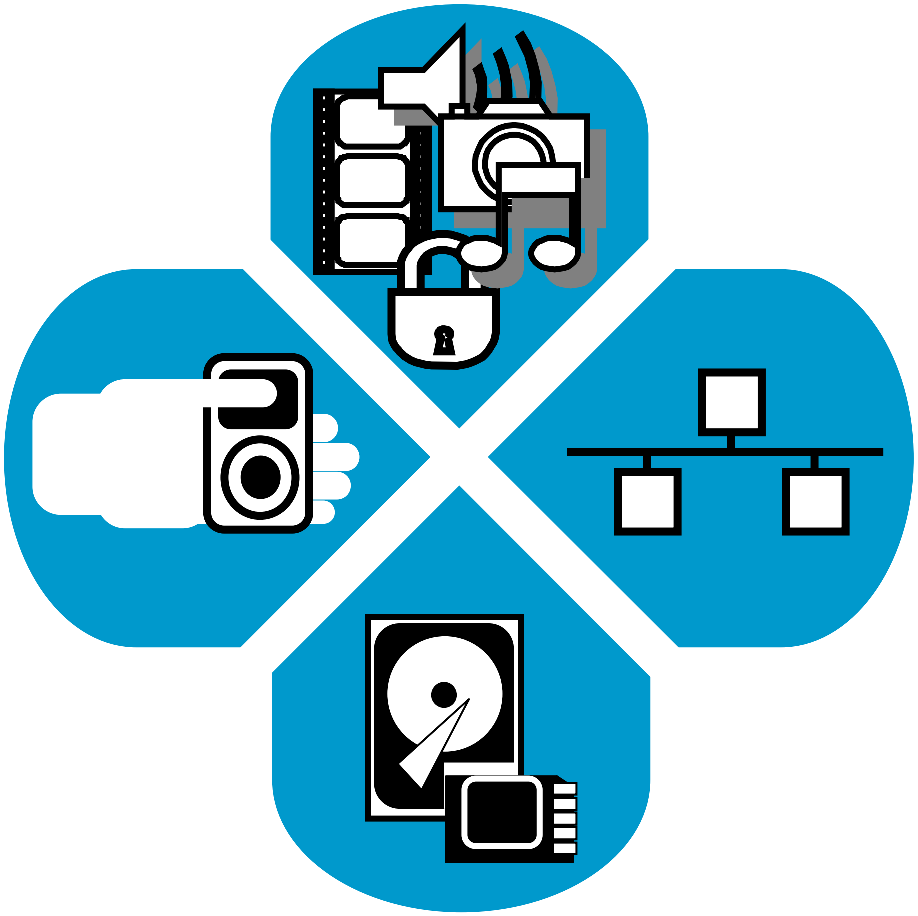

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Unified Scaling with Adaptive Offset for Reference Frame Compression with IBDI

Dzung Hoang JCTVC-D035

Overview

- **Internal Bit Depth Increase**
  - Increase pixel bit depth at input to encoder: 8-bit to 12-bit
  - Decrease pixel bit depth at output of decoder: 12-bit to 8-bit
  - Demonstrated significant gains in coding efficiency
  - Increase in memory storage and bandwidth
- **Reference frame compression methods proposed to reduce memory storage and bandwidth overhead**
- **Toshiba's Dynamic Range Adaptive Scaling (DRAS) scheme for RFC with IBDI appears most promising from both coding efficiency and complexity perspectives**
  - DRAS requires 129 bits in worse case for 4x4 block
  - Fixed-scaling mode has problems for LD-HE configuration with Class E sequences
- **We propose a RFC method that improves upon DRAS**

Executive Summary

- **Proposal: DRAS with following modifications**
  - **Remove fixed scaling**
  - **Variable quantization of minimum pixel value**
  - **Encoder computes reconstruction level offset**
    - Unified Scaling Adaptive Offset (USAO): 1 offset per 4x4 block
    - Unified Scaling Multiple Offset (USMO): 1 offset per 4x2 sub-block
- **Results for USAO**
  - **LD-HE: about half the loss of DRAS**
    - Eliminates losses due to fixed-scaling
    - 0.8% Y, 0.3% Cb, 0.1% Cr BD-rate increases
    - 0.6% RGB BD-rate increase
  - **RA-HE: about same as DRAS**
    - 0.3% Y, 0.1% Cb, 0.1% Cr BD-rate increases
    - 0.2% RGB BD-rate increase

RFC with IBDI System Diagram

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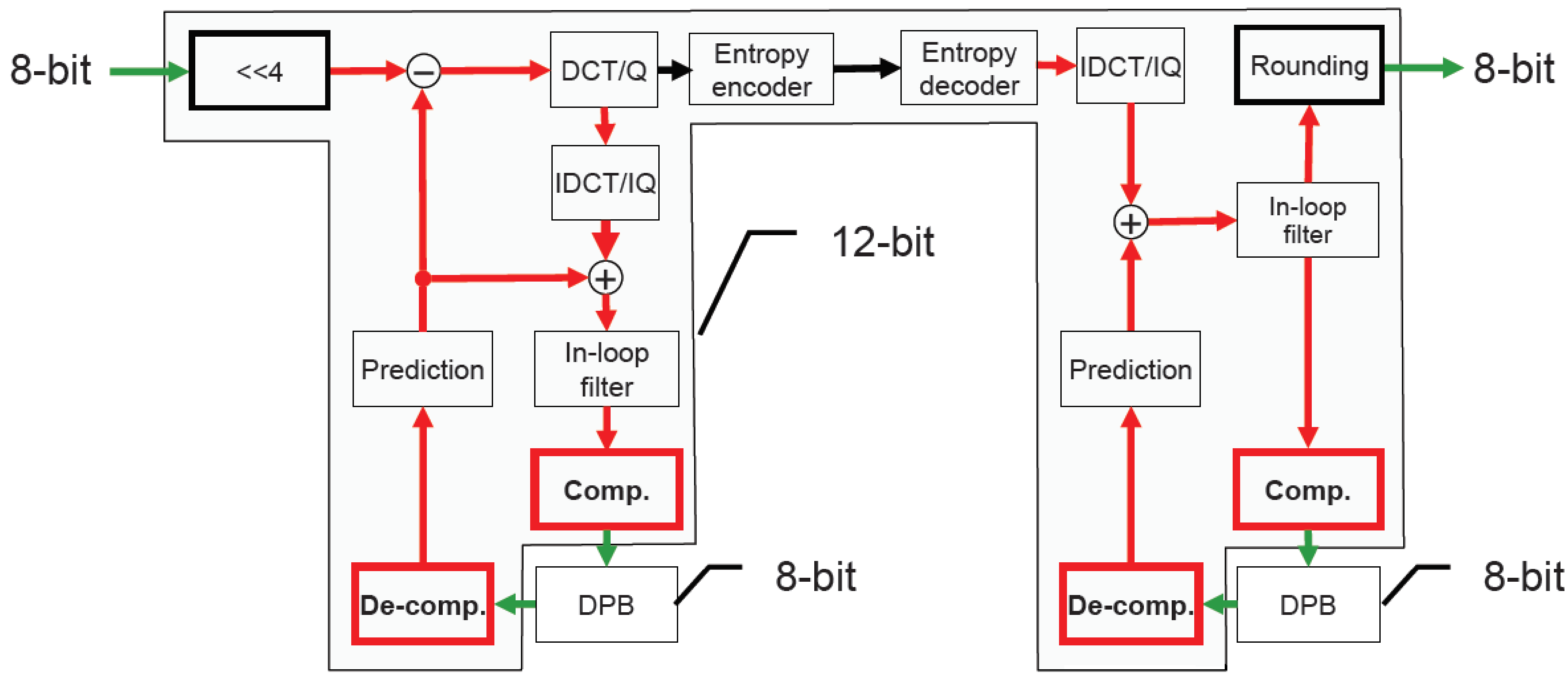
- **From Toshiba's Contribution:**



Toshiba's DRAS Compression

```
M = (minimum pixel value in block) & ~((1<<4)-1)
R = (maximum pixel value in block) - M
for (S=0; R≥(128 << S) && S<4; S++);
if (S == 4) {
    flag = 1
    P[i] = min(255, (pixel_value[i] + 8) >> 4)
} else {
    flag = 0
    P[i] = (pixel_value[i] – M) >> S
}
```

Toshiba's DRAS Format

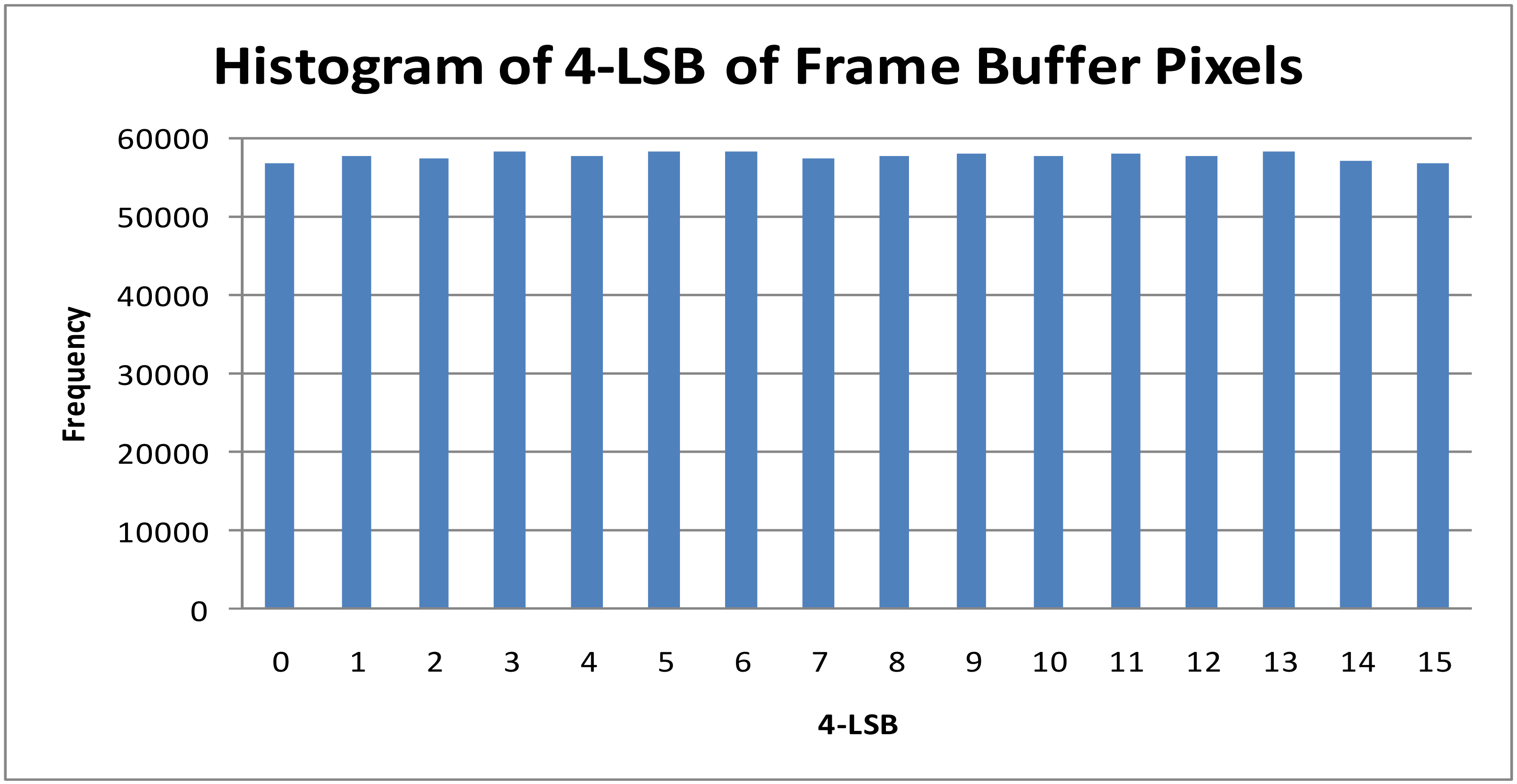
```
flag = u(1);
if (flag) {
  /* fixed scaling 128 bits */
  for (i=0; i<16; i++) u(8);            /* P[i] */
} else {
  /* variable scaling 122 bits */
  u(2);                                 /* S: [0..3] */
  u(8);                                 /* M >> 4 */
  for (i=0; i<16; i++) u(7);            /* P[i] */
}
```

Toshiba DRAS Decompression

```
if (flag) {
  D[i] = P[i] << 4, for all i
} else {
  if (S == 0)
    D[i] = P[i] + M, for all i
  else
    D[i] = (P[i] << S) + M + (1 << (S-1)), for all i
}
```


Study of DRAS

- **Histogram of 4-LSB of frame buffer**
  - First frame of Vidyo1

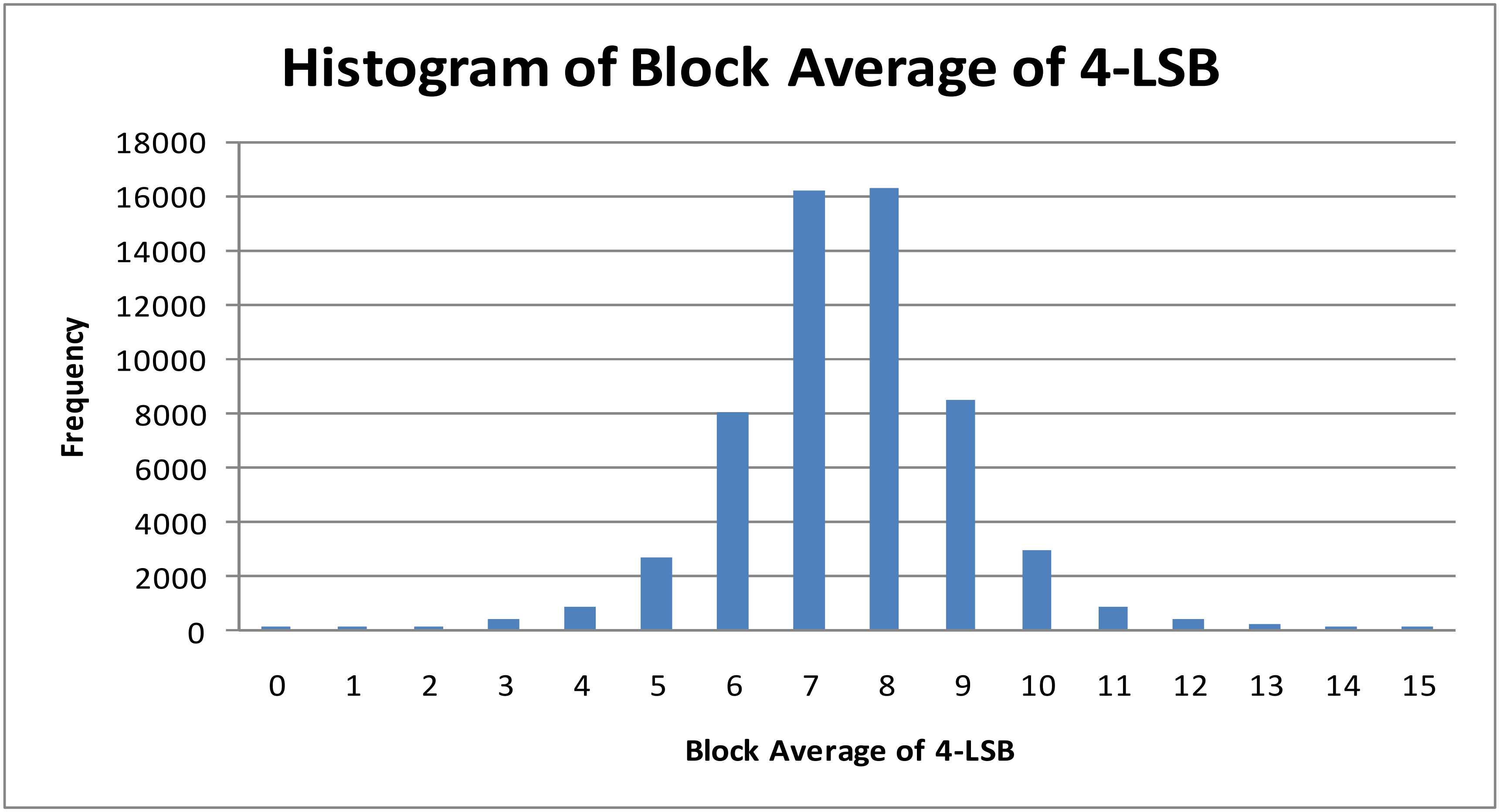


Study of DRAS (continued)

- **Uniform distribution of 4-LSB**
  - **Indicates that IBDI is doing something interesting**
    - Extra bits capture “bit-depth expansion” typical of integer transforms.
    - For example, preserving transform DC coefficient (block average) might cause fractional bits in spatial domain when some AC coefficients are quantized.
  - **Provides support for DRAS rounding**
    - pre-rounding for fixed scaling
    - reconstruction offset of (1 << (S-1)) for adaptive scaling

Study of DRAS (continued)

- **Histogram of block averages of 4-LSB**



Study of DRAS (continued)

- **Distribution of block averages of 4-LSB**
  - Enough variability to suggest application of Lloyd-Max “centroid rule”
  - Optimal reconstruction offset is computed as centroid or average of quantizer error.

Unified Scaling with Adaptive Offset

- **USAO Proposal**
  - Remove fixed scaling
  - Encoder computes scaling factor S
  - Encoder computes reconstruction offset as the average of quantizer error and transmits S bits
  - Encoder computes minimum value (spatial predictor) using 12-S bits

USAO Compressor

M = (minimum pixel value in block)
R = (maximum pixel value in block)
for (S=0; (R >> S) - (M >> S) ≥ 128; S++);
mask = (1 << S) – 1
offset = (sum(pixel_value[i] & mask) + 8) / 16
M = M & ~mask
P[i] = (pixel_value[i] – M) >> S, for all i

USAO Format

u(3);	/* S: [0..5] */
u(12-S);	/* M >> S */
u(S);	/* offset */
for (i=0; i<16; i++) u(7);	/* P[i] */

- **Total of 127 bits**

USAO Decompression

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$D[i] = (P[i] \ll S) + M + offset$, for all i

- (M + offset) can be combined into a single 12-bit unsigned integer

Unified Scaling Multiple Offsets

- Optimize compression format
  - code index of minimum pixel residual
  - omit coding of minimum pixel residual
  - code S using unary coding
  - frees up enough bits to code second offset
- 4x2 sub-block
  - code offset for each 4x2 sub-block

USMO Format

u(6-S);	/* 5-S coded in unary */
u(12-S);	/* M >> S */
u(S);	/* offset 1 */
u(S);	/* offset 2 */
u(4);	/* M_index */
for (i=0; i<15; i++) u(7);	/* P array w/o M_index */

- Total of 127 bits

Encoder Configuration

- **Use HM version 0.9 revision 426**
- **In CommonDef.h**
  - **Set** IBDI_NOCLIP_RANGE **to 0**
- **Compared to anchor 0.9**
  - **Overall 0.0% RGB BD-rate increase**
  - **LD-HE: 0.0% Y, -0.1% Cb, 0.1 Cr BD-rate increase**
  - **RA-HE: 0.0% Y, 0.0% Cb, 0.0% Cr BD-rate increase**

Experiment Results for LD-HE

- **Compared to no-RFC IBDI**

	Dynamic Range Adaptive Scaling				Unified Scaling Adaptive Offset				Unified Scaling Multiple Offsets			
	Y	Cb	Cr	RGB	Y	Cb	Cr	RGB	Y	Cb	Cr	RGB
Class B	0.6	1.2	0.9	0.8	0.5	0.2	-0.1	0.4	0.4	0.1	0.1	0.4
Class C	0.4	0.7	0.7	0.6	0.5	0.3	0.2	0.4	0.4	0.4	0.1	0.4
Class D	0.4	0.6	0.8	0.4	0.4	0.5	0.1	0.4	0.4	0.6	0.2	0.4
Class E	5.9	1.5	2.9	4.9	2.2	0.1	0.4	1.6	2.0	0.2	0.4	1.5
All	**1.5**	**1.0**	**1.2**	**1.4**	**0.8**	**0.3**	**0.1**	**0.6**	**0.7**	**0.3**	**0.2**	**0.6**

Experiment Results for LD-HE

- **Compared to no-IBDI**

	no RFC				Dynamic Range Adaptive Scaling				Unified Scaling Adaptive Offset				Unified Scaling Multiple Offsets			
	Y	**Cb**	**Cr**	**RGB**	**Y**	**Cb**	**Cr**	**RGB**	**Y**	**Cb**	**Cr**	**RGB**	**Y**	**Cb**	**Cr**	**RGB**
Class B	-3.4	-10.1	-11.9	-6.0	-2.8	-9.1	-11.2	-5.2	-2.9	-9.9	-12.0	-5.7	-3.0	-10.0	-11.9	-5.7
Class C	-2.3	-7.0	-7.2	-4.3	-1.9	-6.3	-6.6	-3.7	-1.8	-6.7	-7.1	-3.9	-1.9	-6.7	-7.1	-4.0
Class D	-1.5	-11.7	-11.1	-4.2	-1.2	-11.2	-10.5	-3.8	-1.1	-11.3	-11.0	-3.9	-1.1	-11.3	-10.9	-3.9
Class E	-10.3	-6.9	-8.7	-9.5	-4.9	-5.5	-6.1	-5.1	-8.3	-6.8	-8.4	-8.1	-8.4	-6.6	-8.3	-8.2
All	**-4.0**	**-9.1**	**-9.9**	**-5.8**	**-2.6**	**-8.2**	**-8.9**	**-4.5**	**-3.2**	**-8.9**	**-9.8**	**-5.2**	**-3.3**	**-8.9**	**-9.8**	**-5.3**

Experiment Results for RA-HE

- **Compared to no-RFC IBDI**

	Dynamic Range Adaptive Scaling				Unified Scaling Adaptive Offset				Unified Scaling Multiple Offsets			
	Y	Cb	Cr	RGB	Y	Cb	Cr	RGB	Y	Cb	Cr	RGB
Class A	0.2	0.1	0.1	0.2	0.3	0.1	0.1	0.2	0.3	0.0	-0.1	0.1
Class B	0.1	0.2	0.1	0.2	0.3	0.1	0.0	0.2	0.3	0.0.	0.0	0.2
Class C	0.2	0.2	0.1	0.2	0.3	0.1	0.1	0.2	0.3	0.1	0.2	0.2
Class D	0.2	0.2	0.2	0.2	0.3	0.0	0.1	0.3	0.3	-0.1	0.1	0.2
All	**0.2**	**0.2**	**0.1**	**0.2**	**0.3**	**0.1**	**0.1**	**0.2**	**0.3**	**0.0**	**0.1**	**0.2**

Experiment Results for RA-HE

- **Compared to no-IBDI**

	no RFC				Dynamic Range Adaptive Scaling				Unified Scaling Adaptive Offset				Unified Scaling Multiple Offsets			
	Y	Cb	Cr	RGB	Y	Cb	Cr	RGB	Y	Cb	Cr	RGB	Y	Cb	Cr	RGB
Class A	-1.4	-3.8	-4.5	-2.7	-1.3	-3.7	-4.4	-2.5	-1.1	-3.7	-4.4	-2.5	-1.2	-3.8	-4.6	-2.5
Class B	-2.1	-8.3	-10.1	-4.8	-1.9	-8.2	-10.0	-4.7	-1.8	-8.3	-10.0	-4.6	-1.8	-8.3	-10.1	-4.6
Class C	-1.3	-4.0	-4.3	-2.5	-1.1	-3.8	-4.2	-2.3	-0.9	-3.9	-4.2	-2.3	-1.0	-3.9	-4.2	-2.3
Class D	-0.9	-5.1	-5.9	-2.3	-0.8	-4.9	-5.7	-2.1	-0.6	-5.0	-5.8	-2.0	-0.7	-5.1	-5.8	-2.1
All	**-1.5**	**-5.7**	**-6.7**	**-3.2**	**-1.3**	**-5.5**	**-6.6**	**-3.1**	**-1.2**	**-5.6**	**-6.6**	**-3.0**	**-1.2**	**-5.7**	**-6.6**	**-3.0**

Running Times

- **Running times compared against DRAS**

	LD-HE		RA-HE	
	Unified Scaling Adaptive Offset	Unified Scaling Multiple Offsets	Unified Scaling Adaptive Offset	Unified Scaling Multiple Offsets
Enc Time %	97%	104%	96%	104%
Dec Time %	104%	106%	104%	105%

Memory Bandwidth

- **We do not report simulated memory bandwidth reduction**
  - should be similar to other 4x4 block-based RFC schemes

Summary

- For LD-HE, USAO and USMO retain about 90% of the coding efficiency gains of IBDI compared to 78% for Toshiba DRAS.
- For RA-HE, USAO, USMO, and DRAS are comparable and retain over 90% of the coding efficiency gains of IBDI.
- The complexity of our RFC algorithms is similar to that of DRAS, requiring only additional computation of reconstruction offset.

Recommendation

- **There are some possible minor differences in implementation details between our RFC proposal and others.**
  - **where and when in the decoding/encoding process is RFC is invoked**
  - **where pixel depth decrease (12 to 8) is performed**
  - IBDI_NOCLIP_RANGE **setting**
- **Recommend Core Experiment to evaluate competing RFC proposals under same system architecture**
- **Recommend continuation of AHG to unify related contributions**
- **Our proposal retains 90% of the coding efficiency gains of IBDI in both LD-HE and RA-HE configurations. Therefore we recommend adoption of RFC as an *option* to reduce memory bandwidth penalty of IBDI.**