3D for all!

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Compressing and simplifying complex 3D polyhedra

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What motivates you?

- Problem solving pleasures?
- Peer recognition?
- A hunger for knowledge?
- The need to impact society?

A vision for GVU

- **Invent technologies that will make humans more effective in their professional, scholastic, and private activities**
- **Teach objectives, motivation, creativity, teamwork... the theory... and Java3D**
- **Work with industrials to understand where they are coming from and to help them decide where to go**

How do we get there?

- Study humans and organizations
  - Activities/needs
  - Capabilities/limitations
- Explore technologies and inventions
  - R&D strategies and invention history
  - State-of-the art, possibilities, limitations
  - Hands-on experience/use what you create
- Understand commercialization
  - Market forces and acceptance issues
  - Engineering and testing for usability
  - Development and maintenance

Some Examples

- Multimedia capture of courses
- Mobile visual communication devices
- Intelligent appliances
- VR treatment of phobia
- Collaborative CAD
- Data mining
- Visualization

How big is 3D graphics?

- All graphic adaptors will be 3D enabled
- Next “must” after mouse, color, www
- Perspective = Detail + Background
- Intuitive
- Appealing
- Drives huge markets

What is it good for?

- **3D models of**
  - terrain, underground cavities
  - homes, offices, buildings, cities
  - factories, assembly lines, robots
  - airplanes, cars, ships
  - consumer products
  - human organs, molecules
  - engineering simulation results
  - avatars, shopping malls, enemies

Why would I use it?

- Games, electronic commerce
- Design, PDM
- Design review, ergonomy
- Bids/part catalogs
- Communication/marketing
- Data understanding
- Intuitive navigation/selection
- Training/therapy

Why can't I?

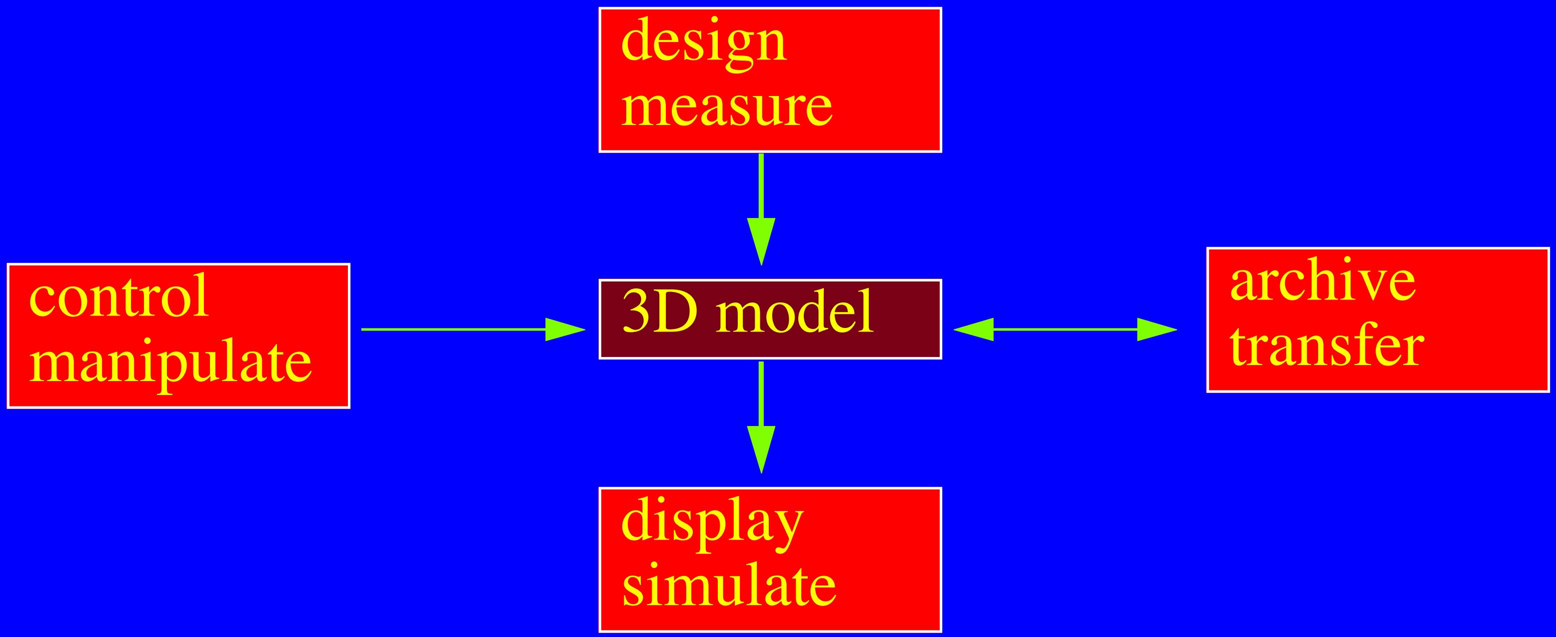
- Complex models
- Accessed through internet/phone
- Slow connections
- Limited rendering speed and storage
- Difficult user interface

What is a 3D graphic model?

- Representation of 3D geometry
- Surfaces and lighting model
- 3D images, textures
- Sampling of 4D light field
- Procedure + parameters for 3D graphics

What is a 3D graphic application?

- **Representation**
  - **Geometry: vertex coordinates**
  - **Topology: triangle/vertex incidence**
  - **Photometry: colors, normals, textures**
- **Architecture of a 3D system**



What makes it effective?

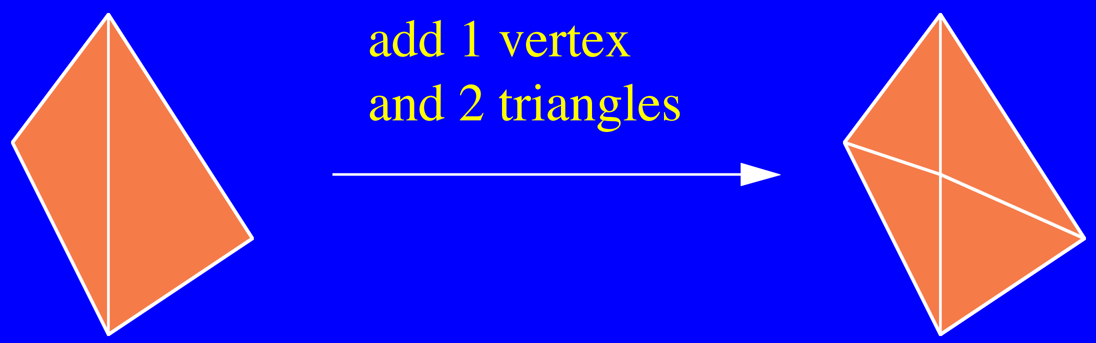
- Fast access to 3D databases
- Internet connectivity
- Intuitive view and model manipulation
- Realtime feedback

The human needs?

- **I want to access the data!**
  - **Compression**
  - **Progressive transmission**
- **I want to see what I am doing!**
  - **Simplification, graphic acceleration**
- **I want to be in control!**
  - **Virtual camera**

Why focus on triangles?

- Optimized rendering systems
- Easily derived from polygons and surfaces
- Good measure of graphic complexity
  - Twice more triangles than vertices



How many do you need?

- A sphere=12x24x2 triangles
- Airplane=50,000,000 triangles
- A city?
- A human body?

How much space do they take?

- Geometry: 3 coordinates per vertex
- Topology: 3 vertex indices per triangle
- Photometry: Normals, textures, colors
- Total: up to a 100 bytes per triangle

Is that a problem?

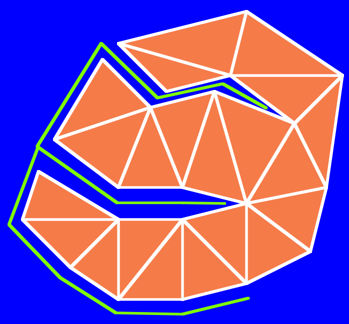
- **A 100MT model takes:**
  - **A month to download over the phone**
  - **An hour to display**
- **Complexity will grow faster than bandwidth and graphic performance**

How to cope with this complexity?

- **Don't bother with unimportant details**
- **Compress**
  - **Helps with transfer, storage, paging**
- **Eliminate redundant graphic operations**
  - **Visibility, back-face culling, triangle-strips**
- **Trade accuracy for performance**
  - **Lossy compression, simplification, images**

How good is compression?

- **Lossless compression**
  - Preserves geometry and topology
  - Reduces # of bits for triangle/vertex incidence
  - Does not compress vertex representation
- **Current approach (Taubin&Rossignac)**
  - Cut surface into tree of corridors
  - Encode internal triangulation of corridors
  - 1.2 to 2.2 bits per Triangle
  - plus the vertex coordinates



Do I need full numeric accuracy?

- Models are approximations anyway
  - Imprecise measures or toleranced dimensions
  - Limited accuracy in geometric computation
  - Truncated coordinates to nearest float or double
- Use very short integers!
  - Floats are bad for geometry
    - » Accuracy grows with distance to origin
    - » Geometric models need uniform accuracy
  - Integers are perfect
    - » Uniform accuracy through out the model
    - » More precise than floats for same number of bits
  - Don’t need 32 bits
    - » 11 bits: 1/2mm for an engine block

Can this save more storage?

- Lossy compression
  - shorter representations of vertex coordinates
  - more frequent repetitions of values
  - efficient entropy coding schemes
- Current approach (Taubin&Rossignac)
  - Quantize vertex coordinates to 8-12 bits
  - Predict location of next vertex
  - Code difference (short corrective vector)
  - Use variable length coding (entropy)
  - Compresses down to about 6 b/T

Do I need all these triangles?

- Can't see most of them
  – quickly discard invisible ones
- Many details are smaller than a pixel
  – remove them or use an impostor
- Surface tesselations are not optimal
  – Need accuracy at silhouettes
  – Could use coarser meshes elsewhere

How do I take advantage of this?

- Preompute approximations of features:
  - surface subsets, objects, groups
- Use approximations to accelerate graphics
  - when resulting visual error acceptable
- Current approaches
  - Coalesce clusters of vertices
    - » How to form the clusters' hierarchy?
    - » Where to place the result of coalescing a cluster?
  - Remove degenerate triangles
  - Dynamically select LOD based on view
    - » How to measure error?
    - » How to allocate rendering time?
    - » How to avoid artifacts?

Do I need training to use 3D?

- Why should you? Your kids got none..
- Few designers/many users
  - Scientists, doctors
  - Non technical professionals
  - Home shoppers
  - Game players

How do I control the view?

- You don’t want a HMD
- You can’t afford a CAVE
- The track ball will break your... enthusiasm
- The mouse is not intuitive
- Use a virtual camera!

What is a virtual camera?

- 3D model
- (Large) screen
- Table with drawing or global view
- Move small camera over the table
- See in 3D what you are pointing at

Outline of the presentation

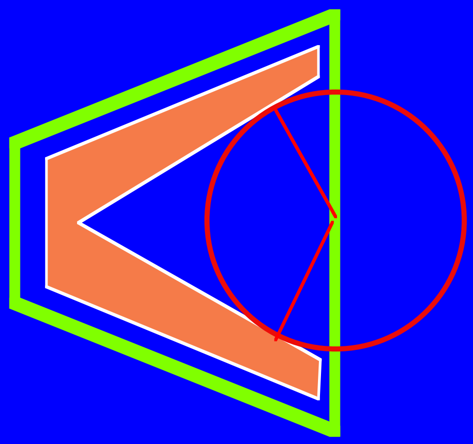
- Geometric and topological compression
  - Taubin&Rossignac
- Grid-based vertex coalescence
  - Rossignac&Borrel
- Edge-collapse vertex coalescence
  - Ronfard&Rossignac
- Real icon for a virtual camera
  - Rossignac&Wolf

How do I measure the error?

- **Geometric 3D deviation**
  - View-independent
  - Allowed by model tolerance
- **Image space error**
  - View-dependent
    - » Silhouettes, color/shading variation
  - Bounded by projection of 3D error
- **Color error**
  - View dependent
  - Error on color reflected by surface point
  - Depends on surface orientation
  - Not important for most applications

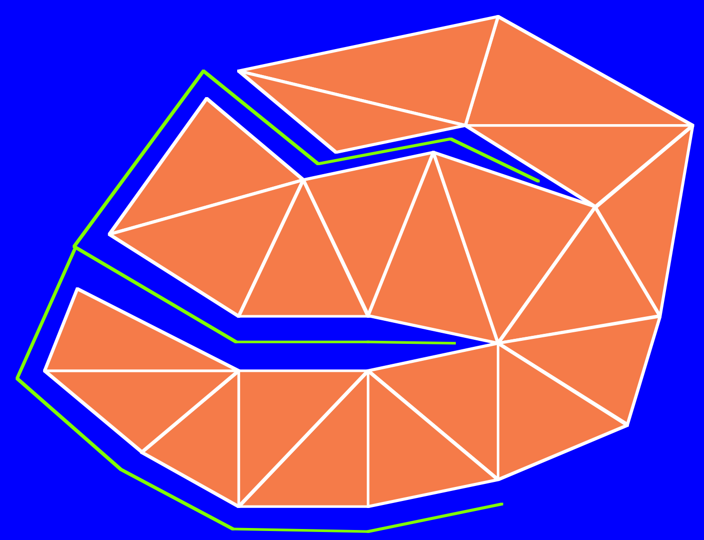
Hausdorff error

- $H(A,B)=\max(d(a,B),d(b,A))$
  - for all a in A and b in B
- Radius of largest ball
  - that has its center on one surface and
  - that is disjoint from the other surface
- Expensive to compute
  - Need not happen at vertex or edge



3D Compression

- **Geometric Compression through Topological Surgery**
  - **Gabriel Taubin and Jarek Rossignac**
  - **IBM Research Report RC 20340,**
  - **Revised 7/1/97**



Mesh representations and storage

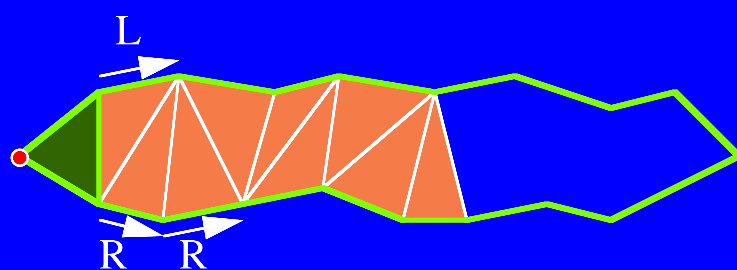
	vertex 1			vertex 2			vertex 3		
Triangle 1	x	y	z	x	y	z	x	y	z
Triangle 2	x	y	z	x	y	z	x	y	z
Triangle 3	x	y	z	x	y	z	x	y	z

Independent triangles: **36** B/T
- 9x4 B/T

Triangle 1	1	2	3
Triangle 2	2	3	4
Triangle 3	3	5	1

vertex 1	x	y	z
vertex 2	x	y	z
vertex 3	x	y	z

Vertex and mesh tables: **18** B/T
- 3x4B/V + 3x4B/T

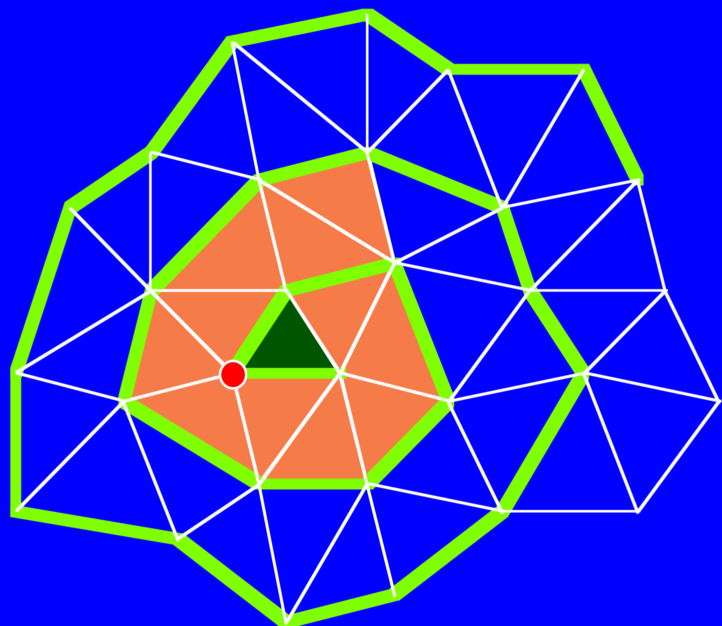


vertex 1	x	y	z
vertex 2	x	y	z
vertex 3	x	y	z

Strip 1	10
Strip 2	7

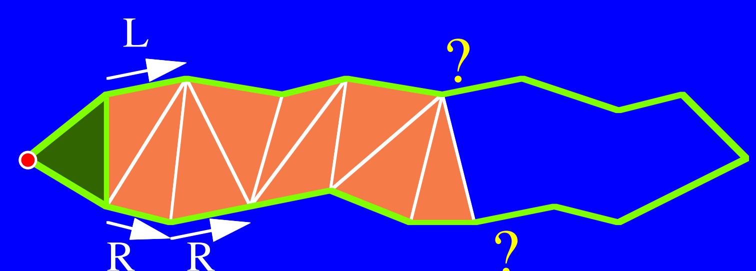
Triangle strips: **13.4** B/T
- 1.1x3x4B/T + 1B/S + 1b/T

Constructing and encoding corridors



Connecting vertices in a spiral cut defines the boundary of a corridor (both sides).

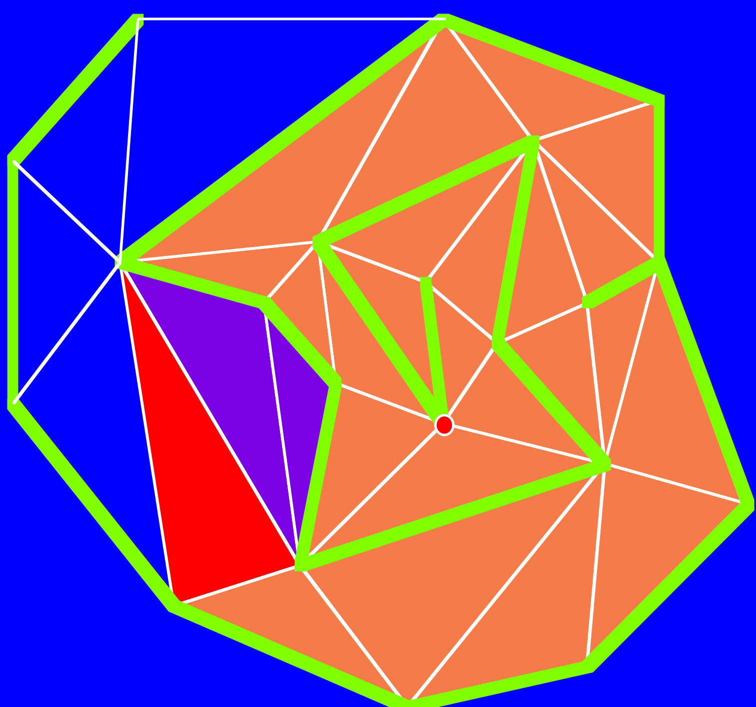
Given the boundary and the starting point, we need 1 bit/triangle to encode a strip

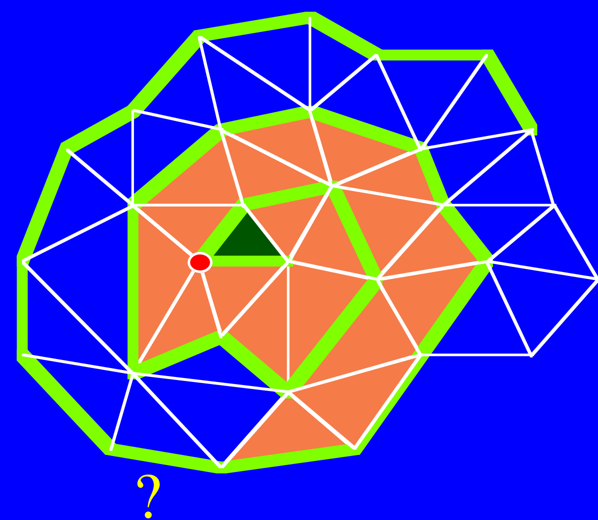


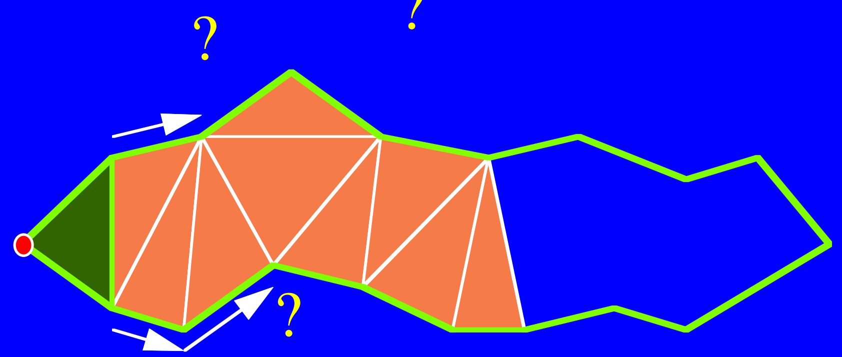
Store vertices in their order along the spiral
Store one L/R bit per triangle (except first)

Wait a minute!

- The corridor may have warts!
- The spiral may cut itself or split!
- The corridor may bifurcate!

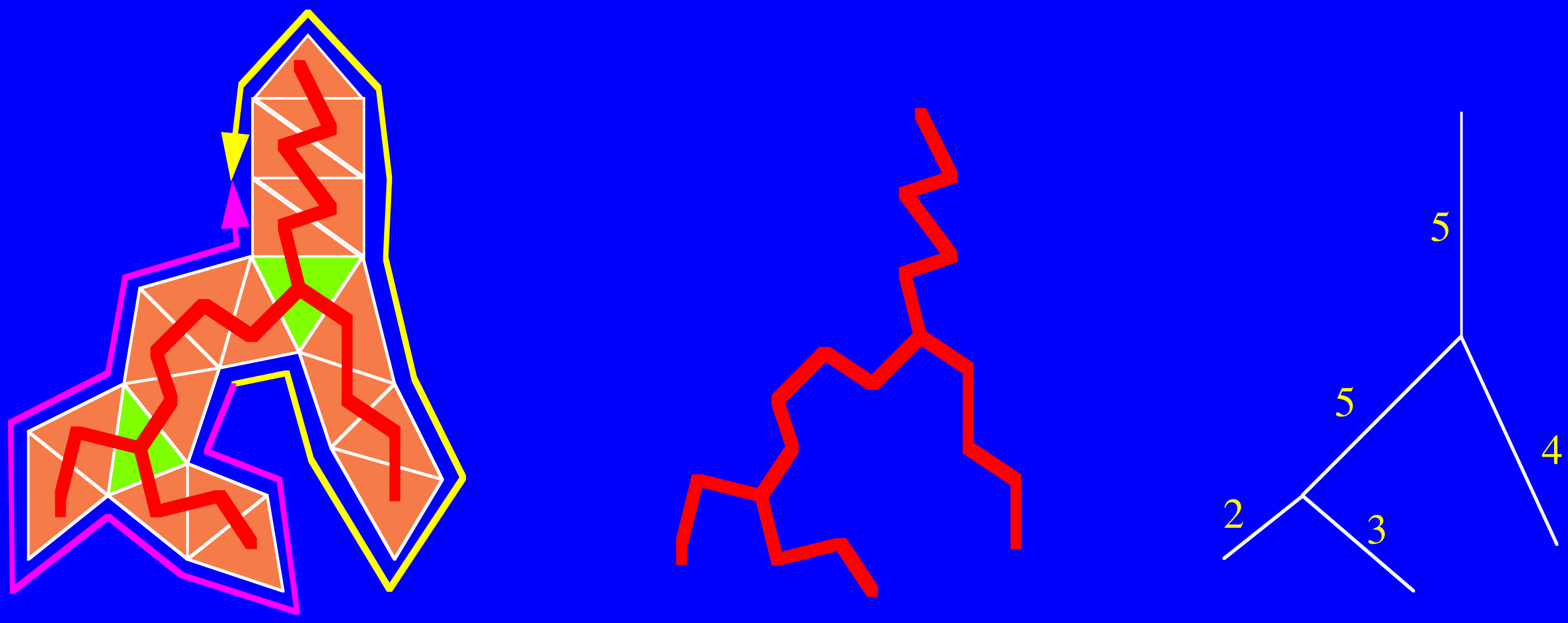






Compression details

- **Compress trees using runs**
  - Cut = Vertex spanning tree (zipper)
  - Corridors = Dual binary tree
- **Encode interior triangulation of corridor**
  - 1 bit per triangle



Lossy geometric compression

- Quantize all vertex coordinates
  - Desired precision
  - Consistent with modeling tolerance
- Use tree ancestors to predict next vertex
  - Optimal linear combination of ancestors
  - Store corrective vectors (error)
- Use variable length coordinates
  - Coordinates of correction are small integers
  - Lots of values repeated for complex models
  - Use short codes to frequently used values
  - Need between 3 and 10 B/T
    - » depending on tolerance

Implementation

- VRML-2 compression/decompression
  - G. Taubin, P. Horn, F. Lazarus (IBM)
  - Compressed models: average of 1 B/T
    - » Depends on complexity, smoothness, tolerance
    - » Example: 160K triangle model
      - Tolerance: 0.0005 of model size (11 bit quantization)
      - Incidence: 1.2 b/T
      - Geometry: 5.4 b/T
  - Decompression speed: 60K T/sec

Other compression techniques

- **Deering (Siggraph'95)**
  - **Extend triangle strip**
    - » **Maintain buffer of 16 vertices for reuse**
    - » **Op-code for building next triangle: 4-6 b/T**
    - » **Vertex quantization and variable length coding**
      - **Local coordinate system**
  - **Good for graphics:**
    - » **In-line fast decoding and small local storage**
- **Hoppe (Siggraph'96)**
  - **Store vertex-split operations**
    - » **Index to vertex**
    - » **Index to 2 adjacent edges**
    - » **Displacement(s) from common vertex to new pair**
      - **Short vectors (variable length coding)**

Model simplification

- **Multi-resolution 3D approximations for rendering complex scenes**
  - Jarek Rossignac and Paul Borrel
  - Geometric Modeling in Computer Graphics'93
- **Full-range approximations of triangulated polyhedra**
  - Remi Ronfard and Jarek Rossignac
  - Eurographics'96 (Computer Graphics Forum)

Multi-resolution models

- Show distant features at lower resolution
- Split the model into small features
  - Use design entities (solids or groups)
  - Split large and complex solids
- Precompute several levels of detail per feature
  - Logarithmic reduction of triangle count
  - Guaranty error bound
- Select appropriate resolution for each feature
  - Perspective projection of error estimate
  - Position on screen, velocity
- Merge groups of small distant features
  - Preserve overall volume and color?

Vertex merge (Rossignac&Borrel)

- Cluster vertices using grid
  - Compute truncated coordinates for each vertex
  - Use them as a cluster identifier
- Coalesce vertex clusters
  - Compute location of representative vertex
  - Associate each vertex with its new location
- Remove degenerate triangles
  - Those with 2 or 3 vertices in the same cluster
- Build display lists for each LOD
  - New/old normals and textures
  - Triangle strips

Pros and cons for Rossignac&Borrel

- **Advantages**
  - Much faster than any other method
  - Very robust (no restriction on input data)
  - Simple code (implement in hours)
  - Guaranteed error bound (cell diagonal)
  - Reduces topological complexity (holes...)
  - Very effective for complicated details
  - Does not create holes of gaps in surface
- **Drawbacks**
  - Suboptimal for simplifying smooth flat surfaces
    - » A vertex cannot travel more than the cell size
  - Simplified surface may self intersect
  - Hard to achieve precise triangle count

Extensions and variations

- Low&Tan, Interactive 3D Graphics'97
  - Sort vertices by importance in each cell
  - Attract vertices from neighboring cells
- Luebke&Erikson, Siggraph'97
  - Octree or other vertex clustering technique
  - Hierarchy of clusters
  - View defines which clusters are active
  - List of active triangles
  - Temporal coherence for adaptive LOD
  - Bad for T-strips and display lists
  - Use only for large, complex solids
- Popovic&Hoppe, Siggraph'97
  - Combine PM with Rossignac-Borrel's proximity

Edge collapse (Ronfard&Rossignac)

- Coalescence vertices
  - that are further apart than the tolerance
  - as long as they slide close to the surface
- Efficient error estimate for a cluster
  - Max distance between representative vertex and all the planes supporting the incident triangles upon the vertices of the cluster
- Approach
  - Evaluate error associated with edge collapses
  - Maintain sorted list of candidate edges
  - Keep collapsing edges until reach
    - » tolerance or
    - » desired triangle count

Pros/cons for Ronfard&Rossignac

- **Advantages**
  - Better simplification ratios for same tolerance
  - Can control error or triangle count
  - Can choose whether to preserve topology or not
- **Drawbacks**
  - Requires maintaining incidence graph
  - Imposes topological restrictions on data
  - Slower than grid-based coalescence
  - Hard to achieve precise triangle count

Extensions and variations

- Garland&Heckbert, Siggraph'97
  - Use least square distance to supporting planes
  - Propagate only 4x4 matrix instead of all planes
  - Not a bound on the error!
- Hoppe, Siggraph'96
  - Store sequence of edge collapse operations
  - Use it's inverse as a progressive mesh (PM)
  - Each split is defined by
    - » 2 adjacent edges in the previous model
    - » The relative position of the 2 new vertices

Conclusion

- Increasingly complex triangular 3D models
- Compress, simplify within tolerance
- Bit-efficient coding: 1 Byte/triangle
- Simplification for fast graphics:
  - Grid-based vertex coalescence
    - » Fast, robust, effective, suboptimal
  - Edge-collapse
    - » Slower, more precise, better results
- Need extractable encoding for
  - view-dependent multi-res transmission