Simplification and LOD
Applications

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Contents

- **Static LOD**
  - Support for LOD-based visualization
    - VRML, Metastrea, Java3d
  - Support for simplification and construction of LOD models
    - Jade, SGI Cosmo, SGI Optimizer, HP Direct Model Tk, IMCompress

- **Dynamic LOD**
  - constant resolution
  - view-dependent resolution

- Use of MultiRes: *data trasmission, GIS, FlightSimulators*

- Resolution Modelling
  - user-driven variable resolution

- Multiresolution for Volume dataset management
Level of detail (LOD)

- LOD repr. [Clark76,Funkhouser93]
  - multiple instances/representations of the same object at different resolutions
  - decide which to render depending on current object position
    - near
    - ...
    - far
  - reduces download time (smaller first)
  - improves frame rate

LOD -- OpenInventor

LOD support under SGI OpenInventor

- scene represented by a tree of shape, property and group nodes
- SoLevelOfDetail node:
  - group node
  - specifies the shape of a single object at multiple level of details (children shape nodes specified in order of decreasing details)
  - at rendering time, object's projected size determines which child is chosen to be displayed
    - uses 3D bounding box to compute the projected area
LOD -- VRML (Virtual Reality Modeling Language)

**LOD support under VRML 2.0**

- **LOD** grouping node (one child displayed at a time):

  ```
  LOD {
    MFNode level[]
    SFVec3f center 0. 0. 0. (-∞, ∞)
    MFFloat range[] (0, ∞)
  }
  ```

- main difference with OpenInventor: object's *distance from the viewer* determines which child is chosen
- level field: list of shape nodes at different level of detail (specified in order of decreasing details)
- center field: object’s baricenter used to compute viewing distance
- range field: defines distances to switch between shape nodes

**LOD -- VRML (Virtual Reality Modeling Language)**

**LOD support under Java3D**

- **LOD Abstract Class**

  ```
  java.lang.Object
  +--javax.media.j3d.SceneGraphObject
  +--javax.media.j3d.Node
  |   +--javax.media.j3d.Leaf
  |       +--javax.media.j3d.Behavior
  |          +--javax.media.j3d.LOD
  |             +--javax.media.j3d.DistanceLOD
  ```

One abstract class *(javax.media.j3d.LOD)* for any possible lod choosing strategy

One implementation *(javax.media.j3d.DistanceLOD)*:

object’s *distance from the viewer* determines which child is chosen
Problems with LOD approach:

1. level transition may generate a popping effect
   - disparity between different LOD instances must be very smooth
   - sudden changes in shaded color or texture are very easily detected by humans!
2. selection of the optimal ranges for LOD transition

(Partial) Solutions

1. generate high quality approximations
2. use dynamic LOD (selection done at run time, adaptively)

LOD Construction

- Standard approach to construct an LOD model
  1. eliminate details
     - textures
     - text
  2. simplify geometry

- But preservation of detail is crucial for good perception
  =>
  use an attribute-preserving simplifier!!
LOD Construction -- Systems for mesh simplification

**Commercial**
- SGI
  - [Cosmo Worlds]
  - OpenGL Optimizer
- HP DirectModel
- IBM Interaction Accelerator
- Innovmetrics IMCompress
- ...

**Public domain**
- VTK (Visualization Toolkit)
- Quadric Error Metrics
- Jade
- Mesh Optimization
- Simpl. Envelopes

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Systems for mesh simplification -- **Jade v2.0**

**Jade 2.0** (Multiresolution Global Error Decim.)

- decimation-based simplifier
  - global error evaluation
  - multiresolution output
  - I/O: SGI OpenInventor

- available on the web (http://miles.cnuce.cnr.it/cgi/enhadecimation.html)

- executable for SGI ws only
Jade’s GUI

**Step 1: Load a mesh**

- Menu bar
- Tools bar
- Status bar
- Reduced mesh window
- Original mesh window

**Step 2: Select the declination parameters**

- Mesh Info
- Declination options

...Jade 2.0...
Jade's GUI

Step 3: Set the history options (if you wish)

Step 4: Start the decimation

Jade's GUI

Step 5: Select an error level

Current mesh info Error slider Error level

Current reduced mesh
Jade’s GUI

Step 6: Save the mesh (or a screen snapshot)

...Jade 2.0...

Jade’s on line HTML User Guide
Cosmo Worlds

- supports creation and editing of virtual 3D worlds (VRML);
- Optimization Tools suite:
  - Polygon Reduction Editor
  - Inline Editor
  - LOD Editor

- Polygon Reduction Editor reduces polygon #:
  - deletes points by curvature
  - discards triangles by area
  - discards edges by length
  - merge initial coordinates (clustering)

but SGI has dismissed the Cosmo division...

... Systems for mesh simplification -- SGI Cosmo Worlds...

Polygon Reduction Editor GUI
**Polygon Reduction Editor**

- clustering-based simplification
- fast
- low quality approximation
- any measure or bound on simplified mesh approximation
- user goes through a number of attempts ==> process cannot be easily reproduced

**Applications**

- Fandisk, 6300 vertices
- Cosmo, 1278 vertices
- Jade, 129 vertices

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**LOD Editor GUI**

A distance LOD produces subsequent levels in the specified target's performance. It's important to measure these levels and compare them with the distance values, based on simulating the same properties.

**Center of the LOD Editor**

- 4 levels of detail
- Lod 0: initial model
- Lod 1: LOD 1
- Lod 2: LOD 2
- Lod 3: LOD 3

**Avoid LODs**

- LOD 0: initial model
- LOD 1: LOD 1
- LOD 2: LOD 2
- LOD 3: LOD 3

**Ranges**

- Range 0: initial model
- Range 1: LOD 1
- Range 2: LOD 2
- Range 3: LOD 3

**Completing Current LOD**

- Once the initial model has been completed, you can select the desired LOD and move or manipulate the objects accordingly.

**Duplicate Current Level**

- Adding a new level will result in a copy of the current level. This allows for easier modification and experimentation.

**Append Current Level**

- Allows for adding additional levels to the existing LODs.

**Stores LOD Data**

- Stores data for each LOD level, enabling easy re-use and modification.

**Create a new LOD**

- A new LOD is created based on the current level. It can be modified and saved for future use.

**IEEE Vis'98 Tutorial**
Systems for mesh simplification -- SGI OpenGL Optimizer

OpenGL Optimizer

- Specifically developed to meet the demands of high performances visualization applications (e.g. CAD/CAM/CAE games, medical, scientific).
- OpenGL API built on top of OpenGL.
- Optimizer v.1.3 will become the core component to SGI/ Microsoft "Fahrenheit" project.

web: http://www.sgi.com/Technology/OpenGL/optimizer/

OpenGL Optimizer Technical Specifications (v.1.1 released June '98)

- Simplification
  - Successive Relaxation Simplifier
    - Target polygon count or percentage
    - Target surface deviation
    - Automatic surface normal recalculation
    - Maintains surface topology
  - Detail removal as percentage of entire model volume space
  - Spatial grid simplifier
    - Non-topological spatial simplification
    - Target model percentage

- Geometry Operators
  - Spatialization - breaks scene graph into optimal spatial sizes
  - Unified triangle stripper and triangle fanner optimizer
  - Spatial and graphics state combiner reduces needless scene graph and rendering overhead
Systems for mesh simplification -- HP Direct Model

- **goal**: enable real-time visualization of very large and highly complex models
- **object oriented toolkit, scene described with a graph**
- **includes different simplification methods (C++ Simplifier classes):**
  - bounding box
  - drop component (discard some nodes from the input graph)
  - convex hull
  - vertex clustering (octree-based), with/without feature edge preservation
  - edge-based decimation
  - tri-stripper

web: http://www.hp.com/unixwork/products/grfx/dmodel

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Systems for mesh simplification -- IBM Interaction Accelerator

**IBM 3D Interaction Accelerator**

- **workstation-based interactive software**
- **enables real-time visualization of very large and highly complex mechanical and architectural CAD models**
- **includes a simplification module, based on the Vertex Clustering algorithm** [Rossignac 93]
Systems for mesh simplification -- IMCompress

**IMCompress** by Innovmetrix
(specialized on range scanner data management; sw by Soucy et al.)

- automatic polygon reduction tool, included in the PolyWorks integrated line of software tools for building 3-D polygonal models from 3-D range scanner data
- adopts a *global error decimation* approach
- guarantees bounded 3-D tolerances between compressed and original models
- preserves local topology, surface edges and color / textures

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...Systems for mesh simplification -- IMCompress...

**IMCompress**
- preserves color / textures
Other systems for Surface Simplification

- **Rational Reducer Surface simplifier**, by System in Motion [http://www.sim.no/polyred.html](http://www.sim.no/polyred.html)

“The future (?)”

- What **near future** will take us?
  - **MPEG 4** -- a new International Standard
  - **Fahrenheit architecture** -- an industrial project (MS + SGI)
**MPEG-4**

- ISO standard from the MPEG (Moving Picture Experts Group)

- Version 1 I.S. in Dec.’98
  - still images and video
  - audio
  - 3D graphics:
    - VRML-like data definition features (with binary format)
    - improved control of 3D data animation and behavior
    - texture compression
  - ... and more...

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**MPEG-4**

- Version 2 planned for Dec.’99
  - 3D graphics:
    - improved animation (body animation)
    - 3D mesh compression
      - topology: topologic surgery
      - geometry: quantization, predictive coding, entropy coding
    - LOD representation
    - progressive representation (and transmission)
  - ... and more...

- See web at: [http://cselt.it/mpeg](http://cselt.it/mpeg)
Fahrenheit Architecture

Collaborative SGI - Microsoft project:
- design of a complete high-performance graphics architecture, for both WinNT and Unix
- three components (API):
  - Fahrenheit Low Level
    - expected Y2000, replaces Direct3D
  - Fahrenheit Scene Graph
    - tree-like data structure for scene representation
    - expected 2Q’99, ~replaces Open Inventor
  - Fahrenheit Large Module Visualization
    - tools for the visualization of large models, based on SGI Performer and HP DirectModel
    - expected 2Q’99, replaces SGI Performer and MS plans to deliver HP DirectModel

Multiresolution Management

Exploit multiresolution representation:
- to speed-up visualization
  - improve visualization frame rate and quality in environments with constrains on data transmission/rendering
  - dynamic LOD
  - view-driven variable resolution
- to enhance geometric data content
  - link geometric detail to a user-driven interpretation of the data
  - resolution modelling
Dynamic LOD

Reasons for the construction of **Dynamic LOD**:

- Produce the **best-fit model** for a given graphics throughput (constant resolution)
  
  Can be done:
  - interactive simplification (very low quality)
  - post-processing (history or progressive mesh)

- Produce the **best-looking model** for a given viewpoint, also known as **adaptive LOD** (or variable resolution)

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**MetaStream™**

(http://www.metastream.com)

- new open PC file format announced jointly by Intel and MetaCreations
- plug-in technology to create, deliver and display 3D objects:
  - **progressive transmission** over Internet of 3D data
  - **dynamic selection of best-fit model** (given the graphics performances of the local host): MetaStream plug-in (or user) may adjust the resolution of any object, so that it will rotate and react in real time
  - developed to manage 3D meshes with **texture-coded detail** (e.g. color)
  - data creation: MetaStream 3D file format conversion plug-in available for Ray Dream Studio™ 5 and Ray Dream 3D™ modelling applications
Metastream plug-in example:
- best-fit model (Pentium 166MHz) 4,667 faces
- user-selected resolution 23,161 faces

Multi-Resolution Geometry SDK™
(http://www.sven-tech.com/products/mrg/)
- software development kit
- to build interactive application based on dynamic lod technology
- available for Web, PC, Playstation, N64
- Integrates with 3DS MAX, Softimage, Maya, Lightwave, and proprietary pipelines/run-time formats.
View-dependent best-looking model:
- distance from the observer
- region of interest

Variable resolution: 1% silhouette error, 20% interior error (1,950 faces).

(c) Sphere with 537 triangles (adaptive LOD)

Variable resolution: 1% silhouette error, 20% interior error (1,950 faces).
Applications: terrain visualization

- full resolution
  - 54K triangles
- variable resolution (view-depend.)
  - 12K triangles

...Dynamic/Adaptive LOD ...

Applications: terrain visualization

- constant resolution
  - 12K triangles
- variable resolution (view-depend.)
  - 12K triangles
Dynamic / Adaptive LOD ...

- once we add shading (and texture-based color) the difference becomes negligible

Original terrain, 54K faces
Variable resolution, 5K faces

MultiRes - Data Transmission

- Moving large meshes over the net is critical
- LOD models:
  - send different levels of detail in a sequence
  - each level gives a full mesh, replacing the previous level
  - levels stored independently --> redundant information transmitted
- Linear sequences (e.g., PM):
  - send data in given sequence and perform incremental reconstruction
  - reconstruction based on progressive refinement: no data wasted
  - Delaunay meshes can be reconstructed in linear time

[Snoeyink Van Kreveld '96 , De Floriani, Magillo and Puppo '97]
Multiresolution applied to terrain data

- Operations:
  - display
  - windowing
  - estimation of local properties
  - contour lines
  - overlay with thematic maps
  - visibility computation and line-of-sight problems

- Each operation can be performed at a level of detail specified by the user/application.

- Hierarchical organization can support structured processing, and speedup data access.

All queries on a multiresolution model can be seen as specialization of a general query

- threshold function \( \tau : \mathbb{R}^2 \rightarrow \mathbb{R} \)
- focus set \( F \) in \( \mathbb{R}^2 \)
- General query:

  return a representation of the surface satisfying \( \tau \), and relevant with respect to \( F \) (e.g., either restricted to \( F \), or made of elements that intersect \( F \)).

- Examples of focus set:
  - a **point**: point location query (to estimate local properties)
  - a **polyline**: configuration of terrain along a street, a river, etc.
  - a **rectangle**: windowing
  - a **sector**: view frustum for perspective display
Multiresolution query processing -- two alternative approaches:

- **two-steps**: extract a mesh, then resolve query on it
  - exploit standard algorithms for single-resolution representations
  - can be less efficient

- **direct**: resolve query directly on the multiresolution model
  - exploit the inherent hierarchical structure of a multiresolution model
  - can be more difficult to implement

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**VARIANT** (VAriable Resolution Interactive ANalysis of Terrain)

- Multiresolution GIS based on the MT
- MT-manager module implements basic operations on the MT:
  - I/O operations
  - update operations
  - general query
- MT-client modules implement applications through primitives provided by the MT-manager:
  - MT-builder: construction
  - MT-viewer: perspective display
  - ............
MultiRes - GIS...

VARIANT (VARIABLE Resolution Interactive ANALYSIS of Terrain)

see web:
http://www.disi.unige.it/research/Geometric_modeling/

MultiRes - Flight Simulation

Based on adaptive LOD. Resolution of extracted mesh is varying with:
- distance from viewpoint
- size of triangles projected onto the screen

Extraction algorithms based on dynamic update of extracted mesh are better suited to navigation

Existing interactive systems:
- Georgia Tech display algorithm (based on implicit hierarchy of right triangles)
- TopoVista from CS Arizona (based on explicit hierarchy of right triangles)
- VARIANT animation mode (based on explicit MT)
- ..................
Resolution Modeling

A three-phases global **modelling conceptual framework** may be conceived as follows:

- **shape modeling**, canonical 3D shape design (CAD design / automatic acquisition / surface fitting) *user-assisted*
- **multiresolution model construction** (supported by surface simplification tools) *semi-automatic*
- **resolution modeling**, construction of variable resolution representations (depends on user interpretation/use of data content) *user-assisted*

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Two different approaches in literature:

- Interactive multiresolution mesh editing based on patch-based surface representations and mesh subdivision
  
  D. Zorin, P. Schroeder, W. Sweldens
  “Interactive Multiresolution Mesh Editing”
  Siggraph ’97

- Zeta, resolution modeling based on multiresolution triangle-based representation
  
  P. Cignoni, C. Montani, C. Rocchini, R. Scopigno
  “Zeta: a Resolution Modeling system”
Zeta [Cignoni et al. ’98]

- construction of **variable resolution models** from a multiresolution mesh represented with the hypertriangulation scheme.

Zeta supports:

- efficient extraction of **fixed resolution meshes**;
- unified and interactive management of **selective refinements** and **selective simplification**;
- easy **composition** of selective ref./simpl. actions;
- **no cracks** in the variable resolution mesh produced;
- **shape editing** capabilities;
- **interactive** response times.

- available on the web - http://miles.cnuce.cnr.it/cg/zeta.html (SGI only)

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Zeta – Hypertriangulation Scheme

- **Zeta input:**
  - a simple multiresolution representation
  - (history of incremental updates of a global_error-based simplificator)

- **Zeta run time representation:** **hypertriangulation scheme**
  - holds in a compact way **geometry, error intervals** and **topology**
  - each single local update is not replaced, but glued to the current multiresolution mesh
Zeta -- Variable resolution modeling

Proposed approach:

- interactive selection of resolution on a base mesh, through the composition of multiple selective refinements / simplification actions each of them affecting a focus region
Zeta -- Region of interest selection

- Interactive selection of a *radius* and a *focus point*, which define the region of interest (roi) affected by the following *selective refinement / simplification actions*.
- Resolution in the updated area will depend on the approximated geodetic distance from the *focus point*.
- Distances computed solving a shortest path tree problem on the surface graph (graph arcs = mesh edges).

Zeta -- Selection of the roi *radius*.

The sphere represents visually the approximate magnitude of the selective refinement region of interest (roi).
Zeta: selective refinement

Error management in selective refinement

- error in the updated area varies following a user-defined function
  ![Error in updated area graph]

- during the topologic expansion the border of the updated area should not self-intersect or fold-over
  (a double heap is adopted to maintain the facet-edges to be further expanded)

- ordering the facet-edge expansion is critical to:
  - minimize size of the current expansion front
  - get a smoother approximation refinement on the updated area

![Facet-edge expansion diagram]
Zeta: **composition** of multiple selective refinements

User changed the current Error function

Zeta: **selective simplification**

Step 1) revert the Error function

Step 2) select the focus point
Zeta: interactive shape editing actions

original mesh

shape editing on the low res. mesh (1)

shape editing on the low res. mesh (2)

results of shape editing in high resolution

Zeta -- Applications

Use Zeta to produce illustrations:

- Use multiple rendering modes which depend on mesh resolution:
  - normalize error in (0., 1.)
  - render shaded with opacity = (1-error)
  - render wireframe with opacity = error
Use of multiple rendering modalities

- normalize error in (0., 1.)
- render shaded with opacity = (1-error)
- render feature edges only with opacity = error

Multiresolution in Volume Visualization

- Why?
  - to reduce \textit{data size} (run time)
  - to improve \textit{interactivity}
    - simplified models, LOD representation
    - progressive rendering
  - to \textit{focus} on region of interest
    - use full resolution only on limited areas
Simplification of Volume Data

- Extension of techniques developed for surfaces:
  - subsampling
  - octree-based decomposition scheme [Wilhelms van Gelder 94]
  - refinement of Delaunay mesh [Cignoni et al. 94, HamannChen, 1994]
  - decimation [RenzeOliver ‘96, Cignoni et al. 97, StaadtGross98]

Multiresolution in VolVis

Approaches based on:

- **hierarchical structures**
  - octrees, k-d trees [WVGel’94]
  - hierarchical Delaunay tetrahedrization [Bertolotto et al., 1994]
  - hierarchy of regular tetrahedra [Zhou et al’ 97]
  - adaptive hierarchy of non regular tetrahedra [Grosso et al ’97, Rumpf et al ’97]

- **linear sequence of tetrahedra** [Cignoni et al ’94, ’97]

- **MT 3D** [under implementation]

- **wavelets** [Muraki92-93,Guo95]
**TAn**  (Tetrahedra Analyzer)  [Cignoni et al.94/97]

- Volume visualization system based on linear sequences of tetrahedra

**Features:**
- both **structured** and **unstructured** data
- simplification based on either **refinement** or **decimation**
- extraction of a mesh at uniform resolution
- efficient extraction and rendering of multiple **isosurfaces**
- **direct volume rendering** through tetrahedra projection
- **hybrid rendering**
- **progressive rendering**

**Multires in VolVis -- Data Compression**

**TAn** - dataset simplification

**some results:**
- SOD
  - 32x32x32, 32K sites
- BuckyBall
  - 32x32x32, 32K sites
- Bluntfin
  - 40x32x32, 40K sites
- Post
  - 38x76x38, 109K sites
... Multires in VolVis -- Data Compression

- bluntfin dataset 40x32x32
  full precision (40K sites) 2% precision (2K sites)

... Multiresolution VolVis ...

A multiresolution organization of the data may support

- **isosurface fitting**: simplified surfaces comes free
  - simplification is operated on the dataset (pre-proc. time);
  - efficient isosurf fitting, no simplification added costs;

- **hierarchical** or **progressive** rendering

- **multiresolution** data rendering
Progressive rendering

The availability of a multiresolution representation allows to:

- visualize a low resolution model when user–system interaction is high (e.g., during interactive view settings);
- visualize a high resolution model when user–system interaction is low.

The choice of the resolution level may depend on:

- complexity of the dataset at full precision;
- graphics performances of the current system;
- required rendering quality and/or frame rate.

Multires in VolVis – Hierarchical Rendering

Multi-dimensional Trees

[Wilhelms et al. 94]

an example of hierarchical Coherent Projection

[Simulated Flow Data (244x256 Rayleigh–Taylor)]

Coherent Projection on RGBA

Hierarchical TWR with Stilling Time

0.5 Einst - 0.4 second

0.2 Einst - 3.2 seconds

0.1 Einst - 1 second

0.5 Einst - 2.2 seconds

Image by J. Wilhelms and A. van Gelder, UCSC
**Multires in VolVis -- Rendering**

**TAn**

- Buckyball
  (chemical dataset, 32x32x32)

- projected tetrahedra algorithm, different data resolutions:
  - 100% of the data
  - ~50% of the data
  - ~10% of the data

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**Multiresolution VolVis**

**Multiresolution rendering**

how multiple levels of detail (LOD) may contribute to a single image?

**if the goal is to produce images of reality:**

- for each object, use an LOD proportional to its visible magnitude or distance to the observer (in the current view)

  (e.g. virtual environment rendering, VRML applications)

**if the goal is to get insight into reality:**

- adopt *viewing filters*, e.g. process the data to give synthetic, enhanced and/or interpreted visual presentation

  (e.g. multiple resolution models and MagicSphere)
**Multiresolution rendering via MagicSphere**

Based on the metaphor of a 3D glass lens:

- User defines a **spherical focus volume** in the data space;
- Two different levels of detail are linked to the interior / exterior of MagicSphere;
- User can define **different rendering modalities** for the data visualized in the interior/exterior of MagicSphere.

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**MagicSphere** with a MultiRes filter.
Multiresolution in VolVis...

**TAn 2 (Tetrahedra Analyzer Second Release)** [Cignoni et al. 94/97]

- Volume visualization system based on **MT** multires data structure

**Features:**
- Portable (win, sgi, linux)
- Unstructured data
- Simplification system based on either refinement or decimation
- Extraction of a mesh at uniform resolution
- Efficient extraction and rendering of multiple isosurfaces
- Fixed and variable resolution dataset management

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Variable resolution features:

Refinement depending on
- Field value
- Space based
- Dataset clipping through MT