Perception of Scale with Distance in 3D Visualization

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1. Introduction

In this poster we describe preliminary work relating the perception of scale (the variance parameter in scale-space filtering) with distance, for applications in 3D online visualization. 3D geometry and texture simplification can be based on scale-space analysis of the surface curvature and feature point distribution, to facilitate online transmission. The scale-space approach differs from other simplification approaches [1,2] in that a few parameters can be used to mathematically control the extent of simplification, and joint texture/mesh simplification is possible with a trade-off between texture and mesh transmission. We will outline our approach to joint TexMesh simplification (differing from purely surface simplification [3]) using scale-space filtering, followed by a description of how scale is perceived by human observers for 3D objects.

2. Scale-space filtering for 3D objects

Scale-space filtering (SSF) [4] is based on analyzing the zero-crossings of a signal for varying scales of smoothing, of the signal. The advantage of using SSF is its ability to smooth locally or globally depending on the filter window size. Fig. 1 is an example of global smoothing using a window size of 201 on a sample space of 256. If a smaller window size is used, smoothing will converge before reaching the bottom scale.

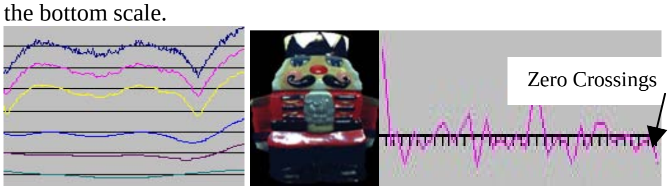

Fig. 1: (Left) Starting from the original signal or scale 0, increasing scale S_i from top to bottom, extracted near the feet of the Nutcracker toy model (middle); and 18 zero-crossings detected using the second derivative of the Gaussian (called Laplacian-of-Gaussian or LoG – Equation 1) for part of the original signal (right).

$$w_{LoG}(x,y) = \begin{cases} -\dfrac{1}{\pi\sigma^4}\left[1-\dfrac{x^2+y^2}{2\sigma^2}\right]e^{-\frac{x^2+y^2}{2\sigma^2}} & (x,y)\in W \\ 0 & elsewhere \end{cases} \qquad (1)$$

While (x,y) represents a pixel in 2D, we use (α,y) and $R_x(\alpha,y)$ to represent a vertex in 3D. SSF in 3D can be summarized by the following equations and are derived from their 2D counterparts:

$$w_G(\alpha,y) = \begin{cases} \dfrac{1}{\sqrt{2\pi\sigma_1\sigma_2}}e^{-\frac{\phi\alpha^2}{2\sigma_1^2}-\frac{\varphi y^2}{2\sigma_2^2}} & (\alpha,y)\in W \\ 0 & elsewhere \end{cases} \qquad (2)$$

$$R_xS(\alpha,y) = \int_{-t}^{t}\int_{-t}^{t} R_x(\alpha+u,y+v)\,w(u,v)\,du\,dv \qquad (3)$$

Where $w_G(\alpha,y)$ represents the weight at pixel (α,y), R_x represents the original signal and *RxS* the smoothed signal. In the implementation, we actually use summation instead of integrals, and normalize the Gaussian weights so that the sum of all the weights equals 1.

We achieve SSF of a 3D model as follows: First note that the data acquired (Figure 2, left) can be represented as $R_x(\alpha,y)$; where α is the angle on a horizontal plane around the y-axis of rotation of an object, y is the vertical location, and R_x denotes the distance to the surface of an object from the y-axis for a given (α,y) pair. SSF for a 3D model

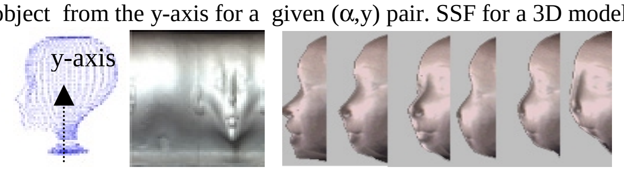

Fig. 2: A sample of 3D points (left), texture (middle) on a face model; and the face features at increasing scales (right).

is thus similar to a 2D image, for the simplified mesh representation considered here, with f(x,y) replaced by $R_x(\alpha,y)$.

For uniform sample points, ϕ and φ equal 1, but for irregular sampling, ϕ and φ are used to accommodate the variable inter-sample distance. Fig. 2 (right) shows the face features change towards a spherical surface going from low to high scales. Note that we will consider using intrinsic filtering [5] in the future, instead of Gaussian, to simplify the processing.

In the following experiments, we fix the texture resolution and analyze the perception of scale with distance.

3. Relating scale to viewing distance and perceptual quality

Preliminary experiments on determining the relationship between viewing distance and scale were conducted with the user interface in Figure 3 (left). Judges decided whether the randomly generated scaled versions were perceptually similar to the original model on the left. If no, they moved the scaled version away to a satisfactory position. If yes, the judges decided on the closest distance a scaled object can be viewed at without noticeable distortions. For each of 5 models (nutcracker, head, dog, grenade and vase), a number of simplified rotating objects are shown in a randomized order. Preliminary results suggest that the relationship between distance and scale is in fact a step function, Figure 3 (right). The x-axis is the scale and y-axis is the distance with zero as the closest distance. At each step (major scale) perceptually important feature points are eliminated causing a noticeable degradation in quality. While in between, features points eliminated by minor scales do not have significant perceptual impact. For example, at distance –8, decreasing the scale from 10 (major scale) to 7 does not improve perceptual quality. Based on this step function property, 3D mesh can be simplified as follows:

(a) Perform SSF analysis of the model and identify regions of persistent structures vs. regions of small variations, at different scales. Generate a priority list of feature points going from strong to weak persistence.

(b) Select a major scale S_i based on viewing distance, pop feature points at scale S_i from priority list and generate the initial coarse model.

(c) When the viewing distance decreases and falls on a higher step, refine the model with feature points belonging to the next lower major scale.

(d) Resolution of the texture associated with each scaled model is determined by feature point distribution on the object surface.

In future work, we will conduct perceptual experiments with groups of judges and determine the reliability of our findings. We will also integrate texture resolution into our perception of scale evaluation.

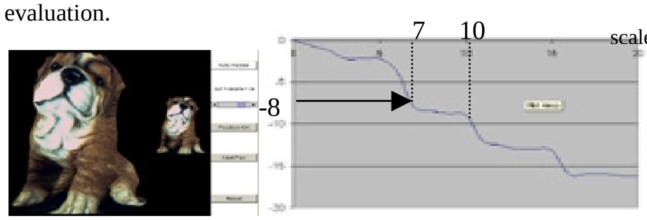

Fig. 3: (Left) Interface to perform perceptual evaluation. (Right) As we increase the number of judges and tests, we expect that the experimental results (blue) will get closer to a step function.

4. References

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[5] P.Boulanger et al., "Intrinsic filtering of range images using a physically based noise model," Vision Interface 2002, Calgary, Canada.