Automatic Selection of Level-of-detail based on Just-Noticeable-Difference (JND) (poster_0104)

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1. Introduction

In this poster we discuss our work on relating the perception of Level-of-detail to the size of features in a displayed 3D object, for applications in online visualization. The distance between grid-points on a display device has been used in the literature to define the smallest inter vertex distance below which vertices need not be inserted to a refined version [Red01]. We will introduce a perceptual metric to predict the perceptual impact on the human visual system (HVS) when refining a mesh, and show how limited network resources, e.g. bandwidth, can be utilized efficiently by stopping mesh refinement before reaching the threshold imposed by the display device resolution.

2. Applying a perceptual metric on mesh refinement

The size of a 3D object is proportional to its distance from the view point in the virtual scene. To determine whether a face in the mesh should be further subdivided, we introduce a perceptual metric based on Weber's fraction to measure whether the stimulus generated by an inserted vertex will have significant impact on the HVS. Insignificant vertices will not be added to refine the mesh. To compare the perceptual impacts, the dimensions of the structures generated by vertex insertion are used as a visual cue in our model. We follow the argument that humans naturally describe an object as consisting of parts. We segment the object into corresponding parts (skeletonization) and infer 3D shapes of these parts [ZN99]. In each edge collapse operation during preprocessing, when a vertex V_R is removed and integrated with V_C, we record the surface change as the difference $\Delta\rho$ between R_R and R_C. R_i is the shortest distance between vertex i and the skeleton. For a spherical object, the skeleton is represented by the center of the object (Fig. 1). $\rho_R = (R_R - R_C)/R_C$ is defined as the *perceptual value* of V_R. Our model is designed for view-independent simplification. In a given view, when a 3D object is projected onto a 2D display, the stimulus can be interpreted by Weber's fraction on shape. Instead of representing the stimulus linearly, an alternative is to use the area of the quadric error generated by removing V_R, but experimental results show that our perceptual metric predicts visual quality well, closely following human perception.

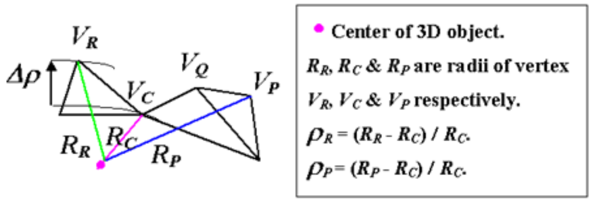

Fig. 1: *V_R and V_P have perceptual values ρ_R and ρ_P respectively.*

Let $\Delta\wp$ be the change after removing V_R and $\wp$ be the distance of V_C from the skeleton. When viewed on a display device, the difference $\Delta\wp$ generates a stimulus to the retina (Fig. 2). The Just-Noticeable-Difference (JND) is the minimum change in perceptual value in order to produce a noticeable variation in visual experience. Weber's Law [GW02] states that at the JND threshold,

$$\frac{\Delta \wp}{\wp} = K \qquad (1)$$, where K is a constant.

A value which is greater than K generates a significant perceptual impact on the HVS. Weber's Law has been applied to a variety of stimuli, including 2D images, brightness, loudness, mass, line length, size, etc., verified by psycho-visual experiments. We extend Weber's fraction to evaluate perceived similarity in 3D textured mesh, and perform perceptual evaluations on different randomly generated quadric surfaces to determine the value of K. The judges were seated at about 22 inches from the monitors and they had to decide which of the two randomly generated stimuli (simplified versions) appeared more similar to the non-simplified mesh. Both stimuli were mapped with texture of the same resolution. 1000 evaluations were performed by 30 judges on four desktop and laptop monitors of different resolutions ranging from 80 to 96 pixels per inch. The difference between the two stimuli was represented by a perceptual value. We divided the range of perceptual values into sub-ranges of length 0.01. In each sub-range we recorded the percentage of correct judgments. We then applied the two-alternatives-forced-choice technique [Usd05] on the recorded data to locate the threshold and found the JND value to be 0.10. This value is consistent with Weber's fraction obtained for other sensations and perceptions in psycho-visual experiments [Usd05] [Joh94].

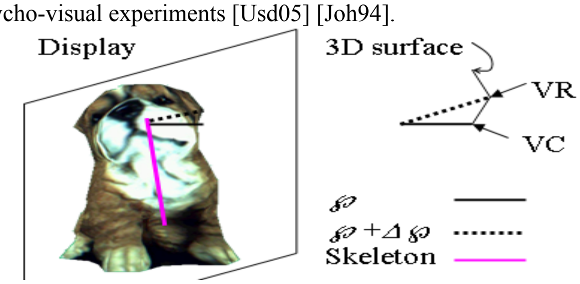

Fig. 2: ***An example of perceptual impact generated by the removal of vertex V_R.***

3. Automatic selection of level-of-detail (LOD)

Suppose R_C (Fig. 1) is 170 pixels. Based on the perceptual metric discussed above, a stimulus less than 17 (170x0.1) pixels does not have significant perceptual impact. In other words, it is not necessary to insert V_R if it does not generate a stimulus of dimension greater than 17 pixels. Similarly if R_C is 90 pixels, a stimulus of dimension less than 9 pixels will not have significant perceptual impact. In both cases, it can be seen that mesh refinement can be terminated before reaching the resolution of the display device.

Screen-space projection was used instead of object-space length when considering a particular view [XEV97]. Since our approach is view-independent, object-space length is used in order to cover all possible viewing directions. Let D pixels be the vertical dimension of an object on a screen. E_S and O_V are respectively the length of the shortest edge and vertical length of the object. If E_S occupies 1 pixel, the object will span O_V/E_S pixels vertically. Based on this estimation, the application can select the LOD which has a O_V/E_S value most matching the desired D value. Since fine details (shorter edges) tend to diminish at lower scales leaving global structures (longer edges) at higher scales [CB05], a coarser mesh will be automatically selected for an object displayed farther away. Given limited resources, e.g. bandwidth, if refining the mesh from (b) to (a) (Fig. 3) does not benefit quality, the strategy will be to allocate the resources to enhance other multimedia data, such as texture, which may improve visual fidelity.

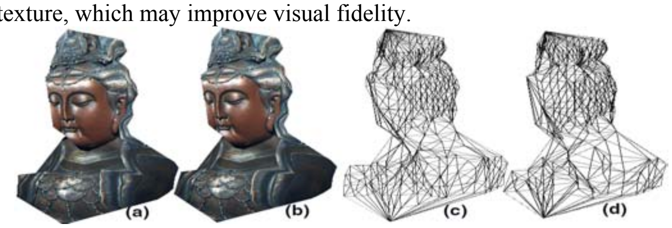

Fig. 3: *Perceptually similar textured meshes (a & b) composed of 774 and 630 triangles respectively (c & d).*

4. References

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