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## Abstract

This document reports the behaviour of sequence-level geometry swizzling as part of core experiment 13.26 [1, N18915].

## Introduction

In the 128th meeting, a high-level syntax to describe the order of the coded axes [2] was adopted. The TMC13v8 software includes encoder support to specify the axis coding order and permutes the point cloud input accordingly.

Changing the sequence-level coding order has the effect of changing not only the geometry coding order, but the order of the 1-D transforms in RAHT, and the search order in the LoD based schemes.

Other than providing flexibility to systems that have different native orders, a principal reason for using a common order for all operations is to avoid the need to reorder the position information between geometry coding and attribute decoding. While the current reference software treats the two coding phases as independent and sorts the points into Morton order after geometry coding, an actual implementation is able to avoid this step and use the Morton ordering generated as a side effect of octree coding.

## Study

In order to understand the effect of changing the sequence level axis coding order, the TMC13v8 software [3] is configured with five different permutations of coding order.

During this experiment, it was discovered that when permuting the axis order, there are other configuration variables that should also be permuted. For the purpose of this experiment, it is sufficient to permute the `lod_neigh_bias` to match the axis coding order since the bias is related to the nature of the content itself. A related contribution [4] suggests further modifications to address this issue.

## Results

Included with the report are individual workbooks containing detailed results for each axis permutation with both RAHT and LoD attribute coders. All results are compared to the TMC13v8.0 anchor results [5] which uses the order XYZ. Summaries of these results are provided in Tables 1 and 2.

However, since the effect of changing the sequence level axis order has an effect on both geometry and attributes, to understand the aggregate behaviour it is necessary to examine the performance relative to the total rate, rather than per-component rates. Summaries using total rates are provided in Tables 3 and 4.

Table 1 – Summary of all non-default axis permutations compared to TMC13v8 anchor (XYZ). Attributes coded using LoD scheme.

Condition	Class	Order	BPP Ratio [%]		Refl	D1	D2	BD-Rate [ $\Delta\%$ ]			R	Avg. of ratio maxrssk [%]		Ratio of avg. runtime [%]	
			Geometry	Colour				Y	Cb	Cr		Encoder	Decoder	Encoder	Decoder
C1_ai	cat1-A	xzy						0.4	0.6	0.9		100	100	97	100
		yxz						-0.1	0.1	0.3		100	100	97	97
		yzx						0.0	-0.0	0.2		100	100	98	99
		zxy						0.6	0.9	0.9		100	100	97	98
		zyx						0.4	0.5	0.8		100	100	99	98
C2_ai	cat1-A	xzy				-0.4!	-0.4!	0.5!	0.3!	1.3!		100	100	98	93
		yxz				0.0	-0.0	-0.6	-0.6	-1.4		100	100	96	96
		yzx				-0.1	-0.1	-0.7	0.4	-1.1		100	100	98	96
		zxy				-0.3	-0.3	0.5	1.3	0.7		100	100	101	98
		zyx				-0.0	-0.0	0.2	0.5	0.0		100	100	100	97
CW_ai	cat1-A	xzy	99.8	100.0								100	100	100	92
		yxz	100.0	99.9								100	100	96	89
		yzx	100.0	100.0								100	100	93	91
		zxy	99.8	100.1								100	100	97	95
		zyx	100.0	100.0								100	100	96	93
CY_ai	cat1-A	xzy						0.1	0.1	0.1		100	101	98	94
		yxz						-0.0	-0.0	-0.0		100	100	97	94
		yzx						0.0	0.0	0.0		100	100	99	93
		zxy						0.1	0.1	0.1		100	101	97	92
		zyx						0.1	0.1	0.1		100	101	96	95
C2_ai	cat1-B	xzy				0.0!	0.0!					100	100	103	86
		yxz				-0.7	-0.7					100	100	83	
		yzx				-0.5	-0.5					100	100	88	90
		zxy				0.0	0.1					100	100	96	89
		zyx				0.1	0.1					100	100	95	91
CW_ai	cat1-B	xzy	100.0									100	100	100	101
		yxz	100.0									100	100	97	100
		yzx	100.0									100	100	99	102
		zxy	100.1									100	100	96	100
		zyx	100.1									100	100	98	95
C1_ai	cat3-frame	xzy									-0.6	100	100	92	91
		yxz									0.5	100	100	90	89
		yzx									0.1	100	100	94	93
		zxy									-1.0	100	100	91	91
		zyx									-0.6	100	100	94	93
C2_ai	cat3-frame	xzy				0.0	0.0				-0.6	100	100	96	96
		yxz				0.0	0.0				0.3	100	100	94	94
		yzx				-0.0	-0.0				-0.1	100	100	92	91
		zxy				0.4	0.4				-1.2	100	100	95	95
		zyx				0.4	0.4				-0.8	100	100	94	93
CW_ai	cat3-frame	xzy	99.9		99.9							100	100	92	92
		yxz	100.0		100.1							100	100	87	87
		yzx	100.0		100.1							100	100	96	98
		zxy	100.0		99.8							100	100	97	96
		zyx	100.0		99.9							100	100	86	85
CY_ai	cat3-frame	xzy									-0.2	100	100	90	90
		yxz									0.2	100	100	88	87
		yzx									0.1	100	100	93	93
		zxy									-0.3	100	100	92	91
		zyx									-0.1	100	100	94	94
C1_ai	cat3-fused	xzy						-0.2	-0.3	-0.2	-0.4	100	100	88	93
		yxz						-0.1	-0.1	-0.1	-0.2	100	100	95	94
		yzx						-0.4	-0.3	-0.4	-0.7	100	100	96	99
		zxy						-0.9	-0.7	-0.9	-1.1	100	100	93	96
		zyx						-0.9	-0.8	-0.9	-1.2	100	100	98	94
C2_ai	cat3-fused	xzy				0.5	0.5	-0.5	0.3	-0.6	-0.4	100	100	102	97
		yxz				0.0	0.0	-0.1	0.3	-0.3	-0.2	99	100	99	97
		yzx				0.5	0.5	-0.7	-0.3	-0.5	-0.6	100	100	101	91
		zxy				1.5	1.5	-0.5	-0.9	-0.6	-0.9	100	100	101	93
		zyx				1.5	1.5	-1.4	-0.6	-0.8	-0.9	100	100	98	95
CW_ai	cat3-fused	xzy	100.3	100.0	99.9							100	100	101	99
		yxz	100.0	100.0	100.0							100	100	94	94
		yzx	100.3	99.9	99.9							100	100	99	103
		zxy	100.2	99.9	99.8							100	100	94	93
		zyx	100.2	99.9	99.8							100	100	106	109
CY_ai	cat3-fused	xzy						-0.1	-0.1	-0.1	-0.1	100	100	97	101
		yxz						-0.0	-0.0	-0.0	-0.0	100	100	92	97
		yzx						-0.1	-0.1	-0.1	-0.2	100	100	97	99
		zxy						-0.2	-0.2	-0.2	-0.4	100	100	94	96
		zyx						-0.2	-0.2	-0.2	-0.4	100	100	94	95
C1_ai	overall	xzy						0.4	0.5	0.7	-0.5	100	100	95	97
		yxz						-0.1	0.1	0.2	0.3	100	100	95	95
		yzx						-0.0	-0.1	0.1	-0.1	100	100	97	98
		zxy						0.4	0.7	0.7	-1.0	100	100	95	96
		zyx						0.2	0.4	0.6	-0.8	100	100	98	96
C2_ai	overall	xzy				-0.1!	-0.1!	0.4!	0.3!	1.1!	-0.5	100	100	100	91
		yxz				-0.3	-0.3	-0.5!	-0.5!	-1.3!	0.1	100	100	90	
		yzx				-0.2	-0.2	-0.7!	0.3!	-1.0!	-0.2	100	100	93	93
		zxy				0.0	0.0	0.4!	1.0!	0.6!	-1.1	100	100	98	93
		zyx				0.1	0.2	0.0!	0.4!	-0.1!	-0.8	100	100	97	94
CW_ai	overall	xzy	100.0	100.0!	99.9							100	100	99	96
		yxz	100.0	100.0!	100.1							100	100	95	94
		yzx	100.0	100.0!	100.0							100	100	96	97
		zxy	100.0	100.0!	99.8							100	100	97	97
		zyx	100.1	100.0!	99.9							100	100	96	94
CY_ai	overall	xzy						0.0	0.0	0.0	-0.2	100	100	96	94
		yxz						-0.0	-0.0	-0.0	0.1	100	100	95	92
		yzx						0.0	0.0	0.0	0.0	100	100	97	93
		zxy						0.0	0.0	0.0	-0.3	100	100	96	93
		zyx						0.1	0.1	0.1	-0.2	100	100	95	95

NOTE — Condition CY metrics reported using Hausdorff PSNR.

Table 2 – Summary of all non-default axis permutations compared to TMC13v8 anchor (XYZ). Attributes coded using RAHT.

Condition	Class	Order	BPP Ratio [%]			Refl	D1	D2	BD-Rate [ $\Delta$ %]			Cr	R	Avg. of ratio maxrssk [%]		Ratio of avg. runtime [%]	
			Geometry	Colour					Y	Cb	Encoder			Decoder	Encoder	Decoder	
C1_ai	cat1-A	xzy							0.9	0.8	1.0			100	100	98	98
		yxz							-0.8	-0.8	-1.0			100	100	97	93
		yzx							-0.7	-1.0	-1.3			100	100	98	96
		zxy							0.9	0.7	0.7			100	100	96	96
C2_ai	cat1-A	zyx							-0.1	-0.4	-0.5			100	100	97	96
		xzy				-0.4	-0.4	0.6	-0.3	0.1			100	100	99	99	
		yxz				0.0	-0.0	-1.0	-1.9	-2.0			100	100	95	100	
		yzx				-0.1	-0.1	-1.1	-3.0	-3.9			100	100	98		
		zxy				-0.3	-0.3	0.5	-0.4	-1.0			100	100	100	98	
		zyx				-0.0	-0.0	-0.6	-2.3	-3.7			100	100	100	93	
C1_ai	cat1-B	xzy							0.0	0.1	0.1			100	100	93	94
		yxz							-0.1	-0.2	-0.3			100	100	96	96
		yzx							-0.2	-0.3	-0.6			100	100	98	96
		zxy							-0.2	-0.2	-0.6			100	100	97	96
C2_ai	cat1-B	zyx							-0.3	-0.5	-0.9			100	100	97	97
		xzy				0.0	0.0	-0.1	0.6	-0.1			100	100	97	95	
		yxz				-0.7	-0.7	-0.9	-1.4	-1.8			100	100	94	99	
		yzx				-0.5	-0.5	-1.0	-1.7	-2.5			100	100	95		
		zxy				0.0	0.1	-0.6	-0.4	-1.1			100	100	98	100	
		zyx				0.1	0.1	-0.9	-1.2	-1.8			100	100	99	99	
C1_ai	cat3-frame	xzy										-1.8	100	100	91	91	
		yxz										0.9	100	100	92	92	
		yzx										-0.2	100	100	92	92	
		zxy										-3.0	100	100	92	92	
C2_ai	cat3-frame	zyx										-2.2	100	100	93	93	
		xzy				0.0	0.0					-1.7	100	100	93	91	
		yxz				0.0	0.0					0.9	100	100	94	94	
		yzx				-0.0	-0.0					-0.2	100	100	96	93	
		zxy				0.4	0.4					-2.9	100	100	99	98	
		zyx				0.4	0.4					-2.2	100	100	95	93	
C1_ai	cat3-fused	xzy							-0.2	-0.6	-0.5	-0.7	100	100	97	100	
		yxz							-0.4	-0.2	-0.4	-0.3	100	100	96	99	
		yzx							-0.8	-1.1	-1.2	-1.4	100	100	97	99	
		zxy							-1.1	-1.9	-1.8	-2.3	100	100	95	94	
C2_ai	cat3-fused	zyx							-1.5	-2.2	-2.2	-2.6	100	100	99	97	
		xzy				0.5	0.5	-1.0	-1.0	-0.9	-1.0	100	100	95	100		
		yxz				0.0	0.0	-0.2	-0.3	-0.4	-0.3	100	100	95	101		
		yzx				0.5	0.5	-1.1	-1.6	-1.7	-1.8	100	100	98	99		
		zxy				1.5	1.5	-1.8	-2.0	-2.2	-2.3	100	100	94	94		
		zyx				1.5	1.5	-1.5	-2.4	-2.7	-2.6	100	100	96	98		
C1_ai	overall	xzy							0.4	0.4	0.5	-1.5	100	100	95	95	
		yxz							-0.4	-0.5	-0.6	0.5	100	100	96	94	
		yzx							-0.4	-0.6	-0.9	-0.6	100	100	97	96	
		zxy							0.2	0.1	-0.1	-2.8	100	100	96	95	
C2_ai	overall	zyx							-0.3	-0.6	-0.8	-2.3	100	100	97	96	
		xzy				-0.1	-0.1	0.2	0.1	-0.0	-1.5	100	100	98	96		
		yxz				-0.3	-0.3	-0.9	-1.6	-1.8	0.5	100	100	95	99		
		yzx				-0.2	-0.2	-1.1	-2.3	-3.0	-0.7	100	100	96			
		zxy				0.0	0.0	-0.2	-0.5	-1.1	-2.7	100	100	98	98		
		zyx				0.1	0.2	-0.8	-1.8	-2.7	-2.3	100	100	99	96		

Table 3 – Total rate summary of all non-default axis permutations compared to TMC13v8 anchor (XYZ). Attributes coded using LoD scheme.

Condition	Class	Order	BPP Ratio [%]		D1	D2	BD-Rate [ $\Delta\%$ ]			R	Avg. of ratio maxrssk [%]		Ratio of avg. runtime [%]	
			Total				Y	Cb	Cr		Encoder	Decoder	Encoder	Decoder
C1_ai	cat1-A	xzy					-0.3	-0.3	-0.3		100	100	97	100
		yxz					0.0	0.0	0.0		100	100	97	97
		yzx					-0.0	-0.0	0.0		100	100	98	99
		zxy					-0.2	-0.2	-0.2		100	100	97	98
C2_ai	cat1-A	zyx					0.0	0.1	0.1		100	100	99	98
		xzy			-0.2!	-0.2!	-0.1!	-0.2!	0.5!		100	100	98	93
		yxz			-0.1	-0.1	-0.3	-0.4	-0.9		100	100	96	96
		yzx			-0.1	-0.1	-0.4	0.3	-0.7		100	100	98	96
CW_ai	cat1-A	zxy			-0.2	-0.2	-0.0	0.5	0.1		100	100	101	98
		zyx			-0.0	-0.0	0.1	0.4	0.1		100	100	100	97
		xzy	100.0								100	100	100	92
		yxz	100.0								100	100	96	89
CY_ai	cat1-A	yzx	100.0								100	100	93	91
		zxy	100.0								100	100	97	95
		zyx	100.0								100	100	96	93
		xzy	100.0				-0.2	-0.2	-0.2		100	101	98	94
		yxz					0.0	0.0	0.0		100	100	97	94
		yzx					-0.0	-0.0	-0.0		100	100	99	93
		zxy					-0.2	-0.2	-0.2		100	101	97	92
		zyx					0.0	0.0	0.0		100	101	96	95
C2_ai	cat1-B	xzy			0.0!	0.0!					100	100	103	86
		yxz			-0.7	-0.7					100	100	83	
		yzx			-0.5	-0.5					100	100	88	90
		zxy			0.0	0.0					100	100	96	89
CW_ai	cat1-B	zyx			0.1	0.1					100	100	95	91
		xzy	100.0								100	100	100	101
		yxz	100.0								100	100	97	100
		yzx	100.0								100	100	99	102
		zxy	100.1								100	100	96	100
		zyx	100.1								100	100	98	95
C1_ai	cat3-frame	xzy								-0.1	100	100	92	91
		yxz								0.0	100	100	90	89
		yzx								-0.0	100	100	94	93
		zxy								-0.1	100	100	91	91
C2_ai	cat3-frame	zyx								0.0	100	100	94	93
		xzy			0.0	-0.0				-0.2	100	100	96	96
		yxz			0.0	0.0				0.0	100	100	94	94
		yzx			-0.0	-0.0				-0.1	100	100	92	91
CW_ai	cat3-frame	zxy			0.4	0.4				-0.0	100	100	95	95
		zyx			0.4	0.4				0.1	100	100	94	93
		xzy	99.9								100	100	92	92
		yxz	100.0								100	100	87	87
CY_ai	cat3-frame	yzx	100.0								100	100	96	98
		zxy	100.0								100	100	97	96
		zyx	100.0								100	100	86	85
		xzy								-0.1	100	100	90	90
		yxz								0.0	100	100	88	87
		yzx								-0.0	100	100	93	93
		zxy								-0.1	100	100	92	91
		zyx								0.0	100	100	94	94
C1_ai	cat3-fused	xzy					0.3	0.2	0.2	0.2	100	100	88	93
		yxz					-0.1	-0.1	-0.1	-0.1	100	100	95	94
		yzx					0.2	0.2	0.2	0.2	100	100	96	99
		zxy					0.1	0.1	0.1	0.1	100	100	93	96
C2_ai	cat3-fused	zyx					0.1	0.1	0.1	0.1	100	100	98	94
		xzy			0.3	0.3	0.1	0.7	0.1	0.2	100	100	102	97
		yxz			-0.0	-0.0	-0.1	0.2	-0.2	-0.1	99	100	99	97
		yzx			0.3	0.3	0.0	0.2	0.2	0.1	100	100	101	91
CW_ai	cat3-fused	zxy			1.1	1.0	1.0	0.5	0.7	0.6	100	100	101	93
		zyx			1.0	1.0	0.4	0.6	0.7	0.6	100	100	98	95
		xzy	100.1								100	100	101	99
		yxz	100.0								100	100	94	94
CY_ai	cat3-fused	yzx	100.1								100	100	99	103
		zxy	100.1								100	100	94	93
		zyx	100.0								100	100	106	109
		xzy					0.2	0.2	0.2	0.2	100	100	97	101
		yxz					-0.0	-0.0	-0.0	-0.0	100	100	92	97
		yzx					0.2	0.2	0.2	0.2	100	100	97	99
		zxy					0.1	0.1	0.1	0.1	100	100	94	96
		zyx					0.1	0.1	0.1	0.1	100	100	94	95
C1_ai	overall	xzy					-0.2	-0.2	-0.2	0.0	100	100	95	97
		yxz					0.0	0.0	0.0	-0.0	100	100	95	95
		yzx					0.0	0.0	0.0	0.0	100	100	97	98
		zxy					-0.2	-0.2	-0.2	-0.0	100	100	95	96
C2_ai	overall	zyx					0.0	0.1	0.1	0.0	100	100	98	96
		xzy			-0.1!	-0.1!	-0.0!	-0.1!	0.4!	-0.1	100	100	100	91
		yxz			-0.3	-0.3	-0.3!	-0.3!	-0.8!	-0.0	100	100	90	
		yzx			-0.2	-0.2	-0.3!	0.3!	-0.6!	-0.0	100	100	93	93
CW_ai	overall	zxy			0.0	0.1	0.1!	0.5!	0.2!	0.2	100	100	98	93
		zyx			0.1	0.1	0.1!	0.4!	0.2!	0.2	100	100	97	94
		xzy	100.0								100	100	99	96
		yxz	100.0								100	100	95	94
CY_ai	overall	yzx	100.0								100	100	96	97
		zxy	100.0								100	100	97	97
		zyx	100.0								100	100	96	94
		xzy					-0.1	-0.1	-0.1	-0.0	100	100	96	94
		yxz					0.0	0.0	0.0	-0.0	100	100	95	92
		yzx					0.0	0.0	0.0	0.0	100	100	97	93
		zxy					-0.1	-0.1	-0.1	0.0	100	100	96	93
		zyx					0.0	0.0	0.0	0.0	100	100	95	95

NOTE — Condition CY metrics reported using Hausdorff PSNR.

Table 4 – Total rate summary of all non-default axis permutations compared to TMC13v8 anchor (XYZ). Attributes coded using RAHT.

Condition	Class	Order	BPP Ratio [%]		D1	D2	BD-Rate [ $\Delta$ %]			Cr	R	Avg. of ratio maxrssk [%]		Ratio of avg. runtime [%]	
			Total				Y	Cb	Cr			Encoder	Decoder	Encoder	Decoder
C1_ai	cat1-A	xzy					-0.3	-0.2	-0.2			100	100	98	98
		yxz					-0.0	-0.0	-0.0			100	100	97	93
		yzx					-0.0	-0.1	-0.1			100	100	98	96
		zxy					-0.2	-0.2	-0.2			100	100	96	96
C2_ai	cat1-A	zyx					0.0	0.0	0.0			100	100	97	96
		xzy			-0.3	-0.3	0.3	-0.4	-0.1			100	100	99	99
		yxz			-0.1	-0.1	-0.5	-1.4	-1.4			100	100	95	100
		yzx			-0.1	-0.1	-0.6	-2.2	-2.6			100	100	98	
		zxy			-0.3	-0.3	0.2	-0.6	-0.9			100	100	100	98
		zyx			-0.1	-0.1	-0.2	-1.6	-2.5			100	100	100	93
C1_ai	cat1-B	xzy					0.0	0.1	0.1			100	100	93	94
		yxz					-0.0	-0.0	-0.0			100	100	96	96
		yzx					0.0	0.1	0.1			100	100	98	96
		zxy					0.1	0.1	0.1			100	100	97	96
C2_ai	cat1-B	zyx					0.1	0.1	0.1			100	100	97	97
		xzy			0.0	0.0	-0.1	0.5	-0.2			100	100	97	95
		yxz			-0.6	-0.6	-0.9	-1.5	-1.7			100	100	94	99
		yzx			-0.5	-0.5	-0.9	-1.5	-2.0			100	100	95	
		zxy			-0.1	-0.0	-0.5	-0.2	-0.9			100	100	98	100
		zyx			-0.0	-0.0	-0.5	-0.7	-1.1			100	100	99	99
C1_ai	cat3-frame	xzy									-0.1	100	100	91	91
		yxz									0.0	100	100	92	92
		yzx									-0.0	100	100	92	92
		zxy									-0.1	100	100	92	92
C2_ai	cat3-frame	zyx									-0.0	100	100	93	93
		xzy			0.0	0.0					-0.9	100	100	93	91
		yxz			0.0	0.0					0.6	100	100	94	94
		yzx			-0.0	-0.0					-0.1	100	100	96	93
		zxy			0.4	0.4					-1.4	100	100	99	98
		zyx			0.4	0.4					-1.0	100	100	95	93
C1_ai	cat3-fused	xzy					0.3	0.2	0.2	0.2		100	100	97	100
		yxz					-0.1	-0.1	-0.1	-0.1		100	100	96	99
		yzx					0.2	0.1	0.1	0.2		100	100	97	99
		zxy					0.1	0.1	0.1	0.1		100	100	95	94
		zyx					0.1	-0.0	0.0	0.0		100	100	99	97
		xzy			0.4	0.4	-0.2	-0.3	-0.2	-0.3		100	100	95	100
C2_ai	cat3-fused	yxz			-0.0	-0.0	-0.0	-0.1	-0.3	-0.3		100	100	95	101
		yzx			0.4	0.4	-0.1	-0.6	-0.7	-0.9		100	100	98	99
		zxy			1.2	1.2	0.2	-0.5	-0.6	-0.6		100	100	94	94
		zyx			1.2	1.2	0.4	-0.7	-1.0	-1.0		100	100	96	98
		xzy					-0.1	-0.1	-0.1	-0.0		100	100	95	95
		yxz					-0.0	-0.0	-0.0	-0.0		100	100	96	94
C1_ai	overall	yzx					0.0	0.0	0.0	0.0		100	100	97	96
		zxy					-0.1	-0.1	-0.1	-0.0		100	100	96	95
		zyx					0.1	0.1	0.1	-0.0		100	100	97	96
		xzy			-0.1	-0.1	0.0	0.0	-0.1	-0.8		100	100	98	96
		yxz			-0.3	-0.3	-0.7	-1.3	-1.5	0.3		100	100	95	99
		yzx			-0.2	-0.2	-0.7	-1.7	-2.2	-0.4		100	100	96	
C2_ai	overall	zxy			-0.0	-0.0	-0.2	-0.4	-0.9	-1.2		100	100	98	98
		zyx			0.1	0.1	-0.3	-1.1	-1.7	-1.0		100	100	99	96

## References

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