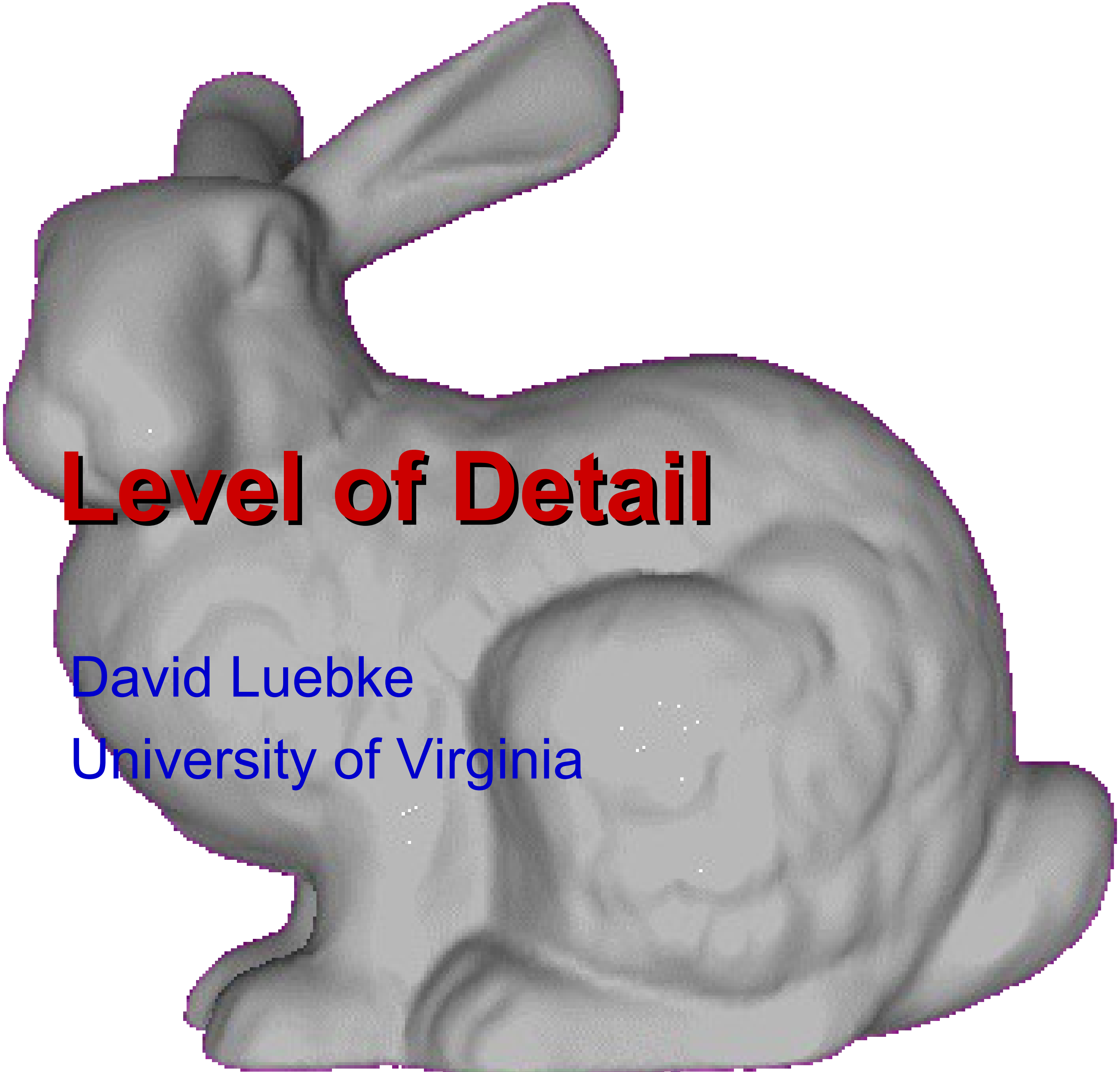
Notice

- Next Tuesday: Final exam
- Next Thursday: Guest speaker
  - NHN platform team director
    - 권택순
  - Will talk about the game development process in NHN
  - 자대생 출석체크 할 것임 .
  - 한글 수업



Level of Detail

David Luebke
University of Virginia

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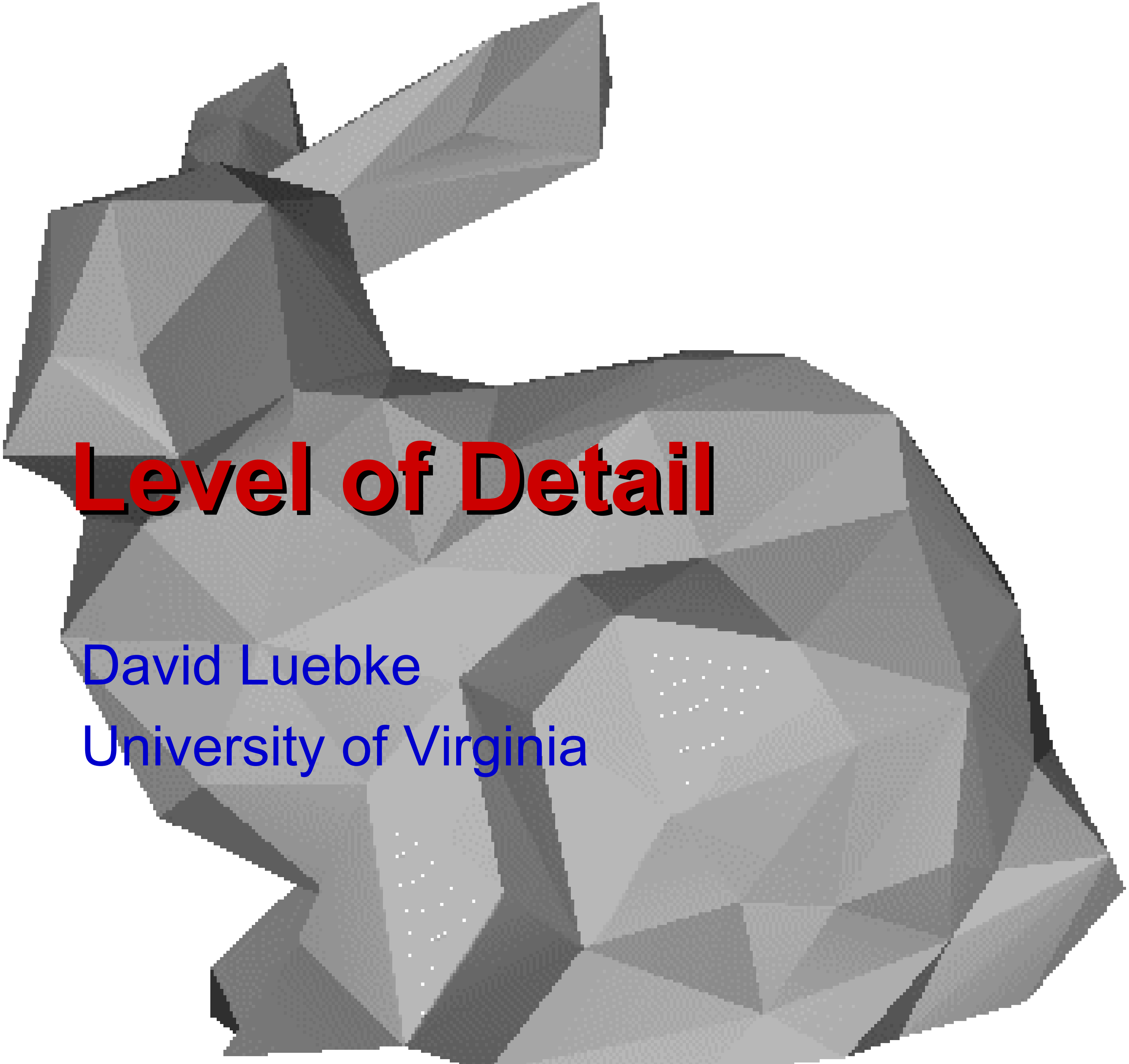
University of Virginia



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Introduction

- Level of detail (LOD) is an important tool for maintaining interactivity
  - Focuses on the fidelity / performance tradeoff
  - Not the only tool! Complementary with:
    - Occlusion culling
    - Image-based rendering [etc]

Level of Detail:
The Basic Idea

- The problem:
  - Geometric datasets can be too complex to render at interactive rates
- One solution:
  - Simplify the polygonal geometry of small or distant objects
  - Known as *Level of Detail* or *LOD*
    - a.k.a. mesh reduction, multiresolution modeling, …

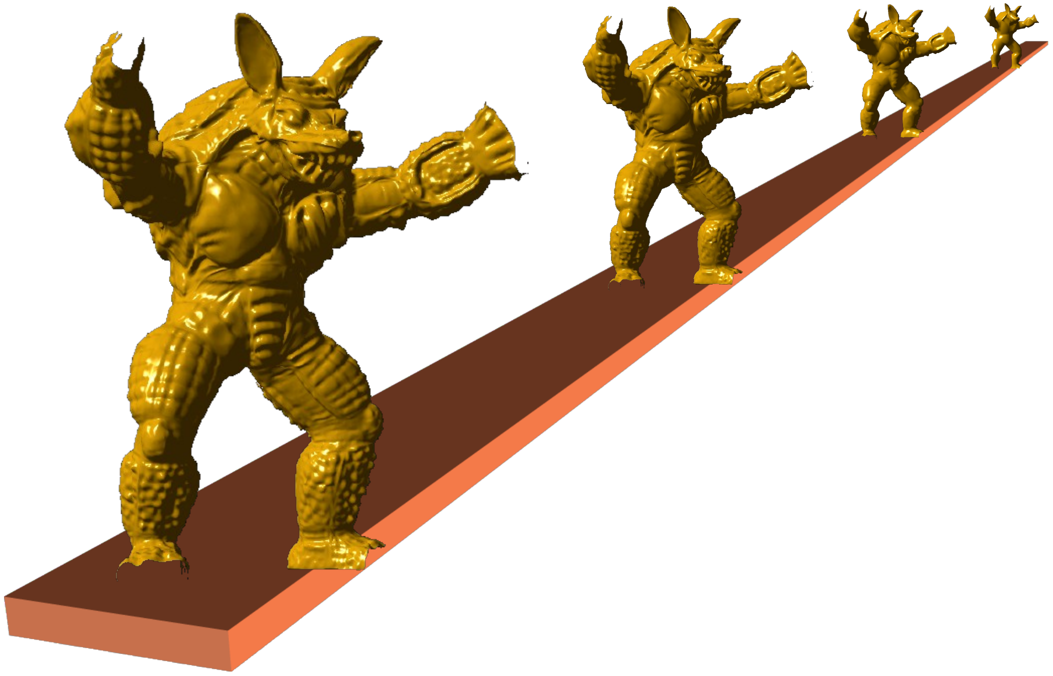
Level of Detail

- A recurring theme in computer graphics: trade fidelity for performance
  - Reduce *level of detail* of distant, small, or unimportant objects

249,924 polys   62,480 polys   7,809 polys   975 polys

Level of Detail

- A recurring theme in computer graphics: trade fidelity for performance
  - Reduce *level of detail* of distant, small, or unimportant objects



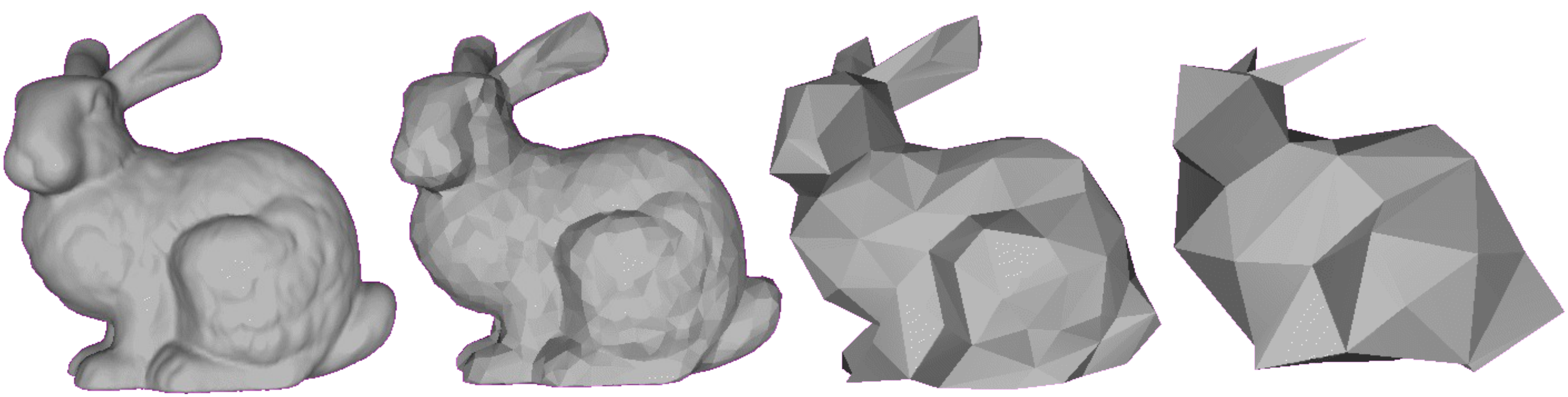
Level of Detail:
Motivation

- Big models!
  - St. Matthew: 372 million polygons
  - David: 1 billion polygons

Courtesy Digital Michelangelo Project

Level of Detail:
Traditional LOD In A Nutshell

- Create *levels of detail* (*LODs*) of objects:

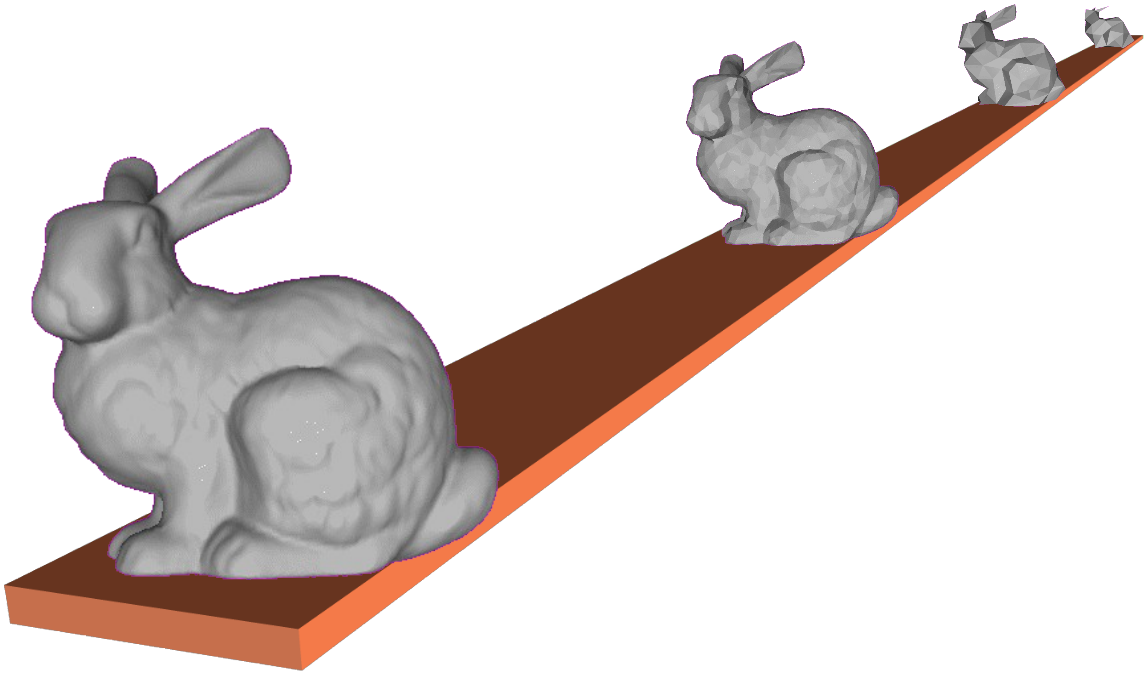


69,451 polys   2,502 polys   251 polys   76 polys

Courtesy Stanford 3D Scanning Repository

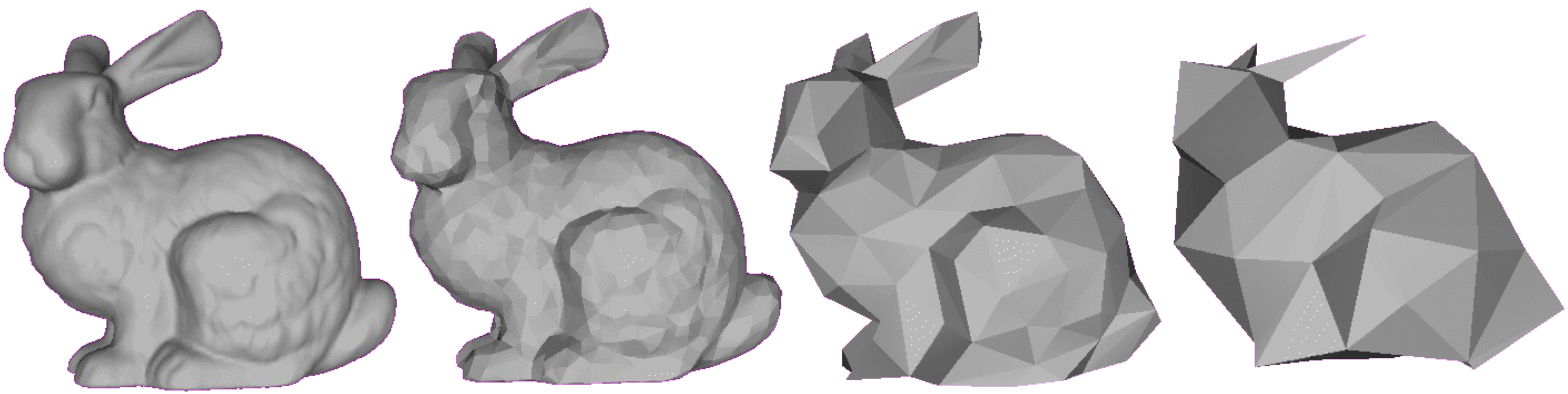
Level of Detail:
Traditional LOD In A Nutshell

- Distant objects use coarser LODs:



Level of Detail:
The Big Questions

- *How to represent and generate simpler versions of a complex model?*

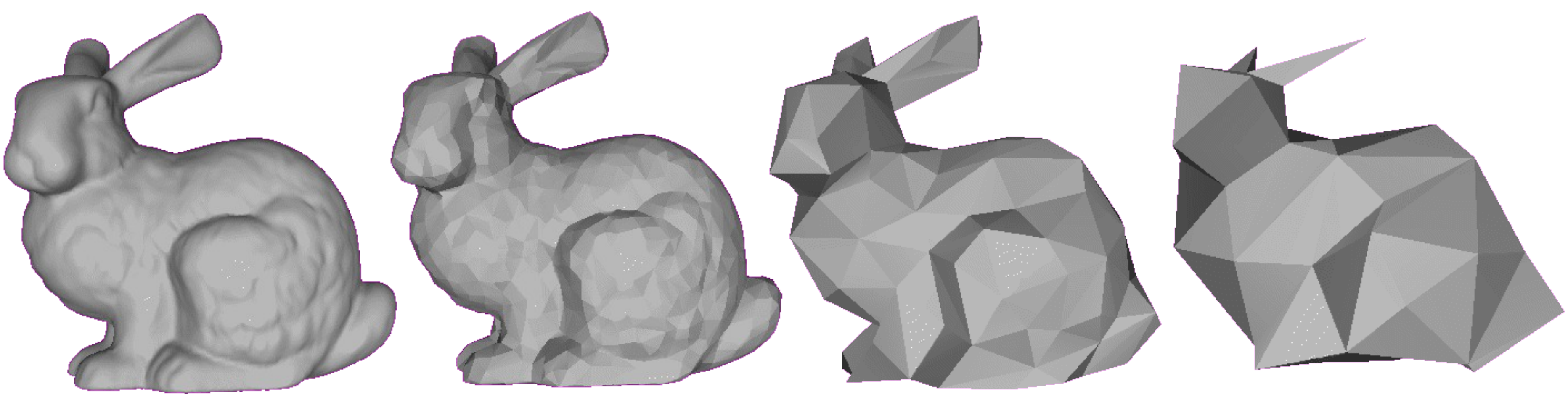


69,451 polys 2,502 polys 251 polys 76 polys

Courtesy Stanford 3D Scanning Repository

Level of Detail:
The Big Questions

- *When to use which LOD of an object?*



69,451 polys 2,502 polys 251 polys 76 polys

Courtesy Stanford 3D Scanning Repository

Traditional Approach:
Discrete Level of Detail

- Traditional LOD in a nutshell:
  - Create LODs for each object separately in a preprocess
  - At run-time, pick each object's LOD according to the object's distance (or similar criterion)
- Since LODs are created offline at fixed resolutions, we call this *discrete LOD*

Discrete LOD:
Advantages

- Simplest programming model; decouples simplification and rendering
  - LOD creation need not address real-time rendering constraints
  - Run-time rendering need only pick LODs

Discrete LOD:
Advantages

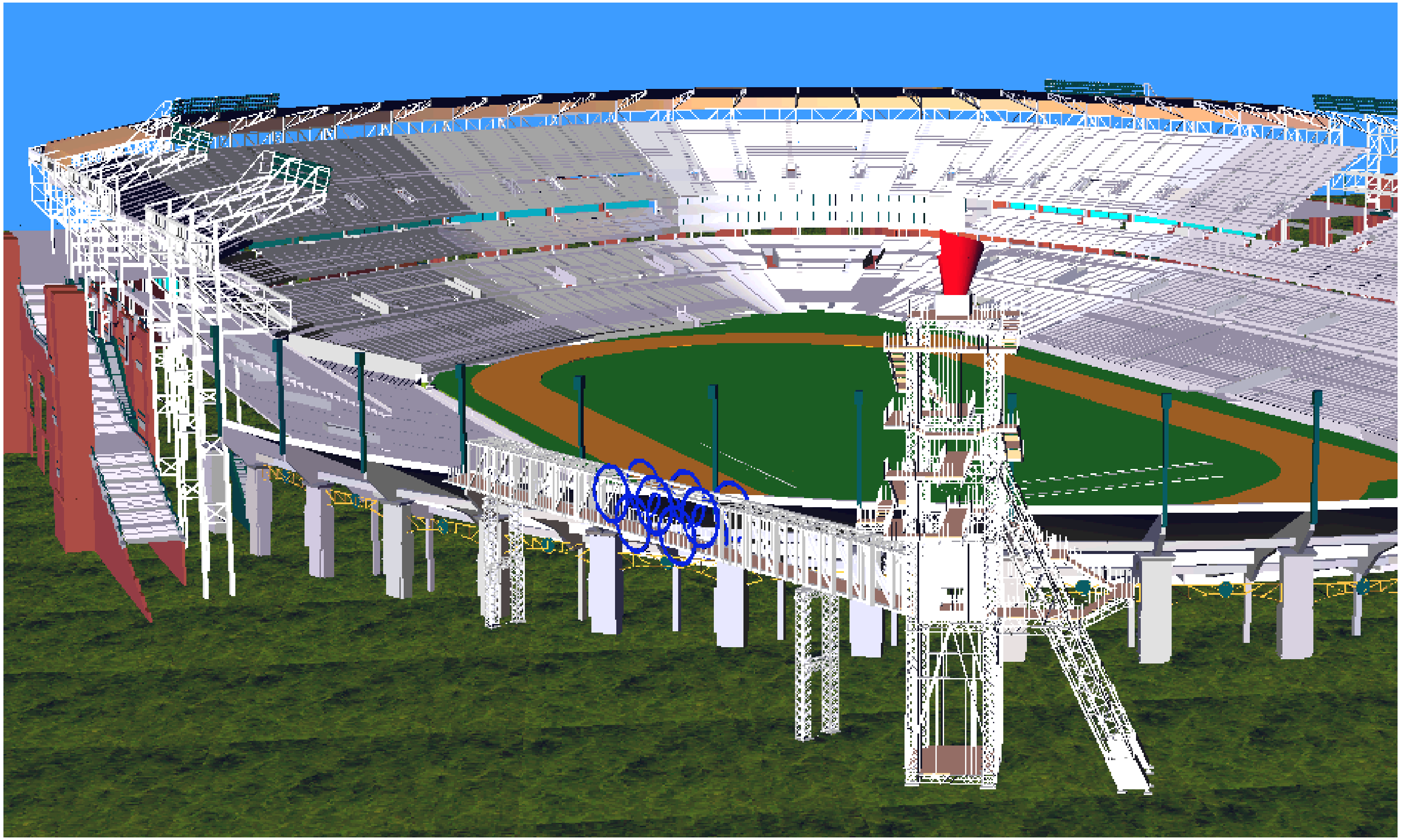
- Fits modern graphics hardware well
  - Easy to compile each LOD into triangle strips, display lists, vertex arrays, …
  - These render *much* faster than unorganized triangles on today's hardware (3-5 x)

Discrete LOD:
Disadvantages

- So why use anything but discrete LOD?
- Answer: sometimes discrete LOD not suited for *drastic simplification*
- Some problem cases:
  - Terrain flyovers
  - Volumetric isosurfaces
  - Super-detailed range scans
  - Massive CAD models

Drastic Simplification:
The Problem With Large Objects

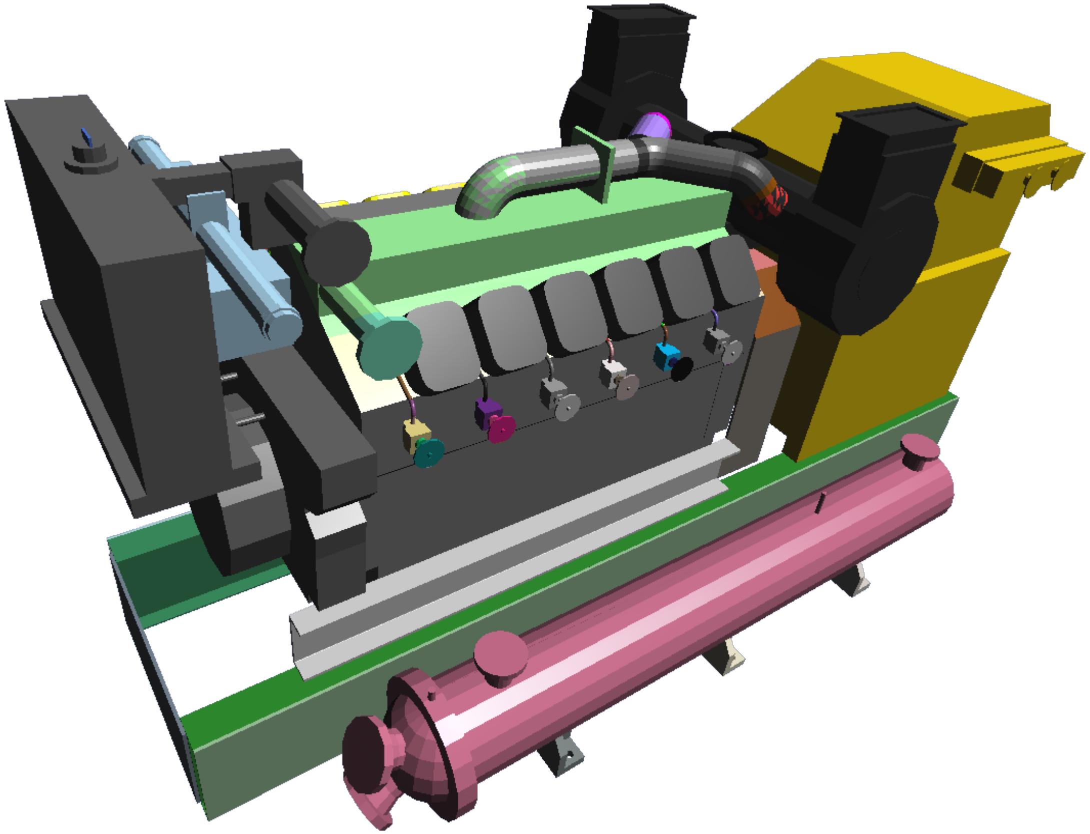
Large objects must be subdivided



Courtesy IBM and ACOG

Drastic Simplification:
The Problem With Small Objects

Small objects must be combined



Courtesy Electric Boat

Drastic Simplification

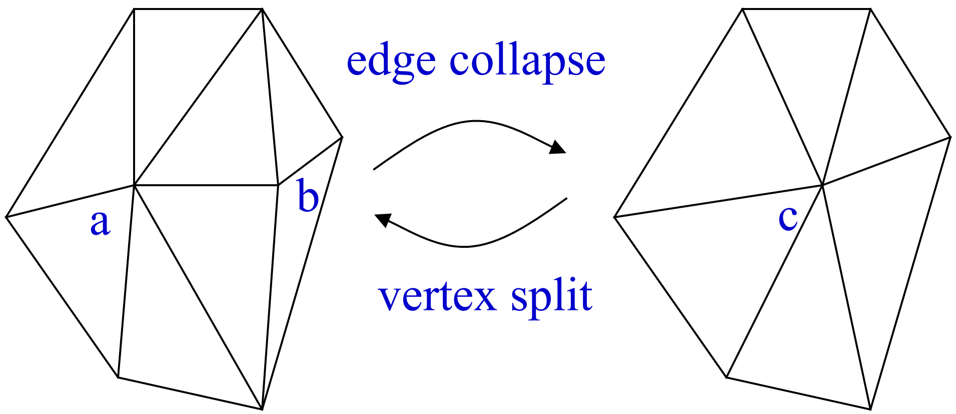
- For drastic simplification:
  - Large objects must be subdivided
  - Small objects must be combined
- Difficult or impossible with discrete LOD
- *So what can we do?*

Continuous Level of Detail

- Discrete LOD: create individual levels of detail in a preprocess
- Continuous LOD: create data structure from which a desired level of detail can be extracted *at run time*.

Continuous Level of Detail

- Edge collapsing introduced by [Hoppe93]



Continuous Level of Detail

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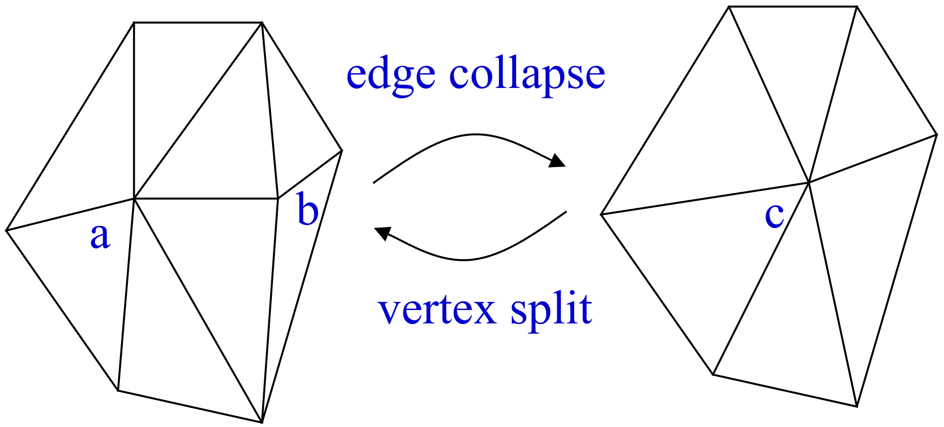
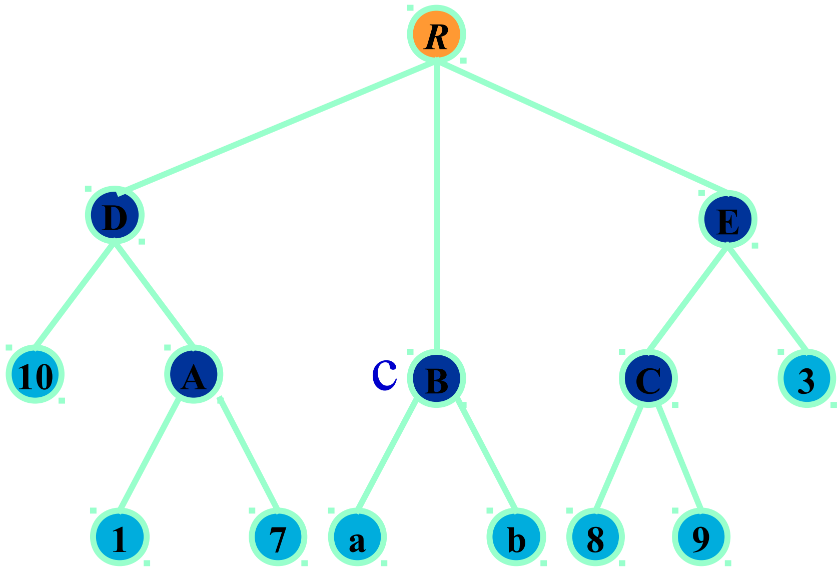
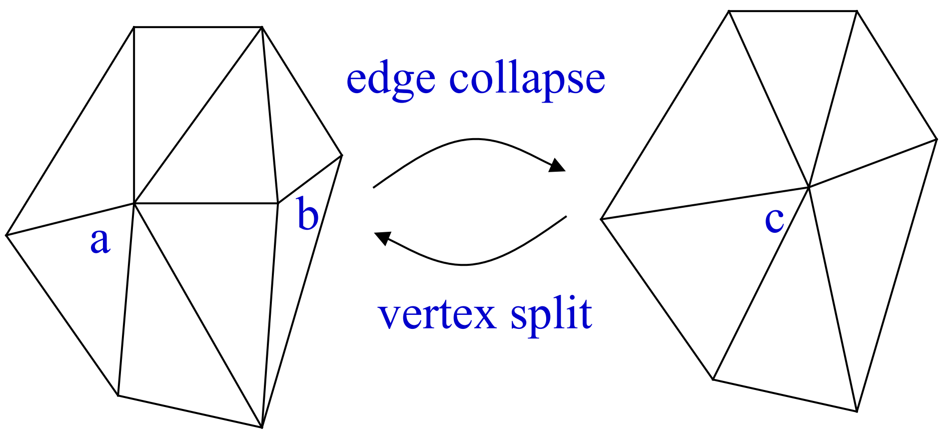


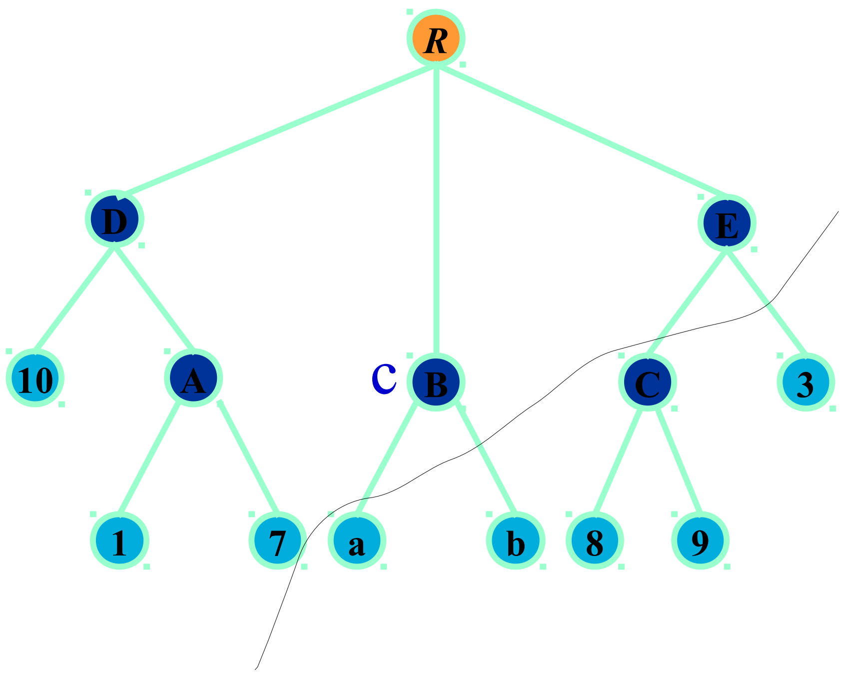


Vertex hierarchy

Continuous Level of Detail

- Edge collapsing introduced by [Hoppe93]





A cut defines an LOD

Continuous LOD: Advantages

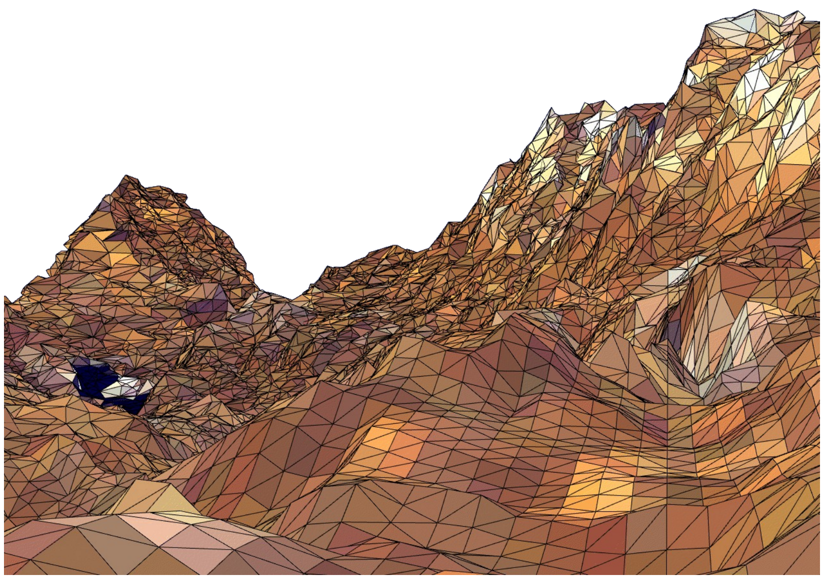
- Better granularity → better fidelity
  - LOD is specified exactly, not chosen from a few pre-created options
  - Thus objects use no more polygons than necessary, which frees up polygons for other objects
  - Net result: better resource utilization, leading to better overall fidelity/polygon

Continuous LOD: Advantages

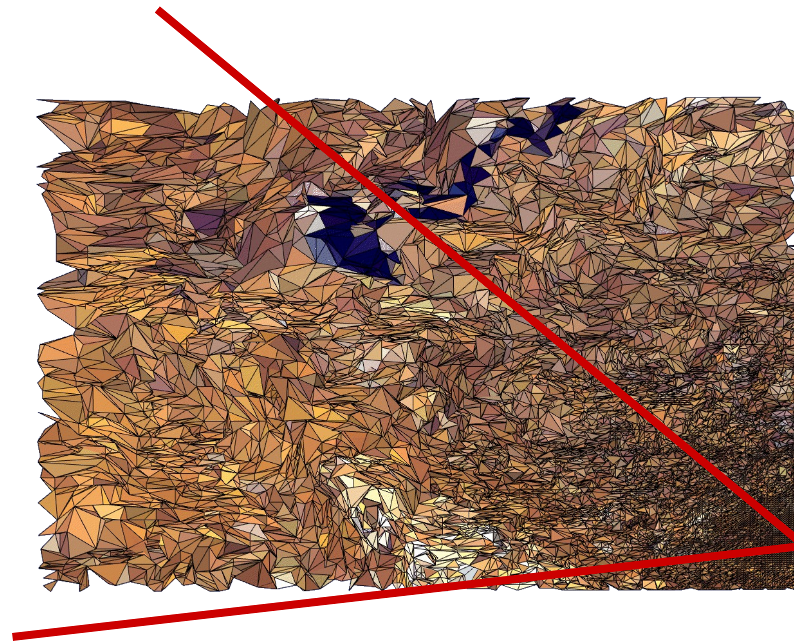
- Better granularity → smoother transitions
  - Switching between traditional LODs can introduce visual “popping” effect
  - Continuous LOD can adjust detail gradually and incrementally, reducing visual pops

View-Dependent LOD: Examples

- Show nearby portions of object at higher resolution than distant portions



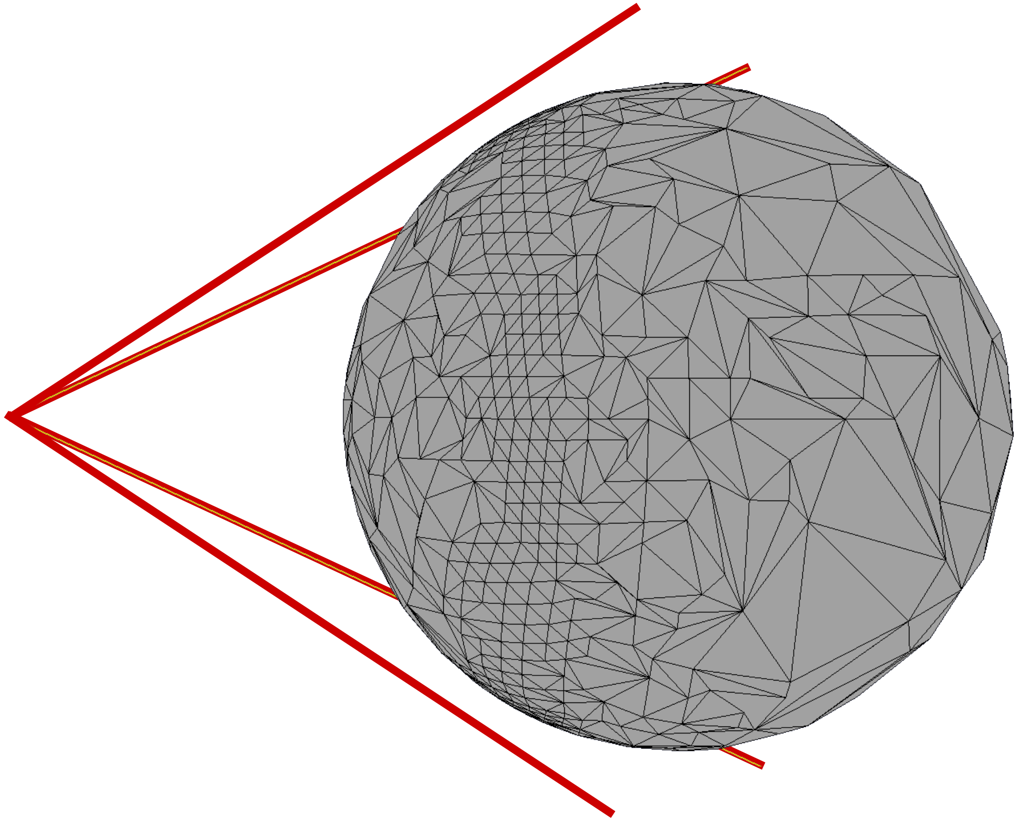
View from eyepoint



Birds-eye view

View-Dependent LOD: Examples

- Show silhouette regions of object at higher resolution than interior regions



View-Dependent LOD: Advantages

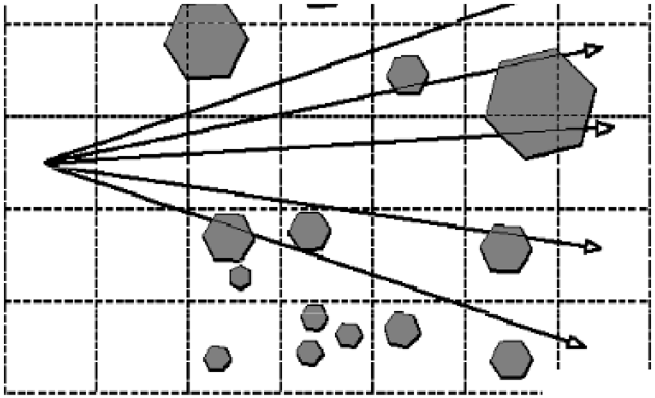
- Even better granularity
  - Allocates polygons where they are most needed, within as well as among objects
  - Enables even better overall fidelity
- Enables drastic simplification of very large objects
  - Example: stadium model
  - Example: terrain flyover

Fundamental LOD issue: where in the scene to allocate detail?

- Run every frame on every object; keep it fast

Choosing LODs

- *Describe a simple method for the system to choose LODs*
  - Assign each LOD a range of distances
  - Calculate distance from viewer to object
  - Use corresponding LOD
- *How might we implement this in a scene-graph based system?*



Choosing LODs

- *What's wrong with this simple approach?*
  - Visual "pop" when switching LODs can be disconcerting
  - Requires someone to assign switching distances by hand
  - Correct switching distance may vary with field of view, resolution, etc.
  - Doesn't maintain constant frame rate; lots of objects still means slow frame times!
- *What can we do about each of these?*

Choosing LODs:
Maintaining constant frame rate

- A better (but harder) solution: predictive LOD selection
- For each LOD estimate:
  - *Cost* (rendering time)
  - *Benefit* (importance to the image)

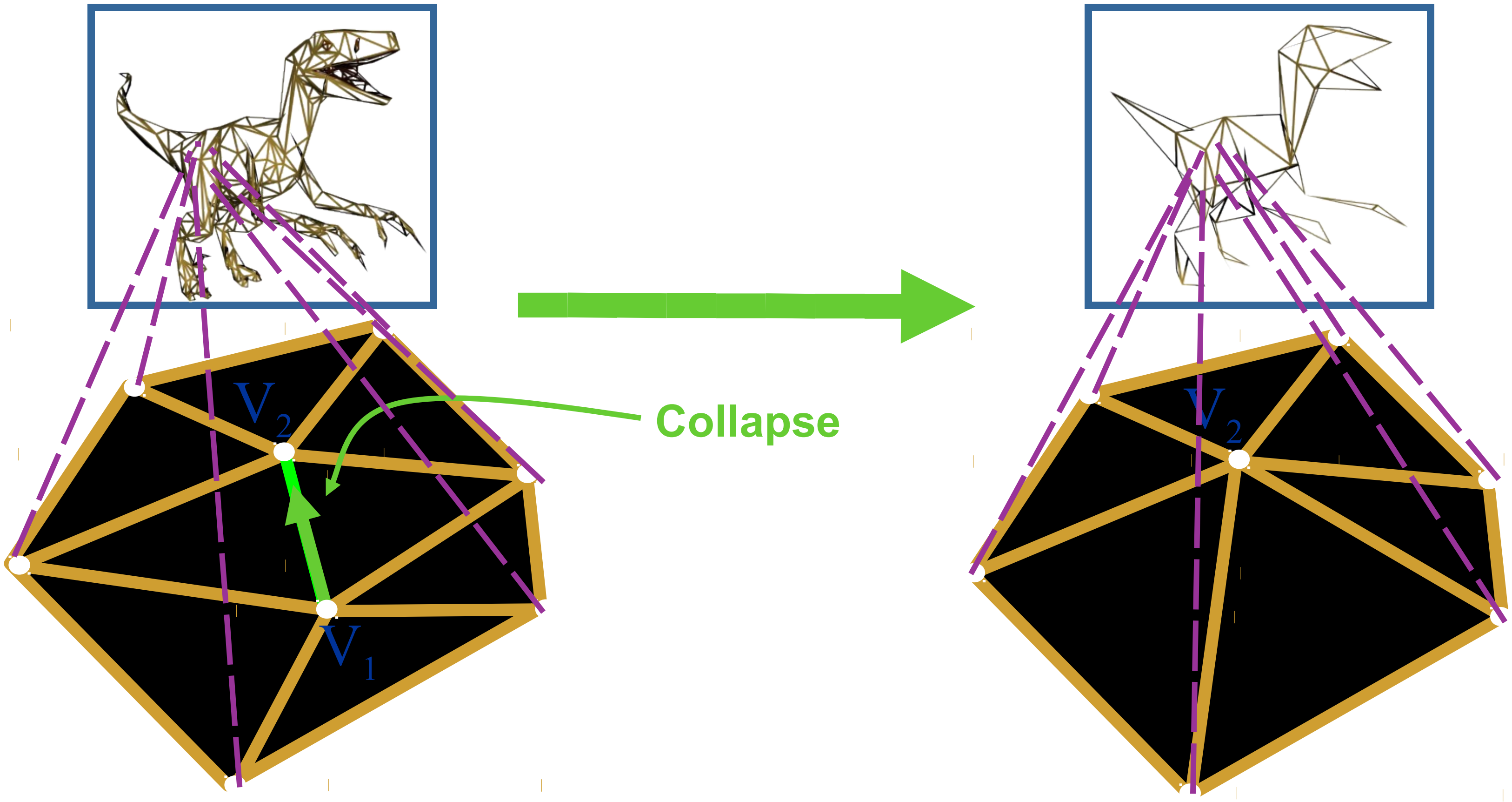
Choosing LODs:
Funkhouser & Sequin, SIGGRAPH 93

- Given a fixed time budget, select LODs to maximize benefit within a cost constraint
  - Variation of the knapsack problem
  - *What do you think the complexity is?*
    - A: NP-Complete (like the 0-1 knapsack problem)
  - In practice, use a greedy algorithm
    - Sort objects by benefit/cost ratio, pick in sorted order until budget is exceeded
    - Guaranteed to achieve at least 50% optimal sol'n
    - Time: O(n lg n)
    - Can use incremental algorithm to exploit coherence

Generating LODs

- Simplification operator:
  - Edge collapse
    - Full edge collapse
      - Better fidelity (show why)
    - Half edge collapse
      - Less memory
      - Sort vertices, tris into VAR array for fast rendering
    - Vertex-pair merge a.k.a. “virtual edge collapse”
      - Merge separate objects

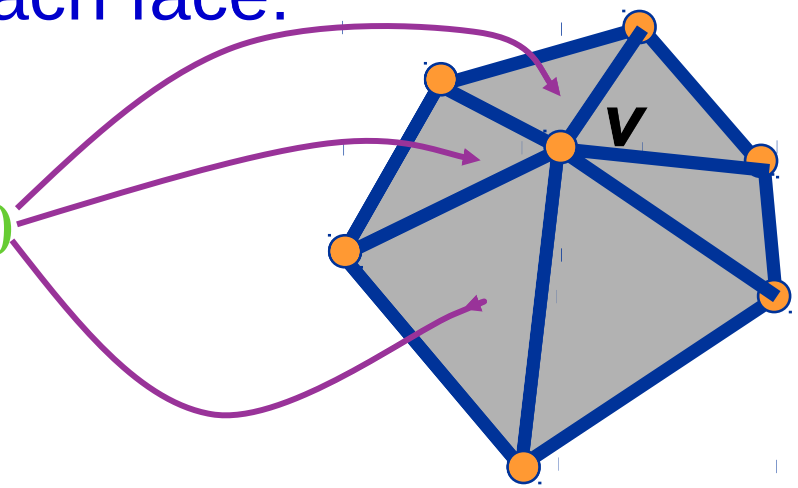
Edge Collapse Algorithm



Quadric Error Metric

- Minimize distance to all planes at a vertex
- Plane equation for each face:

$$p: \quad Ax + By + Cz + D = 0$$



Distance to vertex ***v*** :

$$p^T \cdot v = \begin{bmatrix} A & B & C & D \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Squared Distance At a Vertex

$$\Delta(v) = \sum_{p \in planes(v)} (p^T v)^2$$

$$= \sum_{p \in planes(v)} (v^T p)(p^T v)$$

$$= \sum_{p \in planes(v)} v^T (pp^T) v$$

$$= v^T \left(\sum_{p \in planes(v)} pp^T \right) v$$

Optimal Vertex Placement

- Each vertex has a quadric error metric Q associated with it
  - Error is zero for original vertices
  - Error nonzero for vertices created by merge operation(s)
- Minimize Q to calculate optimal coordinates for placing new vertex
  - Details in paper
  - Authors claim 40-50% less error

View-Dependent LOD: Algorithms

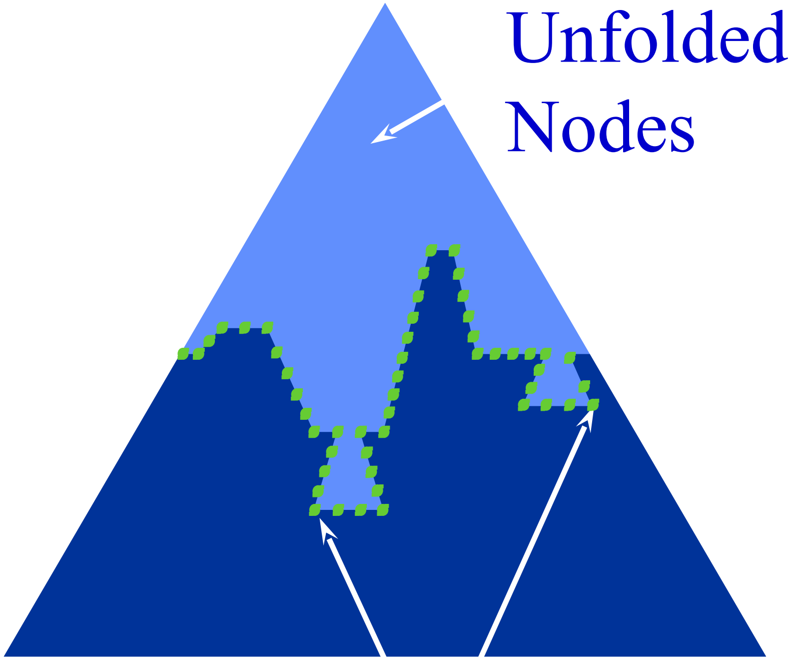
- Many good published algorithms:
  - *Progressive Meshes* by Hoppe [SIGGRAPH 96, SIGGRAPH 97, …]
  - *Hierarchical Dynamic Simplification* by Luebke & Erikson [SIGGRAPH 97]
  - *Multitriangulation* by DeFloriani et al
  - Others…

Temporal Coherence

- Exploit the fact that frame-to-frame changes are small
- One example:
  - Vertex tree

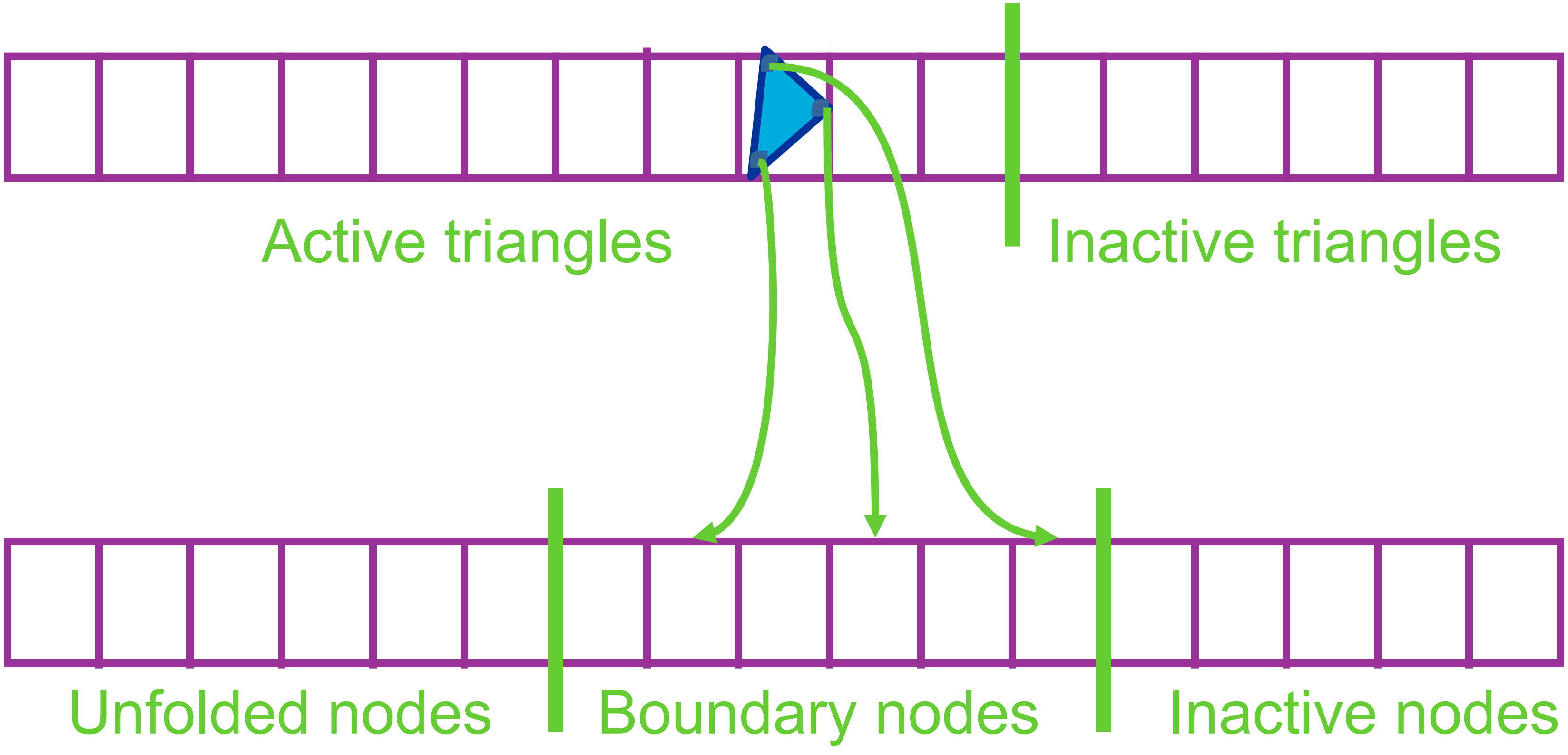
Exploiting Temporal Coherence

- Vertex Tree
  - Few nodes change per frame
  - Don’t traverse whole tree
  - Do local updates only at *boundary nodes*



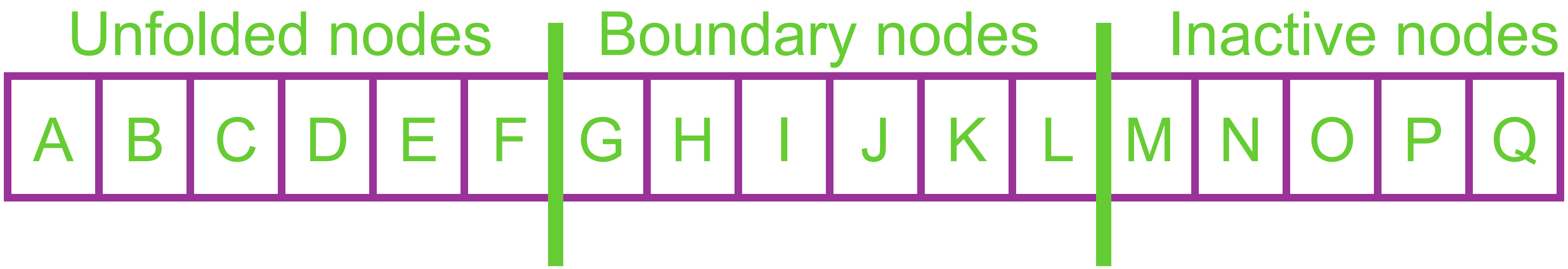
Optimizing For Rendering

- Idea: maintain geometry in coherent arrays



Optimizing For Rendering

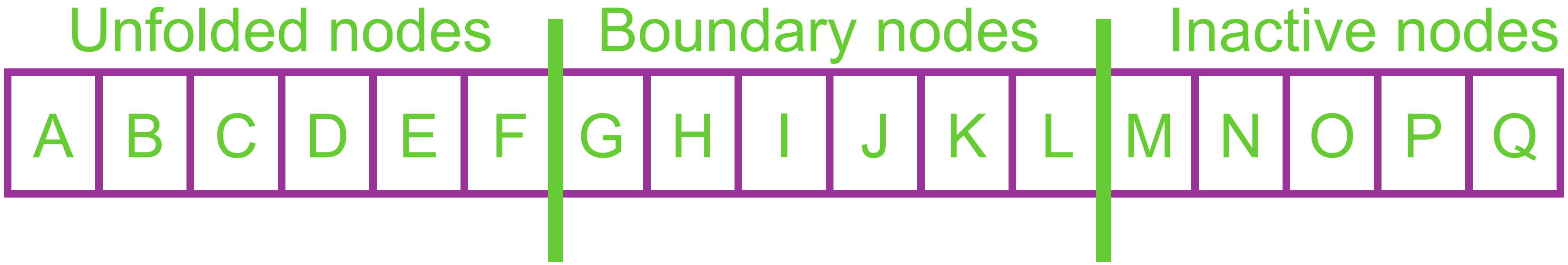
- Idea: use swaps to maintain coherence



Fold node D:

Optimizing For Rendering

- Idea: use swaps to maintain coherence

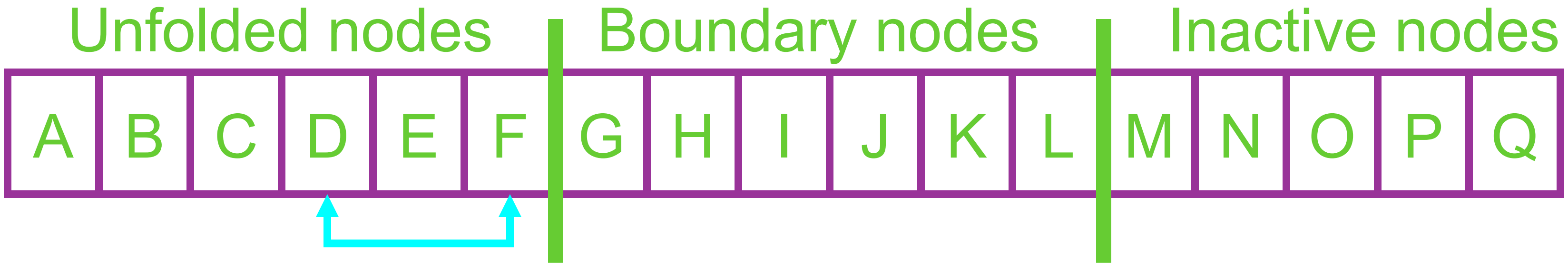


Fold node D:

Swap D with F

Optimizing For Rendering

- Idea: use swaps to maintain coherence



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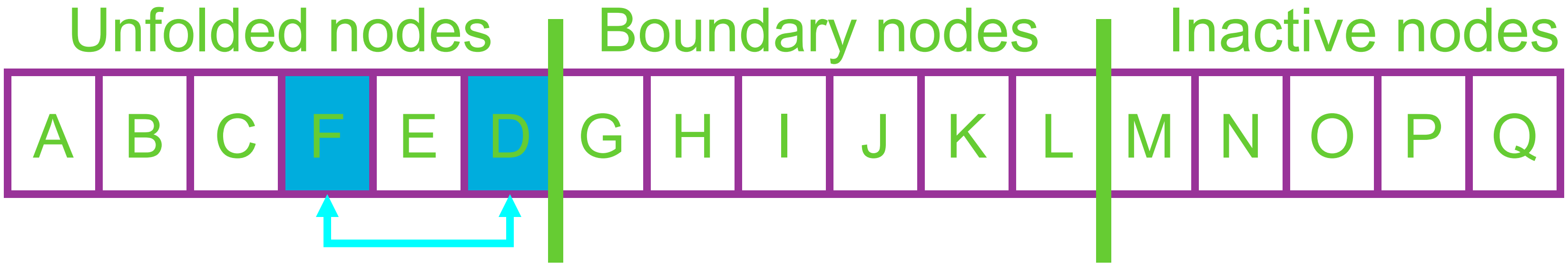

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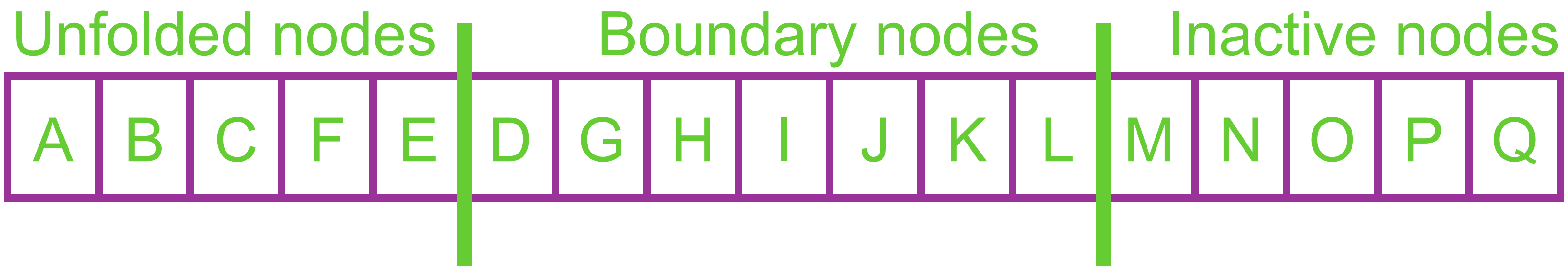
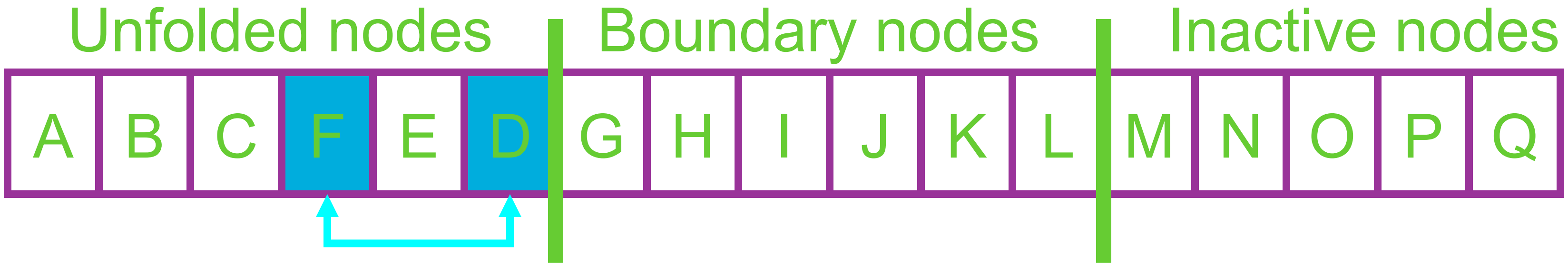


Fold node D:

Move Unfolded/Boundary Marker

Optimizing For Rendering

- Idea: use swaps to maintain coherence



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Optimizing For Rendering

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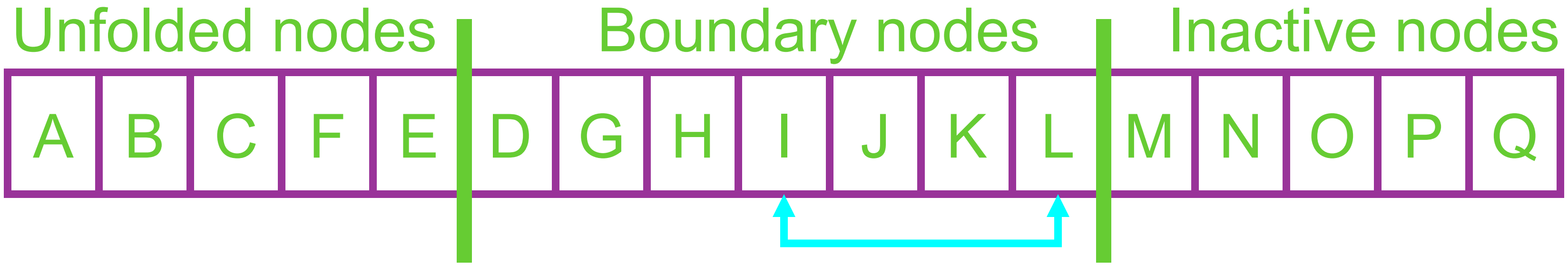
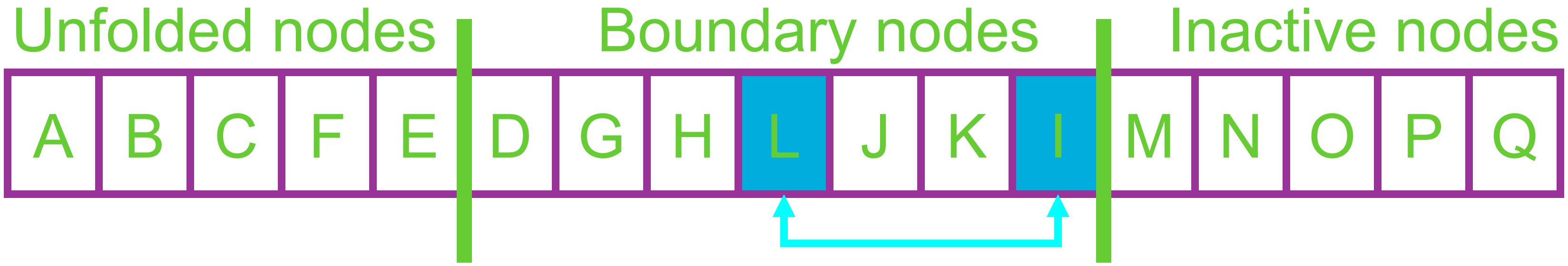


Fold node D:

Deactivate D’s children (swap w/ last boundary node)

Optimizing For Rendering

- Idea: use swaps to maintain coherence



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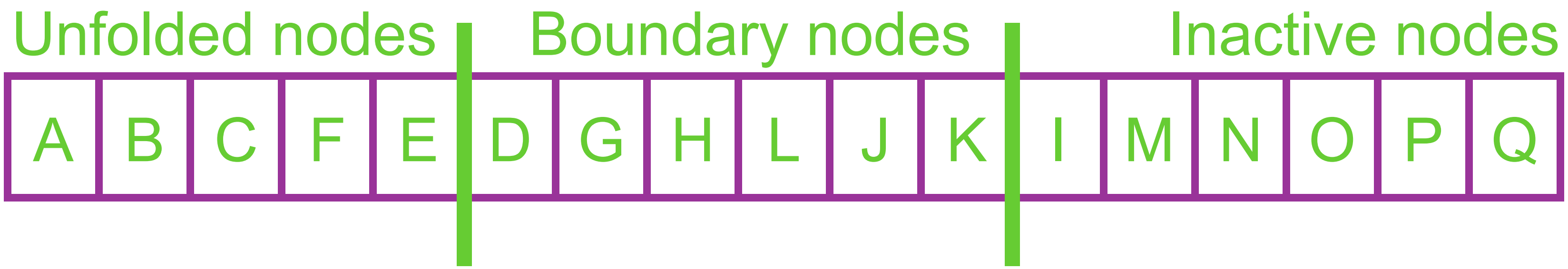

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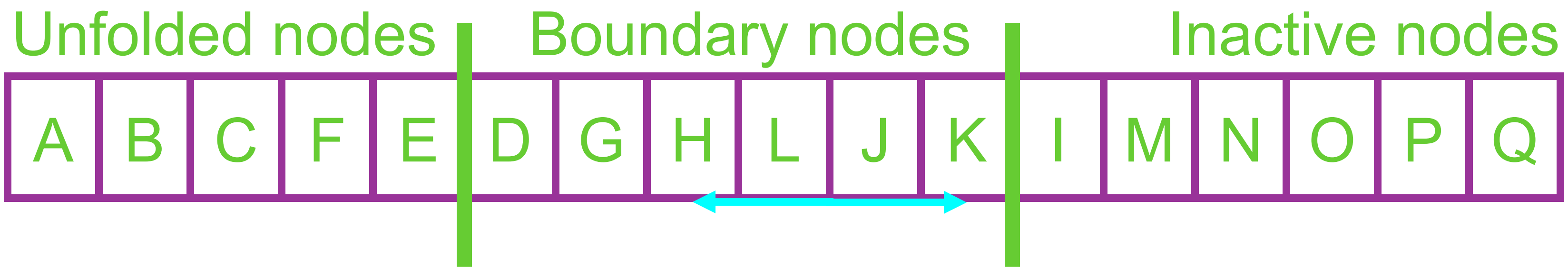

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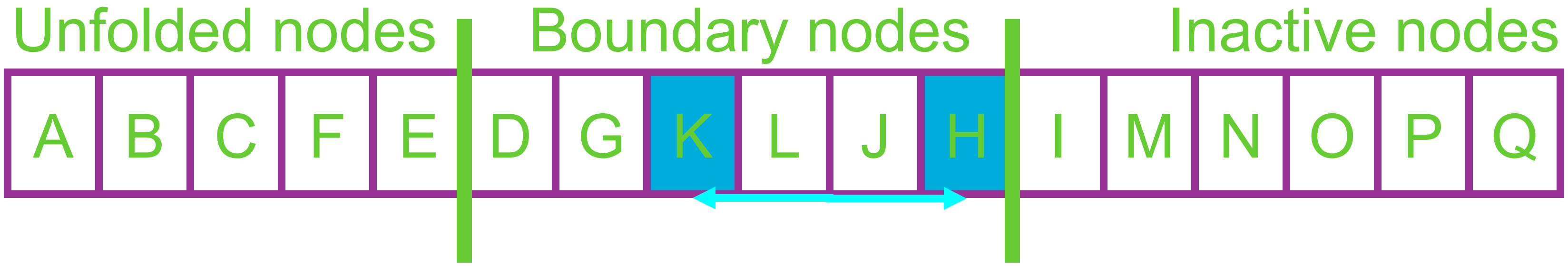

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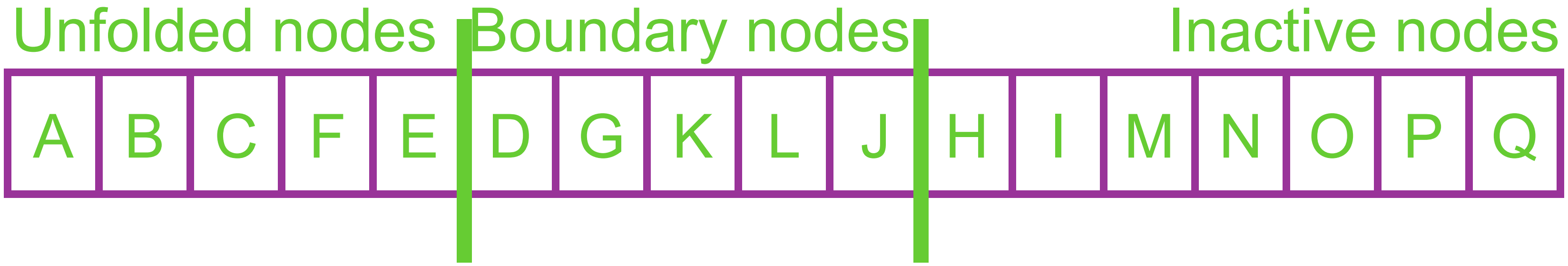

Fold node D:

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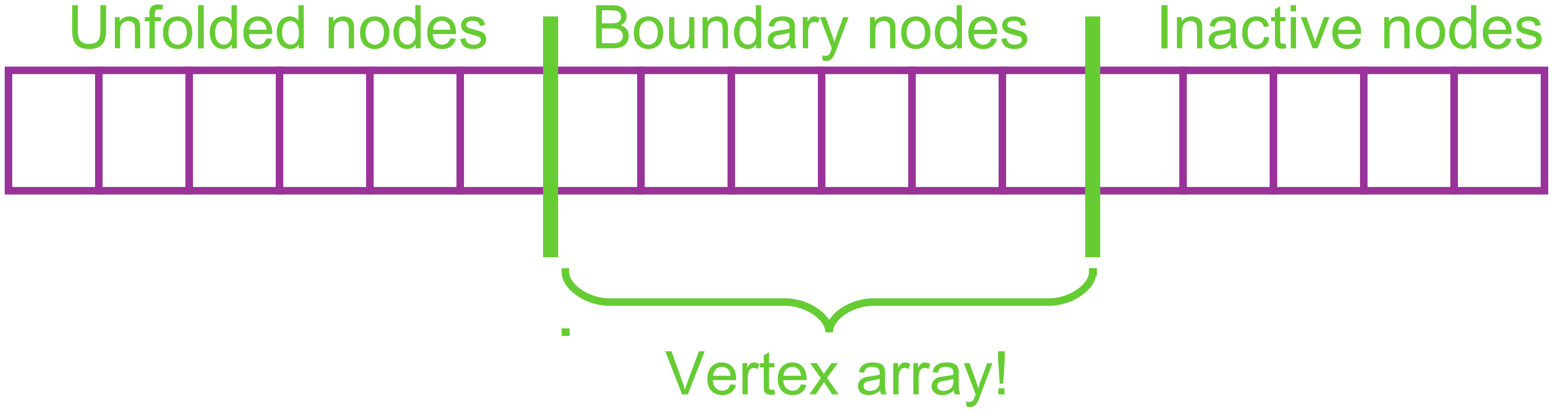
Optimizing For Rendering:
Vertex Arrays

- Biggest win: vertex arrays



  - Actually, keep separate parallel arrays for rendering data (coords, colors, etc)

View-Dependent Versus Discrete LOD

- View-dependent LOD is superior to traditional discrete LOD when:
  - Models contain very large individual objects (e.g., terrains)
  - Simplification must be completely automatic (e.g., complex CAD models)
  - Experimenting with view-dependent simplification criteria

View-Dependent Versus Discrete LOD

- Discrete LOD is often the better choice:
  - Simplest programming model
  - Reduced run-time CPU load
  - Easier to leverage hardware:
    - Compile LODs into vertex arrays/display lists
    - Stripe LODs into triangle strips
    - Optimize vertex cache utilization and such

View-Dependent Versus Discrete LOD

- Applications that may want to use:
  - Discrete LOD
    - Video games (but much more on this later…)
    - Simulators
    - Many walkthrough-style demos
  - Dynamic and view-dependent LOD
    - CAD design review tools
    - Medical & scientific visualization toolkits
    - Terrain flyovers (e.g. google earth)

Continuous LOD:
The Sweet Spot?

- Continuous LOD may be the right compromise on modern PC hardware
  - Benefits of fine granularity without the cost of view-dependent evaluation
  - Can be implemented efficiently with regard to
    - Memory
    - CPU
    - GPU

Summary: LOD Frameworks

- Discrete LOD
  - Generate a handful of LODs for each object
- Continuous LOD (CLOD)
  - Generate data structure for each object from which a spectrum of detail can be extracted
- View-dependent LOD
  - Generate data structure from which an LOD specialized to the current view parameters can be generated on the fly.
  - One object may span multiple levels of detail

Implementation: *VDSlib*

A public-domain view-dependent simplification and rendering package

Available at *http://vdslib.virginia.edu*