reference samples in other reference pictures. Pictures may be referred to as frames, and reference pictures may be referred to as reference frames.

SUMMARY

[0005] In general, this disclosure describes techniques for neural network-based in-loop filtering (NN-ILF) and super resolution in video coding. One example of the neural network is the convolutional neural network (CNN). A NN-based filter architecture is described for usage as in-loop image enhancement, if coding is conducted at the original resolution. The NN-based filter architecture may also be used for in-loop image re-sampling, if coding is done at the resolution different from original and the image is being restored to the original resolution. The example techniques may improve coding performance under complexity and memory requirements constraints. The example techniques may be used in the context of advanced video codecs, such as extensions of Versatile Video Coding (VVC) or the next generation of video coding standards, and any other video codecs.

[0006] In one or more examples, processing circuitry may be configured to implement the NN based filter, and the NN based filter may include a super resolution (SR) backbone, and in some cases, a plurality of SR output layers. One of the inputs to the SR backbone may be scale factor information for modifying a resolution of a current block (e.g., the block that is being filtered). The SR backbone may filter the current block based on the scale factor information to generate intermediate filtered data. By inputting the scale factor information, the SR backbone may generate intermediate filtered data that is optimized to ensure high quality at the target output resolution indicated by the scale factor information.

[0007] The processing circuitry may generate a super resolution current block based on the intermediate filtered data. The super resolution current block may have a resolution that is different than the resolution of the current block.

[0008] In some cases, it may be possible that the intermediate filtered data is the super resolution current block. However, in examples where the NN based filter includes a plurality of SR output layers, each of the SR output layers may be specifically trained to implement NN-based resampling for a target output resolution to generate a block having the target output resolution. In such examples, the processing circuitry may select one of the plurality of SR output layers based on the scale factor information, and utilize the selected SR output layer for processing the intermediate filtered data to generate the super resolution current block.

[0009] In this manner, the processing circuitry may implement the needed SR output layer, instead of implementing all SR output layers, which promotes memory and processing efficiencies. Furthermore, the SR backbone may have a generic structure for all resolutions but may adjust weights and offsets for the intermediate filtered data based on the scale factor information. The plurality of SR output layers may be less complex than the SR backbone, and may also require less training time as compared to examples where there are multiple NN based filters, one for each target output resolution. Accordingly, the example techniques may improve the overall technology of NN based filtering techniques for video processing that is integrated into practical applications of utilizing NN based filtering, such NN-ILF, where the scale factor information is an input to a SR backbone of the NN based filter.

[0010] In one example, the disclosure describes a method of processing video data, the method comprising: receiving, with a headblock of a super resolution (SR) backbone, scale factor information for modifying a resolution of a current block of the video data; filtering, based on the scale factor information, the current block with the SR backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that utilizes the scale factor information; and generating a super resolution current block based on the intermediate filtered data, the super resolution current block having a resolution different than the resolution of the current block.

[0011] In one example, the disclosure describes a device for processing video data, the device comprising: one or more memories configured to store the video data; and

processing circuitry coupled to the one or more memories and configured to: receive, with a headblock of a super resolution (SR) backbone, scale factor information for modifying a resolution of a current block of the video data; filter, based on the scale factor information, the current block with the SR backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that utilizes the scale factor information; and generate a super resolution current block based on the intermediate filtered data, the super resolution current block having a resolution different than the resolution of the current block.

[0012] In one example, the disclosure describes a computer-readable storage medium having stored thereon instructions that, when executed, cause one or more processors to: receive, with a headblock of a super resolution (SR) backbone, scale factor information for modifying a resolution of a current block of video data; filter, based on the scale factor information, the current block with the SR backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that utilizes the scale factor information; and generate a super resolution current block based on the intermediate filtered data, the super resolution current block having a resolution different than the resolution of the current block.

[0013] The details of one or more examples are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description, drawings, and claims.

BRIEF DESCRIPTION OF DRAWINGS

[0014] FIG. **1** is a block diagram illustrating an example video encoding and decoding system that may perform the techniques of this disclosure.

[0015] FIG. **2** is a block diagram of a hybrid video coding framework.

[0016] FIG. **3** is a block diagram illustrating an example video encoder that may perform the techniques of this disclosure.

[0017] FIG. **4** is a block diagram illustrating an example video decoder that may perform the techniques of this disclosure.

[0018] FIG. **5** is a flowchart illustrating an example method for encoding a current block in accordance with the techniques of this disclosure.

[0019] FIG. **6** is a flowchart illustrating an example method for decoding a current block of video data in accordance with the techniques of this disclosure.

[0020] FIG. **7** is a conceptual diagram illustrating an example of hierarchical prediction structures with GOP size equal to 16.

[0021] FIG. **8** is a conceptual diagram illustrating a convolutional neural network (CNN)-based filter with 4 layers.

[0022] FIG. **9** is a conceptual diagram illustrating a CNN-based filter with padded input samples and supplementary data.

[0023] FIG. **10** is a conceptual diagram illustrating a CNN architecture.

[0024] FIG. **11** is a conceptual diagram illustrating an attention residual block of FIG. **10**.

[0025] FIG. **12** is a conceptual diagram illustrating a spatial attention layer.

[0026] FIG. **13** is a conceptual diagram illustrating an example CNN architecture.

[0027] FIG. **14** is a conceptual diagram illustrating an example residual block structure of FIG. **13**.

[0028] FIG. **15** is a conceptual diagram illustrating an example CNN architecture.

[0029] FIG. **16** is a conceptual diagram illustrating an example filter block structure of FIG. **15**.

[0030] FIG. **17** is a conceptual diagram illustrating an example CNN architecture.

[0031] FIG. **18** is a conceptual diagram illustrating an example multiscale feature extraction backbone network with two-component convolution.

[0032] FIG. **19** is a conceptual diagram illustrating an example unified filter with joint model (joint luma and chroma).

[0033] FIG. **20** is a conceptual diagram illustrating an example unified filter with separate luma/chroma models (luma).

[0034] FIG. **21** is a conceptual diagram illustrating an example unified filter with separate luma/chroma models (chroma).

[0035] FIG. **22** is a conceptual diagram illustrating an architecture of a super-resolution filter.

[0036] FIG. **23** is a conceptual diagram illustrating an architecture of a super-resolution filter (low operation point (LOP) configuration).

[0037] FIG. **24** is a block diagram of a neural network (NN)-super resolution (SR) filter.

[0038] FIG. **25** is a block diagram of the NN-SR filter in output layers targeting different resolutions.

[0039] FIG. **26** is a block diagram illustrating NN-SR backbone filter architecture derived from HOP2 (high operation point).

[0040] FIG. **27** is a block diagram illustrating NN-SR backbone filter architecture derived from LOP2 (low operation point).

[0041] FIGS. **28**A and **28**B are conceptual diagrams illustrating examples of NN-SR output layers targeting different resolutions.

[0042] FIG. **29** is a conceptual diagram illustrating an example of NN-SR output layers allowing fractional scaling factors, such as 1.5.

[0043] FIG. **30** is a conceptual diagram illustrating example of a headblock of NN-SR to include scale factor information.

[0044] FIG. **31** is a flowchart illustrating an example method of processing video data.

[0045] FIG. **32** is a flowchart illustrating an example method of processing video data.

DETAILED DESCRIPTION

[0046] A video decoder reconstructs a current block based on information signaled from a video encoder. The reconstruction process may be lossy, and therefore, there may be visual artifacts present in the current block that degrade visual quality. To improve visual quality, the video decoder may include a filter that filters the current block to generate a filtered block. The filtered block is output for display, and additionally may be used as a reference block for decoding a subsequent block. The video encoder may also include a reconstruction loop that reconstructs the encoded current block in the same manner that the video decoder will reconstruct the current block. The video encoder may also filter the current block in the same manner as the video decoder so that the filtered block at the video encoder side

and the filtered block at the video decoder side is the same. This way, when the filtered block is used later as a reference block, the video encoder and the video decoder are using the same reference block with the same sample values.

[0047] One example of filtering is changing the resolution of the current block. For instance, the current block of a picture may be encoded and decoded at one resolution, but based on the type of device on which the picture is displayed, there may be benefit in changing the resolution of the current block. For example, if the pictures of the video are displayed on a smart phone, then a lower resolution may be satisfactory, as compared to a higher resolution if pictures of the video are displayed on a high-resolution television.

[0048] An example technique to change the resolution is referred to as reference picture resampling (RPR). In RPR, the video encoder and the video decoder may utilize interpolation filters, or other such filters to change the resolution in a way that attempts to maintain the visual quality.

[0049] However, while RPR techniques are useful, it may be possible to achieve even better visual quality using neural network (NN) based filtering techniques, sometimes referred to as neural network in-loop filtering (NN-ILF) techniques. In NN-ILF techniques, the processing circuitry of the video encoder or the video decoder implements a trained NN based filter. The input may be the reconstructed block (e.g., current block) and other supplementary inputs such as boundary strength, prediction block used to reconstruct the current block (e.g., reference block of the current block). The NN based filter may extract features from the input, fuse the features, and apply weights and offsets to generate a filtered block.

[0050] NN-ILF techniques function well but may require extensive memory and processing power. For instance, if there were a plurality of complete NN-based filters for changing the resolution of the current block to each of a plurality of resolutions, the amount of memory needed to store the NN-based filters, the processing time and power, and training time to train the NN based filters may be more than available. One way to reduce the memory and processing power or time may be to limit the resolutions that the video encoder or video decoder can modify the current block (e.g., limited to only 2× resolution). However, in such cases, the limited options for changing resolution may be unsatisfactory for all use cases.

[0051] This disclosure describes example techniques for a super resolution (SR) neural network (NN) (SRNN) based filtering that can support a scaling the current block (e.g., modifying a resolution of the current block) to a plurality of resolutions with reduced impact on processing power or time and memory utilization as compared to other techniques. For instance, the SRNN may include an SR backbone. In accordance with one or more examples described in this disclosure, an input to the SR backbone may be scale factor information that indicates how much to scale the current block to modify the resolution to the current block. The scale factor information may indicate the target scaling factor (e.g., target output resolution), and may also be referred to as the scale factor indicator.

[0052] In one or more examples, the SR backbone may include a head block. The head block receives the inputs used to generate a super resolution current block with a different resolution than the current block. For instance, the head block may receive the scale factor information, and other supplementary input data (e.g., context), extract features from the scale factor information and other supplementary input data, and concatenate the extracted features for further processing.

[0053] The SR backbone may be configured to filter, based on the scale factor information, the current block to generate intermediate filtered data. As described, the SR backbone may implement a neural network (NN)-filter that utilizes the scale factor information. As one example, the features of the scale factor information, in addition to the other supplementary input data, may together adjust the weights and offsets of the trained SRNN model so that the intermediate filtered data are optimized for generating a super resolution current block at the desired resolution as indicated by the scale factor information. One example of the intermediate filtered data may be luma and chroma component feature data that is further processed to generate the luma and chroma component sample values for the super resolution current block (e.g., the current block having the modified resolution). In some examples, it may be possible for the intermediate filtered data to be the actual luma and chroma component sample values for the super resolution current block.

[0054] In one or more examples, in addition to the SR backbone, the SRNN may include a plurality of SR output layers. Each of the plurality of SR output layers may be trained to implement NN-based resampling for a target output resolution to generate a block having the target output resolution. For instance, the first SR output layer may be trained to increase the resolution of the current block by 2×, the second SR output layer may be trained to increase the resolution of the current block by 3×, and so forth. In general, the training time and complexity of the SR output layers may be less than having multiple SRNN filters that are each dedicated to a particular resolution.

[0055] For instance, in accordance with one or more examples, the SRNN may include an SR backbone implementing an NN-filter that is common for all resolutions, including no change of resolution. The SR backbone may receive as input the scale factor information, but the processing may be the same for all resolutions. The SRNN may also include a plurality of SR output layers, implementing NN-based resampling to the target output resolution.

[0056] In this manner, the intermediate filtered data from the SR backbone (e.g., luma and component feature data) may be optimized for a particular resolution because the scale factor information is an input to the head block of the SR backbone. The processing circuitry of the video encoder and video decoder may select an SR output layer from the plurality of SR output layers based on the scale factor information, and implement that SR output layer for further processing and generating the super resolution current block (e.g., luma and chroma component sample values for the super resolution current block). The processing circuitry may not need to implement all of the SR output layers.

[0057] This way, the memory storage and processing power and time of implementing the SR backbone and selected SR output layer may be less than memory storage and processing power and time needed to implement a plurality of different SRNNs that are each for a target output resolution. Stated another way, in some examples, because the SR backbone process and the plurality of SR output layers process are separated in one SRNN, the example techniques may promote memory storage and processing

efficiencies as compared to techniques in which multiple end-to-end SRNNs that each support a different target output resolution.

[0058] As described above, one technique, in addition to NN based filter techniques of this disclosure, may be RPR techniques to modify resolution of current block. In some examples, the video encoder and the video decoder may utilize RPR techniques in addition to the SRNN to generate the super resolution current block. For instance, the video encoder and the video decoder may utilize the RPR techniques to generate a base layer and utilize the SRNN to generate an enhancement layer. The video encoder and the video decoder may combine the enhancement layer and the base layer to generate the super resolution current block.

[0059] In this manner, for devices with low processing capabilities that are unable to process NN based filters, only RPR techniques may be used to generate the super resolution current block. However, for devices with higher processing capabilities, the combination of the base layer from the RPR techniques and the enhancement layer from the SRNN may be combined to generate the super resolution current block.

[0060] FIG. **1** is a block diagram illustrating an example video encoding and decoding system **100** that may perform the techniques of this disclosure. The techniques of this disclosure are generally directed to coding (encoding and/or decoding) video data. In general, video data includes any data for processing a video. Thus, video data may include raw, unencoded video, encoded video, decoded (e.g., reconstructed) video, and video metadata, such as signaling data.

[0061] As shown in FIG. **1**, system **100** includes a source device **102** that provides encoded video data to be decoded and displayed by a destination device **116**, in this example. In particular, source device **102** provides the video data to destination device **116** via a computer-readable medium **110**. Source device **102** and destination device **116** may comprise any of a wide range of devices, including desktop computers, notebook (i.e., laptop) computers, mobile devices, tablet computers, set-top boxes, telephone handsets such as smartphones, televisions, cameras, display devices, digital media players, video gaming consoles, video streaming device, broadcast receiver devices, or the like. In some cases, source device **102** and destination device **116** may be equipped for wireless communication, and thus may be referred to as wireless communication devices.

[0062] In the example of FIG. **1**, source device **102** includes video source **104**, memory **106**, video encoder **200**, and output interface **108**. Destination device **116** includes input interface **122**, video decoder **300**, memory **120**, and display device **118**. In accordance with this disclosure, video encoder **200** of source device **102** and video decoder **300** of destination device **116** may be configured to apply the techniques for neural network-based in-loop filtering. Thus, source device **102** represents an example of a video encoding device, while destination device **116** represents an example of a video decoding device. In other examples, a source device and a destination device may include other components or arrangements. For example, source device **102** may receive video data from an external video source, such as an external camera. Likewise, destination device **116** may interface with an external display device, rather than include an integrated display device.

[0063] System **100** as shown in FIG. **1** is merely one example. In general, any digital video encoding and/or decoding device may perform techniques for neural network based in-loop filtering. Source device **102** and destination device **116** are merely examples of such coding devices in which source device **102** generates coded video data for transmission to destination device **116**. This disclosure refers to a "coding" device as a device that performs coding (encoding and/or decoding) of data. Thus, video encoder **200** and video decoder **300** represent examples of coding devices, in particular, a video encoder and a video decoder, respectively. In some examples, source device **102** and destination device **116** may operate in a substantially symmetrical manner such that each of source device **102** and destination device **116** includes video encoding and decoding components. Hence, system **100** may support one-way or two-way video transmission between source device **102** and destination device **116**, e.g., for video streaming, video playback, video broadcasting, or video telephony.

[0064] In general, video source **104** represents a source of video data (i.e., raw, unencoded video data) and provides a sequential series of pictures (also referred to as "frames") of the video data to video encoder **200**, which encodes data for the pictures. Video source **104** of source device **102** may include a video capture device, such as a video camera, a video archive containing previously captured raw video, and/or a video feed interface to receive video from a video content provider. As a further alternative, video source **104** may generate computer graphics-based data as the source video, or a combination of live video, archived video, and computer-generated video. In each case, video encoder **200** encodes the captured, pre-captured, or computer-generated video data. Video encoder **200** may rearrange the pictures from the received order (sometimes referred to as "display order") into a coding order for coding. Video encoder **200** may generate a bitstream including encoded video data. Source device **102** may then output the encoded video data via output interface **108** onto computer-readable medium **110** for reception and/or retrieval by, e.g., input interface **122** of destination device **116**.

[0065] Memory **106** of source device **102** and memory **120** of destination device **116** represent general purpose memories. In some examples, memories **106**, **120** may store raw video data, e.g., raw video from video source **104** and raw, decoded video data from video decoder **300**. Additionally or alternatively, memories **106**, **120** may store software instructions executable by, e.g., video encoder **200** and video decoder **300**, respectively. Although memory **106** and memory **120** are shown separately from video encoder **200** and video decoder **300** in this example, it should be understood that video encoder **200** and video decoder **300** may also include internal memories for functionally similar or equivalent purposes. Furthermore, memories **106**, **120** may store encoded video data, e.g., output from video encoder **200** and input to video decoder **300**. In some examples, portions of memories **106**, **120** may be allocated as one or more video buffers, e.g., to store raw, decoded, and/or encoded video data.

[0066] Computer-readable medium **110** may represent any type of medium or device capable of transporting the encoded video data from source device **102** to destination device **116**. In one example, computer-readable medium **110** represents a communication medium to enable source device **102** to transmit encoded video data directly to destination device **116** in real-time, e.g., via a radio frequency network or computer-based network. Output interface **108** may

modulate a transmission signal including the encoded video data, and input interface **122** may demodulate the received transmission signal, according to a communication standard, such as a wireless communication protocol. The communication medium may comprise any wireless or wired communication medium, such as a radio frequency (RF) spectrum or one or more physical transmission lines. The communication medium may form part of a packet-based network, such as a local area network, a wide-area network, or a global network such as the Internet. The communication medium may include routers, switches, base stations, or any other equipment that may be useful to facilitate communication from source device **102** to destination device **116**.

[0067] In some examples, source device **102** may output encoded data from output interface **108** to storage device **112**. Similarly, destination device **116** may access encoded data from storage device **112** via input interface **122**. Storage device **112** may include any of a variety of distributed or locally accessed data storage media such as a hard drive, Blu-ray discs, DVDs, CD-ROMs, flash memory, volatile or non-volatile memory, or any other suitable digital storage media for storing encoded video data.

[0068] In some examples, source device **102** may output encoded video data to file server **114** or another intermediate storage device that may store the encoded video data generated by source device **102**. Destination device **116** may access stored video data from file server **114** via streaming or download.

[0069] File server **114** may be any type of server device capable of storing encoded video data and transmitting that encoded video data to the destination device **116**. File server **114** may represent a web server (e.g., for a website), a server configured to provide a file transfer protocol service (such as File Transfer Protocol (FTP) or File Delivery over Unidirectional Transport (FLUTE) protocol), a content delivery network (CDN) device, a hypertext transfer protocol (HTTP) server, a Multimedia Broadcast Multicast Service (MBMS) or Enhanced MBMS (eMBMS) server, and/or a network attached storage (NAS) device. File server **114** may, additionally or alternatively, implement one or more HTTP streaming protocols, such as Dynamic Adaptive Streaming over HTTP (DASH), HTTP Live Streaming (HLS), Real Time Streaming Protocol (RTSP), HTTP Dynamic Streaming, or the like.

[0070] Destination device **116** may access encoded video data from file server **114** through any standard data connection, including an Internet connection. This may include a wireless channel (e.g., a Wi-Fi connection), a wired connection (e.g., digital subscriber line (DSL), cable modem, etc.), or a combination of both that is suitable for accessing encoded video data stored on file server **114**. Input interface **122** may be configured to operate according to any one or more of the various protocols discussed above for retrieving or receiving media data from file server **114**, or other such protocols for retrieving media data.

[0071] Output interface **108** and input interface **122** may represent wireless transmitters/receivers, modems, wired networking components (e.g., Ethernet cards), wireless communication components that operate according to any of a variety of IEEE 802.11 standards, or other physical components. In examples where output interface **108** and input interface **122** comprise wireless components, output interface **108** and input interface **122** may be configured to transfer data, such as encoded video data, according to a cellular communication standard, such as 4G, 4G-LTE (Long-Term Evolution), LTE Advanced, 5G, or the like. In some examples where output interface **108** comprises a wireless transmitter, output interface **108** and input interface **122** may be configured to transfer data, such as encoded video data, according to other wireless standards, such as an IEEE 802.11 specification, an IEEE 802.15 specification (e.g., ZigBee™), a Bluetooth™ standard, or the like. In some examples, source device **102** and/or destination device **116** may include respective system-on-a-chip (SoC) devices. For example, source device **102** may include an SoC device to perform the functionality attributed to video encoder **200** and/or output interface **108**, and destination device **116** may include an SoC device to perform the functionality attributed to video decoder **300** and/or input interface **122**.

[0072] The techniques of this disclosure may be applied to video coding in support of any of a variety of multimedia applications, such as over-the-air television broadcasts, cable television transmissions, satellite television transmissions, Internet streaming video transmissions, such as dynamic adaptive streaming over HTTP (DASH), digital video that is encoded onto a data storage medium, decoding of digital video stored on a data storage medium, or other applications.

[0073] Input interface **122** of destination device **116** receives an encoded video bitstream from computer-readable medium **110** (e.g., a communication medium, storage device **112**, file server **114**, or the like). The encoded video bitstream may include signaling information defined by video encoder **200**, which is also used by video decoder **300**, such as syntax elements having values that describe characteristics and/or processing of video blocks or other coded units (e.g., slices, pictures, groups of pictures, sequences, or the like). Display device **118** displays decoded pictures of the decoded video data to a user. Display device **118** may represent any of a variety of display devices such as a liquid crystal display (LCD), a plasma display, an organic light emitting diode (OLED) display, or another type of display device.

[0074] Although not shown in FIG. **1**, in some examples, video encoder **200** and video decoder **300** may each be integrated with an audio encoder and/or audio decoder, and may include appropriate MUX-DEMUX units, or other hardware and/or software, to handle multiplexed streams including both audio and video in a common data stream. If applicable, MUX-DEMUX units may conform to the ITU H.223 multiplexer protocol, or other protocols such as the user datagram protocol (UDP).

[0075] Video encoder **200** and video decoder **300** each may be implemented as any of a variety of suitable encoder and/or decoder circuitry, such as one or more microprocessors, digital signal processors (DSPs), application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), discrete logic, software, hardware, firmware or any combinations thereof. When the techniques are implemented partially in software, a device may store instructions for the software in a suitable, non-transitory computer-readable medium and execute the instructions in hardware using one or more processors to perform the techniques of this disclosure. Each of video encoder **200** and video decoder **300** may be included in one or more encoders or decoders, either of which may be integrated as part of a combined encoder/decoder (CODEC) in a respective device. A device including video encoder **200** and/or video decoder

300 may comprise an integrated circuit, a microprocessor, and/or a wireless communication device, such as a cellular telephone.

[0076] Video encoder 200 and video decoder 300 may operate according to a video coding standard, such as ITU-T H.265, also referred to as High Efficiency Video Coding (HEVC) or extensions thereto, such as the multi-view and/or scalable video coding extensions. Alternatively, video encoder 200 and video decoder 300 may operate according to other proprietary or industry standards, such as ITU-T H.266, also referred to as Versatile Video Coding (VVC). A draft of the VVC standard is described in Bross, et al. "Versatile Video Coding (Draft 10)," Joint Video Experts Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, 18th Meeting: by teleconference, 22 Jun.-1 Jul. 2020, JVET-S2001-vA (hereinafter "VVC Draft 10"). The techniques of this disclosure, however, are not limited to any particular coding standard.

[0077] In general, video encoder 200 and video decoder 300 may perform block-based coding of pictures. The term "block" generally refers to a structure including data to be processed (e.g., encoded, decoded, or otherwise used in the encoding and/or decoding process). For example, a block may include a two-dimensional matrix of samples of luminance and/or chrominance data. In general, video encoder 200 and video decoder 300 may code video data represented in a YUV (e.g., Y, Cb, Cr) format. That is, rather than coding red, green, and blue (RGB) data for samples of a picture, video encoder 200 and video decoder 300 may code luminance and chrominance components, where the chrominance components may include both red hue and blue hue chrominance components. In some examples, video encoder 200 converts received RGB formatted data to a YUV representation prior to encoding, and video decoder 300 converts the YUV representation to the RGB format. Alternatively, pre- and post-processing units (not shown) may perform these conversions.

[0078] This disclosure may generally refer to coding (e.g., encoding and decoding) of pictures to include the process of encoding or decoding data of the picture. Similarly, this disclosure may refer to coding of blocks of a picture to include the process of encoding or decoding data for the blocks, e.g., prediction and/or residual coding. An encoded video bitstream generally includes a series of values for syntax elements representative of coding decisions (e.g., coding modes) and partitioning of pictures into blocks. Thus, references to coding a picture or a block should generally be understood as coding values for syntax elements forming the picture or block.

[0079] HEVC defines various blocks, including coding units (CUs), prediction units (PUs), and transform units (TUs). According to HEVC, a video coder (such as video encoder 200) partitions a coding tree unit (CTU) into CUs according to a quadtree structure. That is, the video coder partitions CTUs and CUs into four equal, non-overlapping squares, and each node of the quadtree has either zero or four child nodes. Nodes without child nodes may be referred to as "leaf nodes," and CUs of such leaf nodes may include one or more PUs and/or one or more TUs. The video coder may further partition PUs and TUs. For example, in HEVC, a residual quadtree (RQT) represents partitioning of TUs. In HEVC, PUs represent inter-prediction data, while TUs represent residual data. CUs that are intra-predicted include intra-prediction information, such as an intra-mode indication.

[0080] As another example, video encoder 200 and video decoder 300 may be configured to operate according to VVC. According to VVC, a video coder (such as video encoder 200) partitions a picture into a plurality of coding tree units (CTUs). Video encoder 200 may partition a CTU according to a tree structure, such as a quadtree-binary tree (QTBT) structure or Multi-Type Tree (MTT) structure. The QTBT structure removes the concepts of multiple partition types, such as the separation between CUs, PUs, and TUs of HEVC. A QTBT structure includes two levels: a first level partitioned according to quadtree partitioning, and a second level partitioned according to binary tree partitioning. A root node of the QTBT structure corresponds to a CTU. Leaf nodes of the binary trees correspond to coding units (CUs).

[0081] In an MTT partitioning structure, blocks may be partitioned using a quadtree (QT) partition, a binary tree (BT) partition, and one or more types of triple tree (TT) (also called ternary tree (TT)) partitions. A triple or ternary tree partition is a partition where a block is split into three sub-blocks. In some examples, a triple or ternary tree partition divides a block into three sub-blocks without dividing the original block through the center. The partitioning types in MTT (e.g., QT, BT, and TT), may be symmetrical or asymmetrical.

[0082] In some examples, video encoder 200 and video decoder 300 may use a single QTBT or MTT structure to represent each of the luminance and chrominance components, while in other examples, video encoder 200 and video decoder 300 may use two or more QTBT or MTT structures, such as one QTBT/MTT structure for the luminance component and another QTBT/MTT structure for both chrominance components (or two QTBT/MTT structures for respective chrominance components).

[0083] Video encoder 200 and video decoder 300 may be configured to use quadtree partitioning per HEVC, QTBT partitioning, MTT partitioning, or other partitioning structures. For purposes of explanation, the description of the techniques of this disclosure is presented with respect to QTBT partitioning. However, it should be understood that the techniques of this disclosure may also be applied to video coders configured to use quadtree partitioning, or other types of partitioning as well.

[0084] In some examples, a CTU includes a coding tree block (CTB) of luma samples, two corresponding CTBs of chroma samples of a picture that has three sample arrays, or a CTB of samples of a monochrome picture or a picture that is coded using three separate color planes and syntax structures used to code the samples. A CTB may be an N×N block of samples for some value of N such that the division of a component into CTBs is a partitioning. A component is an array or single sample from one of the three arrays (luma and two chroma) that compose a picture in 4:2:0, 4:2:2, or 4:4:4 color format or the array or a single sample of the array that compose a picture in monochrome format. In some examples, a coding block is an M×N block of samples for some values of M and N such that a division of a CTB into coding blocks is a partitioning.

[0085] The blocks (e.g., CTUs or CUs) may be grouped in various ways in a picture. As one example, a brick may refer to a rectangular region of CTU rows within a particular tile in a picture. A tile may be a rectangular region of CTUs

within a particular tile column and a particular tile row in a picture. A tile column refers to a rectangular region of CTUs having a height equal to the height of the picture and a width specified by syntax elements (e.g., such as in a picture parameter set). A tile row refers to a rectangular region of CTUs having a height specified by syntax elements (e.g., such as in a picture parameter set) and a width equal to the width of the picture.

[0086] In some examples, a tile may be partitioned into multiple bricks, each of which may include one or more CTU rows within the tile. A tile that is not partitioned into multiple bricks may also be referred to as a brick. However, a brick that is a true subset of a tile may not be referred to as a tile.

[0087] The bricks in a picture may also be arranged in a slice. A slice may be an integer number of bricks of a picture that may be exclusively contained in a single network abstraction layer (NAL) unit. In some examples, a slice includes either a number of complete tiles or only a consecutive sequence of complete bricks of one tile.

[0088] This disclosure may use "N×N" and "N by N" interchangeably to refer to the sample dimensions of a block (such as a CU or other video block) in terms of vertical and horizontal dimensions, e.g., 16×16 samples or 16 by 16 samples. In general, a 16×16 CU will have 16 samples in a vertical direction (y=16) and 16 samples in a horizontal direction (x=16). Likewise, an N×N CU generally has N samples in a vertical direction and N samples in a horizontal direction, where N represents a nonnegative integer value. The samples in a CU may be arranged in rows and columns. Moreover, CUs need not necessarily have the same number of samples in the horizontal direction as in the vertical direction. For example, CUs may comprise N×M samples, where M is not necessarily equal to N.

[0089] Video encoder **200** encodes video data for CUs representing prediction and/or residual information, and other information. The prediction information indicates how the CU is to be predicted in order to form a prediction block for the CU. The residual information generally represents sample-by-sample differences between samples of the CU prior to encoding and the prediction block.

[0090] To predict a CU, video encoder **200** may generally form a prediction block for the CU through inter-prediction or intra-prediction. Inter-prediction generally refers to predicting the CU from data of a previously coded picture, whereas intra-prediction generally refers to predicting the CU from previously coded data of the same picture. To perform inter-prediction, video encoder **200** may generate the prediction block using one or more motion vectors. Video encoder **200** may generally perform a motion search to identify a reference block that closely matches the CU, e.g., in terms of differences between the CU and the reference block. Video encoder **200** may calculate a difference metric using a sum of absolute difference (SAD), sum of squared differences (SSD), mean absolute difference (MAD), mean squared differences (MSD), or other such difference calculations to determine whether a reference block closely matches the current CU. In some examples, video encoder **200** may predict the current CU using uni-directional prediction or bi-directional prediction.

[0091] Some examples of VVC also provide an affine motion compensation mode, which may be considered an inter-prediction mode. In affine motion compensation mode, video encoder **200** may determine two or more motion vectors that represent non-translational motion, such as zoom in or out, rotation, perspective motion, or other irregular motion types.

[0092] To perform intra-prediction, video encoder **200** may select an intra-prediction mode to generate the prediction block. Some examples of VVC provide sixty-seven intra-prediction modes, including various directional modes, as well as planar mode and DC mode. In general, video encoder **200** selects an intra-prediction mode that describes neighboring samples to a current block (e.g., a block of a CU) from which to predict samples of the current block. Such samples may generally be above, above and to the left, or to the left of the current block in the same picture as the current block, assuming video encoder **200** codes CTUs and CUs in raster scan order (left to right, top to bottom).

[0093] Video encoder **200** encodes data representing the prediction mode for a current block. For example, for inter-prediction modes, video encoder **200** may encode data representing which of the various available inter-prediction modes is used, as well as motion information for the corresponding mode. For uni-directional or bi-directional inter-prediction, for example, video encoder **200** may encode motion vectors using advanced motion vector prediction (AMVP) or merge mode. Video encoder **200** may use similar modes to encode motion vectors for affine motion compensation mode.

[0094] Following prediction, such as intra-prediction or inter-prediction of a block, video encoder **200** may calculate residual data for the block. The residual data, such as a residual block, represents sample by sample differences between the block and a prediction block for the block, formed using the corresponding prediction mode. Video encoder **200** may apply one or more transforms to the residual block, to produce transformed data in a transform domain instead of the sample domain. For example, video encoder **200** may apply a discrete cosine transform (DCT), an integer transform, a wavelet transform, or a conceptually similar transform to residual video data. Additionally, video encoder **200** may apply a secondary transform following the first transform, such as a mode-dependent non-separable secondary transform (MDNSST), a signal dependent transform, a Karhunen-Loeve transform (KLT), or the like. Video encoder **200** produces transform coefficients following application of the one or more transforms.

[0095] As noted above, following any transforms to produce transform coefficients, video encoder **200** may perform quantization of the transform coefficients. Quantization generally refers to a process in which transform coefficients are quantized to possibly reduce the amount of data used to represent the transform coefficients, providing further compression. By performing the quantization process, video encoder **200** may reduce the bit depth associated with some or all of the transform coefficients. For example, video encoder **200** may round an n-bit value down to an m-bit value during quantization, where n is greater than m. In some examples, to perform quantization, video encoder **200** may perform a bitwise right-shift of the value to be quantized.

[0096] Following quantization, video encoder **200** may scan the transform coefficients, producing a one-dimensional vector from the two-dimensional matrix including the quantized transform coefficients. The scan may be designed to place higher energy (and therefore lower frequency) transform coefficients at the front of the vector and to place

lower energy (and therefore higher frequency) transform coefficients at the back of the vector. In some examples, video encoder **200** may utilize a predefined scan order to scan the quantized transform coefficients to produce a serialized vector, and then entropy encode the quantized transform coefficients of the vector. In other examples, video encoder **200** may perform an adaptive scan. After scanning the quantized transform coefficients to form the one-dimensional vector, video encoder **200** may entropy encode the one-dimensional vector, e.g., according to context-adaptive binary arithmetic coding (CABAC). Video encoder **200** may also entropy encode values for syntax elements describing metadata associated with the encoded video data for use by video decoder **300** in decoding the video data.

[0097] To perform CABAC, video encoder **200** may assign a context within a context model to a symbol to be transmitted. The context may relate to, for example, whether neighboring values of the symbol are zero-valued or not. The probability determination may be based on a context assigned to the symbol.

[0098] Video encoder **200** may further generate syntax data, such as block-based syntax data, picture-based syntax data, and sequence-based syntax data, to video decoder **300**, e.g., in a picture header, a block header, a slice header, or other syntax data, such as a sequence parameter set (SPS), picture parameter set (PPS), or video parameter set (VPS). Video decoder **300** may likewise decode such syntax data to determine how to decode corresponding video data.

[0099] In this manner, video encoder **200** may generate a bitstream including encoded video data, e.g., syntax elements describing partitioning of a picture into blocks (e.g., CUs) and prediction and/or residual information for the blocks. Ultimately, video decoder **300** may receive the bitstream and decode the encoded video data.

[0100] In general, video decoder **300** performs a reciprocal process to that performed by video encoder **200** to decode the encoded video data of the bitstream. For example, video decoder **300** may decode values for syntax elements of the bitstream using CABAC in a manner substantially similar to, albeit reciprocal to, the CABAC encoding process of video encoder **200**. The syntax elements may define partitioning information for partitioning of a picture into CTUs, and partitioning of each CTU according to a corresponding partition structure, such as a QTBT structure, to define CUs of the CTU. The syntax elements may further define prediction and residual information for blocks (e.g., CUs) of video data.

[0101] The residual information may be represented by, for example, quantized transform coefficients. Video decoder **300** may inverse quantize and inverse transform the quantized transform coefficients of a block to reproduce a residual block for the block. Video decoder **300** uses a signaled prediction mode (intra- or inter-prediction) and related prediction information (e.g., motion information for inter-prediction) to form a prediction block for the block. Video decoder **300** may then combine the prediction block and the residual block (on a sample-by-sample basis) to reproduce the original block. Video decoder **300** may perform additional processing, such as performing a deblocking process to reduce visual artifacts along boundaries of the block.

[0102] All video coding standards since H.261 have been based on the so-called hybrid video coding principle, which is illustrated in FIGS. **2-4**. The term hybrid refers to the combination of two means to reduce redundancy in the video signal, i.e., prediction and transform coding with quantization of the prediction residual. Whereas prediction and transforms reduce redundancy in the video signal by decorrelation, quantization decreases the data of the transform coefficient representation by reducing their precision, ideally by removing only irrelevant details. This hybrid video coding design principle is also used in the two most recent standards HEVC and VVC. As shown in FIG. **2**, a modern hybrid video coder is composed for various building blocks.

[0103] FIG. **2** is a conceptual diagram illustrating a hybrid video coding framework. As shown in FIG. **2**, a modern hybrid video coder **130** generally performs block partitioning, motion-compensated or inter-picture prediction, intra-picture prediction, transformation, quantization, entropy coding, and post/in-loop filtering. In the example of FIG. **2**, video coder **130** includes summation unit **134**, transform unit **136**, quantization unit **138**, entropy coding unit **140**, inverse quantization unit **142**, inverse transform unit **144**, summation unit **146**, loop filter unit **148**, decoded picture buffer (DPB) **150**, intra prediction unit **152**, inter-prediction unit **154**, and motion estimation unit **156**.

[0104] In general, video coder **130** may, when encoding video data, receive input video data **132**. Block partitioning is used to divide a received picture (image) of the video data into smaller blocks for operation of the prediction and transform processes. Early video coding standards used a fixed block size, typically 16×16 samples. Recent standards, such as HEVC and VVC, employ tree-based partitioning structures to provide flexible partitioning.

[0105] Motion estimation unit **156** and inter-prediction unit **154** may predict input video data **132**, e.g., from previously decoded data of DPB **150**. Motion-compensated or inter-picture prediction takes advantage of the redundancy that exists between (hence "inter") pictures of a video sequence. According to block-based motion compensation, which is used in the modern video codecs, the prediction is obtained from one or more previously decoded pictures, e.g., the reference picture(s). The corresponding areas to generate the inter-prediction are indicated by motion information, including motion vectors and reference picture indices. In recent video codecs, hierarchical prediction structures inside a group of pictures (GOP) is applied to improve coding efficiency. FIG. **7** is a conceptual diagram illustrating an example of hierarchical prediction structures **166** with GOP size equal to 16.

[0106] Summation unit **134** may calculate residual data as differences between input video data **132** and predicted data from intra prediction unit **152** or inter-prediction unit **154**. Summation unit **134** provides residual blocks to transform unit **136**, which applies one or more transforms to the residual block to generate transform blocks. Quantization unit **138** quantizes the transform blocks to form quantized transform coefficients. Entropy coding unit **140** entropy encodes the quantized transform coefficients, as well as other syntax elements, such as motion information or intra-prediction information, to generate output bitstream **158**.

[0107] Meanwhile, inverse quantization unit **142** inverse quantizes the quantized transform coefficients, and inverse transform unit **144** inverse transforms the transform coefficients, to reproduce residual blocks. Summation unit **146** combines the residual blocks with prediction blocks (on a sample-by-sample basis) to produce decoded blocks of

video data. Loop filter unit **148** applies one or more filters (e.g., at least one of a neural network-based filter, a neural network-based loop filter, a neural network-based post loop filter, an adaptive in-loop filter, or a pre-defined adaptive in-loop filter) to the decoded block to produce filtered decoded blocks.

[0108] A block of video data, such as a CTU or CU, may in fact include multiple color components, e.g., a luminance or "luma" component, a blue hue chrominance or "chroma" component, and a red hue chrominance (chroma) component. The luma component may have a larger spatial resolution than the chroma components, and one of the chroma components may have a larger spatial resolution than the other chroma component. Alternatively, the luma component may have a larger spatial resolution than the chroma components, and the two chroma components may have equal spatial resolutions with each other. For example, in 4:2:2 format, the luma component may be twice as large as the chroma components horizontally and equal to the chroma components vertically. As another example, in 4:2:0 format, the luma component may be twice as large as the chroma components horizontally and vertically. The various operations discussed above may generally be applied to each of the luma and chroma components individually (although certain coding information, such as motion information or intra-prediction direction, may be determined for the luma component and inherited by the corresponding chroma components).

[0109] Intra-picture prediction exploits spatial redundancy that exists within a picture (hence "intra") by deriving the prediction for a block from already coded/decoded, spatially neighboring (reference) samples. The directional angular prediction, DC prediction and plane or planar prediction are used in the most recent video codec, including AVC, HEVC, and VVC.

[0110] Hybrid video coding standards apply a block transform to the prediction residual (regardless of whether it comes from inter- or intra-picture prediction). In early standards, including H.261, H.262, and H.263, a discrete cosine transform (DCT) is employed. In HEVC and VVC, more transform kernel besides DCT are applied, in order to account for different statistics in the specific video signal.

[0111] Quantization aims to reduce the precision of an input value or a set of input values in order to decrease the amount of data needed to represent the values. In hybrid video coding, quantization is typically applied to individual transformed residual samples, i.e., to transform coefficients, resulting in integer coefficient levels. In recent video coding standards, the step size is derived from a so-called quantization parameter (QP) that controls the fidelity and bit rate. A larger step size lowers the bit rate but also deteriorates the quality, which e.g., results in video pictures exhibiting blocking artifacts and blurred details.

[0112] Entropy coding unit **140** may perform context-adaptive binary arithmetic coding (CABAC) on encoded video. CABAC is used in recent video codecs, e.g. AVC, HEVC and VVC, due to its high efficiency.

[0113] Loop filter unit **148** may perform post-loop or in-loop filtering. Post/In-Loop filtering is a filtering process (or combination of such processes) that is applied to the reconstructed picture to reduce the coding artifacts. The input of the filtering process is generally the reconstructed picture (or reconstructed block of a picture), which is the combination of the reconstructed residual signal (e.g., the reconstruction samples), where the reconstruction samples include quantization error, and the prediction (e.g., the prediction samples). As shown in FIG. **2**, the reconstructed pictures after in-loop filtering are stored in decoded picture buffer (DPB) **150** and are used as a reference for inter-picture prediction of subsequent pictures.

[0114] The coding artifacts are mostly determined by the QP (quantization parameter), therefore QP information is generally used in design of the filtering process. In HEVC, the in-loop filters include deblocking filtering and sample adaptive offset (SAO) filtering. In the VVC standard, an adaptive loop filter (ALF) was introduced as a third filter. The filtering process of ALF is as shown below:

$$R'(i,j) = R(i,j) + \left(\left(\sum_{k\neq 0}\sum_{l\neq 0} f(k,l)\times K(R(i+k,j+l)-R(i,j),\ c(k,l)) + 64\right) \gg 7\right) \quad (1)$$

where can R(i,j) is the samples before filtering process, R'(i,j) is the sample value after filtering process. f(k,l) denotes the filter coefficients, K(x,y) is the clipping function and c(k,l) denotes the clipping parameters. The variable k and l varies between

$$-\frac{L}{2}$$

and

$$\frac{L}{2}$$

where L denotes the filter length. The clipping function K(x,y)=min(y,max(−y,x)) which corresponds to the function Clip3 (−y,y,x). The clipping operation introduces non-linearity to make ALF more efficient by reducing the impact of neighbor sample values that are too different with the current sample value. In VVC, the filtering parameters can be signalled in the bit stream, it can be selected from the pre-defined filter sets. The ALF filtering process can also be summarised as following equation.

$$R'(i,j) = R(i,j) + \text{ALF\_residual\_ouput}\ (R) \quad (2)$$

[0115] Adaptive Resolution Change (ARC) is a process of changing spatial resolution during video content coding or delivery (e.g. broadcast, or streaming) in order to adapt parameters of the coded bitstreams to changing network conditions. In earlier generations of video coding standards, such as AVC or HEVC, changing spatial resolution may require a key frame, such as an IDR, to be sent to reset the stream and allow start at the new spatial resolution. The latter video coding technology, such as VVC, the Reference Picture Resampling (RPR) coding tool was introduced to allow spatial resolution change within a coded video sequence. In RPR, a spatial resolution of coded image can be changed with a predefined resolution ratio according to encoding strategy, and the decoded image can be used as reference picture even if the spatial resolutions of coded and

reference picture are not matching. To achieve resolutions alignment, a normative up- and down-sampling are being applied to the reference picture.

[0116] RPR is supported in the VVC Main **10** profile and while VVC allows high flexibility with regards to scaling factors and frequency of resolution change at any picture, application specifications may provide some constraints on how often and which resolutions can be used by the codec. For example, specification of DVB TS 101 154, which allows RPR use in VVC profiles, restricts downsampling scaling factors to ⅔ and ½ while new coded resolutions can be introduced at minimum interval of 2 seconds. However, different application standards may choose to adopt different sets of constraints for the use of RPR functionality.

[0117] The following describes neural network (NN) based filtering for video coding. Many works show that embedding neural networks into a hybrid video coding framework can improve compression efficiency. Neural networks have been used for intra prediction and inter prediction to improve the prediction efficiency. Neural network (NN)-based in-loop filtering is also a prominent research topic in recent years. In some works, the filtering process is applied as a post-filter. In this case, the filtering process is only applied to the output picture and the unfiltered picture is used as reference picture.

[0118] The NN-based filter can be applied additionally to the existing filters such as deblocking filter, SAO and ALF. The NN-based filter can also be applied exclusively, where it is designed to replace all the existing filters.

[0119] An example of an NN-based filter is shown in FIG. **8**. FIG. **8** is a conceptual diagram illustrating a CNN-based filter with 4 layers. The NN-based filtering process takes the reconstructed luma and chroma samples, packed in a 3D volume with 6 planes. As inputs, and the intermediate outputs are residual samples, which are added back to the input to refine the input samples. The NN-based filter may use all color components as input to exploit the cross-component correlations. The different component may share the same filters (including network structure and model parameters) or each component has its own specific filters.

[0120] For instance, NN-based filter **170** can be applied in addition to the existing filters, such as deblocking filters, sample adaptive offset (SAO), and/or adaptive loop filtering (ALF). NN-based filters can also be applied exclusively, where NN-based filters are designed to replace all of the existing filters. Additionally, or alternatively, NN-based filters, such as NN-based filter **170**, may be designed to supplement, enhance, or replace any or all of the other filters.

[0121] The NN-based filtering process of FIG. **8** may take the reconstructed samples (e.g., luma and chroma samples which, in some examples, may be packed in a 3D volume with 6 planes) as inputs, and the intermediate outputs are residual samples, which are added back to the input to refine the input samples. The NN-based filter may use all color components (e.g., Y, U, and V, or Y, Cb, and Cr, e.g., luminance data **172**A, blue-hue chrominance **172**B, and red-hue chrominance **172**C) as inputs **172** to exploit cross-component correlations. Different color components may share the same filter(s) (including network structure and model parameters) or each component may have its own specific filter(s).

[0122] The filtering process can also be generalized as follows:

$$R'(i, j) = R(i, j) + \text{NN\_filter\_residual\_ouput } (R) \tag{3}$$

[0123] The model structure and model parameters of NN-based filter(s) can pre-defined and be stored at encoder and decoder. The filters can also be signalled in the bit stream.

[0124] In the example of FIG. **8**, the NN-based filter **170** may include a series of feature extraction layers, followed by an output convolution. In FIG. **8**, the feature extraction layers may include a 3×3 convolution (conv) layer followed by a parametric rectified linear unit (PReLU) layer. The convolution layer applies a convolution operation to the input data, which involves a filter or kernel sliding over the input data (e.g., the reconstruction samples of input **172**) and computing dot products at each position. The convolution operation essentially captures local patterns within the input data. For example, in the context of image processing, these patterns could be edges, textures, or other visual features. The filter or kernel is a small matrix of weights that gets updated during the training process. By sliding this filter across the input data (or feature map from a previous layer) and computing the dot product at each position, the convolution layer creates a feature map that encodes spatial hierarchies and patterns detected in the input.

[0125] The output of a convolution layer is a set of feature maps, each corresponding to one filter, capturing different aspects of the input data. This layer helps the neural network to learn increasingly complex and abstract features as the data passes through deeper layers of the network. The first 3×3 in the nomenclature 3×3 conv 3×3×6×8 in FIG. **8** indicates that the convolution layer has a 3×3 filter size (e.g., a 3×3 matrix). 3×3×6×8 refers to both the input and output dimensions of the convolution layer, where 6 is the number of input channels, and 8 is the number of output channels.

[0126] The PRELU layer is an activation function used in neural networks, and was introduced as a variant of the ReLU (Rectified Linear Unit) activation function. As described above, the convolution layer outputs feature maps, each corresponding to one filter, representing detected features in the input. Following the convolution layer, the PRELU layer applies the PRELU activation function to each element of the feature maps produced by the convolution layer. For positive values, the PRELU layer acts like a standard ReLU, passing the value through. For negative values, instead of setting them to zero (e.g., as ReLU does), the PRELU layer allows a small, linear, negative output. This keeps the neurons active and maintains the gradient flow, which can be beneficial for learning in deep networks.

[0127] In summary, when a convolution layer is followed by a PRELU layer, the convolution layer first extracts features from the input data through a set of learned filters. The resulting feature maps are then passed through the PRELU activation function, which introduces non-linearity and helps to avoid the problem of dying neurons by allowing a small gradient when the inputs are negative. This combination is effective in learning complex patterns in the data while maintaining robust gradient flow, especially beneficial in deeper network architectures.

[0128] When NN-based filtering is applied in video coding, the whole video signal (pixel data) might be split into

multiple processing units (e.g. 2D blocks), and each processing unit can be processed separately or be combined with other information associated with this block of pixels. The possible choices of processing unit include a frame, a slice/tile, a CTU or any pre-defined or signaled shapes and sizes.

[0129] To further improve the performance of NN-based filtering, different types of input data can be processed jointly to produce the filtered output. Input data may include, but not limited to, reconstructed, prediction pixels, pixels after the loop filter(s), partitioning structure information, deblocking parameters (boundary strength (BS)), quantization parameter (QP) values, slice or picture types or filters applicability or coding modes map. Input data can be provided at the different granularity. Luma reconstruction and prediction samples could be provided at the original resolution, whereas chroma samples could be provided at lower resolution, e.g., for 4:2:0 representation, or can be up-sampled to the Luma resolution to achieve per-pixel representation. Similarly, QP, BS, partitioning or coding mode information can be provided at lower resolution, including cases with a single value per frame/slice or processing block (e.g., QP), or this value can be expanded (replicated) to achieve per-pixel representation.

[0130] An example of an architecture utilizing supplementary data was proposed in Wang et al "EE1-1.4: Test on Neural Network-based In-Loop Filter with Large Activation Layer," JVET-V0115, April 2021 (hereinafter, JVET-V0115) and shown in FIG. **9**. FIG. **9** is a conceptual diagram illustrating a CNN-based filter with padded input samples and supplementary data. Pixels of the processing block (4 subblocks of interlaced Luma samples plane and associated Cb and Cr planes) are combined with supplementary information such as QP steps and BS. The area of the processing pixel is extended with 4 padded pixels from each side. The total size of the processing volume is (4+64+4)×(4+64+4)×(4 Y+2UV+1QP+3BS).

[0131] For example, NN-based filter **171** uses pixels/samples of the processing block combined with supplementary data as input **174**. The input **174** may include 4 subblocks of interlaced luma samples (Yx4) **174**A and associated blue hue chrominance (U) data **174**B and red hue chrominance (V) data **174**C. The supplementary data includes a quantization parameter (QP) step **176** and a boundary strength (BS) **178**. The area of the input pixels/samples may be extended with 4 padded pixels/samples from each side. The resulting dimensions of the processing volume is (4+64+4)×(4+64+4)×(4 Y+2UV+1QP+3BS).

[0132] Relative to the NN-based filter in FIG. **8**, NN-based filter **171** may include two or more hidden layers that utilize both 1×1 convolutions and a Leaky ReLU layer. A leaky ReLU layer. Similar to a PRELU layer, a Leaky ReLU layer allows a small, non-zero gradient to be output when the layer is not active. Instead of outputting zero for negative inputs, the Leaky ReLU multiplies these inputs by a small constant. This small slope ensures that even neurons that would otherwise be inactive still contribute a small amount to the network's learning, reducing the likelihood of the dying ReLU problem.

[0133] Video encoder **200** and video decoder **300** may be configured to perform NN-based filtering with multi-mode design. To further improve the performance of NN based filtering, multi-mode solutions can be designed. For example, for each processing unit, encoder may select among a set of modes based on rate-distortion optimization and the choice can be signaled in the bit-stream, the different modes may include different NN models, different values that used as the input information of the NN models. As an example, Y. Li et al "EE1-1.7: Combined Test of EE1-1.6 and EE1-1.3," JVET-Z0113, April 2022 (hereinafter, JVET-Z0113) proposed a NN based filtering solution that created multiple modes based on a single NN model by using different QP values as input of the NN model for different modes.

[0134] This following section presents examples of CNN In-Loop Filtering (ILF) architecture that are being actively developed in JVET. In JVET-Z0113, an NN based filtering solution with multiple modes was proposed. The structure of the network is shown in FIG. **10**. FIG. **10** is a conceptual diagram illustrating a CNN architecture.

[0135] In the first part (FIG. **10**), the different input data types are convolved with number of kernels size of 3×3 to produce feature maps, undergo activation and results for each data type are concatenated, fused and subsampled once to create the output y. The number of feature maps used in JVET-Z0113 is 96. This output is then fed through N=8 attention residual blocks, each one with the structure shown in FIG. **10**. The output from the last attention residual block z is fed into the last part of the network.

[0136] For example, the NN-based filter of FIG. **10** includes a first portion including input 3×3 convolutions **510**A-**510**E and respective parametric rectified linear units (PReLUs) **512**A-**512**E for each of the inputs to generate feature maps (e.g., the feature extraction section of the NN-filter). Concatenation unit **514** concatenates the feature maps and provides them to fuse block **516** and transition block **522**. While shown as fuse block **516** and transition block **522**, in some examples, fuse block **516** and transition block **522** may together be referred to as a fusion block. The NN-based filter in FIG. **10** further includes a set **528** of attention residual (AttRes) blocks **530**A-**530**N; and a last portion (e.g., the tail section) including 3×3 convolution **550**, PRELU **552**, 3×3 convolution **554**, and pixel shuffle unit **556**. The AttRes blocks may also be referred to as backbone blocks.

[0137] In the first portion (e.g., the feature extraction section), different inputs, including quantization parameter (QP) **500**, partition information (part) **502**, boundary strength (BS) **504**, prediction information (pred) **506**, and reconstruction samples (rec) **508** are received. Respective 3×3 convolutions **510**A-**510**E and PRELUs **512**A-**512**E convolve and activate the respective inputs to produce feature maps. Concatenation unit **514** then concatenates the feature maps. Fuse block **516**, including 1×1 convolution **518** and PRELU **520**, fuses the concatenated feature maps. Transition block, including 3×3 convolution **524** and PRELU **526**, subsamples the fused inputs to create output **188**. Output **188** is then fed through set **528** of attention residual blocks **530**A-**530**N, which may include a various number of attention residual blocks, e.g., 8. The attention block is explained further with respect to FIG. **11**. Output **189** from the last of the set **528** of attention residual blocks **530** is fed to the last portion of the NN-based filter. In the last portion, which may be a tail block, 3×3 convolution **550**, PRELU **552**, 3×3 convolution **554**, and pixel shuffle unit **556** processes output **189**, and addition unit **558** combines this result with the original input reconstructed samples **508**. This ultimately forms the filtered output for presentation and

storage as reference for subsequent inter-prediction, e.g., in a decoded picture buffer (DPB). In some examples, the NN-based filter of FIG. **6** uses 96 feature maps.

[0138] FIG. **11** is a conceptual diagram illustrating an attention residual block of FIG. **10**. That is, FIG. **11** depicts attention residual block **530**, which may include components similar to those of attention residual blocks **530**A-**530**N of FIG. **10**. In this example, attention residual block **530** includes first 3×3 convolution **532**, parametric rectified linear unit (PRELU) filter **534**, second 3×3 convolution **536**, an attention block **538**, and addition unit **540**. Addition unit **540** combines the output of attention block **538** and output **188**, initially received by convolution **532**, to generate output **189**.

[0139] The spatial attention layer in AttRes block is illustrated in FIG. **12** in JVET-Z0113. FIG. **12** is a conceptual diagram illustrating a spatial attention layer. As shown in FIG. **12**, a spatial attention layer of attention residual block **530** includes 3×3 convolution **706**, PRELU **708**, 3×3 convolution **710**, size expansion unit **712**, 3×3 convolution **720**, PRELU **722**, and 3×3 convolution **724**. 3×3 convolution **706** receives inputs **702**, corresponding to quantization parameter (QP) **500**, partition information (part) **502**, boundary strength (BS) **504**, prediction information (pred) **506**, and reconstructed samples (rec) **508** of FIG. **10**. 3×3 convolution **720** receives Z_K value **704**. The outputs of size expansion unit **712** and **3**×3 convolution **724** are combined, and then combined with R value **730** to generate S value **732**. S value **732** is then combined with Z_K value **704** to generate output Z_{K+1} value **734**.

[0140] In S. Eadie, M. Coban, M. Karczewicz, EE1-1.9: Reduced complexity CNN-based in-loop filtering, JVET-AC0155, January 2023 (hereinafter, "JVET-AC0155"), an alternative design of NN architecture was proposed. It was proposed to use larger number of low complexity residual blocks in the backbone of the JVET-Z0113 CNN filter along with reduced number of channels (feature maps) and removal of the attention modules. The proposed CNN filtering structure (for Luma filtering) is shown in FIG. **13**. FIG. **13** is a conceptual diagram illustrating an example CNN-architecture. FIG. **14** shows the CNN architecture of JVET-AC0155 for a filter block.

[0141] FIG. **13** is a block diagram illustrating an example of a simplified CNN-based filter architecture. The NN-based filter of FIG. **13** includes 3×3 convolutions **810**A-**810**E and PRELUs **812**A-**812**E, which convolve corresponding inputs, i.e., QP **800**, Part **802**, BS **804**, Pred **806**, and Rec **808** to generate feature maps (e.g. the feature extraction section). Concatenation unit **814** concatenates the convolved inputs (e.g., the feature maps). Fuse block **816** then fuses the concatenated feature maps using 1×1 convolution **818** and PRELU **820**. Transition block **822** then processes the fused data using 3×3 convolution **824** and PRELU **826**. While shown as fuse block **816** and transition block **822**, in some examples, fuse block **816** and transition block **822** may together be referred to as a fusion block.

[0142] In this example, the NN-based filter includes a set **828** of residual blocks **830**A-**830**N (also called backbone blocks), each of which may be structured according to residual block structure **830** of FIG. **14**, as discussed below. Residual blocks **830**A-**830**N may replace AttRes blocks **530**A-**530**N of FIG. **10**. The example of FIG. **13** may be used for luminance (luma) filtering, although as discussed below, similar modifications may be made for chrominance (chroma) filtering.

[0143] The number of residual blocks and channels included in set **828** of FIG. **13** can be configured differently. That is, N may be set to a different value, and the number of channels in residual block structure **830** may be set to a number different than 160, to achieve different performance-complexity tradeoffs. Chroma filtering may be performed with these modifications for processing of chroma channels.

[0144] Set **828** of residual blocks **830**A-**830**N has N instances of residual block structure **830**. In one example, N may be equal to 32, such that there are 32 residual block structures. Residual blocks **830**A-**830**N may use 64 feature maps, which is reduced relative to the 96 feature maps used in the example of FIG. **10**.

[0145] In the last portion of FIG. **13**, 3×3 convolution **850**, PRELU **852**, 3×3 convolution **854**, and pixel shuffle unit **856** processes output of set **828**, and addition unit **858** combines this result with the original input reconstructions samples (REC) **808**. This ultimately forms the filtered output for presentation and storage as reference for subsequent inter-prediction, e.g., in a decoded picture buffer (DPB).

[0146] The quantity of residual blocks used is M=24. The quantity of feature maps (convolutions) is reduced to 64. In the ResBlocks, the quantity of channels firstly goes up to 160 before the activation layer, and then goes down to 64 after the activation layer. The number of residual blocks and channels can be configured differently (M set to another value and the number of channels in the residual block can be set to a number different than 160) for different performance-complexity trade-offs. Chroma filtering follows the concept in JVET-Z0113 (e.g., of FIG. **10**) with the above modifications to its backbone for processing of chroma channels.

[0147] FIG. **14** is a conceptual diagram illustrating an example residual block structure **830** of FIG. **13**. In this example, residual block structure **830** includes first 1×1 convolution **832**, which may increase a number of input channels to 160, before an activation layer (PRELU **834**) processes the input channels. PRELU **834** may thereby reduce the number of channels to 64 through this processing. Second 1×1 convolution **836** then processes the reduced channels, followed by 3×3 convolution **838**. Finally, combination unit **840** may combine the output of 3×3 convolution **838** with the original input received by residual block structure **830**.

[0148] In a further modification, the bypass branch around convolution and activation layers in the residual block in the previous solution is removed, as shown in FIG. **15**. The number of channels and number of filter blocks can be configurable, for example, 64 channels, 24 filter blocks, with 160 channels before and after the activation, which results in the the complexity of the network is 605.93 kMAC and the number of parameters is 1.5M for the intra luma model.

[0149] Further complexity reduction of CCN ILF architecture is achieved with utilization of the separable convolution in place of 2D convolutions (3×3). In Seregin et al., "EE2: Summary report of exploration experiment on enhanced compression beyond VVC capability" JVET-AD0023, (hereinafter, "JVET-AD0023"), EE1 test 1.3.5, a low-rank convolution approximation decomposes a 3×3×M×N convolution into a pixel-wise convolution (1×1×M×R), two separable convolutions (3×1×R×R, 1×3×R×R) and

another pixel-wise convolution (1×1×R×N) was applied to the residual block of the architecture described in JVET-AC0155. Here, R is the rank of the approximation, and can ablate the performance/complexity of the approximation.

[0150] FIG. **15** is a conceptual diagram illustrating another example filtering block structure that may be substituted for the set of attention residual blocks of FIG. **10** according to the techniques of this disclosure. The NN-based filter of FIG. **15** includes 3×3 convolutions **1010**A-**1010**E and PRELUs **1012**A-**1012**E, which convolve respective inputs, i.e., QP **1000**, Part **1002**, BS **1004**, Pred **1006**, and Rec **1008** to form feature maps (e.g., the feature extraction section). Concatenation unit **1014** concatenates the feature maps. Fuse block **1016** then fuses the concatenated inputs using 1×1 convolution **1018** and PRELU **1020**. Transition block **1022** then processes the fused data using 3×3 convolution **1024** and PRELU **1026**. While shown as fuse block **1016** and transition block **1022**, in some examples, fuse block **1016** and transition block **1022** may together be referred to as a fusion block.

[0151] In this example, the NN-based filtering unit includes a set **1028** of N filter blocks **1030**A-**1030**N (also called backbone blocks), each of which may have the structure of filter block structure **1030** of FIG. **16** as discussed below. Filter block structure **1030** may be substantially similar to residual block structure **830**, except that combination unit **840** is omitted from filter block structure **1030**, such that input is not combined with output. Instead, output of each residual block structure may be fed directly to the subsequent block.

[0152] In the last portion of FIG. **15**, 3×3 convolution **1050**, PRELU **1052**, 3×3 convolution **1054**, and pixel shuffle unit **1056** processes output of set **1028**, and addition unit **1058** combines this result with the original input reconstructions samples (REC) **1008**. This ultimately forms the filtered output for presentation and storage as reference for subsequent inter-prediction, e.g., in a decoded picture buffer (DPB).

[0153] FIG. **16** is a conceptual diagram illustrating an example filter block structure **1030** of FIG. **15**. In this example, filter block structure **1030** includes first 1×1 convolution **1032**, which may increase a number of input channels to 160, before an activation layer (PReLU **1034**) processes the input channels. PReLU **1034** may thereby reduce the number of channels to 64 through this processing. Second 1×1 convolution **1036** then processes the reduced channels, followed by 3×3 convolution **1038**. As discussed above, filter block structure **1030** does not include a combination unit, in contrast with the residual block structure **830** of FIG. **14**.

[0154] In one example, the architecture of FIG. **15**, with decomposition illustrated in FIG. **16**, is implemented with parameters K=64, M=160 and R=51, and total number of 24 residual blocks results in the complexity of the network is 356.43 kMAC and the number of parameters is 1.07M for the intra luma model.

[0155] FIG. **17** is a block diagram illustrating an example multiscale feature extraction backbone network with two-component convolution. The example of FIG. **17** may use of an approximation of a 3×3×K×K convolution with a 3×1×K×R convolution and a 1×3×R×K convolution.

[0156] In the example of FIG. **17**, residual block **1420** includes a 1×1×K×M convolution **1402**, followed by PRELU **1404**. The output of PRELU **1404** is input to 1×1×M×K convolution **1406**. A 3×3×K×K convolution **1408** of residual block **1420** is approximated by a 3×1×K×R convolution **1400** and then a 1×3×R×K convolution **1410**. The output of 1×3×R×K convolution **1410** may be input to combination unit **1412** which may combine the output of 1×3×R×K convolution **1410** with an input to 1×1×K×M convolution **1402**. R is the canonical rank of the decomposition. A lower rank implies a larger complexity reduction.

[0157] A multiscale feature extraction with a two-component convolution network is proposed in Y. Li, S. Eadie, D. Rusanovskyy, M. Karczewicz, EE1-Related: Combination test of EE1-1.3.5 and multi-scale component of EE1-1.6, JVET-AD0211, April 2023 (hereinafter, "JVET-AD0211"), which is illustrated in FIG. **18**, the 3×3 convolutions are decomposed into a 3×1×C1×R convolution and followed by a 1×3×R×C2 convolution, where C1 and C2 are the number of input and output channels, respectively, and R is the rank of the approximation. The parameter R can be made proportional to R=C1×C2/(C1+C2) and controls the complexity of the approximation.

[0158] FIG. **18** is a conceptual diagram illustrating an example multiscale feature extraction backbone network with two-component convolution. FIG. **18** shows an architecture with 3×3 convolution blocks being replaced by separable convolutions of 3×1 and 1×3. In this example, residual block structure **1430** includes first 1×1 convolution **1432** before a first activation layer (PReLU **1434**) and, in parallel with the first 1×1 convolution **1432** and PRELU **1434**, a 3×3 convolution **1440** and a second activation layer (PRELU **1442**). A second 1×1 convolution **1436** then processes the combined output of PRELU **1434** and PRELU **1442**, followed by 3×3 convolution **1438**. In the example of FIG. **18**, however, 3×3 convolution **1440** may be approximated using a plurality of separable convolutions, shown as 3×1 convolution **1450** and 1×3 convolution **1452** in FIG. **18**. Similarly, 3×3 convolution **1438** may be approximated using a plurality of separable convolutions, shown as 3×1 convolution **1460** and 1×3 convolution **1462** in FIG. **18**.

[0159] As an example, the architecture illustrated in FIG. **18** can be implemented with parameters R1=8, R2=44, M1=160 and M2=16, and total number of 24 residual blocks, the complexity of the network will be 358.43 kMAC and the number of parameters is 1.07M for the intra luma model.

[0160] The multiscale feature extraction backbone with the two-component decomposition has been integrated into the unified model in EE. In addition, the specification from the EE contains two versions of the model, which are 1) a unified model for joined luma and chroma, see FIG. **19**, and 2) separate models for luma and chroma, respectively, see FIG. **20** and FIG. **21**. FIG. **19** is a conceptual diagram illustrating an example unified filter with joint model (joint luma and chroma). FIG. **20** is a conceptual diagram illustrating an example unified filter with separate luma/chroma models (luma). FIG. **21** is a conceptual diagram illustrating an example unified filter with separate luma/chroma models (chroma).

[0161] The various components illustrated in FIGS. **19-21** may be similar to other similarly references components above. FIG. **19** illustrates an example where the output is the reconstructed (e.g., filtered) luma and chroma components using the same architecture. FIG. **20** illustrates an example where the output is the reconstructed luma component, and FIG. **21** illustrates an example where the output is the

reconstructed chroma components, where the luma and chroma filtering (e.g., reconstruction) is performed separately in FIGS. **20** and **21**.

[0162] For example, FIG. **19** illustrates unified filter **1900** that receives as inputs IPB mode **1902** (e.g., whether intra-frame (I), predicted frame (P), or bi-directional predicted frame (B)), the QP slice parameter **1904**, the QP base parameter **1906**, the boundary strength (BS) **1908**, the prediction block (e.g., block used to predict current block) **1910**, current block **1912**, luma component **1914**, and chroma components **1916**. The inputs are processed through the convolution and PRELU components of headblock **1918**.

[0163] The output from headblock **1918** is combined and processed through convolution layers and PRELU blocks, and then process through backbone blocks **1920**A-**1920**N. FIG. **19** also illustrates an example backbone block **1920**.

[0164] Because filter **1900** is a unified filter, the luma and chroma components are processed together. Using a pixel shuffle and crop operation, the luma and chroma components are separated out to generate filtered chroma components **1918** and filtered luma components **1920**.

[0165] FIG. **20** illustrates luma filter **2000** that receives as inputs IPB mode **2002** (e.g., whether intra-frame (I), predicted frame (P), or bi-directional predicted frame (B)), the QP base parameter **2004**, the boundary strength (BS) **2006**, the prediction block (e.g., block used to predict current block) **2008**, current block **2010**, and luma component **2012**. The inputs are processed through the convolution and PRELU components of headblock **2014**.

[0166] The output from headblock **2014** is combined and processed through convolution layers and PReLU blocks, and then process through backbone blocks **2016**A-**2016**N. FIG. **20** also illustrates an example backbone block **2016**.

[0167] Because filter **2000** is a luma filter, the luma component is processed separately from the chroma components. Using a pixel shuffle and crop operation, the luma components are separated out to generate filtered luma components **2018**.

[0168] FIG. **21** illustrates chroma filter **2100** that receives as inputs IPB mode **2102** (e.g., whether intra-frame (I), predicted frame (P), or bi-directional predicted frame (B)), the QP base parameter **2104**, the boundary strength (BS) **2106**, the prediction block (e.g., block used to predict current block) **2108**, current block **2110**, and luma component **2112**. The inputs are processed through the convolution and PReLU components of headblock **2114**.

[0169] The output from headblock **2114** is combined and processed through convolution layers and PRELU blocks, and then process through backbone blocks **2116**A-**2116**N. FIG. **21** also illustrates an example backbone block **2116**.

[0170] Because filter **2100** is a chroma filter, the chroma components are processed separately from the luma component. Using a pixel shuffle and crop operation, the chroma components are separated out to generate filtered chroma components **2118**.

[0171] The following describes CNN filter architecture for super resolution. There are two CNN-based filter architectures for Super Resolution have been proposed, tested, and adopted to JVET NNVC reference software.

[0172] The SR design proposed in Chang et al. "EE1-2.2: GOP Level Adaptive Resampling with CNN-based Super Resolution," JVET-AC0196, January 2023, (hereinafter JVET-AC0196), is shown in FIG. **22**. FIG. **22** is a conceptual diagram illustrating an architecture of a super-resolution filter.

[0173] Along with the low-resolution reconstruction Y_{lr}^{rec} **2200**, the low-resolution prediction Y_{lr}^{pred} **2202**, slice QP **2206** and base QP **2204** are also fed into the proposed network. The RPR reconstruction Y_{hr}^{rpr} **2208** upsampled by conventional RPR mechanism is adopted to generate the high-resolution reconstruction Y_{hr}^{rec} **2210**. The number of resblocks **2212** is set to 24, and the channels K and M in the resblock **2212** are set to 64 and 192 respectively. The NN structure for chroma is similar to the network structure for luma. Since the cross-component correlation is beneficial to the super resolution of chroma components, the luma reconstruction is fed into the network. Besides, the slice type is also taken as one input for better generalization. Separate models are trained for I slices and B slices.

[0174] Another SR (super resolution) design proposed in Lin et al. "AHG11: Unified CNN super resolution for resampling-based video coding) JVET-AF0143, October 2023 (hereinafter "JVET-AF0143") utilized a modified Unified Filter Architecture described above to introduce SR methods with HOP (high operation point) (~470 kMAC/pixel) and LOP (low operation point) complexity (~20 kMAC/pixel). The later model introduced changes that were limited to removal of the Transition Block which conducted convolution with stride 2. For the HOP configuration, the SR architecture would include Backbone block and configuration similar to that described in FIG. **16**. A single model is trained for both, Y and CbCr components and Intra and Inter coded picture.

[0175] FIG. **23** is a conceptual diagram illustrating an architecture of a super-resolution filter (low operation point (LOP) configuration). For instance, FIG. **23** illustrates the architecture of the super-resolution filter (LOP configuration) proposed in JVET-AF0143.

[0176] FIG. **23** illustrates combined luma and chroma filter **2300** that receives as inputs IPB mode **2302** (e.g., whether intra-frame (I), predicted frame (P), or bi-directional predicted frame (B)), the QP slice parameter **2304**, the QP base parameter **2306**, the boundary strength (BS) **2308**, the prediction block (e.g., block used to predict current block) **2310**, current block **2312** including reconstructed luma and chroma components. The inputs are processed through the convolution and PRELU components of headblock **2316**.

[0177] The output from headblock **2316** is combined and processed through convolution layers and PRELU blocks, and then process through backbone blocks **2318**A-**2318**N_Y for luma filtering, and through backbone blocks **2318**A-**2318**N_C for chroma filtering. FIG. **23** also illustrates an example backbone block **2318**.

[0178] Because filter **2300** is a unified filter, the luma and chroma components are processed together. Using a pixel shuffle and crop operation, the luma and chroma components are separated out to generate filtered chroma components **2322** and filtered luma components **2324**.

[0179] In the example of FIG. **23**, filter **2300** may also include RPR block **2320**, which may perform reference picture resampling of the reconstructed luma and chroma components but with interpolation filters or other such filters. For instance, in some examples, RPR block **2320** may not utilize NN-based techniques. In filter **2300**, the output from RPR block **2320** may be combined with the outputs

from the NN-based techniques to generate filtered chroma components **2322** and filtered luma components **2324**.

[0180] There may be issues with using NN-based techniques. NN-based filtering methods proposed with respect to JVET-AC0155, have been proposed and tested in JVET NNVC software in a form of post-processing with utilization framework roughly depicted in FIG. **24**. Scaling Factor 2 was tested by JVET. ARC methods, implemented by VVC RPR technique is used for resolution change within a coding loop of codec. However, it is expected that wide range of scaling factors would need to be used in practical applications, as pointed out in ARC (adaptive resolution change) description above. To accommodate a wide range of scaling factors, currently proposed methods would require a separate NN model architecture, separate training and separate trained model data (side information) for each of the scaling factors. This is expected to lead to a significant increase in the memory requirements and implementation complexity.

[0181] For example, as illustrated in FIG. **24**, there are a plurality of super resolution (SR) neural network (NN) (SRNN) units **2402**A-**2402**N that may be each associated with different scaling factors (e.g., target output resolution). RPR unit **2404** may be configured to perform reference picture resampling, such as interpolation or other filtering techniques. The output from each may be added together with adder **2405** to generate output data **2406**. Input data **2400** may be a block of video data (e.g., after or without initial filtering such as SAO or other NN-ILF techniques) including luma and chroma components, and output data **2406** may be a super resolution block including luma and chroma components. In this example, each of SSNR units **2402**A-**2402**N may be a separate NN model architecture, with separate training and separate trained model data (side information) for each of the scaling factors.

[0182] Another challenge of the proposed SR methods is a computation complexity. Both methods introduce NN-based filtering in addition to NN-based In-Loop Filter (NN-ILF) and RPR filter. Complexity of NN filters is significantly larger than conventional video coding tools of VVC, such as interpolation filter of RPR. Therefore, introducing of the additional NN-based SR filter sequentially to existing NN-based loop filter, as may be not providing optimal performance-complexity tradeoff.

[0183] The following describes example techniques that may address the above issues. The techniques should not be considered as limited or requiring to address the above issues.

[0184] To improve complexity-performance tradeoffs of NN-based SR methods in video coding and enable support of multiple scaling factors in NN filters used for Adaptive Resolution Change (ARC), several alternative architectures and inference techniques are described.

[0185] To enable support of multiple scale factors with reduced memory requirement, side information and training complexity, examples of NNSR architecture are described. A simplified block diagram of the architecture is shown in FIG. **25**. In the architecture of FIG. **25**, SRNN **2502** comprises of two components: SR backbone **2504** implementing NN-filter common for all resolutions, including no change of resolution (e.g., equivalent of the NN-ILF), and SR output layers **2506**A-**2506**N, implementing NN-based resampling to the target output resolution. In some examples, SR backbone **2504** may also receive as input scale factor information that SR backbone **2504** uses for generating intermediate filtered data that is fed to SR output layers **2506**A-**2506**N.

[0186] In some examples, SR backbone **2504** and multiple SR output layers **2506**A can be implemented in single NN architecture with SR output layers **2506**A being branched with network, similarly to luma/chroma branches of NNVC LOP2. Stated another way, in some examples, SR backbone **2504** and the plurality of SR output layers **2506**A-**2506**N are implemented in a single NN architecture. In some examples, SR backbone **2504** and SR output layers **2506**A-**2506**N may be separated in different networks, and being communicated by external process, e.g. during inference. Stated another way, in some examples, SR backbone **2504** and the plurality of SR output layers **2506**A-**2506**N are implemented in a separate, different NN architectures. Such model separation may allow greater flexibility in supporting of multiple scale factors and NN models updates.

[0187] In some examples, SR backbone **2504** operates at the input resolution and may be used as ILF or combined with existing ILF for video coding through the mean of data scope, format and inference method, e.g. RDO of encoder. For example, a headblock of SR backbone **2504** may receive scale factor information for modifying a resolution of a current block **2500** of the video data. SR backbone **2504** may filter, based on the scale factor information, current block **2500** to generate intermediate filtered data. In this example, SR backbone **2504** may implement a NN-filter that utilizes the scale factor information. The intermediate filter data may be feature data such as luma component feature data and chroma component feature data of the luma component and the chroma component of current block **2500**.

[0188] In some examples, the NN-filter of SR backbone **2504** may be common for all resolutions. That is, SR backbone **2504** may apply the same filtering operations for all resolutions but would also include as input the scale factor information (e.g., in the headblock of SR backbone **2504**). This way, the intermediate filtered data (e.g., luma component feature data and chroma component feature data) may be better optimized for the target output resolution indicated by the scale factor information.

[0189] SRNN **2502** may be configured to a super resolution current block (e.g., one of SR block **2510**A, SR block **2510**B, or SR block **2510**C) based on the intermediate filtered data. The super resolution current block (e.g., one of SR block **2510**A, SR block **2510**B, or SR block **2510**C) has a resolution different than the resolution of the current block **2500**. In the example illustrated in FIG. **25**, video encoder **200** or video decoder **300** may select a SR output layer from a plurality of SR output layers **2506**A-**2506**N based on the scale factor information. Each of the plurality of SR output layers **2506**A-**2506**N is trained to implement NN-based resampling for a target output resolution to generate a block having the target output resolution.

[0190] In this example, SRNN **2502** may generate, using the selected SR output layer, the super resolution current block (e.g., one of SR block **2510**A, SR block **2510**B, or SR block **2510**C). However, in some examples, the output from SR backbone **2504** may be the super resolution current block. In such examples, SR output layers **2506**A-**2506**N may not be needed. Also, it may be possible that SR backbone **2504** performs different operations based on the resolution.

[0191] As illustrated in FIG. **25**, in some examples, RPR unit **2508** may also generate a different resolution block that is combined with the output from SR output layers **2506**A-**2506**N to generate the super resolution current block. The use of RPR unit **2508** may be optional. However, some devices may support RPR unit **2508**, but may not have the processing or memory storage capabilities to implement SRNN **2502**. For such devices, only RPR unit **2508** may be used to generate a super resolution current block.

[0192] Even for devices that have the capability of implementing SRNN **2502**, video encoder **200** and video decoder **300** may utilize RPR unit **2508** to generate a base layer of current block **2500**. Video encoder **200** and video decoder **300** may utilize SRNN **2502** (e.g., output of selected one of SR output layers **2506**A-**2506**N) to generate an enhancement layer based on the intermediate filtered data (e.g., luma and chroma component feature data output from SR backbone **2504**). As illustrated in FIG. **25** with the adders, video encoder **200** and video decoder **300** may combine the enhancement layer and the base layer to generate the super resolution current block.

[0193] Examples of implementations of SR backbone **2504** based on JVET ILF LOP and HOP resolutions are shown in FIGS. **26** and **27**. FIG. **26** is a block diagram illustrating NN-SR backbone filter architecture derived from HOP2 (high operation point). FIG. **27** is a block diagram illustrating NN-SR backbone filter architecture derived from LOP2 (low operation point). Similarly to the base architectures, the reconstructed and predicted samples of chroma components (Cb,Cr) are upsampled to a resolution of the Y component, if needed.

[0194] For example, in FIG. **26**, SR backbone **2504** includes headblock **2600** that receives as input the IPB mode (e.g., whether intra-frame (I), predicted frame (P), or bi-directional predicted frame (B)), the QP slice parameter, the QP base parameter, the boundary strength (BS), the prediction block (e.g., block used to predict current block **2500**), and current block **2500**. Although not shown in FIG. **26**, headblock **2600** may also receive as input the scale factor information. The inputs other than the scale factor information may be referred to as supplementary input data.

[0195] Headblock **2600** (e.g., using the convolution and PRELU functions) may be configured to extract feature information from the scale factor information and the one or more supplementary input data. Headblock **2600** may combine (e.g., concatenate) the feature information (e.g., of the scale factor information and the supplementary input data) to generate combined information. SR backbone **2504** of FIG. **26** may then filter current block **2500** based on the combined information.

[0196] For instance, fusion block **2602** may fuse the combined information and extract features of the combined information for output to the backbone blocks for luma and chroma. The components of the backbone blocks for luma and chroma are also illustrated in FIG. **26**. The output of the backbone blocks for luma and chroma may be the filtered intermediate data (e.g., luma and chroma component feature data, represented as YCbCr features in FIG. **26**).

[0197] As illustrated in FIG. **26**, the output of headblock **2600** may be tensor (e.g., layer output). The width of the tensor is W, the height of the tensor is H, and the **272** represents the number of channels. In fusion block **2602**, the tensor is reduced to 48 channels, and then increased again to 64. In the backbone, the tensor has 182 channels, reduced down to 64. The YCbCr (luma and chroma) features have 64 channels.

[0198] The example of SR backbone **2504** in FIG. **27** may be similar to that of FIG. **26**, but the luma component feature data and the chroma component feature data may be separately generated. For example, in FIG. **27**, SR backbone **2504** includes headblock **2700** that receives as input the IPB mode (e.g., whether intra-frame (I), predicted frame (P), or bi-directional predicted frame (B)), the QP slice parameter, the QP base parameter, the boundary strength (BS), the prediction block (e.g., block used to predict current block **2500**), and current block **2500**. Although not shown in FIG. **27**, headblock **2700** may also receive as input the scale factor information. The inputs other than the scale factor information may be referred to as supplementary input data.

[0199] Headblock **2700** (e.g., using the convolution and PRELU functions) may be configured to extract feature information from the scale factor information and the one or more supplementary input data. Headblock **2700** may combine (e.g., concatenate) the feature information (e.g., of the scale factor information and the supplementary input data) to generate combined information. SR backbone **2504** of FIG. **27** may then filter current block **2500** based on the combined information.

[0200] For instance, fusion block **2702** may fuse the combined information and extract features of the combined information for output to the backbone blocks for luma and chroma. The components of the backbone blocks for luma and chroma are also illustrated in FIG. **27**. However, in FIG. **27**, there may be backbone blocks chroma that generates the chroma component feature data (e.g., which is one example of the filtered intermediate data), and backbone blocks luma and chroma generates the luma component feature data and may also generate the chroma component feature data that is discarded. The output of the backbone blocks for luma and chroma may be the filtered intermediate data (e.g., luma and chroma component feature data, represented as Y features in FIG. **27** for the luma component feature data and CbCr features in FIG. **27** for the chroma components).

[0201] As illustrated in FIG. **27**, the output of headblock **2700** may be tensor (e.g., layer output). The width of the tensor is W, the height of the tensor is H, and the 24 represents the number of channels. In fusion block **2702**, the tensor output has 32 channels. In the backbone, the tensor has 64 channels. The CbCr (chroma) features and the Y (luma) features have 16 channels.

[0202] In some examples, other parameter configurations or structure of SRNN backbone **2504** or its subcomponents may be used. In some examples, a reduced complexity Fusion Block, e.g. without downsampling convolution (3×3, with stride 2) and sequential activation nonlinearity (PReLU) may be used, similarly to the architecture in FIG. **23**.

[0203] Examples of SR output layers **2506**A-**2506**N are shown in FIGS. **28**A and **28**B for a NN architecture with a single branch for Y, CbCr components, e.g. FIG. **28**A, and NN architecture with separate branches for Y and CbCr components, e.g. FIG. **28**B. Tail block parameter oc determines number of output channels (2D planes). This translates by the means of pixel rearrangement, which reshapes the data tensor to the output with supported output resolution. Example of the relationship of parameters oc (model at

FIG. **28**A) and oc Y/ocUV (model at FIG. **28**B) to the scaling factor are shown in Table below.

Scale	FIG. 28A	FIG. 28B	
Factor	oc	ocY	ocUV
1	6	4	2
2	24	16	8
3	54	36	18
. . .	. . .	. . .	. . .

[0204] As illustrated in FIG. **28**A, one of SR output layers **2506**A-**2506**N may receive YCbCR features **2800**, which may be the luma and chroma component feature data (e.g., intermediate filtered data) generated by SR backbone **2504**. Tail block **2802** may perform convolution and PRELU operations, including having a convolution block that takes as input the oc parameter. Pixel rearrange **2804** may rearrange samples because the resolutions of the luma component and the chroma components may be different. The output may be the luma sample values **2806** for the luma component of the super resolution current block and the chroma sample values **2808** for the chroma components of the super resolution block.

[0205] FIG. **28**B may be similar to FIG. **28**A, but the generation of the luma sample values for the luma component and the chroma sample values for the chroma components may be separated out. As illustrated in FIG. **28**B, one of SR output layers **2506**A-**2506**N may receive YCbCR features **2810**, which may be the luma and chroma component feature data (e.g., intermediate filtered data) generated by SR backbone **2504**.

[0206] Tail block **2812** may perform convolution and PRELU operations, including having a convolution block that takes as input the oc parameter. Pixel rearrange **2814** may rearrange samples because the resolutions of the luma component and the chroma components may be different. The output may be the luma sample values for the luma component of the super resolution current block and the chroma sample values for the chroma components of the super resolution block, represented as YCbCr **2816**. In this example, generation of the chroma sample values may be optional or may be discarded.

[0207] Tail block **2818** may perform convolution and PRELU operations, including having a convolution block that takes as input the ocUV parameter. Pixel rearrange **28120** may rearrange samples because the resolutions of the luma component and the chroma components may be different. The output may be the chroma sample values **2822** for the chroma components of the super resolution block.

[0208] Accordingly, in the example of FIG. **28**A, video encoder **200** and video decoder **300** may be configured to generate, using the selected SR output layer of SR output layers **2506**A-**2506**N, a luma component and at least one chroma component of the super resolution current block. In the example of FIG. **28**B, video encoder **200** and video decoder **300** may be configured to generate, using the selected SR output layer (e.g., with tail block **2812**), a luma component of the super resolution current block, and generate, using a second SR output layer (e.g., with tail block **2818**), at least one chroma component of the super resolution current block.

[0209] In some examples, SR output layers **2506**A-**2506**N can be modified to include a downsampling process to achieve fractional ratios. Stated another way, in some examples, the resolution of the super resolution current block is a non-integer factor of the resolution of the current block. For example, scaling ratio 1.5 can be achieved by sequentially upsampling data by 3, followed by downsampling by factor of 2. Alternatively, downsampling by 2 can precede the upsampling by 3×. Other fractional scaling ratios can be achieved in similar way. Example of such NNSR output layer with downsampling implemented by conv3×3 with parameter stride st=2 is shown in FIG. **29**. In some examples, convolution with stride can take value not equal to 2.

[0210] In some examples, NNSR output layers module can be extended by including additional convolution or activation layers. Multiple layers of convolutions with stride >1 can be employed to extend range spatial filter support and range of achievable scaling factors.

[0211] As illustrated in FIG. **29**, one of SR output layers **2506**A-**2506**N may receive YCbCR features **2900**, which may be the luma and chroma component feature data (e.g., intermediate filtered data) generated by SR backbone **2504**. Tail block **2902** may perform convolution and PRELU operations, including having a convolution block that takes as input the oc parameter followed by a convolution block that takes st as input. By using the oc parameter and the st parameter it may be possible to achieve a resolution of the super resolution current block that is a non-integer factor of the resolution of current block **2500**. Pixel rearrange **2904** may rearrange samples because the resolutions of the luma component and the chroma components may be different. The output may be the luma sample values **2906** for the luma component of the super resolution current block and the chroma sample values **2908** for the chroma components of the super resolution block.

[0212] In some examples, set of supplementary input data (context) provided to the SR backbone **2504** architecture can be extended to include indicator of the target scaling factor (e.g., scale factor information). Scale factor indicator (also called scale factor information) can be provided as independent input, similar to QP or BS values, or can be aggregated with other supplementary data, such as IPB mode. Example of architecture with extended input data is shown in FIG. **30**.

[0213] For example, in FIG. **30**, headblock **3014**, which is an example of a headblock of SR backbone **2504**, may receive as input scale factor information **3000**, IPB mode **3002**, QP slice **3004**, QP base **3006**, boundary strength **3008**, prediction block **3010**, and reconstructed block (e.g., current block **2500**) **3012**. Using the convolution blocks, and PRELU (not shown) blocks of headblock **3014**, headblock **3014** may extract feature information from scale factor information **3000** and one or more supplementary input data (e.g., one or more of IPB mode **3002**, QP slice **3004**, QP base **3006**, boundary strength **3008**, prediction block **3010**, and reconstructed block **3012**). Headblock **3014** may be configured to combine the feature information to generate combined information, and SR backbone **2504** may then filter current block **2500** based on the combined information (e.g., via the fusion blocks and the backbone blocks for luma and chroma as illustrated in FIGS. **26** and **27**).

[0214] The example techniques may be applicable to in-loop filters with a wide range of complexity by choosing different parameter configurations. With the example tech-

niques, NNVC architectures could reduce computation complexity and memory bandwidth requirements and provide a competitive performance. Examples described in this document are related to NN-assisted loop filtering, however, the example techniques are applicable to any NN-based video coding tool that consumes input data with certain statistical properties, such as static content or sparse representation.

[0215] FIG. **3** is a block diagram illustrating an example video encoder **200** that may perform the techniques of this disclosure. FIG. **3** is provided for purposes of explanation and should not be considered limiting of the techniques as broadly exemplified and described in this disclosure. For purposes of explanation, this disclosure describes video encoder **200** according to the techniques of VVC (ITU-T H.266, under development), and HEVC (ITU-T H.265). However, the techniques of this disclosure may be performed by video encoding devices that are configured to other video coding standards.

[0216] In the example of FIG. **3**, video encoder **200** includes video data memory **230**, mode selection unit **202**, residual generation unit **204**, transform processing unit **206**, quantization unit **208**, inverse quantization unit **210**, inverse transform processing unit **212**, reconstruction unit **214**, filter unit **216**, decoded picture buffer (DPB) **218**, and entropy encoding unit **220**. Any or all of video data memory **230**, mode selection unit **202**, residual generation unit **204**, transform processing unit **206**, quantization unit **208**, inverse quantization unit **210**, inverse transform processing unit **212**, reconstruction unit **214**, filter unit **216**, DPB **218**, and entropy encoding unit **220** may be implemented in one or more processors or in processing circuitry. For instance, the units of video encoder **200** may be implemented as one or more circuits or logic elements as part of hardware circuitry, or as part of a processor, ASIC, or FPGA. Moreover, video encoder **200** may include additional or alternative processors or processing circuitry to perform these and other functions.

[0217] Video data memory **230** may store video data to be encoded by the components of video encoder **200**. Video encoder **200** may receive the video data stored in video data memory **230** from, for example, video source **104** (FIG. **1**). DPB **218** may act as a reference picture memory that stores reference video data for use in prediction of subsequent video data by video encoder **200**. Video data memory **230** and DPB **218** may be formed by any of a variety of memory devices, such as dynamic random access memory (DRAM), including synchronous DRAM (SDRAM), magnetoresistive RAM (MRAM), resistive RAM (RRAM), or other types of memory devices. Video data memory **230** and DPB **218** may be provided by the same memory device or separate memory devices. In various examples, video data memory **230** may be on-chip with other components of video encoder **200**, as illustrated, or off-chip relative to those components.

[0218] In this disclosure, reference to video data memory **230** should not be interpreted as being limited to memory internal to video encoder **200**, unless specifically described as such, or memory external to video encoder **200**, unless specifically described as such. Rather, reference to video data memory **230** should be understood as reference memory that stores video data that video encoder **200** receives for encoding (e.g., video data for a current block that is to be encoded). Memory **106** of FIG. **1** may also provide temporary storage of outputs from the various units of video encoder **200**.

[0219] The various units of FIG. **3** are illustrated to assist with understanding the operations performed by video encoder **200**. The units may be implemented as fixed-function circuits, programmable circuits, or a combination thereof. Fixed-function circuits refer to circuits that provide particular functionality, and are preset on the operations that can be performed. Programmable circuits refer to circuits that can be programmed to perform various tasks, and provide flexible functionality in the operations that can be performed. For instance, programmable circuits may execute software or firmware that cause the programmable circuits to operate in the manner defined by instructions of the software or firmware. Fixed-function circuits may execute software instructions (e.g., to receive parameters or output parameters), but the types of operations that the fixed-function circuits perform are generally immutable. In some examples, one or more of the units may be distinct circuit blocks (fixed-function or programmable), and in some examples, one or more of the units may be integrated circuits.

[0220] Video encoder **200** may include arithmetic logic units (ALUs), elementary function units (EFUs), digital circuits, analog circuits, and/or programmable cores, formed from programmable circuits. In examples where the operations of video encoder **200** are performed using software executed by the programmable circuits, memory **106** (FIG. **1**) may store the instructions (e.g., object code) of the software that video encoder **200** receives and executes, or another memory within video encoder **200** (not shown) may store such instructions.

[0221] Video data memory **230** is configured to store received video data. Video encoder **200** may retrieve a picture of the video data from video data memory **230** and provide the video data to residual generation unit **204** and mode selection unit **202**. Video data in video data memory **230** may be raw video data that is to be encoded.

[0222] Mode selection unit **202** includes a motion estimation unit **222**, a motion compensation unit **224**, and an intra-prediction unit **226**. Mode selection unit **202** may include additional functional units to perform video prediction in accordance with other prediction modes. As examples, mode selection unit **202** may include a palette unit, an intra-block copy unit (which may be part of motion estimation unit **222** and/or motion compensation unit **224**), an affine unit, a linear model (LM) unit, or the like.

[0223] Mode selection unit **202** generally coordinates multiple encoding passes to test combinations of encoding parameters and resulting rate-distortion values for such combinations. The encoding parameters may include partitioning of CTUs into CUs, prediction modes for the CUS, transform types for residual data of the CUs, quantization parameters for residual data of the CUs, and so on. Mode selection unit **202** may ultimately select the combination of encoding parameters having rate-distortion values that are better than the other tested combinations.

[0224] Video encoder **200** may partition a picture retrieved from video data memory **230** into a series of CTUs, and encapsulate one or more CTUs within a slice. Mode selection unit **202** may partition a CTU of the picture in accordance with a tree structure, such as the QTBT structure or the quad-tree structure of HEVC described above. As described above, video encoder **200** may form one or more

CUs from partitioning a CTU according to the tree structure. Such a CU may also be referred to generally as a "video block" or "block."

[0225] In general, mode selection unit **202** also controls the components thereof (e.g., motion estimation unit **222**, motion compensation unit **224**, and intra-prediction unit **226**) to generate a prediction block for a current block (e.g., a current CU, or in HEVC, the overlapping portion of a PU and a TU). For inter-prediction of a current block, motion estimation unit **222** may perform a motion search to identify one or more closely matching reference blocks in one or more reference pictures (e.g., one or more previously coded pictures stored in DPB **218**). In particular, motion estimation unit **222** may calculate a value representative of how similar a potential reference block is to the current block, e.g., according to sum of absolute difference (SAD), sum of squared differences (SSD), mean absolute difference (MAD), mean squared differences (MSD), or the like. Motion estimation unit **222** may generally perform these calculations using sample-by-sample differences between the current block and the reference block being considered. Motion estimation unit **222** may identify a reference block having a lowest value resulting from these calculations, indicating a reference block that most closely matches the current block.

[0226] Motion estimation unit **222** may form one or more motion vectors (MVs) that defines the positions of the reference blocks in the reference pictures relative to the position of the current block in a current picture. Motion estimation unit **222** may then provide the motion vectors to motion compensation unit **224**. For example, for uni-directional inter-prediction, motion estimation unit **222** may provide a single motion vector, whereas for bi-directional inter-prediction, motion estimation unit **222** may provide two motion vectors. Motion compensation unit **224** may then generate a prediction block using the motion vectors. For example, motion compensation unit **224** may retrieve data of the reference block using the motion vector. As another example, if the motion vector has fractional sample precision, motion compensation unit **224** may interpolate values for the prediction block according to one or more interpolation filters. Moreover, for bi-directional inter-prediction, motion compensation unit **224** may retrieve data for two reference blocks identified by respective motion vectors and combine the retrieved data, e.g., through sample-by-sample averaging or weighted averaging.

[0227] As another example, for intra-prediction, or intra-prediction coding, intra-prediction unit **226** may generate the prediction block from samples neighboring the current block. For example, for directional modes, intra-prediction unit **226** may generally mathematically combine values of neighboring samples and populate these calculated values in the defined direction across the current block to produce the prediction block. As another example, for DC mode, intra-prediction unit **226** may calculate an average of the neighboring samples to the current block and generate the prediction block to include this resulting average for each sample of the prediction block.

[0228] Mode selection unit **202** provides the prediction block to residual generation unit **204**. Residual generation unit **204** receives a raw, unencoded version of the current block from video data memory **230** and the prediction block from mode selection unit **202**. Residual generation unit **204** calculates sample-by-sample differences between the current block and the prediction block. The resulting sample-by-sample differences define a residual block for the current block. In some examples, residual generation unit **204** may also determine differences between sample values in the residual block to generate a residual block using residual differential pulse code modulation (RDPCM). In some examples, residual generation unit **204** may be formed using one or more subtractor circuits that perform binary subtraction.

[0229] In examples where mode selection unit **202** partitions CUs into PUs, each PU may be associated with a luma prediction unit and corresponding chroma prediction units. Video encoder **200** and video decoder **300** may support PUs having various sizes. As indicated above, the size of a CU may refer to the size of the luma coding block of the CU and the size of a PU may refer to the size of a luma prediction unit of the PU. Assuming that the size of a particular CU is 2N×2N, video encoder **200** may support PU sizes of 2N×2N or N×N for intra prediction, and symmetric PU sizes of 2N×2N, 2N×N, N×2N, N×N, or similar for inter prediction. Video encoder **200** and video decoder **300** may also support asymmetric partitioning for PU sizes of 2N×nU, 2N×nD, nL×2N, and nR×2N for inter prediction.

[0230] In examples where mode selection unit **202** does not further partition a CU into PUs, each CU may be associated with a luma coding block and corresponding chroma coding blocks. As above, the size of a CU may refer to the size of the luma coding block of the CU. The video encoder **200** and video decoder **300** may support CU sizes of 2N×2N, 2N×N, or N×2N.

[0231] For other video coding techniques such as an intra-block copy mode coding, an affine-mode coding, and linear model (LM) mode coding, as some examples, mode selection unit **202**, via respective units associated with the coding techniques, generates a prediction block for the current block being encoded. In some examples, such as palette mode coding, mode selection unit **202** may not generate a prediction block, and instead generate syntax elements that indicate the manner in which to reconstruct the block based on a selected palette. In such modes, mode selection unit **202** may provide these syntax elements to entropy encoding unit **220** to be encoded.

[0232] As described above, residual generation unit **204** receives the video data for the current block and the corresponding prediction block. Residual generation unit **204** then generates a residual block for the current block. To generate the residual block, residual generation unit **204** calculates sample-by-sample differences between the prediction block and the current block.

[0233] Transform processing unit **206** applies one or more transforms to the residual block to generate a block of transform coefficients (referred to herein as a "transform coefficient block"). Transform processing unit **206** may apply various transforms to a residual block to form the transform coefficient block. For example, transform processing unit **206** may apply a discrete cosine transform (DCT), a directional transform, a Karhunen-Loeve transform (KLT), or a conceptually similar transform to a residual block. In some examples, transform processing unit **206** may perform multiple transforms to a residual block, e.g., a primary transform and a secondary transform, such as a rotational transform. In some examples, transform processing unit **206** does not apply transforms to a residual block.

[0234] Quantization unit **208** may quantize the transform coefficients in a transform coefficient block, to produce a quantized transform coefficient block. Quantization unit **208** may quantize transform coefficients of a transform coefficient block according to a quantization parameter (QP) value associated with the current block. Video encoder **200** (e.g., via mode selection unit **202**) may adjust the degree of quantization applied to the transform coefficient blocks associated with the current block by adjusting the QP value associated with the CU. Quantization may introduce loss of information, and thus, quantized transform coefficients may have lower precision than the original transform coefficients produced by transform processing unit **206**.

[0235] Inverse quantization unit **210** and inverse transform processing unit **212** may apply inverse quantization and inverse transforms to a quantized transform coefficient block, respectively, to reconstruct a residual block from the transform coefficient block. Reconstruction unit **214** may produce a reconstructed block corresponding to the current block (albeit potentially with some degree of distortion) based on the reconstructed residual block and a prediction block generated by mode selection unit **202**. For example, reconstruction unit **214** may add samples of the reconstructed residual block to corresponding samples from the prediction block generated by mode selection unit **202** to produce the reconstructed block.

[0236] Filter unit **216** may perform one or more filter operations on reconstructed blocks. For example, filter unit **216** may perform deblocking operations to reduce blockiness artifacts along edges of CUs. Operations of filter unit **216** may be skipped, in some examples. In one or more examples, filter unit **216** may be configured to perform the example techniques of this disclosure. For example, filter unit **216** may include SRNN **2502** and RPR unit **2508**, as illustrated in FIG. **25**.

[0237] Video encoder **200** stores reconstructed blocks in DPB **218**. For instance, in examples where operations of filter unit **216** are not performed, reconstruction unit **214** may store reconstructed blocks to DPB **218**. In examples where operations of filter unit **216** are performed, filter unit **216** may store the filtered reconstructed blocks to DPB **218**. Motion estimation unit **222** and motion compensation unit **224** may retrieve a reference picture from DPB **218**, formed from the reconstructed (and potentially filtered) blocks, to inter-predict blocks of subsequently encoded pictures. In addition, intra-prediction unit **226** may use reconstructed blocks in DPB **218** of a current picture to intra-predict other blocks in the current picture.

[0238] In general, entropy encoding unit **220** may entropy encode syntax elements received from other functional components of video encoder **200**. For example, entropy encoding unit **220** may entropy encode quantized transform coefficient blocks from quantization unit **208**. As another example, entropy encoding unit **220** may entropy encode prediction syntax elements (e.g., motion information for inter-prediction or intra-mode information for intra-prediction) from mode selection unit **202**. Entropy encoding unit **220** may perform one or more entropy encoding operations on the syntax elements, which are another example of video data, to generate entropy-encoded data. For example, entropy encoding unit **220** may perform a context-adaptive variable length coding (CAVLC) operation, a CABAC operation, a variable-to-variable (V2V) length coding operation, a syntax-based context-adaptive binary arithmetic coding (SBAC) operation, a Probability Interval Partitioning Entropy (PIPE) coding operation, an Exponential-Golomb encoding operation, or another type of entropy encoding operation on the data. In some examples, entropy encoding unit **220** may operate in bypass mode where syntax elements are not entropy encoded.

[0239] Video encoder **200** may output a bitstream that includes the entropy encoded syntax elements needed to reconstruct blocks of a slice or picture. In particular, entropy encoding unit **220** may output the bitstream.

[0240] The operations described above are described with respect to a block. Such description should be understood as being operations for a luma coding block and/or chroma coding blocks. As described above, in some examples, the luma coding block and chroma coding blocks are luma and chroma components of a CU. In some examples, the luma coding block and the chroma coding blocks are luma and chroma components of a PU.

[0241] In some examples, operations performed with respect to a luma coding block need not be repeated for the chroma coding blocks. As one example, operations to identify a motion vector (MV) and reference picture for a luma coding block need not be repeated for identifying a MV and reference picture for the chroma blocks. Rather, the MV for the luma coding block may be scaled to determine the MV for the chroma blocks, and the reference picture may be the same. As another example, the intra-prediction process may be the same for the luma coding block and the chroma coding blocks.

[0242] Video encoder **200** represents an example of a device configured to encode video data including a memory configured to store video data, and one or more processing units implemented in circuitry and configured to perform the example techniques described in this disclosure.

[0243] FIG. **4** is a block diagram illustrating an example video decoder **300** that may perform the techniques of this disclosure. FIG. **4** is provided for purposes of explanation and is not limiting on the techniques as broadly exemplified and described in this disclosure. For purposes of explanation, this disclosure describes video decoder **300** according to the techniques of VVC (ITU-T H.266, under development), and HEVC (ITU-T H.265). However, the techniques of this disclosure may be performed by video coding devices that are configured to other video coding standards.

[0244] In the example of FIG. **4**, video decoder **300** includes coded picture buffer (CPB) memory **320**, entropy decoding unit **302**, prediction processing unit **304**, inverse quantization unit **306**, inverse transform processing unit **308**, reconstruction unit **310**, filter unit **312**, and decoded picture buffer (DPB) **314**. Any or all of CPB memory **320**, entropy decoding unit **302**, prediction processing unit **304**, inverse quantization unit **306**, inverse transform processing unit **308**, reconstruction unit **310**, filter unit **312**, and DPB **314** may be implemented in one or more processors or in processing circuitry. For instance, the units of video decoder **300** may be implemented as one or more circuits or logic elements as part of hardware circuitry, or as part of a processor, ASIC, or FPGA. Moreover, video decoder **300** may include additional or alternative processors or processing circuitry to perform these and other functions.

[0245] Prediction processing unit **304** includes motion compensation unit **316** and intra-prediction unit **318**. Prediction processing unit **304** may include additional units to perform prediction in accordance with other prediction

modes. As examples, prediction processing unit **304** may include a palette unit, an intra-block copy unit (which may form part of motion compensation unit **316**), an affine unit, a linear model (LM) unit, or the like. In other examples, video decoder **300** may include more, fewer, or different functional components.

[0246] CPB memory **320** may store video data, such as an encoded video bitstream, to be decoded by the components of video decoder **300**. The video data stored in CPB memory **320** may be obtained, for example, from computer-readable medium **110** (FIG. **1**). CPB memory **320** may include a CPB that stores encoded video data (e.g., syntax elements) from an encoded video bitstream. Also, CPB memory **320** may store video data other than syntax elements of a coded picture, such as temporary data representing outputs from the various units of video decoder **300**. DPB **314** generally stores decoded pictures, which video decoder **300** may output and/or use as reference video data when decoding subsequent data or pictures of the encoded video bitstream. CPB memory **320** and DPB **314** may be formed by any of a variety of memory devices, such as DRAM, including SDRAM, MRAM, RRAM, or other types of memory devices. CPB memory **320** and DPB **314** may be provided by the same memory device or separate memory devices. In various examples, CPB memory **320** may be on-chip with other components of video decoder **300**, or off-chip relative to those components.

[0247] Additionally or alternatively, in some examples, video decoder **300** may retrieve coded video data from memory **120** (FIG. **1**). That is, memory **120** may store data as discussed above with CPB memory **320**. Likewise, memory **120** may store instructions to be executed by video decoder **300**, when some or all of the functionality of video decoder **300** is implemented in software to be executed by processing circuitry of video decoder **300**.

[0248] The various units shown in FIG. **4** are illustrated to assist with understanding the operations performed by video decoder **300**. The units may be implemented as fixed-function circuits, programmable circuits, or a combination thereof. Similar to FIG. **3**, fixed-function circuits refer to circuits that provide particular functionality, and are preset on the operations that can be performed. Programmable circuits refer to circuits that can be programmed to perform various tasks, and provide flexible functionality in the operations that can be performed. For instance, programmable circuits may execute software or firmware that cause the programmable circuits to operate in the manner defined by instructions of the software or firmware. Fixed-function circuits may execute software instructions (e.g., to receive parameters or output parameters), but the types of operations that the fixed-function circuits perform are generally immutable. In some examples, one or more of the units may be distinct circuit blocks (fixed-function or programmable), and in some examples, one or more of the units may be integrated circuits.

[0249] Video decoder **300** may include ALUs, EFUs, digital circuits, analog circuits, and/or programmable cores formed from programmable circuits. In examples where the operations of video decoder **300** are performed by software executing on the programmable circuits, on-chip or off-chip memory may store instructions (e.g., object code) of the software that video decoder **300** receives and executes.

[0250] Entropy decoding unit **302** may receive encoded video data from the CPB and entropy decode the video data to reproduce syntax elements. Prediction processing unit **304**, inverse quantization unit **306**, inverse transform processing unit **308**, reconstruction unit **310**, and filter unit **312** may generate decoded video data based on the syntax elements extracted from the bitstream.

[0251] In general, video decoder **300** reconstructs a picture on a block-by-block basis. Video decoder **300** may perform a reconstruction operation on each block individually (where the block currently being reconstructed, i.e., decoded, may be referred to as a "current block").

[0252] Entropy decoding unit **302** may entropy decode syntax elements defining quantized transform coefficients of a quantized transform coefficient block, as well as transform information, such as a quantization parameter (QP) and/or transform mode indication(s). Inverse quantization unit **306** may use the QP associated with the quantized transform coefficient block to determine a degree of quantization and, likewise, a degree of inverse quantization for inverse quantization unit **306** to apply. Inverse quantization unit **306** may, for example, perform a bitwise left-shift operation to inverse quantize the quantized transform coefficients. Inverse quantization unit **306** may thereby form a transform coefficient block including transform coefficients.

[0253] After inverse quantization unit **306** forms the transform coefficient block, inverse transform processing unit **308** may apply one or more inverse transforms to the transform coefficient block to generate a residual block associated with the current block. For example, inverse transform processing unit **308** may apply an inverse DCT, an inverse integer transform, an inverse Karhunen-Loeve transform (KLT), an inverse rotational transform, an inverse directional transform, or another inverse transform to the transform coefficient block.

[0254] Furthermore, prediction processing unit **304** generates a prediction block according to prediction information syntax elements that were entropy decoded by entropy decoding unit **302**. For example, if the prediction information syntax elements indicate that the current block is inter-predicted, motion compensation unit **316** may generate the prediction block. In this case, the prediction information syntax elements may indicate a reference picture in DPB **314** from which to retrieve a reference block, as well as a motion vector identifying a location of the reference block in the reference picture relative to the location of the current block in the current picture. Motion compensation unit **316** may generally perform the inter-prediction process in a manner that is substantially similar to that described with respect to motion compensation unit **224** (FIG. **3**).

[0255] As another example, if the prediction information syntax elements indicate that the current block is intra-predicted, intra-prediction unit **318** may generate the prediction block according to an intra-prediction mode indicated by the prediction information syntax elements. Again, intra-prediction unit **318** may generally perform the intra-prediction process in a manner that is substantially similar to that described with respect to intra-prediction unit **226** (FIG. **3**). Intra-prediction unit **318** may retrieve data of neighboring samples to the current block from DPB **314**.

[0256] Reconstruction unit **310** may reconstruct the current block using the prediction block and the residual block. For example, reconstruction unit **310** may add samples of the residual block to corresponding samples of the prediction block to reconstruct the current block.

[0257] Filter unit **312** may perform one or more filter operations on reconstructed blocks. For example, filter unit **312** may perform deblocking operations to reduce blockiness artifacts along edges of the reconstructed blocks. Operations of filter unit **312** are not necessarily performed in all examples. In one or more examples, filter unit **312** may be configured to perform the example techniques of this disclosure. For example, filter unit **312** may include SRNN **2502** and RPR unit **2508**, as illustrated in FIG. **25**.

[0258] Video decoder **300** may store the reconstructed blocks in DPB **314**. For instance, in examples where operations of filter unit **312** are not performed, reconstruction unit **310** may store reconstructed blocks to DPB **314**. In examples where operations of filter unit **312** are performed, filter unit **312** may store the filtered reconstructed blocks to DPB **314**. As discussed above, DPB **314** may provide reference information, such as samples of a current picture for intra-prediction and previously decoded pictures for subsequent motion compensation, to prediction processing unit **304**. Moreover, video decoder **300** may output decoded pictures (e.g., decoded video) from DPB **314** for subsequent presentation on a display device, such as display device **118** of FIG. **1**.

[0259] In this manner, video decoder **300** represents an example of a video decoding device including a memory configured to store video data, and one or more processing units implemented in circuitry and configured to perform the example techniques described in this disclosure.

[0260] FIG. **5** is a flowchart illustrating an example method for encoding a current block in accordance with the techniques of this disclosure. The current block may comprise a current CU. Although described with respect to video encoder **200** (FIGS. **1** and **3**), it should be understood that other devices may be configured to perform a method similar to that of FIG. **5**.

[0261] In this example, video encoder **200** initially predicts the current block (**350**). For example, video encoder **200** may form a prediction block for the current block. Video encoder **200** may then calculate a residual block for the current block (**352**). To calculate the residual block, video encoder **200** may calculate a difference between the original, unencoded block and the prediction block for the current block. Video encoder **200** may then transform the residual block and quantize transform coefficients of the residual block (**354**). Next, video encoder **200** may scan the quantized transform coefficients of the residual block (**356**). During the scan, or following the scan, video encoder **200** may entropy encode the transform coefficients (**358**). For example, video encoder **200** may encode the transform coefficients using CAVLC or CABAC. Video encoder **200** may then output the entropy encoded data of the block (**360**).

[0262] FIG. **6** is a flowchart illustrating an example method for decoding a current block of video data in accordance with the techniques of this disclosure. The current block may comprise a current CU. Although described with respect to video decoder **300** (FIGS. **1** and **4**), it should be understood that other devices may be configured to perform a method similar to that of FIG. **6**.

[0263] Video decoder **300** may receive entropy encoded data for the current block, such as entropy encoded prediction information and entropy encoded data for transform coefficients of a residual block corresponding to the current block (**370**). Video decoder **300** may entropy decode the entropy encoded data to determine prediction information for the current block and to reproduce transform coefficients of the residual block (**372**). Video decoder **300** may predict the current block (**374**), e.g., using an intra- or inter-prediction mode as indicated by the prediction information for the current block, to calculate a prediction block for the current block. Video decoder **300** may then inverse scan the reproduced transform coefficients (**376**), to create a block of quantized transform coefficients. Video decoder **300** may then inverse quantize the transform coefficients and apply an inverse transform to the transform coefficients to produce a residual block (**378**). Video decoder **300** may ultimately decode the current block by combining the prediction block and the residual block (**380**).

[0264] FIG. **31** is a flowchart illustrating an example method of processing video data. For ease, reference is made to FIGS. **25-30**. Headblock **3014**, which is an example of headblock **2600** or headblock **2700**, of SR backbone **2504** being implemented by video encoder **200** or video decoder **300**, may receive scale factor information **3000** for modifying a resolution of current block **2500** of the video data (**3100**). Scale factor information **3000** may be separate input as illustrated in FIG. **30**, or may be combined with other supplementary input data such as IPB mode **3002**, QP slice **3004**, QP base **3006**, boundary strength **3008**, prediction block **3010**, and reconstructed block (e.g., current block **2500**) **3012**.

[0265] Video encoder **200** or video decoder **300** may filter, based on the scale factor information, the current block **2500** with the SR backbone **2504** to generate intermediate filtered data (**3102**). SR backbone **2504** may implement a NN-filter that utilizes the scale factor information. For example, fusion block **2602** (FIG. **26**) or **2702** (FIG. **27**) and the respective backbone blocks for luma and/or chroma of FIGS. **26** and **27** may filter current block **2500**, where the weights and offsets of the convolution and PRELU blocks may be adjusted or controlled by the scale factor information **3000**. The intermediate filtered data may be the luma and chroma component feature data, such as YCbCr features of FIG. **26**, or CbCR features and Y features of FIG. **27**. The NN-filter of SR backbone **2504** may be common for all resolutions (e.g., the process may be the same for all resolutions), but the scale factor information **3000** may be another input used to generated the filtered intermediate data.

[0266] Video encoder **200** or video decoder **300** may generate a super resolution current block (e.g., one of SR blocks **2510**A, **2510**B, or **2510**C) based on the intermediate filtered data (**3104**). The super resolution current block may have a resolution different than the resolution of current block **2500**. Video encoder **200** and video decoder **300** may store the super resolution current block as a reference block for inter-prediction encoding or decoding a subsequent block. Video decoder **300** may be configured to output for display the super resolution current block.

[0267] FIG. **32** is a flowchart illustrating an example method of processing video data. For ease, reference is made to FIGS. **25-30**. Similar to FIG. **31**, headblock **3014**, which is an example of headblock **2600** or headblock **2700**, of SR backbone **2504** being implemented by video encoder **200** or video decoder **300**, may receive scale factor information **3000** for modifying a resolution of current block **2500** of the video data (**3200**). Scale factor information **3000** may be separate input as illustrated in FIG. **30**, or may be combined with other supplementary input data such as IPB mode **3002**,

QP slice **3004**, QP base **3006**, boundary strength **3008**, prediction block **3010**, and reconstructed block (e.g., current block **2500**) **3012**.

[0268] Video encoder **200** or video decoder **300** via SR backbone **2504** may extract feature information from the scale factor information **3000** and one or more supplementary input data (e.g., IPB mode **3002**, QP slice **3004**, QP base **3006**, boundary strength **3008**, prediction block **3010**, and reconstructed block **3012**), and combine the feature information to generate combined information (**3202**). For example, as illustrated in FIGS. **26**, **27**, and **30**, with the convolution blocks and the PRELU process, headblocks **2600**, **2700**, or **3014** may extra feature information and combine the feature information.

[0269] Video encoder **200** or video decoder **300** via SR backbone **2504** may filter the current block **2500** based on the combined information to generate intermediate filtered data (**3204**). For instance, for filtering, the combined information may be input into fusion block **2602** or **2702**, and fusion block **2602** or **2702** may output to backbone blocks for luma and/or chroma, as illustrated in FIGS. **26** and **27**. The intermediate filtered data may be the luma and chroma component feature data, represented as YCbCR features in FIG. **26** or Y features and CbCr features in FIG. **27**.

[0270] Video encoder **200** or video decoder may select an SR output layer from plurality of SR output layers **2506**A-**2506**N based on the scale factor information **3000** (**3206**). As described, each of the plurality of SR output layers **2506**A-**2506**N is trained to implement NN-based resampling for a target output resolution to generate a block having the target output resolution. Accordingly, based on the scale factor information, video encoder **200** and video decoder **300** may select the SR output layer that is trained to generate a block having the target output resolution that aligns with the scale factor information.

[0271] Video encoder **200** or video decoder **300** may generate an enhancement layer based on the intermediate filtered data (**3208**). For example, the output from the selected SR output layer from plurality of SR output layers **2506**A-**2506**N may be considered as an enhancement layer. Video encoder **200** or video decoder **300** may generate a base layer based on reference picture resampling (RPR) (e.g., via RPR unit **2508**) of the current block **2500** (**3210**). Video encoder **200** or video decoder **300** may combine the enhancement layer and the base layer to generate the super resolution current block (e.g., one of SR blocks **2510**B or **2510**C) (**3212**).

[0272] In some examples, video encoder **200** and video decoder **300** may store the super resolution current block as a reference block for inter-prediction encoding or decoding a subsequent block. In some examples, video decoder **300** may output for display the super resolution current block.

[0273] The following describes examples techniques that may be implemented together or separately.

[0274] Clause 1A. A method of processing video data, the method comprising: filtering video data input with a super resolution (SR) backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that is common for all resolutions of video data; and resampling the intermediate filtered data with one or more SR output layers to generate target output resolution video data, the one or more SR output layers implementing NN-based resampling.

[0275] Clause 2A. The method of clause 1A, wherein the SR back and the one or more SR output layers are implemented in a single NN architecture.

[0276] Clause 3A. The method of clause 1A, wherein the SR back and the one or more SR output layers are implemented in separate, different NN architectures.

[0277] Clause 4A. The method of any of clauses 1A-3A, wherein the method(s) are performed as part of a video decoder generating pictures for display.

[0278] Clause 5A. The method of any of clauses 1A-3A, wherein the method(s) are performed as part of a video encoder or a video decoder generating pictures that are used as reference pictures.

[0279] Clause 6A. A device for processing video data, the device comprising: one or more memories configured to store the video data; and processing circuitry coupled to the one or more memories and configured to perform the method of any of clauses 1A-5A.

[0280] Clause 7A. A device for processing video data, the device comprising one or more means for performing the method of any of clauses 1A-5A.

[0281] Clause 8A. The device of clause 7A, wherein the one or more means comprise one or more processors implemented in circuitry.

[0282] Clause 9A. The device of any of clauses 7A and 8A, further comprising one or more memories to store the video data.

[0283] Clause 10A. The device of any of clauses 6A-9A, further comprising a display configured to display decoded video data.

[0284] Clause 11A. The device of any of clauses 6A-10A, wherein the device comprises one or more of a camera, a computer, a mobile device, a broadcast receiver device, or a set-top box.

[0285] Clause 12A. The device of any of clauses 6A-11A, wherein the device comprises a video decoder.

[0286] Clause 13A. The device of any of clauses 6A-12A, wherein the device comprises a video encoder.

[0287] Clause 14A. A computer-readable storage medium having stored thereon instructions that, when executed, cause one or more processors to perform the method of any of clauses 1A-5A.

[0288] Clause 1B. A method of processing video data, the method comprising: receiving, with a headblock of a super resolution (SR) backbone, scale factor information for modifying a resolution of a current block of the video data; filtering, based on the scale factor information, the current block with the SR backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that utilizes the scale factor information; and generating a super resolution current block based on the intermediate filtered data, the super resolution current block having a resolution different than the resolution of the current block.

[0289] Clause 2B. The method of clause 1B, wherein the intermediate filtered data comprises luma and chroma component feature data.

[0290] Clause 3B. The method of any of clauses 1B and 2B, further comprising: extracting feature information from the scale factor information and one or more supplementary input data; and combining the feature

information to generate combined information, wherein filtering the current block comprises filtering the current block based on the combined information.

[0291] Clause 4B. The method of any of clauses 1B-3B, wherein the NN-filter is common for all resolutions.

[0292] Clause 5B. The method of any of clauses 1B-4B, further comprising: selecting a SR output layer from a plurality of SR output layers based on the scale factor information, wherein each of the plurality of SR output layers is trained to implement NN-based resampling for a target output resolution to generate a block having the target output resolution, wherein generating the super resolution current block comprises generating, using the selected SR output layer, the super resolution current block.

[0293] Clause 6B. The method of clause 5B, wherein generating, using the selected SR output layer, the super resolution current block comprises generating, using the selected SR output layer, a luma component and at least one chroma component of the super resolution current block.

[0294] Clause 7. The method of any of clauses 5B and 6B, wherein the selected SR output layer is a first SR output layer, and wherein generating, using the selected SR output layer, the super resolution current block comprises: generating, using the selected SR output layer, a luma component of the super resolution current block; and generating, using a second SR output layer, at least one chroma component of the super resolution current block.

[0295] Clause 8B. The method of any of clauses 1B-7B, wherein generating the super resolution current block based on the intermediate filtered data comprises: generating an enhancement layer based on the intermediate filtered data; generating a base layer based on reference picture resampling (RPR) of the current block; and combining the enhancement layer and the base layer to generate the super resolution current block.

[0296] Clause 9B. The method of any of clauses 1B-8B, wherein the resolution of the super resolution current block is a non-integer factor of the resolution of the current block.

[0297] Clause 10B. The method of any of clauses 1B-9B, further comprising one or more of: storing the super resolution current block as a reference block for inter-prediction encoding or decoding a subsequent block; and outputting for display the super resolution current block.

[0298] Clause 11B. A device for processing video data, the device comprising: one or more memories configured to store the video data; and processing circuitry coupled to the one or more memories and configured to: receive, with a headblock of a super resolution (SR) backbone, scale factor information for modifying a resolution of a current block of the video data; filter, based on the scale factor information, the current block with the SR backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that utilizes the scale factor information; and generate a super resolution current block based on the intermediate filtered data, the super resolution current block having a resolution different than the resolution of the current block.

[0299] Clause 12B. The device of clause 11B, wherein the intermediate filtered data comprises luma and chroma component feature data.

[0300] Clause 13B. The device of any of clauses 11B and 12B, wherein the processing circuitry is configured to: extract feature information from the scale factor information and one or more supplementary input data; and combine the feature information to generate combined information, wherein to filter the current block, the processing circuitry is configured to filter the current block based on the combined information.

[0301] Clause 14B. The device of any of clauses 11B-13B, wherein the NN-filter is common for all resolutions.

[0302] Clause 15B. The device of any of clauses 11B-14B, wherein the processing circuitry is configured to: select a SR output layer from a plurality of SR output layers based on the scale factor information, wherein each of the plurality of SR output layers is trained to implement NN-based resampling for a target output resolution to generate a block having the target output resolution, wherein to generate the super resolution current block, the processing circuitry is configured to generate, using the selected SR output layer, the super resolution current block.

[0303] Clause 16B. The device of clause 15B, wherein to generate, using the selected SR output layer, the super resolution current block, the processing circuitry is configured to generate, using the selected SR output layer, a luma component and at least one chroma component of the super resolution current block.

[0304] Clause 17B. The device of any of clauses 15B or 16B, wherein the selected SR output layer is a first SR output layer, and wherein to generate, using the selected SR output layer, the super resolution current block, the processing circuitry is configured to: generate, using the selected SR output layer, a luma component of the super resolution current block; and generate, using a second SR output layer, at least one chroma component of the super resolution current block.

[0305] Clause 18B. The device of any of clauses 11B-17B, wherein to generate the super resolution current block based on the intermediate filtered data, the processing circuitry is configured to: generate an enhancement layer based on the intermediate filtered data; generate a base layer based on reference picture resampling (RPR) of the current block; and combine the enhancement layer and the base layer to generate the super resolution current block.

[0306] Clause 19B. The device of any of clauses 11B-18B, wherein the resolution of the super resolution current block is a non-integer factor of the resolution of the current block.

[0307] Clause 20B. A computer-readable storage medium having stored thereon instructions that, when executed, cause one or more processors to: receive, with a headblock of a super resolution (SR) backbone, scale factor information for modifying a resolution of a current block of video data; filter, based on the scale factor information, the current block with the SR backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that utilizes the scale factor information; and generate

a super resolution current block based on the intermediate filtered data, the super resolution current block having a resolution different than the resolution of the current block.

[0308] It is to be recognized that depending on the example, certain acts or events of any of the techniques described herein can be performed in a different sequence, may be added, merged, or left out altogether (e.g., not all described acts or events are necessary for the practice of the techniques). Moreover, in certain examples, acts or events may be performed concurrently, e.g., through multi-threaded processing, interrupt processing, or multiple processors, rather than sequentially.

[0309] In one or more examples, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium and executed by a hardware-based processing unit. Computer-readable media may include computer-readable storage media, which corresponds to a tangible medium such as data storage media, or communication media including any medium that facilitates transfer of a computer program from one place to another, e.g., according to a communication protocol. In this manner, computer-readable media generally may correspond to (1) tangible computer-readable storage media which is non-transitory or (2) a communication medium such as a signal or carrier wave. Data storage media may be any available media that can be accessed by one or more computers or one or more processors to retrieve instructions, code and/or data structures for implementation of the techniques described in this disclosure. A computer program product may include a computer-readable medium.

[0310] By way of example, and not limitation, such computer-readable storage media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage, or other magnetic storage devices, flash memory, or any other medium that can be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer. Also, any connection is properly termed a computer-readable medium. For example, if instructions are transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. It should be understood, however, that computer-readable storage media and data storage media do not include connections, carrier waves, signals, or other transitory media, but are instead directed to non-transitory, tangible storage media. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc, where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

[0311] Instructions may be executed by one or more processors, such as one or more DSPs, general purpose microprocessors, ASICs, FPGAs, or other equivalent integrated or discrete logic circuitry. Accordingly, the terms "processor" and "processing circuitry," as used herein may refer to any of the foregoing structures or any other structure suitable for implementation of the techniques described herein. In addition, in some aspects, the functionality described herein may be provided within dedicated hardware and/or software modules configured for encoding and decoding, or incorporated in a combined codec. Also, the techniques could be fully implemented in one or more circuits or logic elements.

[0312] The techniques of this disclosure may be implemented in a wide variety of devices or apparatuses, including a wireless handset, an integrated circuit (IC) or a set of ICs (e.g., a chip set). Various components, modules, or units are described in this disclosure to emphasize functional aspects of devices configured to perform the disclosed techniques, but do not necessarily require realization by different hardware units. Rather, as described above, various units may be combined in a codec hardware unit or provided by a collection of interoperative hardware units, including one or more processors as described above, in conjunction with suitable software and/or firmware.

[0313] Various examples have been described. These and other examples are within the scope of the following claims.

What is claimed is:

1. A method of processing video data, the method comprising:

receiving, with a headblock of a super resolution (SR) backbone, scale factor information for modifying a resolution of a current block of the video data;

filtering, based on the scale factor information, the current block with the SR backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that utilizes the scale factor information; and

generating a super resolution current block based on the intermediate filtered data, the super resolution current block having a resolution different than the resolution of the current block.

2. The method of claim **1**, wherein the intermediate filtered data comprises luma and chroma component feature data.

3. The method of claim **1**, further comprising:

extracting feature information from the scale factor information and one or more supplementary input data; and

combining the feature information to generate combined information,

wherein filtering the current block comprises filtering the current block based on the combined information.

4. The method of claim **1**, wherein the NN-filter is common for all resolutions.

5. The method of claim **1**, further comprising:

selecting a SR output layer from a plurality of SR output layers based on the scale factor information, wherein each of the plurality of SR output layers is trained to implement NN-based resampling for a target output resolution to generate a block having the target output resolution,

wherein generating the super resolution current block comprises generating, using the selected SR output layer, the super resolution current block.

6. The method of claim **5**, wherein generating, using the selected SR output layer, the super resolution current block comprises generating, using the selected SR output layer, a luma component and at least one chroma component of the super resolution current block.

7. The method of claim 5, wherein the selected SR output layer is a first SR output layer, and wherein generating, using the selected SR output layer, the super resolution current block comprises:

generating, using the selected SR output layer, a luma component of the super resolution current block; and

generating, using a second SR output layer, at least one chroma component of the super resolution current block.

8. The method of claim 1, wherein generating the super resolution current block based on the intermediate filtered data comprises:

generating an enhancement layer based on the intermediate filtered data;

generating a base layer based on reference picture resampling (RPR) of the current block; and

combining the enhancement layer and the base layer to generate the super resolution current block.

9. The method of claim 1, wherein the resolution of the super resolution current block is a non-integer factor of the resolution of the current block.

10. The method of claim 1, further comprising one or more of:

storing the super resolution current block as a reference block for inter-prediction encoding or decoding a subsequent block; and

outputting for display the super resolution current block.

11. A device for processing video data, the device comprising:

one or more memories configured to store the video data; and

processing circuitry coupled to the one or more memories and configured to:

receive, with a headblock of a super resolution (SR) backbone, scale factor information for modifying a resolution of a current block of the video data;

filter, based on the scale factor information, the current block with the SR backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that utilizes the scale factor information; and

generate a super resolution current block based on the intermediate filtered data, the super resolution current block having a resolution different than the resolution of the current block.

12. The device of claim 11, wherein the intermediate filtered data comprises luma and chroma component feature data.

13. The device of claim 11, wherein the processing circuitry is configured to:

extract feature information from the scale factor information and one or more supplementary input data; and

combine the feature information to generate combined information,

wherein to filter the current block, the processing circuitry is configured to filter the current block based on the combined information.

14. The device of claim 11, wherein the NN-filter is common for all resolutions.

15. The device of claim 11, wherein the processing circuitry is configured to:

select a SR output layer from a plurality of SR output layers based on the scale factor information, wherein each of the plurality of SR output layers is trained to implement NN-based resampling for a target output resolution to generate a block having the target output resolution,

wherein to generate the super resolution current block, the processing circuitry is configured to generate, using the selected SR output layer, the super resolution current block.

16. The device of claim 15, wherein to generate, using the selected SR output layer, the super resolution current block, the processing circuitry is configured to generate, using the selected SR output layer, a luma component and at least one chroma component of the super resolution current block.

17. The device of claim 15, wherein the selected SR output layer is a first SR output layer, and wherein to generate, using the selected SR output layer, the super resolution current block, the processing circuitry is configured to:

generate, using the selected SR output layer, a luma component of the super resolution current block; and

generate, using a second SR output layer, at least one chroma component of the super resolution current block.

18. The device of claim 11, wherein to generate the super resolution current block based on the intermediate filtered data, the processing circuitry is configured to:

generate an enhancement layer based on the intermediate filtered data;

generate a base layer based on reference picture resampling (RPR) of the current block; and

combine the enhancement layer and the base layer to generate the super resolution current block.

19. The device of claim 11, wherein the resolution of the super resolution current block is a non-integer factor of the resolution of the current block.

20. A computer-readable storage medium having stored thereon instructions that, when executed, cause one or more processors to:

receive, with a headblock of a super resolution (SR) backbone, scale factor information for modifying a resolution of a current block of video data;

filter, based on the scale factor information, the current block with the SR backbone to generate intermediate filtered data, the SR backbone implementing a neural network (NN)-filter that utilizes the scale factor information; and

generate a super resolution current block based on the intermediate filtered data, the super resolution current block having a resolution different than the resolution of the current block.

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