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A Predictor for Triangle Mesh Compression Working in Tangent Space

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Presentation outline

- Problem definition
- Traversal-based methods in general
- Weighted parallelogram
- Encoding in a local coordinate system
- Experiments
- Conclusion

Problem definition

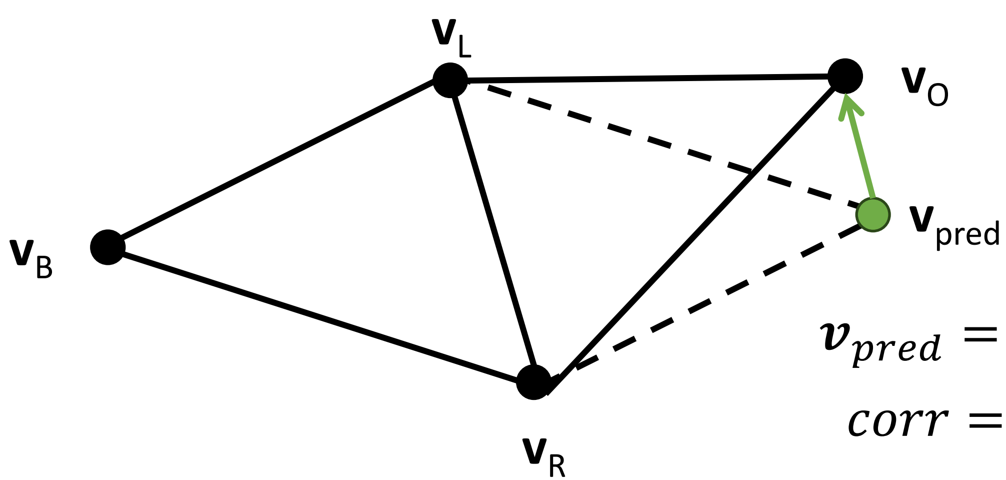
- Compression of triangle mesh $\mathcal{M}$ geometry
  - Encode vertex positions V with the best possible ratio between bitrate and mesh distortion
  - Traversal, connectivity-first methods
    - Progressively increasing area of encoded mesh triagnles
    - Connectivity is available during the geometry prediction

$$\mathcal{M} = (\mathrm{V}, \mathrm{F})$$

$$\mathrm{V} = \{\boldsymbol{v}_i\}_{i=1}^{n}, \boldsymbol{v}_i \in \mathbb{R}^3$$

Traversal-based methods in general

- Based on using prediction schemes, such as:
  - Parallelogram [1], Dual parallelogram [2]
  - Valence-based encoding [3], Weighted parallelogram [4]
- Idea: Use the already decoded part of the geometry and connectivity to predict the encoded vertex
- Encoding correction vector instead of absolute vertex position

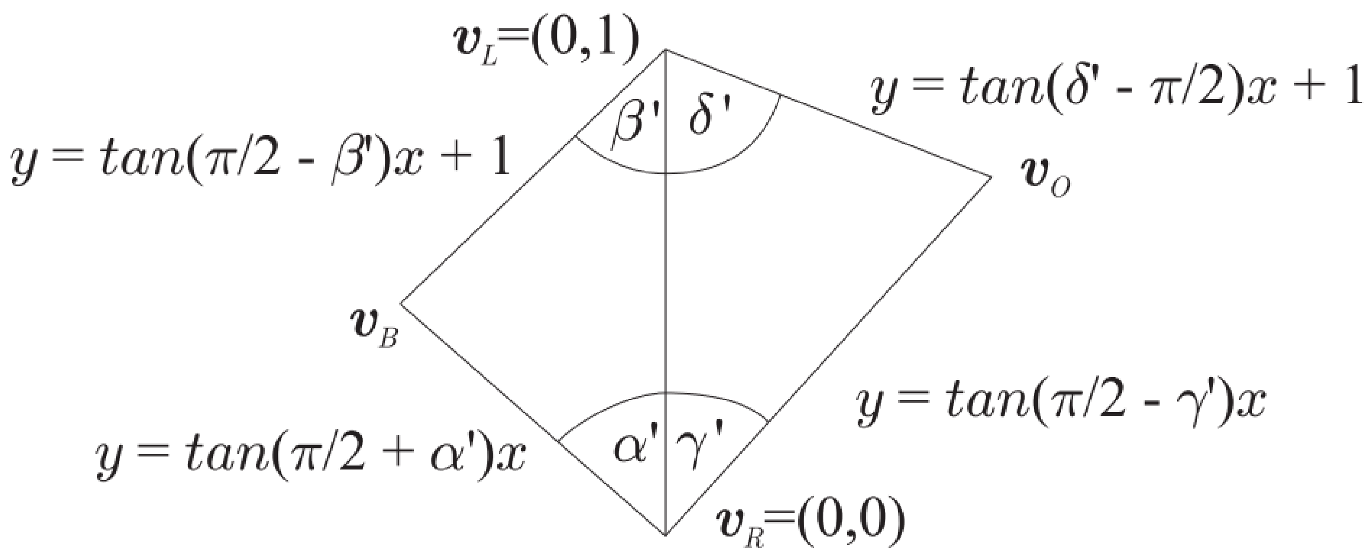


$$\boldsymbol{v}_{pred} = \boldsymbol{v}_L + \boldsymbol{v}_R - \boldsymbol{v}_B$$

$$corr = \boldsymbol{v}_O - \boldsymbol{v}_{pred}$$

Weighted parallelogram [4]

- Prediction based on
  - Connectivity
    - Valences of vertices
  - Known vertex positions (Base, Left, Right)
  - Known inner angles in decoded triangles



Weighted parallelogram [4] – Inner angles

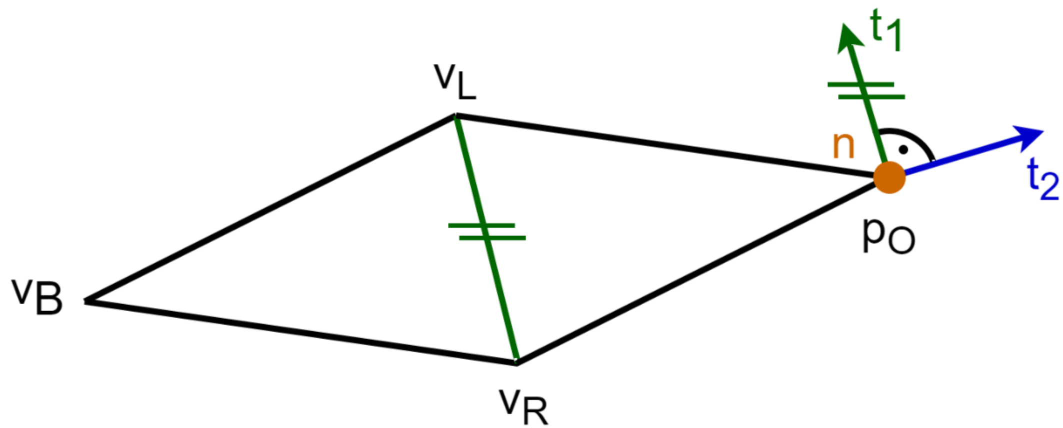
- Inner angles are known in the base triangle
- Can be estimated in the current triangle
  - Assuming zero Gaussian curvature
    - $\alpha_i = \frac{2\pi}{n(i)}$
  - Using known angles
    - $\alpha_i = \frac{2\pi - \sum already\ decoded\ angles}{n(i) - n_{decoded}(i)}$

Weighted parallelogram [4] – Inner angles

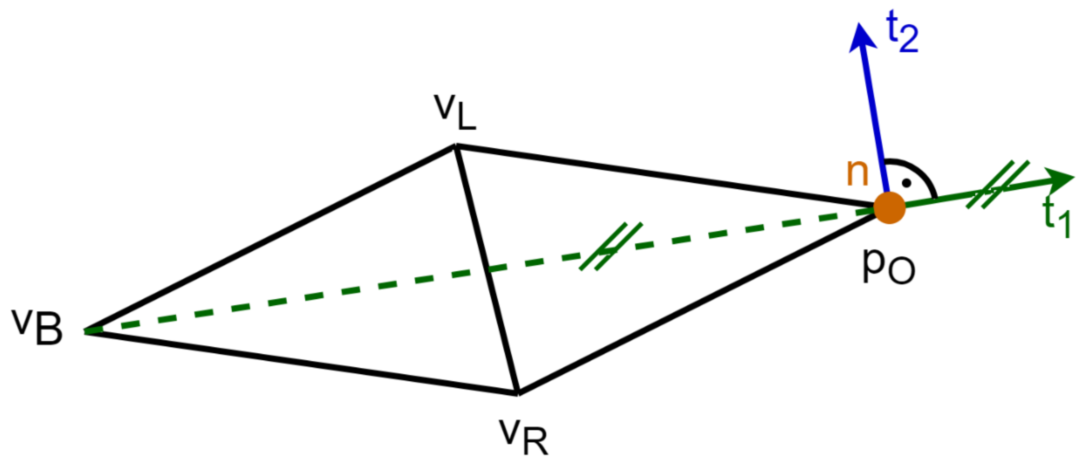
- Weighted predictor
  - $\boldsymbol{v}_{pred} = w_1\boldsymbol{v}_L + w_2\boldsymbol{v}_R + (1 - w_1 - w_2)\boldsymbol{v}_B$
  - $(w_1, w_2) = \left(\frac{\cot(\beta') + \cot(\delta')}{\cot(\delta') + \cot(\gamma')}, \frac{\cot(\alpha') + \cot(\gamma')}{\cot(\delta') + \cot(\gamma')}\right)$
- Correction vectors are quantized and encoded using arithmetic coder (in global coordinate system)
  - $corr = \left(\Delta_x, \Delta_y, \Delta_z\right)$

Local coordinate system

- Transform correction vectors into the local coordinate system
- Two tangential and one normal basis vectors:
  - $\boldsymbol{n} = \frac{(\boldsymbol{v}_L - \boldsymbol{v}_R)\times(\boldsymbol{v}_B - \boldsymbol{v}_R)}{\|(\boldsymbol{v}_L - \boldsymbol{v}_R)\times(\boldsymbol{v}_B - \boldsymbol{v}_R)\|}$
  - $\boldsymbol{t}_1 = \frac{\boldsymbol{v}_L - \boldsymbol{v}_R}{\|\boldsymbol{v}_L - \boldsymbol{v}_R\|}$
  - $\boldsymbol{t}_2 = \boldsymbol{n} \times \boldsymbol{t}_1$



  - $\boldsymbol{n} = \frac{(\boldsymbol{v}_L - \boldsymbol{v}_R)\times(\boldsymbol{v}_B - \boldsymbol{v}_R)}{\|(\boldsymbol{v}_L - \boldsymbol{v}_R)\times(\boldsymbol{v}_B - \boldsymbol{v}_R)\|}$
  - $\boldsymbol{t}_1 = \frac{\boldsymbol{p}_O - \boldsymbol{v}_B}{\|\boldsymbol{p}_O - \boldsymbol{v}_B\|}$
  - $\boldsymbol{t}_2 = \boldsymbol{n} \times \boldsymbol{t}_1$

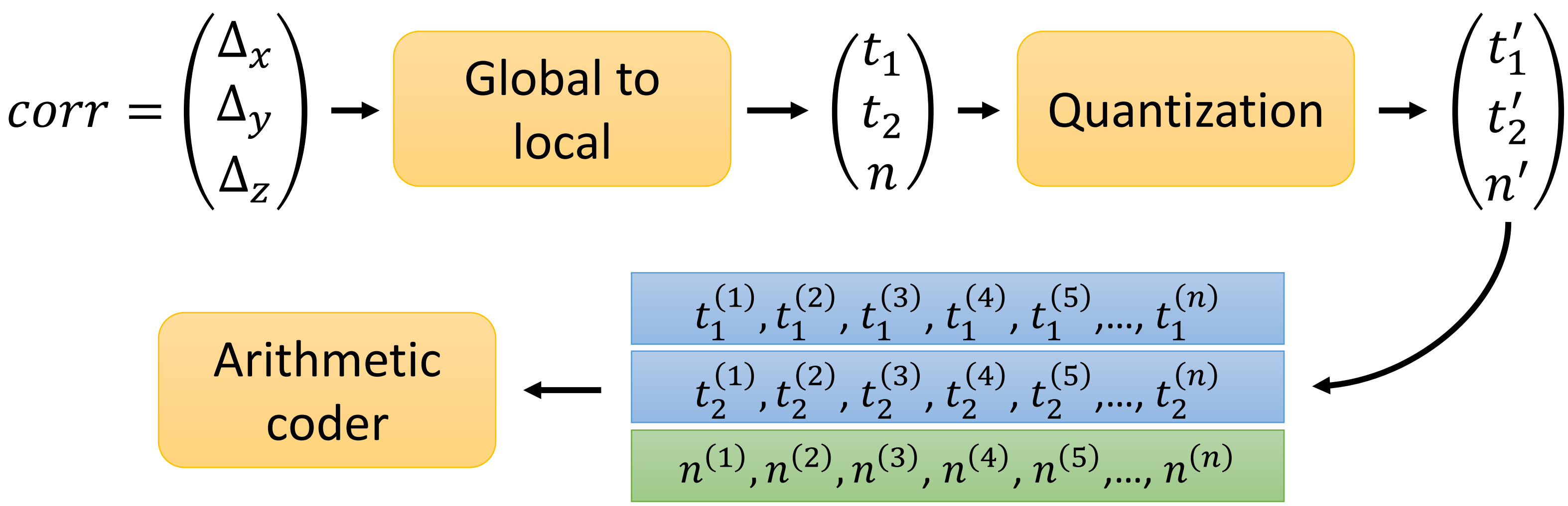


Local coordinate system

- Gumhold and Amjoun, 2003 [9]
  - Cylindrical system: (x, y, α)
  - Two tangential components and bending angle
  - $\boldsymbol{v}_{pred} = \frac{(\boldsymbol{v}_L + \boldsymbol{v}_R)}{2} + x\boldsymbol{x}_2 + \sin(\alpha) y \boldsymbol{x}_1 + \cos(\alpha) y \boldsymbol{x}_3$
  - Problems with uniformity of quantization

Local coordinate system

- Correction vectors expressed in local coordinate system
  - $\boldsymbol{corr} = t_1\boldsymbol{x}_1 + t_2\boldsymbol{x}_2 + n\boldsymbol{x}_3$
- Uniform quantization
- Correction vectors are encoded using adaptive arithmetic coder
  - Individual components coded into separate contexts

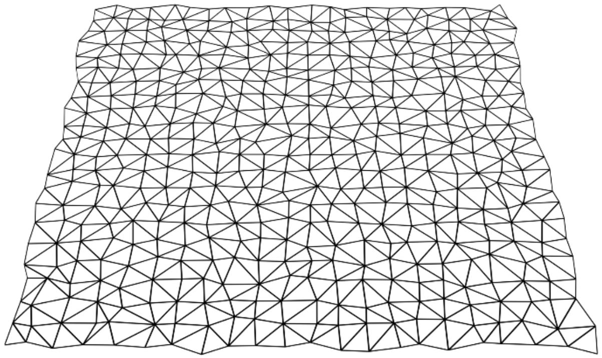


Local coordinate system

- Transformation of the correction vector to the local coordinate system
  - Results in sequences with lower entropy
    - (Original delta coordinates were correlated)
  - Allows the use of different quantization constants for tangential and normal components coded into separate contexts
    - If the surface is sufficiently smooth and well-sampled, tangential distortion is less observable than normal distortion
    - Better results in terms of mechanistic and perceptual metrics (DAME)

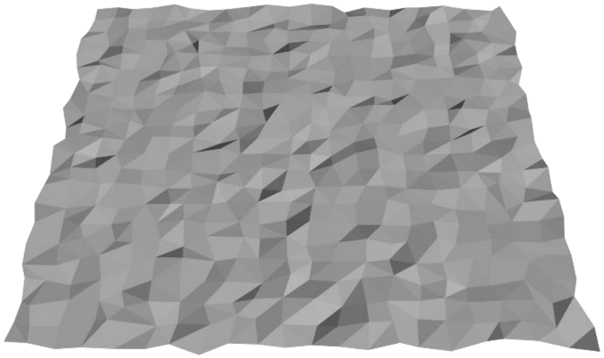
Experiments – Plane quantization

Plane rotated 17,5° around the x-axis, compression rate of approx. 13 bpv

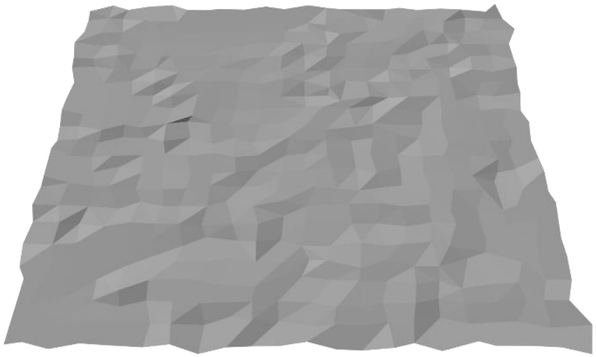


Original mesh (wireframe)

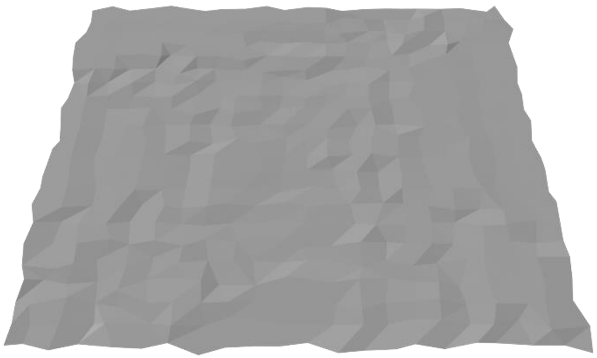
Original mesh (shaded)



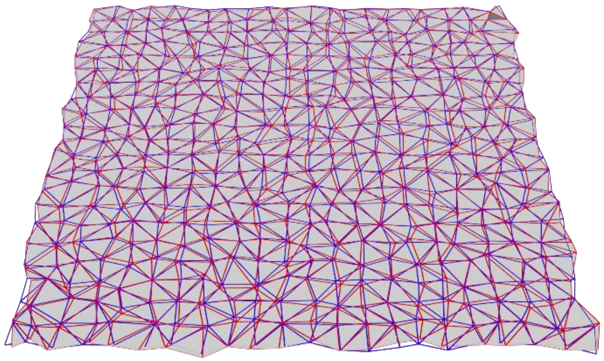
Compression in world space



Compression in local space



Compression in local space
(finer quantization of normal)

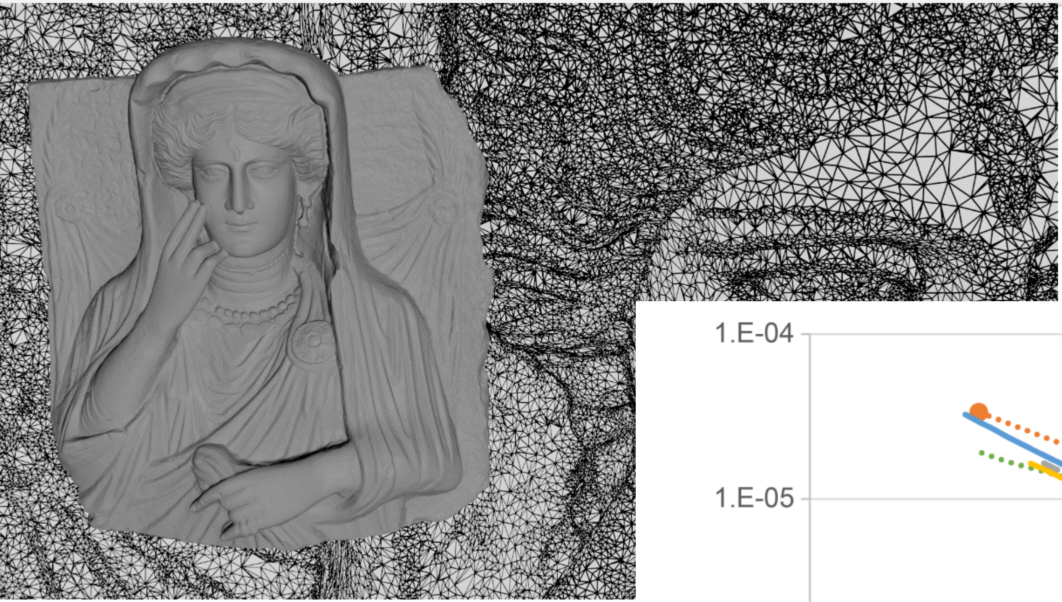


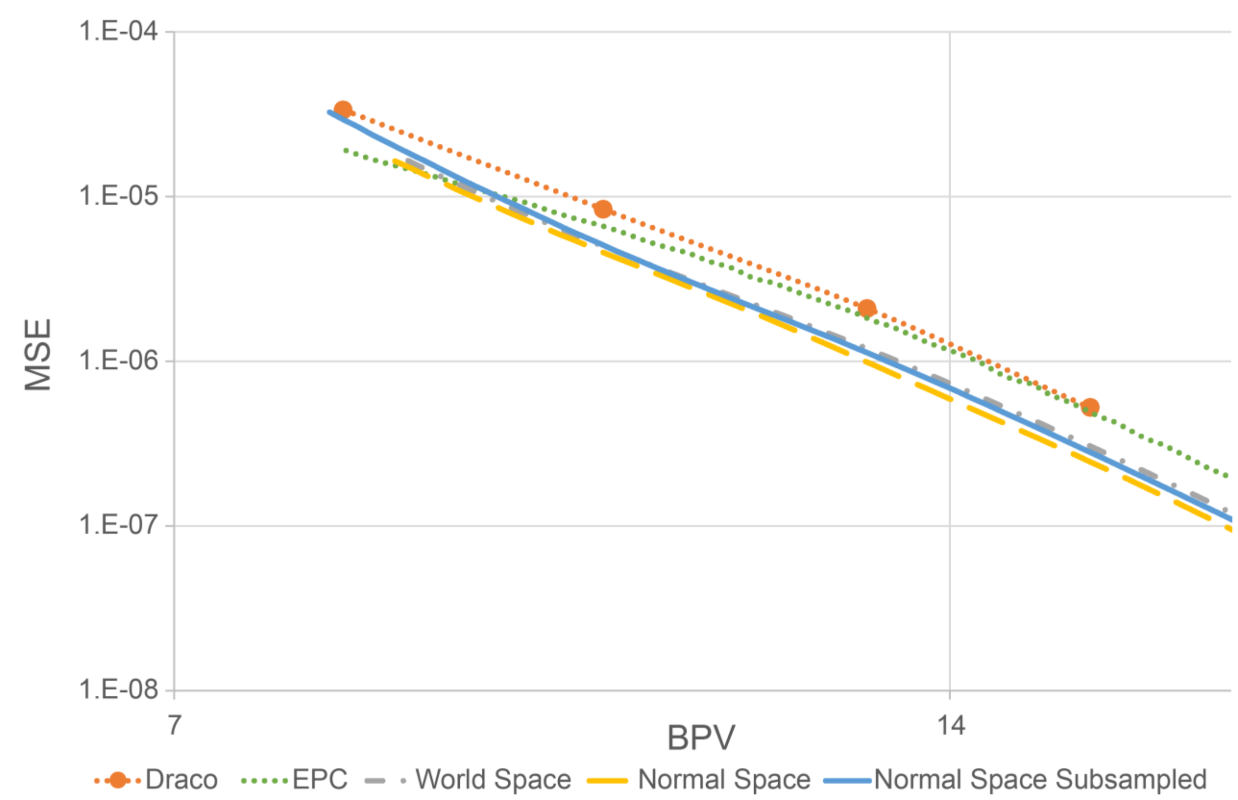
Precise encoding of
the 1st triangle (8.6 bpv)

Experiments – Quality assessment metrics

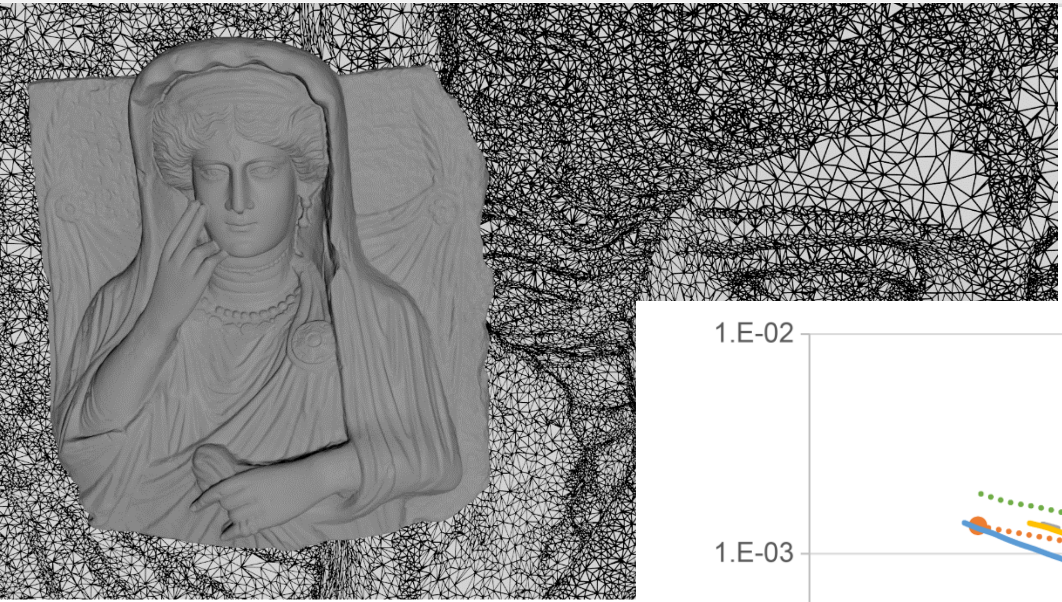
- Mechanistic metrics
  - Vertex Mean Squared Error (MSE)
    - $MSE = \sum_{i=1}^{n} \|\boldsymbol{v}_i - \boldsymbol{v}_i'\|^2$
  - Metro – AvgD [5]
    - Average distance between surfaces
- Perceptual metrics
  - Dihedral Angle Mesh Arror (DAME) [6]
- Reference methods
  - Original Weighted Parallelogram [4]
  - Draco [8]
  - Error Propagation Control (EPC) [7] - laplacian mesh compression

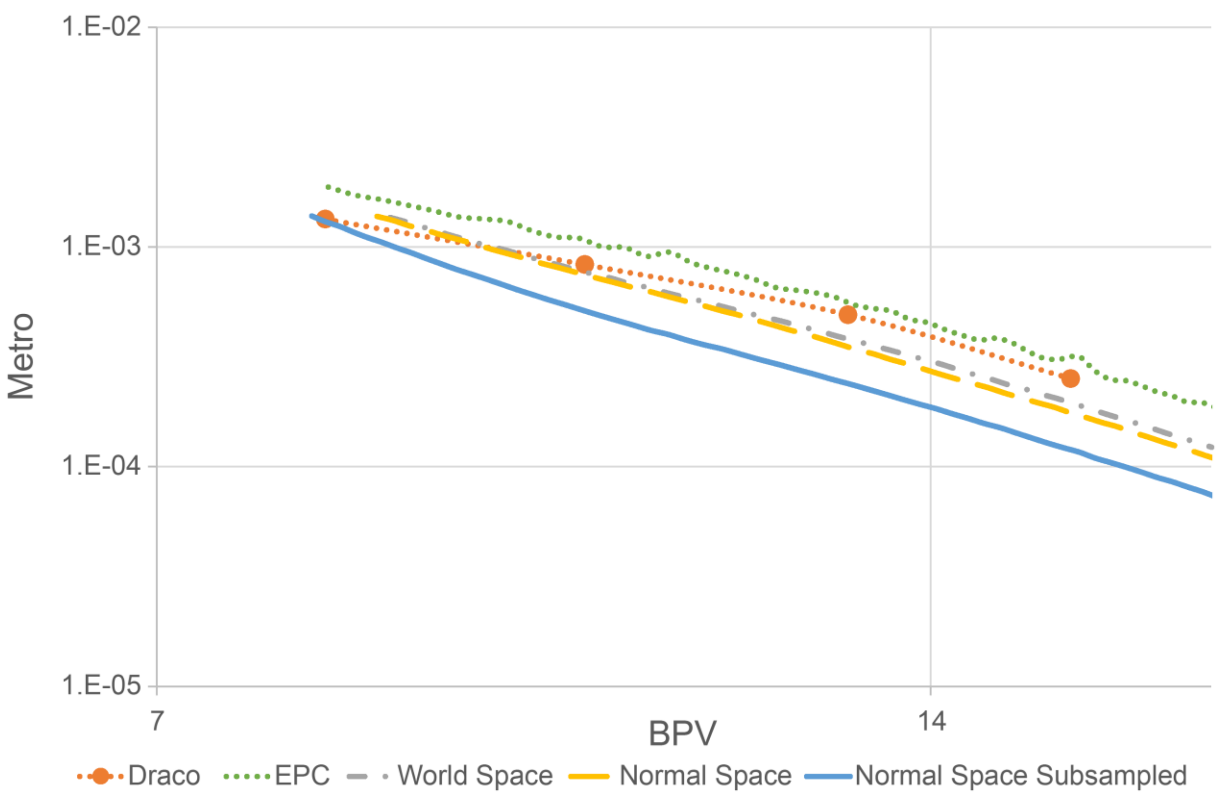
Experiments – Palmyra MSE



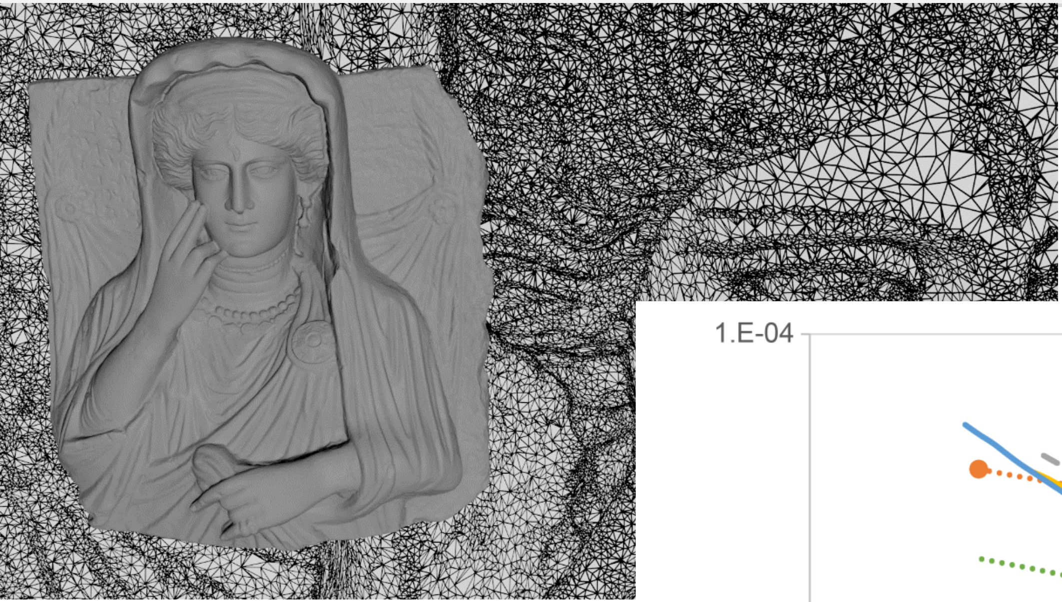


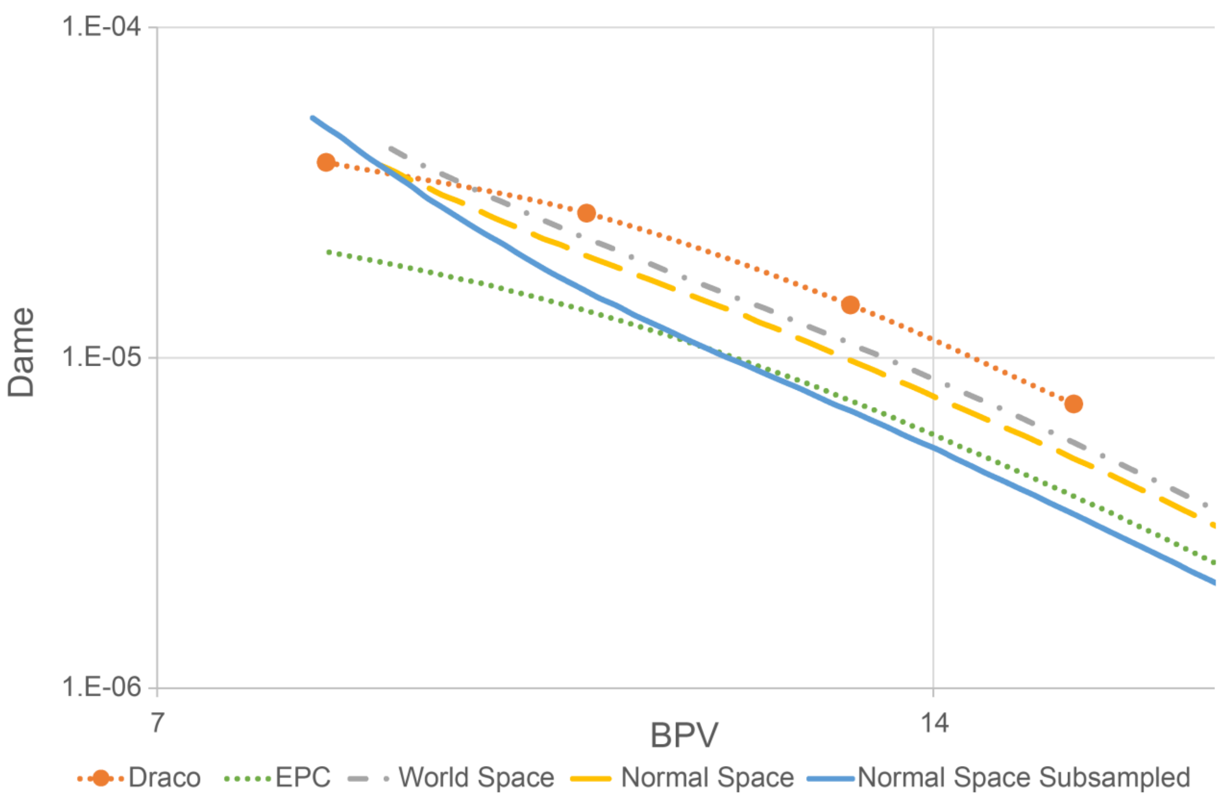
Experiments – Palmyra Metro



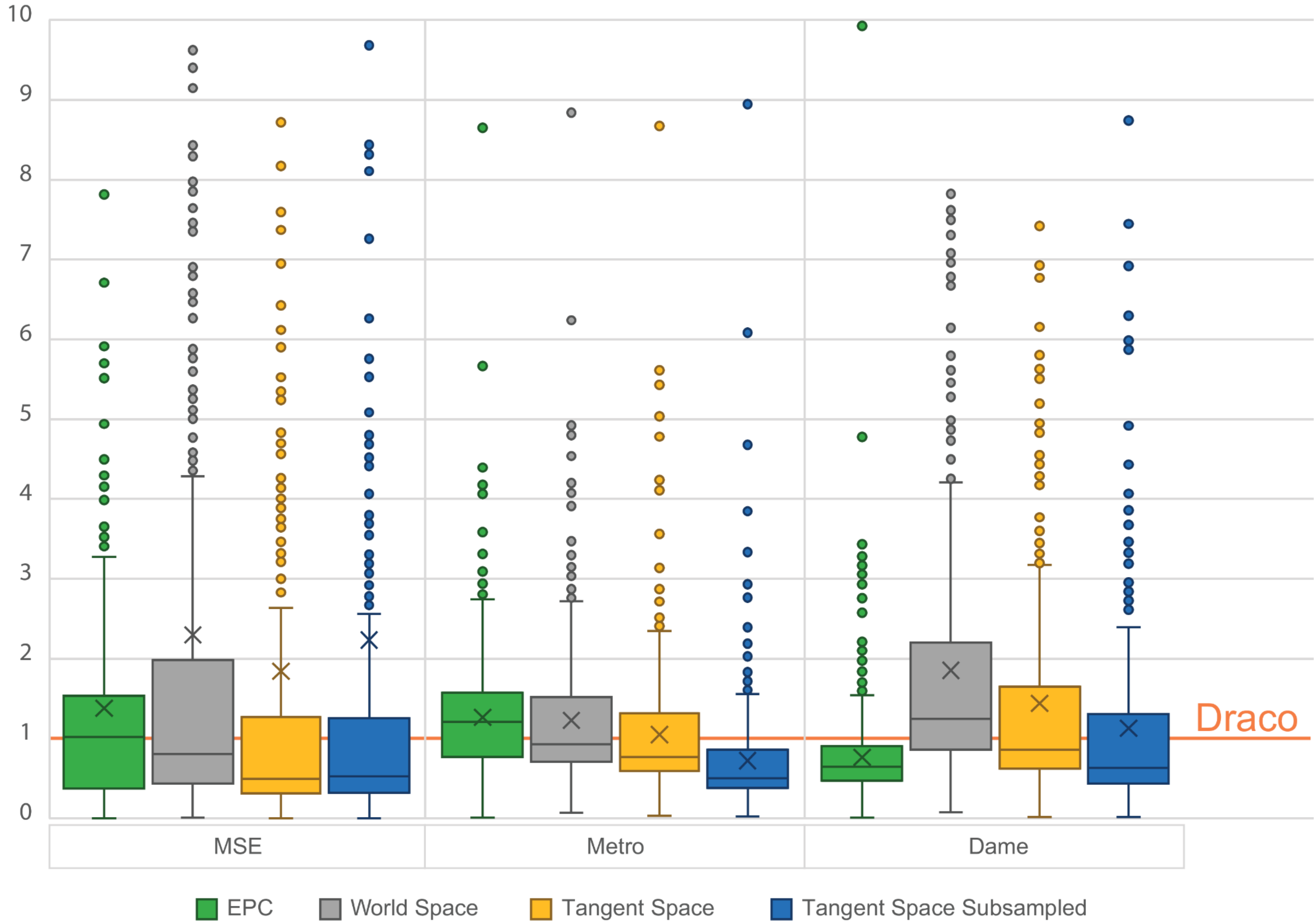


Experiments – Palmyra DAME

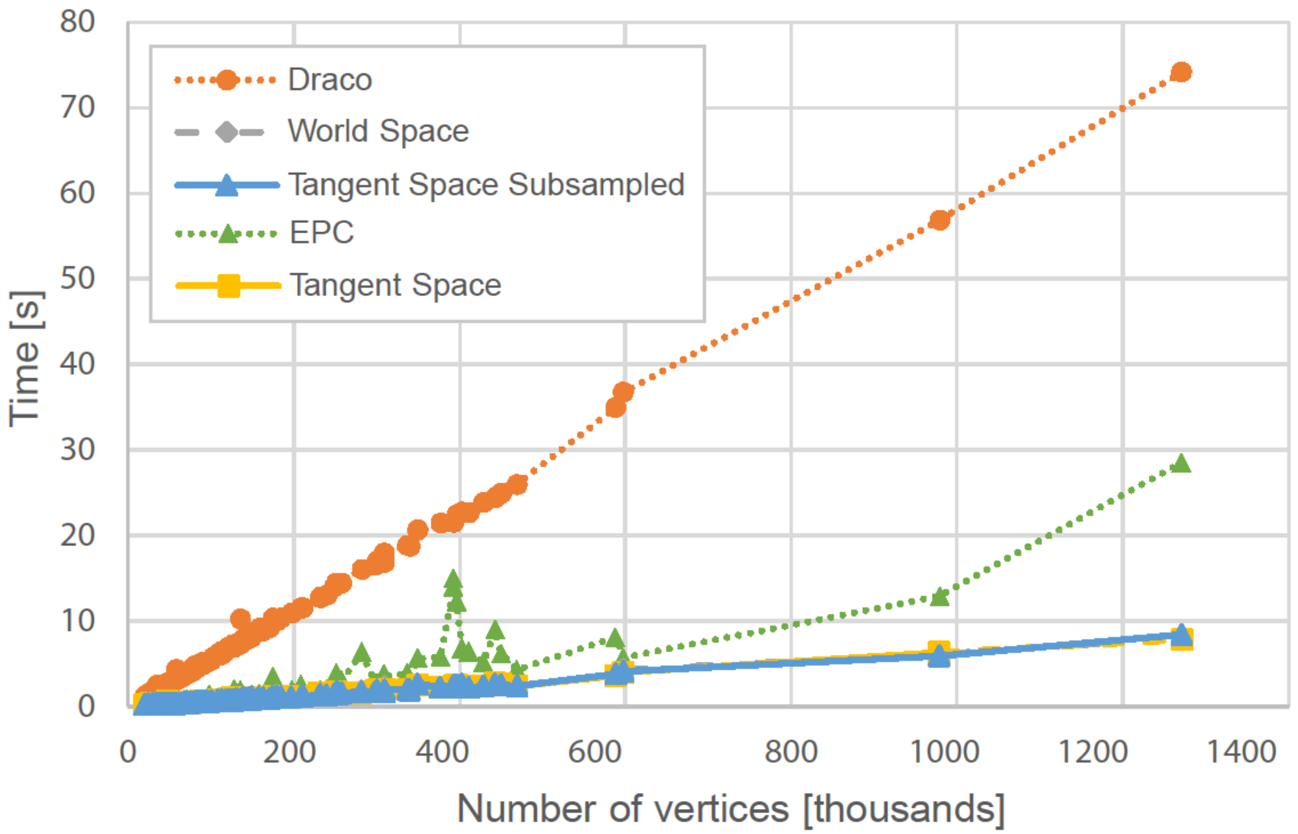




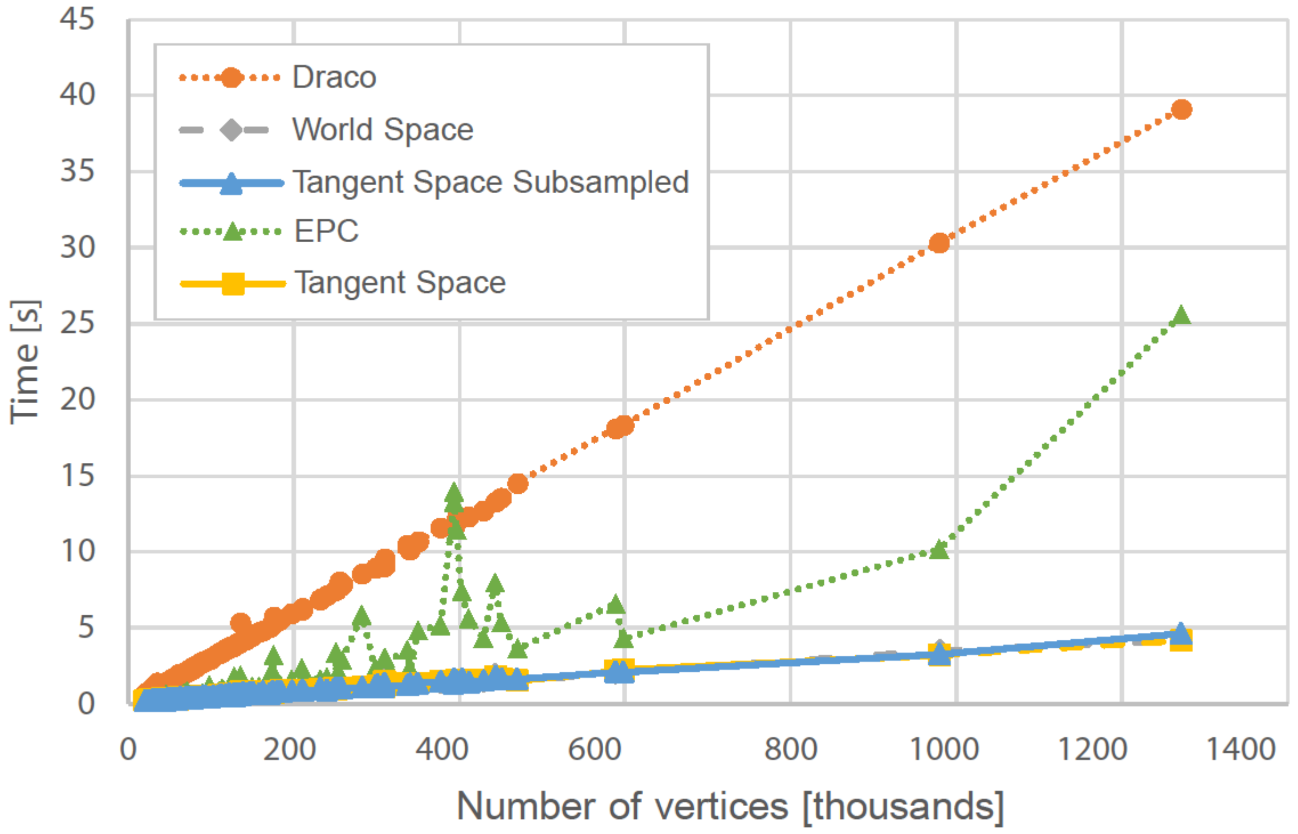
Experiments – Thingi10k dataset



Experiments – Time complexity - compression



Experiments – Time complexity - decompression



Conclusion

- Using the Weighted Parallelogram with the local coordinates encoding
  - requires only a slight change in the implementation
  - leads to better results than using the global coordinate system
  - does not have negative impact on compression and decompression time
  - has comparable or better results than WP, EPC, and Draco in terms of MSE and AvgD
  - has comparable or better results than WP, and Draco in terms of DAME

References

[1] Costa Touma and Craig Gotsman. Triangle mesh compression. In Proceedings of the Graphics Interface 1998 Conference, June 18-20, 1998, Vancouver, BC, Canada, pages 26–34, June 1998.

[2] Jae-Young Sim, Chang-Su Kim, and Sang-Uk Lee. An efficient 3d mesh compression technique based on triangle fan structure. Signal Processing: Image Communication, 18(1):17–32, 2003.

[3] Felix Kälberer, Konrad Polthier, Ulrich Reitebuch, and Max Wardetzky. Freelence - coding with free valences. Computer Graphics Forum, 24(3):469–478, 2005.

[4] Libor Vasa and Guido Brunnett. Exploiting connectivity to improve the tangential part of geometry prediction. IEEE Transactions on Visualization and Computer Graphics, 19(9):1467–1475, 2013.

[5] P. Cignoni, C. Rocchini, and R. Scopigno. Metro: Measuring error on simplified surfaces. Computer Graphics Forum, 17(2):167–174, 1998.

[6] Libor Váša and Jan Rus. Dihedral angle mesh error: a fast perception correlated distortion measure for fixed connectivity triangle meshes. Computer Graphics Forum, 31(5):1715–1724, 2012.

[7] Váša, L. and Dvořák, J. (2018), Error propagation control in Laplacian mesh compression. Computer Graphics Forum, 37: 61-70. https://doi.org/10.1111/cgf.13491

[8] Galligan, F., Hemmer, M., Stava, O., Zhang, F., and Brettle, J. (2018). Google/draco: a library for compressing and decompressing 3d geometric meshes and point Clouds.

[9] Gumhold, S. and Amjoun, R. (2003). Higher order prediction for geometry compression. In Proceedings of Shape Modeling International 2003, SMI ’03, page 59, USA. IEEE Computer Society.

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