To Splat Straight with Crooked Points: Rendering Noisy Meshes and Point Clouds using Coherent Tangent Vector Fields

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Abstract

Surface aligned splatting is a popular rendering technique to visualize reconstructed meshes and point clouds scanned from the real world. Such data typically presents some degree of noise that jeopardizes any attempt to render a perfectly smooth normal field and, more importantly, the estimated tangent vector fields are not locally continuous, thus affecting the overall visual quality. In this work, we compare two splat orientation techniques for rendering 3D noisy data, namely, the Covariance Matrix and the Householder formula. We evaluate both techniques using four publicly available meshes with synthetic noise, and four scanned point clouds with natural noise. Results indicate that the Householder technique is better suited for surface aligned splatting as it generates more coherent tangent vector fields, while Covariance Matrix reacts poorly to noise.

CCS Concepts

• ***Computing methodologies*** $\rightarrow$ ***Non-photorealistic rendering;***

1. Introduction

Within surface aligned splatting, each individual splat is oriented according to the estimated tangent vector fields from the 3D point data [Rus09]. For clean data sets, splat generation requires the computation of surface curvature directions, typically through a Covariance Matrix (CM) approach, so that splats become aligned with the direction of minimal curvature. However, when dealing with noisy 3D data this may not be the best option as splat orientation will also be affected by noise. Alternatively, a study performed by Anjos et al. [dARLP17] revealed the potential of the Householder (HH) formula for painterly rendering of point clouds, which were acquired from a depth sensor and had a perceptible amount of noise. The HH formula does not consider information about surface curvature, but computes locally and globally coherent tangent vector fields given the normal vector field of a point cloud or mesh [LSA13], thus, generating coherent splat orientations. In this paper, our goal is to verify if the HH formula has an advantage over CM for surface aligned splatting of noisy 3D data. In particular, we aim to verify how well the resulting tangent vector fields reproduce acceptable flow features, namely local and global coherence between splats, for rendering noisy meshes and point clouds acquired with a depth sensor and meshes with varying levels of noise.

2. Splatting with HH and CM tangent vector fields

To evaluate both techniques, we considered four 3D scanned datasets with natural noise and other four mesh datasets (publicly available) to which increasing levels of synthetic noise was introduced to their surface normal vectors (Table 1). In order to perform a fair evaluation, both HH and CM used exactly the same point and normal vector data. Regarding CM, the splat normal vectors and orientations are estimated with Plane Principal Component Analysis [Rus09]. This method relies on solving the eigenvalue and eigenvector problems associated to a covariance matrix, which takes into account the average squared sum of distances between the points and centroid point where the splat is placed [Rus09]. The resulting vectors consist of the estimated normal (lowest eigenvalue) and two tangent vectors (greatest eigenvalues). As for HH, we considered the formula presented in Lopes et al. [LSA13] to compute the HH matrices for each splat, where the first column is collinear to the splat's normal vector, while the second and third columns are orthogonal to the normal and to each other, hence, defining the splat's orientation.

2.1. Results and Discussion

Figure 1 presents the splat rendering results of two datasets (more results can be found in the video attached to this paper). By visual inspection, several features can be noticed: (i) the HH technique does not create vectors oriented in perpendicular or opposing directions; (ii) in both low and high noise scenarios, HH is able to represent small details (e.g., HH clearly distinguishes the lumps of the bunny's its body representing its fur or the finer details of the Armadillo's feet and torso); (iii) for increasing levels of noise, CM shows increasing variations in tangent vector directions even in close neighborhoods where similar normal vectors are expected;

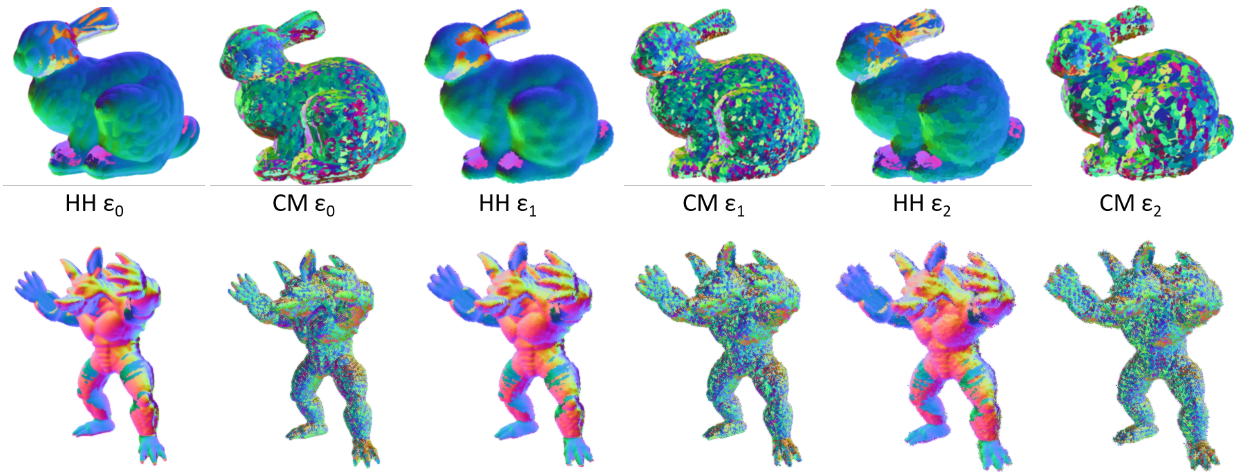

Figure 1: *Tangent field of the bunny and armadillo models, alternating between HH and CM, and increasing levels of noise. Colors represent the direction of the normalized tangent field, transposed to a [0,1] interval to fit the RGB spectrum ($R = t_x$, $G = t_y$, $B = t_z$), thus, similar colors represent similarly oriented tangent vectors. Each individual splat was rendered as an ellipsoid with a user defined size.*

Model	Armadillo	Buddah	Bunny	Dragon	Bee	Vase	Cathedral	Male
N° points	172.973	540.227	35.946	437.420	188.278	147.420	576.064	146.963
HH ε_0	3.89	5.12	3.94	4.13	4.58	2.87	5.13	6.5
	2.29,7.62	2.43,9.94	2.31,8.26	2.30,7.88	2.22,11.49	1.77,4.96	1.06,18.67	3.04,15.96
CM ε_0	38.54	35.399	29.43	39.28	43.48	35.26	29.05	31.01
	17.03,63.35	15.49,57.89	13.04,50.56	16.73,63.28	19.73,68.12	15.06,59.01	12.74,49.37	14.28,51.95
HH ε_1	5.06	7.95	4.24	8.42	-	-	-	-
	3.18,9.45	4.79,14.75	2.56,8.63	5.26,14.77	-	-	-	-
CM ε_1	44.52	35.61	39.79	45.34	-	-	-	-
	20.06,69.69	15.74,58.06	18.61,62.77	21.54,68.95	-	-	-	-
HH ε_2	8.35	13.03	5.43	23.56	-	-	-	-
	5.31,15.52	7.6,26.13	3.46,10.32	13.43,41.78	-	-	-	-
CM ε_2	45.57	35.86	44.64	57.10	-	-	-	-
	21.44,70.07	15.99,58.35	20.57,68,89	31.12,78.06	-	-	-	-

Table 1: *Local angular deviations of the tangent vector fields. Each line lists the values for HH or CM for increasing noise levels ε_0, ε_1, and ε_2. All angular deviation calculations considered precomputed normal vectors estimated from the CM approach with the same kernel size* 5ε *(ε - estimated average point distribution). Empty table cells correspond to datasets scanned from the real world that present natural noise.*

(iv) CM aligns splats only locally that are less coherent than those computed by the HH formula; (v) CM creates more discontinuities (holes) between splats; (vi) HH generates normalized tangent vectors while CM produces eigenvalues that can be used to define the size of each splat; (vii) HH is not rotationally invariant but CM produces shape-aware directions which are rotationally invariant; and (viii) the eigenvalues of CM allow to resize splats while HH always requires predefined splat dimensions.

Table 1 shows the local angular deviation using the HH formula is considerably smaller than the values obtained with the CM technique. Overall, the Householder formula had lower dispersion than the covariance matrix approach, having in average only 11.85% of the estimated deviation for the covariance matrix approach, while being able to correctly represent different aspects of the underlying surfaces. The highest registered value for HH (23.56) was still lower than the lowest value found for the CM approach (32.30). The inter-quartile range is also notably smaller in the HH approach, showing that it is consistent through the range of datasets.

References

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