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Title [GSC][V-PCC][Amd1][Late] Three component quaternions with W maximized over 24 rotations
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1 Abstract

This late document presents, that the approach with normalizing the quaternion by dividing all its components by earlier maximized w can be further enhanced by analyzing more rotations of the Gaussian splats. The recommendation is to have a CE on 3-component quaternions for the V-PCC amendment for the next meeting cycle.

[V4 of the document contains full results, including both lego sequences.](#)

2 Basic approach

In [m75562] (and previously in [m74618] we have proposed an approach where the quaternion is represented as $[W/W, X/W, Y/W, Z/W]$, resulting in 3-component representation plus W component equal to 1 for all the splats. This approach works efficiently if initial W component is possibly smallest \Rightarrow the smaller the W , the smaller the range of three remaining rotation components, resulting in more accurate quantization.

To maximize W , four different rotations of each quaternion are analyzed (and the scales of the splat are swapped accordingly):

- No rotation,
- 90-degree rotation around X axis,
- 90-degree rotation around Y axis,
- 90-degree rotation around Z axis.

In [m75857], additional three rotations were considered (-90 degrees around each axis), resulting in six considered permutations and thus more consistent results (method 2 in Fig. below):

| | | | 1F: Forward facing sequences | | | 1F: Object-centric sequences | | |
|--------|---|--------------------|------------------------------|----------|----------|------------------------------|----------|----------|
| Method | | | BD-rate | BD-rate | BD-rate | BD-rate | BD-rate | BD-rate |
| | | | RGB-PSNR | YUV-PSNR | YUV-SSIM | RGB-PSNR | YUV-PSNR | YUV-SSIM |
| G-PCC | 1 | canonicalize w=1 | -3.8% | -3.8% | -4.7% | -6.7% | -6.7% | -7.3% |
| | 2 | maximize w w=1 | -6.8% | -6.8% | -7.3% | -6.8% | -6.8% | -7.2% |
| | 3 | maximize w unitary | -7.0% | -7.0% | -7.4% | -7.0% | -7.0% | -7.4% |

| | | | 1F: Forward facing sequences | | | 1F: Object-centric sequences | | |
|--------|---|--------------------|------------------------------|----------|----------|------------------------------|----------|----------|
| Method | | | BD-rate | BD-rate | BD-rate | BD-rate | BD-rate | BD-rate |
| | | | RGB-PSNR | YUV-PSNR | YUV-SSIM | RGB-PSNR | YUV-PSNR | YUV-SSIM |
| V-PCC | 1 | canonicalize w=1 | -4.6% | -4.6% | -5.3% | -6.1% | -6.1% | -6.9% |
| | 2 | maximize w w=1 | -6.9% | -6.9% | -7.8% | -6.3% | -6.3% | -7.3% |
| | 3 | maximize w unitary | -7.1% | -7.1% | -7.9% | -6.3% | -6.3% | -7.3% |

Figure. Results from [m75857].

The method was, however, worse than Nokia's method 3 [m75523], based on making the quaternions unitary.

However, we believe that our method can be further enhanced by considering more rotations, thus maximizing the W even more. In total, a cube has 24 rotational symmetries:

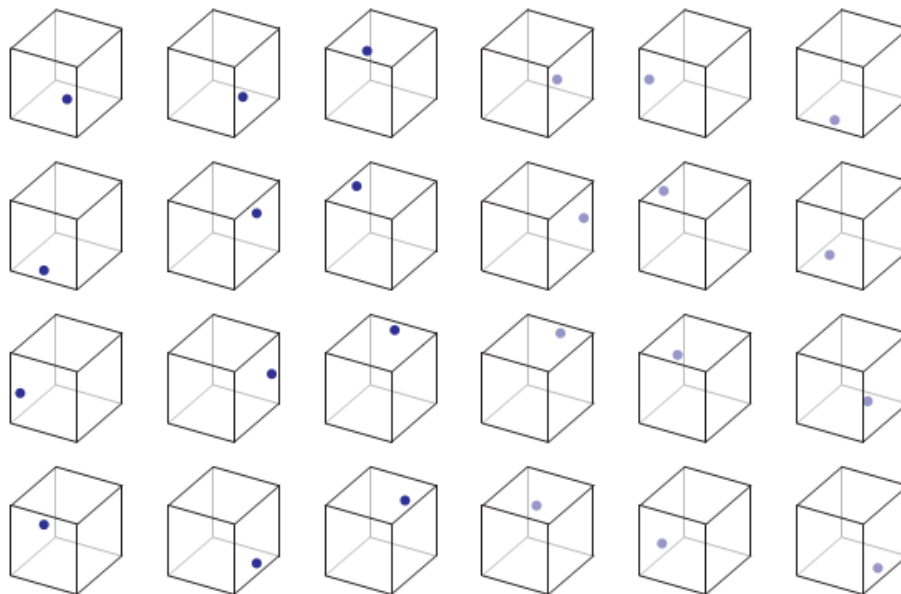


Fig. Rotational symmetries of a cube. Source:

<https://freethoughtblogs.com/atrivialknot/2017/09/13/what-is-a-symmetry-group/>

Each of 24 rotations results in a different quaternion. The main concept is to choose the largest of 24 W 's, and to proceed with the "divide by W " algorithm.

2.1 Results (to be updated)

The proposed approach significantly reduces the range of all remaining rotation components.

Example – bartender sequence:

With the analysis of 4 rotations:

minima: [1. -1.9448202 -1.9401733 -1.8839604]
maxima: [1. 1.909112 1.8947868 1.8812536]

With the analysis of 24 rotations:

minima: [1. -0.41420642 -0.41421184 -0.41421095]
maxima: [1. 0.414213 0.41420883 0.4142083]

CTC experiments have been started, the section will be updated.

2.1.1 CTC results, range adjusted to data: ~[-0.41, 0.41]

1F: Forward facing sequences

| Sequence | BD-rate RGB-PSNR | BD-rate YUV-PSNR | BD-rate YUV-SSIM | EncT Total | DecT Total | EncT Geometry | DecT Geometry | EncT Attributes | DecT Attributes | MaxRSS Encoder | MaxRSS Decoder |
|-----------------------|---------------------|---------------------|---------------------|--------------|--------------|------------------|------------------|--------------------|--------------------|-------------------|-------------------|
| bartender_semitracked | -4.8% | -4.8% | -7.4% | 44.9% | 56.9% | 22.9% | 76.9% | 32.7% | 69.6% | 99.1% | 98.8% |
| cinema_semitracked | -4.8% | -4.8% | -7.1% | 42.7% | 41.1% | 24.3% | 53.9% | 29.5% | 46.0% | 99.1% | 98.8% |
| breakfast_semitracked | -5.0% | -5.1% | -6.7% | 44.1% | 43.6% | 24.4% | 45.0% | 27.8% | 44.4% | 99.0% | 98.8% |
| breakfast_untracked | -7.1% | -7.0% | -7.7% | 44.3% | 46.9% | 22.6% | 43.3% | 24.1% | 40.1% | 99.1% | 98.8% |
| breakdance_untracked | -8.2% | -8.0% | -10.6% | 42.3% | 68.3% | 27.3% | 79.4% | 33.9% | 70.2% | 99.1% | 98.9% |
| bartender_tracked | -4.3% | -4.3% | -6.7% | 43.3% | 41.1% | 24.9% | 51.9% | 26.8% | 43.8% | 99.1% | 98.8% |
| cinema_tracked | -4.9% | -4.8% | -7.1% | 47.6% | 48.2% | 20.5% | 37.9% | 25.5% | 35.8% | 99.1% | 98.8% |
| breakfast_tracked | -4.7% | -4.6% | -6.1% | 44.2% | 43.7% | 23.6% | 49.6% | 26.7% | 45.5% | 99.1% | 98.8% |
| Average | -5.5% | -5.4% | -7.4% | 44.2% | 48.7% | 23.8% | 54.7% | 28.4% | 49.4% | 99.1% | 98.8% |

1F: Object-centric sequences

| Sequence | BD-rate RGB-PSNR | BD-rate YUV-PSNR | BD-rate YUV-SSIM | EncT Total | DecT Total | EncT Geometry | DecT Geometry | EncT Attributes | DecT Attributes | MaxRSS Encoder | MaxRSS Decoder |
|----------------------|---------------------|---------------------|---------------------|--------------|--------------|------------------|------------------|--------------------|--------------------|-------------------|-------------------|
| manwithfruit_tracked | -5.3% | -5.4% | -6.9% | 35.9% | 37.9% | 19.6% | 52.8% | 16.6% | 19.9% | 99.2% | 98.5% |
| lego_ferrari | -5.6% | -5.6% | -7.5% | 31.2% | 33.6% | 12.3% | 36.4% | 14.7% | 23.0% | 99.0% | 98.7% |
| lego_bugatti | -8.4% | -8.4% | -9.2% | 53.4% | 50.2% | 19.2% | 68.2% | 30.4% | 36.8% | 99.0% | 98.7% |
| cricket_player | -7.7% | -8.1% | -8.4% | 52.8% | 67.0% | 23.8% | 48.0% | 23.9% | 35.5% | 99.1% | 98.8% |
| plant | -6.2% | -6.2% | -6.8% | 53.4% | 68.0% | 23.6% | 40.9% | 25.0% | 36.6% | 99.0% | 98.8% |
| solo_tango_female | -4.5% | -4.5% | -7.0% | 53.6% | 64.8% | 25.0% | 39.4% | 24.2% | 34.6% | 99.1% | 98.8% |
| solo_tango_male | -4.9% | -4.8% | -7.1% | 52.3% | 60.9% | 21.9% | 38.4% | 24.1% | 32.6% | 99.0% | 98.7% |
| tango_duo | -4.9% | -4.8% | -7.0% | 48.3% | 47.3% | 32.8% | 51.6% | 27.3% | 39.9% | 99.0% | 98.7% |
| tennis_player | -5.1% | -5.1% | -7.1% | 52.9% | 63.9% | 22.9% | 38.5% | 24.3% | 39.0% | 99.1% | 98.8% |
| library | | | | | | | | | | | |
| flowerdance | -5.7% | -5.6% | -6.2% | 53.2% | 58.5% | 23.8% | 84.0% | 43.7% | 65.9% | 99.1% | 98.8% |
| gymnast | -4.3% | -4.4% | -3.4% | 52.0% | 67.1% | 27.1% | 86.3% | 40.9% | 72.5% | 99.2% | 98.9% |
| Average | -5.7% | -5.7% | -7.0% | 49.0% | 56.3% | 22.9% | 53.1% | 26.8% | 39.7% | 99.1% | 98.7% |

2.1.2 CTC results, range as in anchor: [-1.0, 1.0]

1F: Forward facing sequences

| Sequence | BD-rate RGB-PSNR | BD-rate YUV-PSNR | BD-rate YUV-SSIM | EncT Total | DecT Total | EncT Geometry | DecT Geometry | EncT Attributes | DecT Attributes | MaxRSS Encoder | MaxRSS Decoder |
|-----------------------|---------------------|---------------------|---------------------|--------------|--------------|------------------|------------------|--------------------|--------------------|-------------------|-------------------|
| bartender_semitracked | -6.8% | -6.8% | -7.5% | 47.8% | 44.7% | 20.5% | 67.9% | 35.1% | 58.2% | 99.0% | 98.7% |
| cinema_semitracked | -7.0% | -7.0% | -7.7% | 47.7% | 32.6% | 21.2% | 44.1% | 33.2% | 38.8% | 99.0% | 98.8% |
| breakfast_semitracked | -7.2% | -7.2% | -7.8% | 52.1% | 39.6% | 26.1% | 43.6% | 33.0% | 43.2% | 99.0% | 98.7% |
| breakfast_untracked | -10.9% | -10.8% | -11.3% | 51.6% | 43.8% | 22.4% | 47.1% | 28.3% | 45.3% | 99.0% | 98.7% |
| breakdance_untracked | -4.9% | -4.8% | -5.0% | 49.9% | 68.8% | 30.1% | 63.2% | 40.1% | 59.6% | 99.1% | 98.8% |
| bartender_tracked | -6.6% | -6.6% | -7.3% | 49.1% | 39.0% | 22.3% | 48.3% | 30.7% | 42.7% | 99.0% | 98.8% |
| cinema_tracked | -7.2% | -7.2% | -8.0% | 51.1% | 47.6% | 11.7% | 46.6% | 27.7% | 41.8% | 99.0% | 98.7% |
| breakfast_tracked | -6.9% | -6.9% | -7.5% | 51.3% | 39.8% | 26.0% | 48.8% | 31.1% | 47.5% | 99.0% | 98.8% |
| Average | -7.2% | -7.2% | -7.8% | 50.1% | 44.5% | 22.5% | 51.2% | 32.4% | 47.2% | 99.0% | 98.7% |

1F: Object-centric sequences

| Sequence | BD-rate RGB-PSNR | BD-rate YUV-PSNR | BD-rate YUV-SSIM | EncT Total | DecT Total | EncT Geometry | DecT Geometry | EncT Attributes | DecT Attributes | MaxRSS Encoder | MaxRSS Decoder |
|----------------------|---------------------|---------------------|---------------------|--------------|--------------|------------------|------------------|--------------------|--------------------|-------------------|-------------------|
| manwithfruit_tracked | -9.1% | -9.2% | -10.0% | 25.7% | 28.0% | 13.0% | 16.1% | 11.7% | 14.0% | 99.1% | 98.5% |
| lego_ferrari | -6.9% | -6.9% | -7.8% | 32.2% | 30.9% | 12.2% | 34.7% | 15.1% | 22.4% | 98.9% | 98.6% |
| lego_bugatti | -7.7% | -7.6% | -8.2% | 33.9% | 31.7% | 13.0% | 46.5% | 19.2% | 26.5% | 98.9% | 98.6% |
| cricket_player | -7.6% | -7.7% | -7.9% | 54.3% | 44.8% | 22.5% | 35.5% | 24.7% | 28.9% | 99.0% | 98.7% |
| plant | -7.3% | -7.3% | -7.9% | 55.1% | 48.8% | 19.0% | 36.5% | 26.0% | 30.5% | 98.9% | 98.7% |
| solo_tango_female | -6.1% | -6.1% | -8.0% | 54.3% | 46.6% | 19.2% | 30.4% | 24.7% | 28.8% | 98.9% | 98.7% |
| solo_tango_male | -7.3% | -7.3% | -8.6% | 53.0% | 50.5% | 14.6% | 34.5% | 24.6% | 30.5% | 99.0% | 98.7% |
| tango_duo | -6.3% | -6.2% | -7.9% | 54.3% | 35.6% | 30.3% | 39.6% | 31.0% | 31.3% | 98.9% | 98.6% |
| tennis_player | -6.5% | -6.5% | -7.9% | 54.3% | 46.7% | 19.2% | 27.6% | 25.1% | 33.2% | 98.9% | 98.7% |
| library | | | | | | | | | | | |
| flowerdance | -6.2% | -6.2% | -6.3% | 51.8% | 51.7% | 21.7% | 68.3% | 42.6% | 62.9% | 99.1% | 98.8% |
| gymnast | -4.7% | -4.8% | -4.9% | 50.2% | 48.0% | 24.6% | 69.4% | 39.5% | 61.9% | 99.1% | 98.9% |
| Average | -6.9% | -6.9% | -7.8% | 47.2% | 42.1% | 19.0% | 39.9% | 25.8% | 33.7% | 99.0% | 98.7% |

3 Recommendations

We recommend having a CE on 3-component quaternions for the V-PCC amendment for the next meeting cycle.

4 Acknowledgment

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