Efficient 16 and 32-point Transforms

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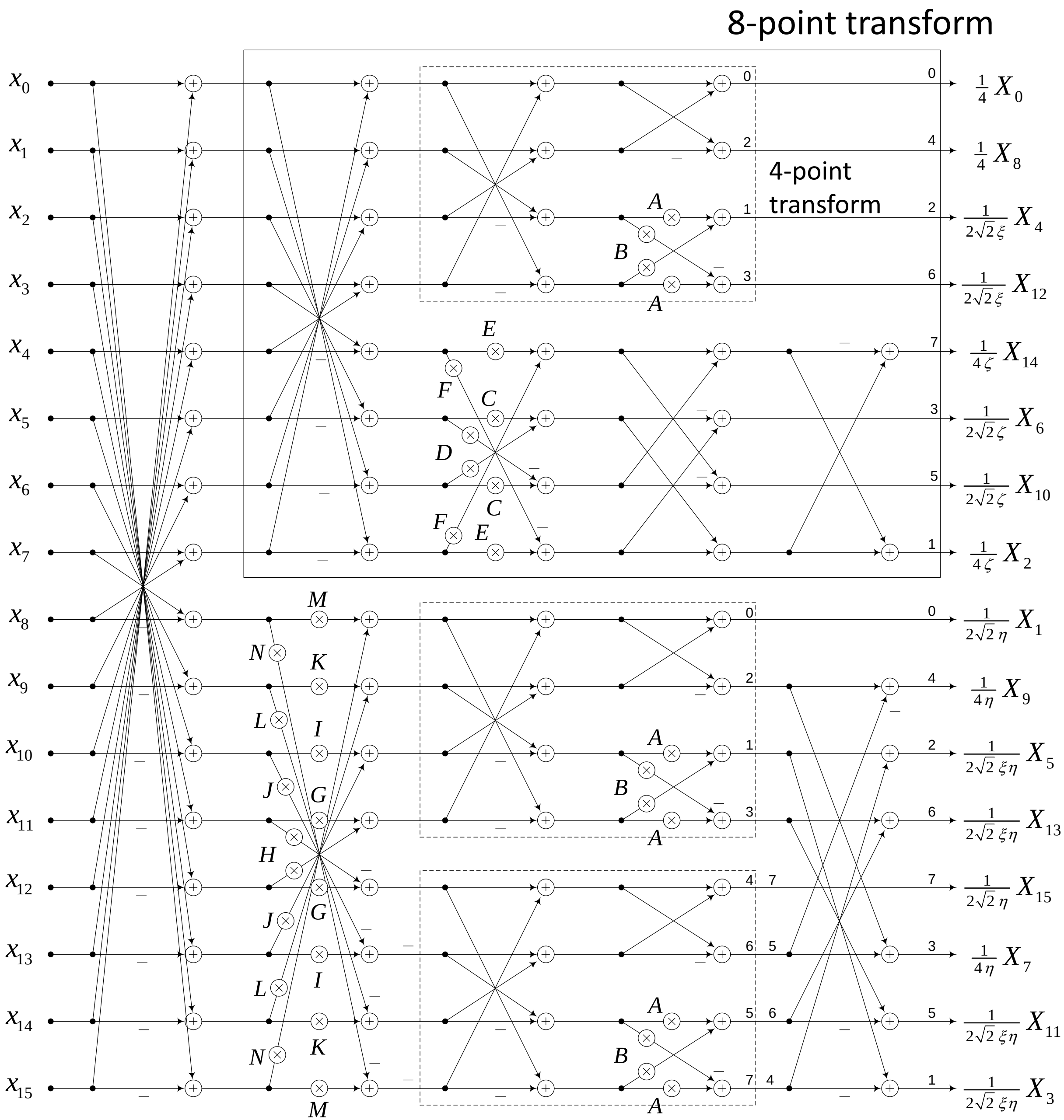
Motivation

- Existing HEVC Test Model transforms based on Chen and Smith factorization.
- Better factorizations are known
  - LLM factorization
    - Numerically stable and computationally efficient.
    - But does not fully reuse lower sized transform blocks.

Proposed transforms

- Properties of the proposed transforms:
  - Based on LLM factorization
  - Supporting a simple recursive factorization structure leading to a faster implementation.
  - Integer arithmetic.
  - orthogonal after appropriate scaling has been applied.



Butterfly diagram for a 16-point transform

Recursive Structure of proposed transforms

- 16-point transform
  - An 8-point DCT-II residing in the even part.
  - Two 8-point DCT-IIs in the odd part.
- 32-point transform
  - A 16-point DCT-II residing in the even part.
  - Two 8-point DCT-IIs in the odd part.

Choice of butterfly factors

$$Z4 = \sqrt{A4^2 + B4^2},$$

$$Z8 = \sqrt{A8^2 + B8^2} = \sqrt{C8^2 + D8^2},$$

$$Z16 = \sqrt{A16^2 + B16^2} = \sqrt{C16^2 + D16^2} = \sqrt{E16^2 + F16^2} = \sqrt{G16^2 + H16^2}.$$

Similarly for 32-point transform

$$Z32 = \sqrt{A32^2 + B32^2} = \sqrt{C32^2 + D32^2} \ldots$$

Choice of butterfly factors

A4	B4	A8	B8	C8	D8
17/64	41/64	111/128	22/128	94/128	63/128

A16	B16	C16	D16	E16	F16	G16	H16
232/256	29/256	224/256	67/256	203/256	116/256	181/256	148/256

A32	C32	E32	G32	I32	K32	M32	O32
1013/1024	1003/1024	982/1024	958/1024	922/1024	859/1024	827/1024	757/1024
B32	D32	F32	H32	J32	L32	N32	P32
34/1024	146/1024	251/1024	331/1024	421/1024	538/1024	586/1024	674/1024

Choice of butterfly factors

- Dyadic rationals
  - Right shifts introduced to balance the dynamic range.
  - All the butterfly factors fit in the range [-1, 1].
- Bit-depth expansion
  - Worst case for DC component
  - 5 bit increase for 1-D transform

Complexity of the proposed transforms

		Chen 32T	Proposed transform
16-point	Additions	74	72
	Multiplications	44	36
32-point	Additions	194	186
	Multiplications	116	92

Complexity of the proposed transforms

- Multiplications can be completely eliminated
  - Each pair of multiplies in a butterfly can be converted into add and shifts.

Transform	Complexity of full multiplierless transform
4-point	12 adds + 4 shifts
8-point	44 adds + 12 shifts
16-point	124 adds + 46 shifts
32-point	348 adds + 156 shifts

Storage of quant / dequant matrices

- 32-point transform
  - Only 12 distinct scale factors
  - 12×12 matrix (16 bit)
  - LUT of size 32
- Total storage needed for quant and dequant matrices is $12 \times 12 \times 6 \times 2 \times 2 + 32 = 3488$ bytes.
- Scale factors for 16, 8 and 4-point transforms already present in the 12×12 matrix .
  - Only 16+8+4=28 bytes of additional LUTS needed.

Results

Config	BD-rate			Encoding Time	Decoding Time
	Y	U	V		
Intra	0.0	0.0	-0.1	94%	103%
Intra LoCo	0.0	0.0	0.0	94%	107%
RA	0.0	0.0	0.1	105%	100%
RA LoCo	0.0	0.0	0.1	99%	101%
LD	0.0	-0.3	-0.1	96%	100%
LD LoCo	0.0	0.0	0.0	97%	100%

Conclusion

- Proposed 16 and 32-point transform
  - Less computational complexity compared to the transforms in the current test model
    - Multiplierless implementation
  - Very similar BD-rate performance