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## Progressive Compression of Point-Sampled Models

## Preview of the Presentation

- Short introduction to data compression
- The compression method for point-based models proposed in [Waschbüsch et al, Eurographics, 2004]
- point-based models
- the architecture of the algorithm
- Experimental results and future develpment


## Introduction to Information Theory

- Developed by Claude Shannon in late 1940 s
- Shows how to quantify the information
- The information content of a message resides in the amount of surprise it contains
- Formally: considering a source $S$ with an alphabet of n symbols having the probabilities $P_{j}$, the entropy of the source is defined as:
$H(S)=-\Sigma_{1}^{n} P_{j} \log _{2} P_{i}$
- H (entropy) is the amount of information per symbol generated by the source
- it is measured in bits


## Data Compression

- Lossless compression
- compression by removing the redundancy
- example: text compression
- Lossy compression
- applied in multimedia
- compression by removing the irrelevancy and redundancy
- Progressive compression
- Examples of redundancy and irrelevancy
- redundancy: text (e.g in English language) in ASCII format
- irrelevancy: continuous-tone image


# Compression for Point Based 3D <br> Ioan Cleju Models 

- Input: an unstructured set of 3D points
- each point is associated to a surfel (surface element) that represents the surface in the immediate neighborhood of the point
- The surfel contains information about:
- position
- color
- normal
- radius
- Task: compression of positions, normals and colors
- Compression pipeline:
Multiresolution

Decomposition $\rightarrow$\begin{tabular}{c}
Differential <br>
Coding

$\rightarrow$

Zerotree <br>
Coding

$\rightarrow$

Arithmetic <br>
Coding
\end{tabular}

- Multiresolution decomposition
- hierarchically decomposes the original set to a series of lower resolution subsets
- Differential coding
- predict a higher resolution set from a lower resolution one and store the prediction errors as detail coefficients
- the original model can be fully reconstructed from the lowest resolution set and the hierarchy of detail coefficient sets
- quantize the set to reduce irrelevancy
- Zerotree coding
- remove further coherencies among detail coefficients
- Arithmetic coding
- eliminate the redundancy


## Multiresolution Decomposition

- Iteratively reduce the size of the set to half
- define a distance between points
- compute a set of pairs (minimum weight perfect matching problem) of the higher resolution set $\left(\lambda^{-1}\right)$
- form the lower resolution set $\left(\lambda^{-i-1}\right)$ by representing each pair by its mean
- After $k$ steps, results a hierarchy of $k+1$ sets with the sizes respectively $N, N / 2, \ldots, N /(2 * * k)$
- The decomposition algorithm can be seen as building a forest of binary trees, starting from the bottom layer
- Define the $n$-neighborhood of one point (in a certain resolution set) by considering $n$ points of the set that contributed to the same point from a lower resolution set (equivalently, have a common ancestor in tree).


## Multiresolution Decomposition

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- the distance between the points is computed from the distances between the positions, the normals and the cosines of the angles of contraction between current and previous decompositions


## Predictive Differential Coding

- Try to predict, based on the information of the lower resolution set $\lambda^{-k-1}$, the next higher resolution set $\lambda^{-k}$
- Save the differences from the predicted values $\lambda^{-k}$ to the real values of $\lambda^{-k}$ as a set of detail coefficients $\left(\gamma^{-k}\right)$
- For a better prediction, transform the coordinate system to a local coordinate system, based on the neighborhood of each point



## Positions Prediction

- Try to predict from $\lambda_{i}^{-k}$ the points $\lambda_{2 i}{ }^{-k+1}$ and $\lambda_{2 i+1}{ }^{-k+1}$
- Coordinate transform:
- find the 4-neighborhood of the point $\lambda_{i}^{-k}$
- form the least squares plane of the neighborhood, represent the points in cylindrical coordinates, align the system to the first principal component and move the origin in $\lambda_{i}^{-k}$
- Prediction:
- in the local coordinate system
- predict elevation to 0
- predict radius to the average distance in the neighbor set divided by $2^{*}$ squt(2)
- predict $\theta$ to 0


## Positions Prediction

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Coordinate transform based on the 4-neighborhood (red points, marked with x), predicted position and difference to the real point coordinate

## Normals and Colors Prediction

- Normals
- store the angle between the average normal and one of the normals of the points
- use spherical coordinates
- allign the polar reference to the average normal
- allign the azimuthal reference to the projection of the eigenvector (see the coordinate transform) on the plane perpendicular to the normal
- $\quad \phi$ - azimuthal angle, bwtween 0 and $2^{*} \pi$
- $\theta$ - polar angle, between 0 and $\pi$
- predict the changes of $\phi$ and $\theta$ to 0
- Colors
- use YUV color space (useful in quantization)
- predict the color changes to 0


## Data Reconstruction

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- The data set is decorrelated by multiresolution decomposition and predictive differential coding
- The original data ( $\lambda^{0}$ ) can be completely reconstructed, before quantization takes place
- The total size is the same


## Quantization

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- After multireslution decomposition:
- the size of the data is still the same
- the data is less correlated
- the detail coefficients have values close to 0
- Quantization maps the symbols of a set to symbols of a set with smaller size
- increases the redundancy, keeping the same set size
- To prevent recursive error accumulation, after a layer of coefficients is quantized the error is propagated to the next higher rezolution layer



## Zerotree Coding

## - Embedded coding

- all the encodings of the data set at lower bit rates are encoded at the beginning of the bit stream at a higher rate
- Use the significant maps for coding wavelet coefficients
- apply succesively a set of thresholds (with decreasing values) to code the values that are significant for the given threshold
- Zerotree coding for significance maps
- do not send the whole significance map, each step
- hypothesis: if a coefficient at a coarse scale is insignificant (relative to a threshold), then all the coefficients of the same orientation at the same location at finer scale are likely to be insignificant (relative to the same threshold)
- zerotree coding: introduce a new symbol to code that the current coefficient and all the related finer scale coefficients are insignificant relative to the given threshold


## Zerotree Coding

- Zerotree algorithm iterates two steps:
- dominant step: creates the significance map for current threshold and passes the significant values to subordinate list
- subordinate step: refines the magnitudes of the values in the list (reduces the uncertainty interval by 1/2)



## A)

- The encoded data after zerotree coding contains 7 symbols
- POS, NEG, IZ, ZT, Z (from the significance map)
- 0,1 (interval refining, in the subordinate pass)
- Arithmetic coding:
- a message is represented by an interval between 0 and 1
- depending on the current symbol, the interval is refined
- as the message is longer, the interval is smaller (the number of bits to specify the interval grows)
- Comparison to Huffman codes
- Huffman compression assigns lower number of bits for more probable symbols; it is optimal if probabilities are negative powers of two
- arithmetic compression relates symbols to intervals proportional to symbols probabilities; it is always optimal


## Experiments

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distance $=$ position_distance $\left(1+0.6\left(\left|\cos \_1\right|+\left|\cos \_2\right|\right)+\left(1-\cos \_\right.\right.$normal) $\left.) / 2\right)$


Radius prediction error for layer 2


Radius prediction error for layer 3


Teta prediction error for layer 1


Teta prediction error for layer 2



Height prediction error for layer 2



## Future Development

- Find a distance function that will give good results
- Improve the prediction scheme
- Study other possibilities for the decomposition

