Online 3D Retrieval based on Perceptual Quality

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Challenges with High Resolution 3D imaging and Online Visualization

- Creating the High Resolution 3D Images
- Adapting 3D Objects to Available Resources
- Deciding the tradeoff between Mesh and Texture resolutions
3D Capture Hardware
Sample Images Captured
Perceptual Quality for 3D

- Factors involved
  - Mesh
    - How many vertices should we use?
  - Texture
    - How much detail should the surface image have?
  - Others
    - Factors not affecting bandwidth are kept unchanged for all versions of an object.
  - Tradeoff
    - What is the effect of changing mesh quality vs. texture quality?
Demonstration I (Estimating Perceptual Quality)

- Object shown with:
  - Different mesh (wireframe) resolutions
  - Different texture resolutions at a fixed mesh resolution
  - Question: How does perceptual quality vary on a qualitative scale:
    
    very poor (1), poor (2), fair (3), good (4), very good (5).
Referential Stimuli
Findings

- Perceptual quality varies following an exponential model for mesh

- Given a fixed mesh resolution, quality varies following a linear model for texture resolution

(Details to appear in IEEE Trans. on Multimedia)
Metric approximating perceptual quality

Graph of Mean Quality vs Wireframe and Texture Resolution: Nutcracker

Texture Resolution = 100%,
* a1=0.200000, b1=0.800000, c1=4.523092, sse1=0.162499

Texture Resolution = 50%,
* a2=0.333333, b2=0.666667, c2=4.523092, sse2=0.159338

Texture Resolution = 25%,
* a3=0.500000, b3=0.500000, c3=4.523092, sse3=0.178129
Metric approximating perceptual quality

Graph of Quality vs Texture Resolution (100% geometry resolution)

- Diagonal
- Nutcracker
- Head
- Dog
- Doll
Metric approximating perceptual quality

\[
\text{Quality}(g',t) = \frac{1}{\frac{1}{f(t)} + \left(\frac{1}{m} - \frac{1}{f(t)}\right)(1 - g')^c}
\]  \hspace{1cm} (1)

\[
f(t) = m + (M - m)t, \quad t \in [0, 1]
\]  \hspace{1cm} (2)

\[
\text{Quality}(g,t) = \frac{1}{\frac{1}{m+(M-m)t} + \left(\frac{1}{m} - \frac{1}{m+(M-m)t}\right)(1 - g)^c}
\]  \hspace{1cm} (3)

Bandwidth vs. perceptual quality for different levels of texture resolutions
Demonstration II (Online Retrieval based on Perceptual Quality)

- Online Interface with several Objects stored at Multiple Representations
  - Normally a user specifies maximum retrieval time; optimal version of requested 3D object is retrieved based on monitored bandwidth
  - In this demo we compare a 3D object representation having optimum perceptual quality with others having similar size, but lower perceptual quality
Reliability of User Evaluations

- How do we know if the Ratings are reliable?
  - Normally, following Psychometric methods, we need to have pairs of judges with similar judging behavior & measure correlation of ratings in pairs
  - We formed two groups of 10 judges, groups formed by similar types of people, and measured correlation between the average ratings of the two groups
  - Correlations were higher than 95% in most cases, showing high reliability
Reducing Judging Fatigue

- How can we reduce the number of stimuli a judge needs to evaluate?
  - We believe we are the first to have introduced the concept of Balanced Incomplete Block Design (BIBD) for perceptual user evaluations
    - Each judge evaluates a fraction of the total number of stimuli.
    - However, every stimuli gets judged by a fixed proportion of the total number of judges.
    - Also, to keep the effect of interactions among multiple stimuli constant, each pair of stimuli gets judged by a fixed proportion of judges.
Properties of a BIBD

BIBDs have been shown to have statistical properties similar to complete designs, at a much smaller cost for agricultural experiments. The parameters of a BIBD are \( v \), \( b \), \( k \), \( \lambda \) and \( r \). BIBD can be easily related to perceptual evaluations by defining the parameters as:

- \( v \) — number of models to be evaluated;
- \( b \) — number of judges;
- \( k \) — number of models evaluated by each judge;
- \( \lambda \) — number of different judges evaluating a given pair of models; and
- \( r \) — number of different judges evaluating a given model.

These parameters of a BIBD satisfy the properties:

**Property A:** \( vr = bk \)

**Property B:** \( \lambda(v - 1) = r(k - 1) \)

In addition, the parameters of a BIBD must be positive integers considering the literal interpretations of their definitions.
AN EXAMPLE:

In our experiments, for a given texture resolution, 6 models were evaluated by each judge. To reduce the judging workload by 50%, we can consider a BIBD with the parameters: number of judges \( b = 10 \), number of models \( v = 6 \), number of models evaluated by each judge \( k = 3 \), number of different judges evaluating the same model \( r = 5 \), and number of different judges evaluating a given pair of models \( \lambda = 2 \). It is easy to verify that the following design satisfies the parameters above, where \( J_i \) indicates the set of models evaluated by the \( i^{th} \) judge: \( J_1 = (0, 1, 2); J_2 = (0, 1, 4); J_3 = (0, 2, 3); J_4 = (0, 3, 5); J_5 = (0, 4, 5); J_6 = (1, 2, 5); J_7 = (1, 3, 4); J_8 = (1, 3, 5); J_9 = (2, 3, 4); J_{10} = (2, 4, 5). \) Where, 0, 1, 2, 3, 4, & 5 indicate the 6 models.