Impostors for Interactive Parallel Computer Graphics

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Overview

- Impostors Basics
- Impostors Research
- Parallel Graphics Basics
- Parallel Impostors
- Parallel Planned Work
- Graphics Planned Work

Thesis Statement

- Parallel impostors can improve performance and quality for interactive computer graphics
  - Impostors are 2D standins for 3D geometry
  - Parallel impostors are impostor images computed on a parallel server
  - Interactive means there's a human watching and controlling the action with fast response times

Importance of Computer Graphics

- "The purpose of computing is insight, not numbers!" R. Hamming
- Vision is a key tool for analyzing and understanding the world
- Your eyes are your brain's highest bandwidth input device
  - Vision: >300MB/s
    - 1600x1200 24-bit 60Hz
  - Sound: <1 MB/s
    - 96KHz 24-bit stereo
  - Touch: <100 per second
  - Smell/taste: <10 per second

Impostors

Fundamentals
Prior Work

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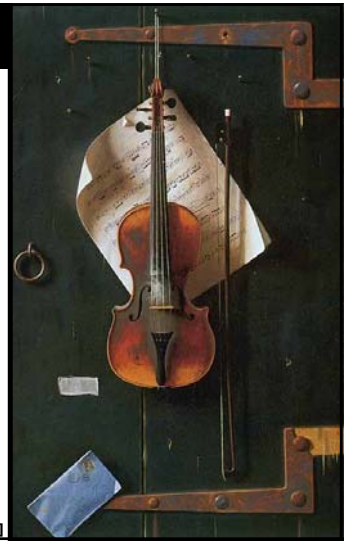
Impostors

- Replace 3D geometry with a 2D image
- 2D image fools viewer into thinking 3D geometry is still there
- Prior work
  - Pompeii murals
  - *Trompe l'oeil* ("trick of the eye") painting style
  - Theater/movie backdrops
- **Big limitation:**
  - No parallax

[Harnett 1886]



Graphics Cards

- Draws *only* polygons, lines, and points
- Supports image texture mapping, transparent blending
- Portable, usable OpenGL software interface

- Interactive graphics now *means* graphics hardware
  - SGI pioneered modern generation (early 1990's)
  - Explosion of independent companies (1995)
  - Consumer hardware vertex processing (1999)
  - Programmable hardware pixel shaders (2001)
  - Hardware floating-point pixel processing (2003)

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Graphics Card Performance

Triangle Setup
Projection, lighting, clipping, …

→

Pixel Rendering
Texturing, blending

$$t = \max(\alpha, \beta(s + \gamma r))$$

t	total time to draw (seconds)
α	triangle setup time (about 100ns), 1.0/triangle rate
β	pixel rendering time (about 2ns), 1.0/fill rate
s	area of triangle (pixels)
r	rows in triangle
γ	pixel cost per row (about 3 pixels/row)

!

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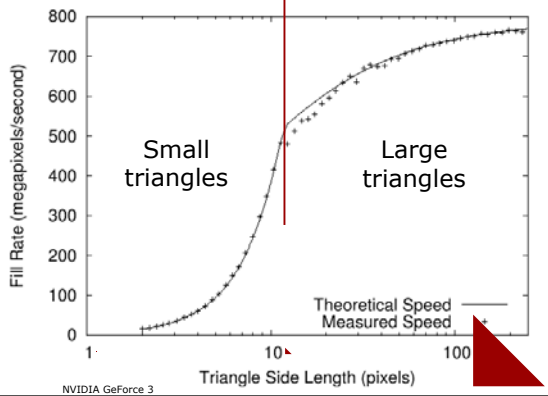
Graphics Card: Usable Fill Rate

$$B_C = \frac{s}{t} = \min(\frac{s}{\alpha}, \frac{1}{\beta(1+\gamma r/s)})$$



NVIDIA GeForce 3

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Impostors Technique

- For efficient rendering, must use large triangles; for more detailed rendering, must use smaller triangles
- Impostors can resolve this conflict:
  - First, render set of small triangles into a large texture: an impostor
  - Now we can render impostor texture (on a large triangle) instead of the many small triangles
- Helps when impostors can be reused across many frames
  - Works best with continuous camera motion and high framerate!
- Many modifications, much prior work:

[Maciel95], [Shade96], [Schaufler96]

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Impostors: Example

- We render a set of geometry into an impostor (image/texture)

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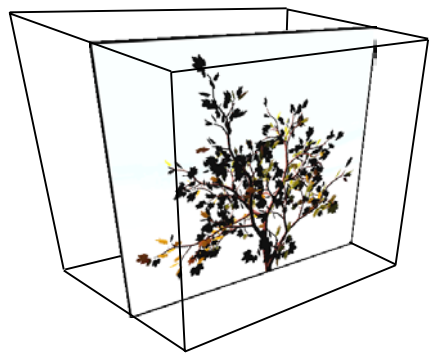
Impostors: Example

- We can re-use this impostor in 3D for several frames



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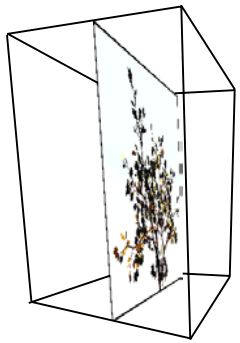
Impostors : Example

- **Eventually, we have to update the impostor**



Updating: Impostor Reuse

- **Far away or flat impostors can be reused many times, so impostors help substantially**

	$d = 0.05$	$d = 0.25$	$d = 1$	$d = 5$
$z = 1$	1	1	1	1
$z = 5$	10	2	1	1
$z = 25$	263	52	12	2
$z = 100$	4216	841	208	40

$$R = \frac{z(z-d)\Delta s H}{kdV}$$

R	Number of frames of guaranteed reuse
z	Distance to impostor (meters)
d	Depth flattened from impostor (meters)
Δs	Acceptable screen-space error (1 pixel)
H	Framerate (60 Hz)
k	Screen resolution (1024 pixels across)
V	Camera velocity (20 kmph)

Impostors Challenges

- **Geometry Decomposition**
  - **Must be able to cut up world into impostor-type pieces**
    - **[Shade96] based on scene hierarchy**
    - **[Aliaga99] gives automatic portal method**
  - **Update equation tells us to cut world into flat (small d) pieces for maximum reuse**
- **Update equation shows reuse is low for nearby geometry**
  - **Impostors don't help much nearby**
  - **Use regular polygon rendering up close**
- **Lots of other reasons for updating:**
  - **Changing object shape, like swaying trees**
  - **Non-diffuse appearance, like reflections**

Impostors Research

Antialiasing
Motion Blur

Rendering Quality: Antialiasing

Aliased point samples

Antialiased filtering

- Real objects can cover only part of a pixel
  - Blends object boundaries
- Prior Work:
  - Ignore partial coverage
    - Aliasing ("the jaggies")
  - Oversample and average
    - Graphics hardware: FSAA
    - Not theoretically correct; close
  - Random point samples
    - [Cook, Porter, Carpenter 84]
    - Needs a *lot* of samples:

$$\sigma' = \frac{\sigma}{\sqrt{n}}$$

  - Integration
    - Trapezoids
    - Circles [Amanatides 84]
    - Polynomial splines [McCool 95]
    - Procedures [Carr & Hart 99]

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Antialiased Impostors

Antialiased Impostor

- Texture map filtering is mature
  - Very fast on graphics hardware
  - Bilinear interpolation for nearby textures
  - Mipmaps for distant textures
  - Anisotropic filtering becoming available
  - Works well with alpha channel transparency

  [Haeberli & Segal 93]

- Impostors let us use texture map filtering on *geometry*
  - Antialiased edges
  - Mipmapped distant geometry
  - Substantial improvement over ordinary polygon rendering

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Antialiased Impostor Challenges

- Must generate antialiased impostors to start with
  - Just pushes antialiasing up one level
  - Can use any antialiasing technique. We use:
    - Trapezoid-based integration
    - Blended splats
- Must render with transparency
  - Not compatible with Z-buffer
  - Painter's algorithm:
    - Draw from back-to-front
    - A radix sort works well
    - For terrain, can avoid sort by traversing terrain properly

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Rendering Quality: Motion Blur

- Fast-moving objects blur
- Prior Work (as before)
  - Just temporal aliasing
- Usual method
  - Draw geometry shifted to different times
  - One shift per pixel of blur distance
  - Average shifted images together using accumulation buffer
- New Idea: fast exponentiation blur
  - Draw geometry *once*
  - Read back, shift, repeat
  - No accumulation buffer needed

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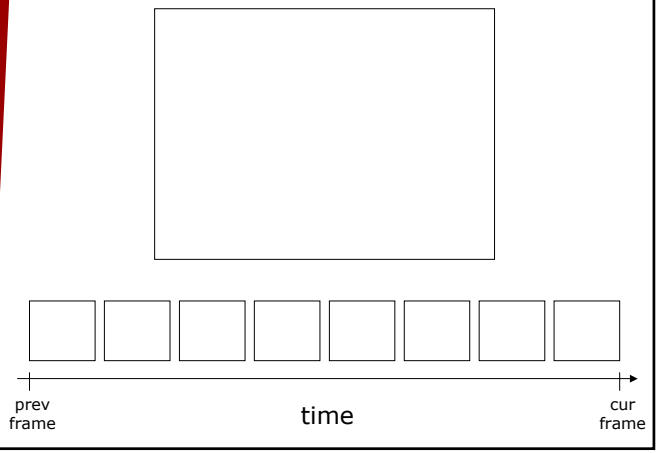
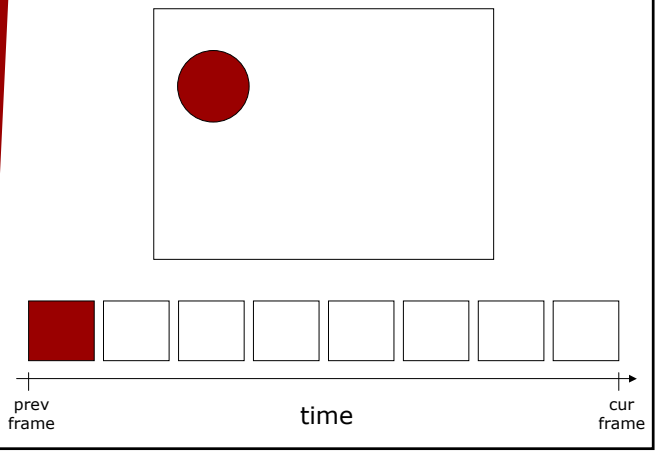
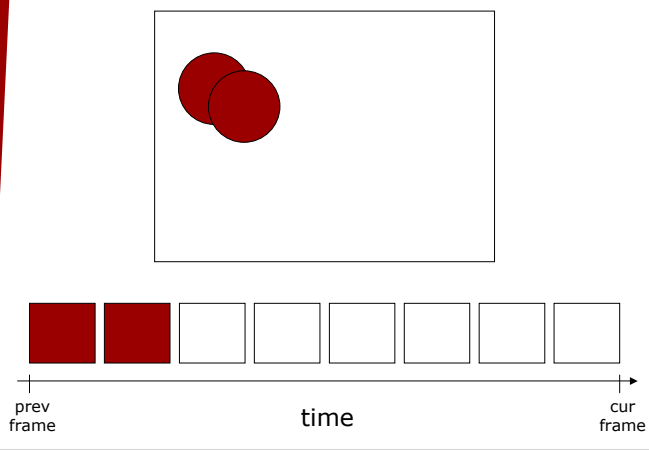
Normal Motion Blur



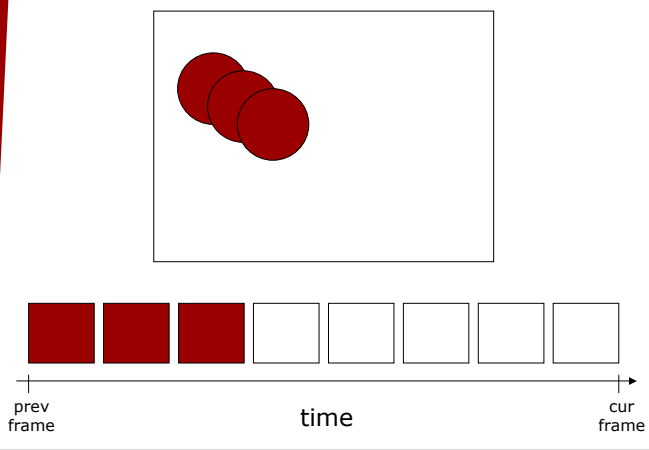
Normal Motion Blur



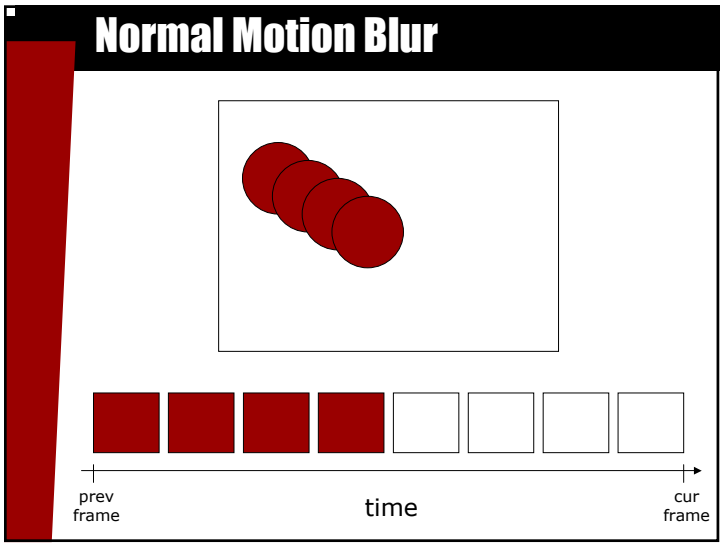
Normal Motion Blur



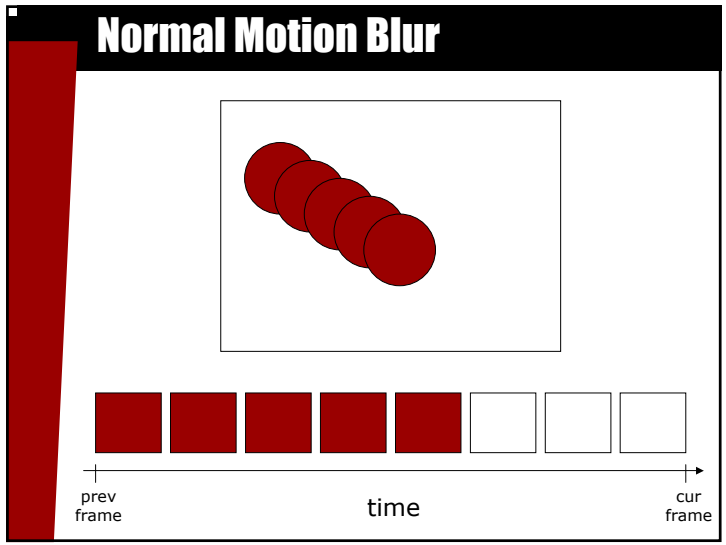
Normal Motion Blur



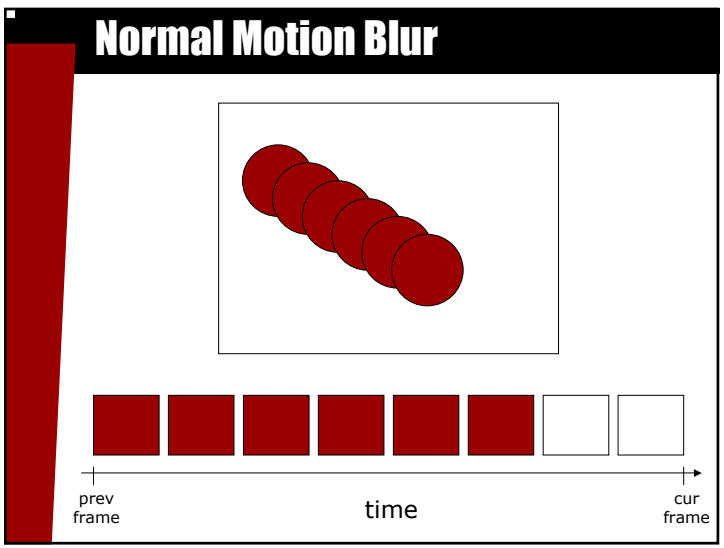
Normal Motion Blur



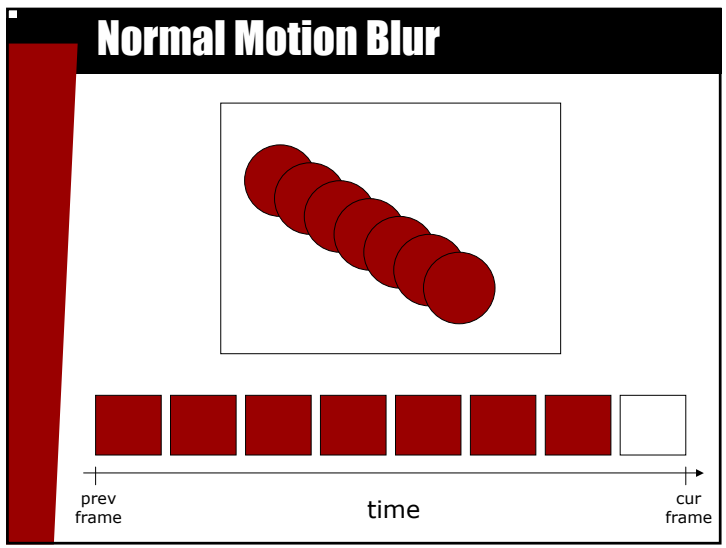
Normal Motion Blur



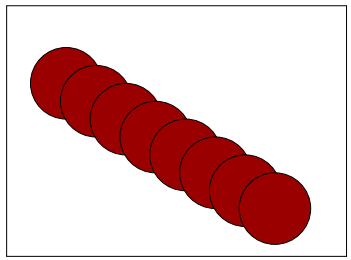
Normal Motion Blur



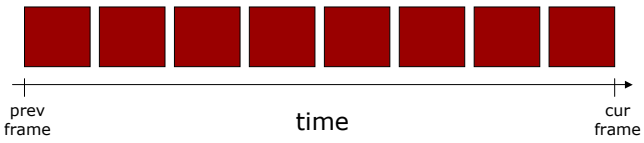
Normal Motion Blur



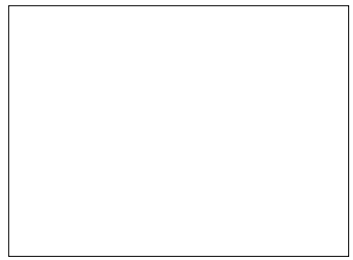
Normal Motion Blur

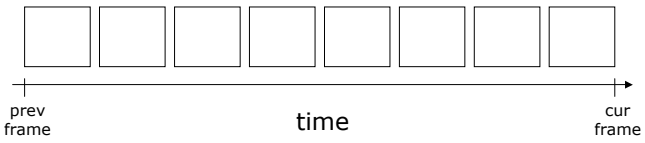


n shifts take $O(n)$ time

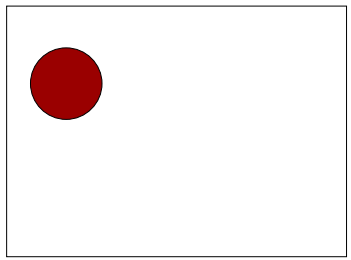


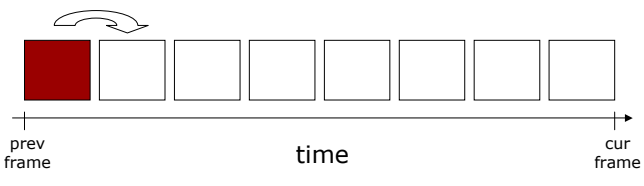
Fast Exponentiation Blur



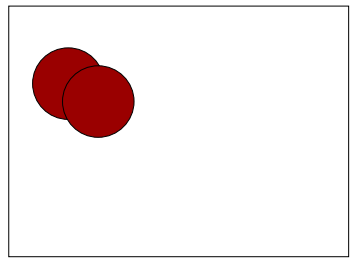


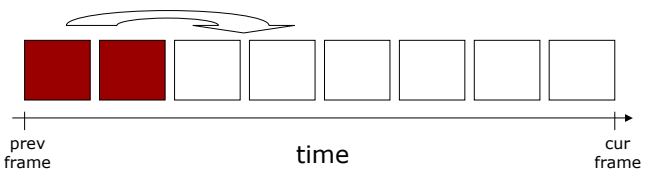
Fast Exponentiation Blur



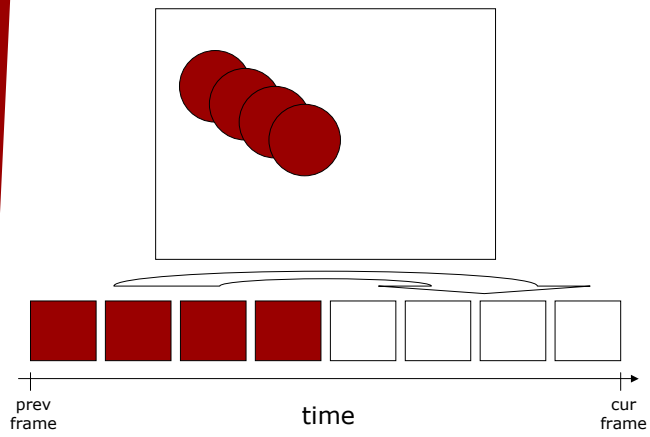


Fast Exponentiation Blur

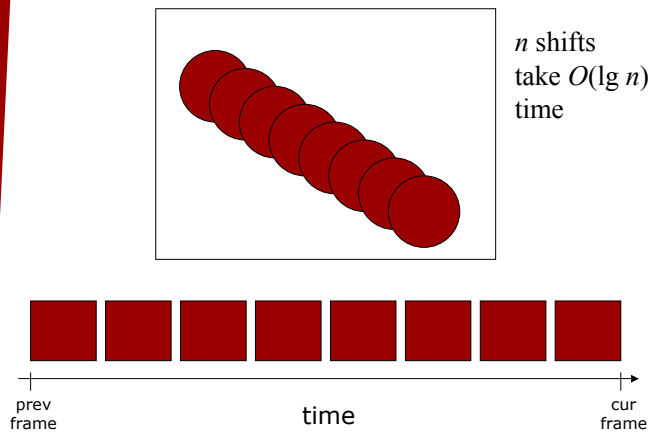




Fast Exponentiation Blur



Fast Exponentiation Blur



Impostors Research Summary

- **Impostors can improve the rendering quality, not just speed**
  - **Antialiasing**
  - **Motion Blur**
- **This is possible because impostors let you process *geometry* like a *texture***
  - **Filtering for antialiasing**
  - **Repeated readback for motion blur**

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Parallel Rendering

Fundamentals
Prior Work

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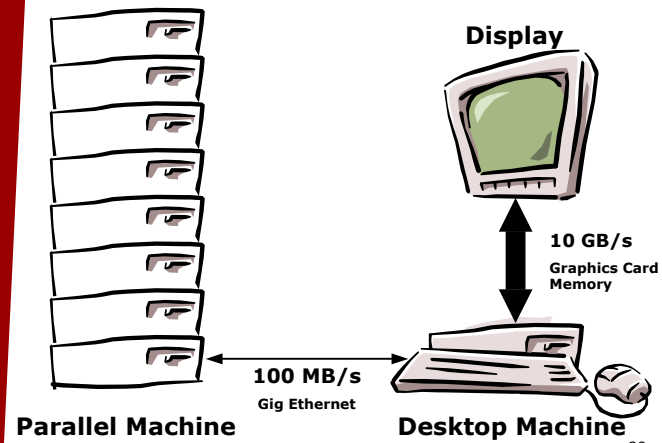
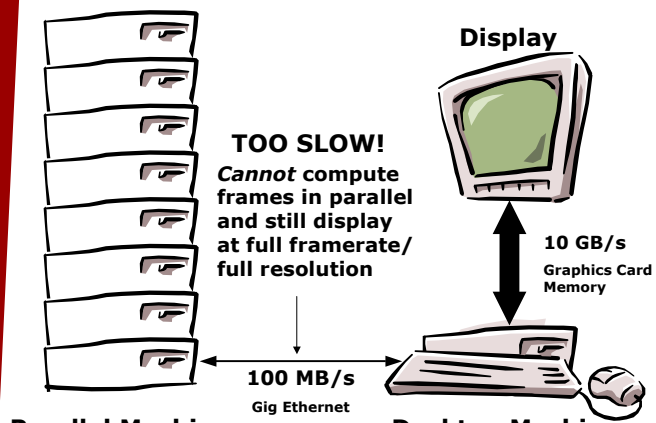
Parallel Rendering

- Huge amounts of prior work in offline rendering
  - Non-interactive: no human in the loop
  - Not bound by framerate: can take seconds to hours
- Tons of raytracers [John Stone's Tachyon], radiosity solvers [Stuttard 95], volume visualization [Lacroute 96], etc
- "Write an MPI raytracer" is a homework assignment
- Movie visual effects studios use frame-parallel offline rendering ("render farm")
- Basically a solved problem

Interactive Parallel Rendering

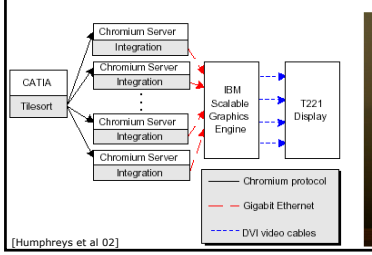


Interactive Parallel Rendering

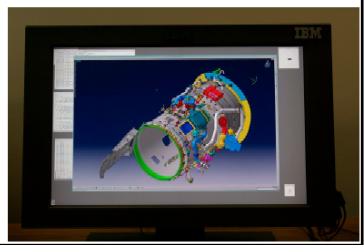


Interactive Parallel Rendering

- Humphreys et al's Chromium (aka Stanford's WireGL)
  - Binary-compatible OpenGL shared library
  - Routes OpenGL commands across processors efficiently
  - Flexible routing--arbitrary processing possible
  - Typical usage: parallel geometry generation, screen-space divided parallel rendering
  - Big limitation: screen image reassembly bandwidth
    - Multi-pipe custom image assembly hardware on front end

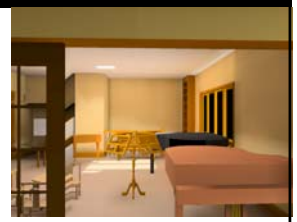


[Humphreys et al 02]



Interactive Parallel Rendering

- Bill Mark's post-render warping
  - Parallel server sends every N'th frame to client
  - Client interpolates remaining frames by warping server frames according to depth



[Mark 99]

[Ward 99]

- Greg Ward's "ray cache"
  - Parallel Radiance server renders and sends bundles of rays to client
  - Client interpolates available nearby rays to form image

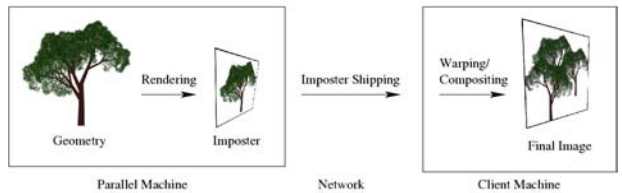
Parallel Impostors

Our Main Technique

Parallel Impostors Technique

- Render pieces of geometry into impostor images on parallel server
  - Parallelism is across impostors
    - Fine grained-- lots of potential parallelism
    - Geometry is partitioned by impostors anyway
  - Reassemble world on serial client
    - Uses rendering bandwidth of graphics card
- Impostor reuse cuts required network bandwidth to client
  - Only update images when necessary
- Uses the speed and memory of the parallel machine

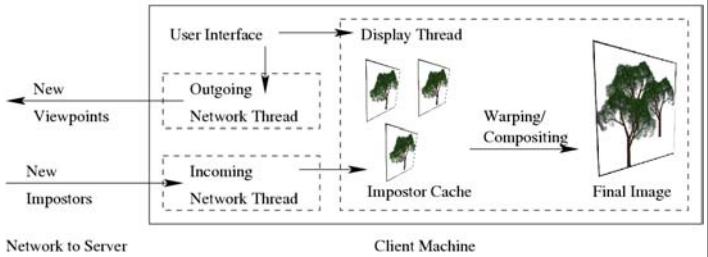
Client/Server Architecture



- Client sits on user's desk
  - Sends server new viewpoints
  - Receives and displays new impostors
- Server can be anywhere on network
  - Renders and ships back new impostors as needed
- Implementation uses TCP/IP sockets
  - CCS & PUP protocol [Jyothi and Lawlor 04]
  - Works over NAT/firewalled networks

Client Architecture

- Client should *never* wait for server
  - Display existing impostors at fixed framerate
    - Even if they're out of date
  - Prefers spatial error (due to out of date impostor) to temporal error (due to dropped frames)
- Implementation uses OpenGL, kernel threads



Server Architecture

- Server accepts a new viewpoint from client
- Decides which impostors to render
- Renders impostors in parallel
- Collects finished impostor images
- Ships images to client

- Implementation uses Charm++ parallel runtime
  - Different phases all run *at once*
    - Overlaps everything, to avoid synchronization
    - Much easier in Charm than in MPI
  - Geometry represented by efficient migrateable objects called array elements [Lawlor and Kale 02]
  - Geometry rendered in priority order
  - Create/destroy array elements as geometry is split/merged

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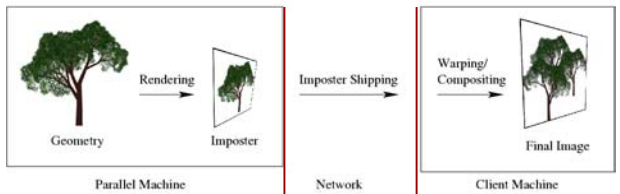
Architecture Analysis



$$B = \min(B_R P R, B_N C_N R, B_C)$$

Benefit from Parallelism

Benefit from Impostors

B	Delivered bandwidth (e.g., 300Mpixels/s)
B_R	Rendering bandwidth per processor (e.g., 1Mpixels/s/cpu)
P	Parallel speedup (e.g., 30 effective cpus)
R	Number of frames impostors are reused (e.g., 10 reuses)
B_N	Network bandwidth (e.g., 60 Mbytes/s)
C_N	Network compression rate (e.g., 0.5 pixels/byte)
B_C	Client rendering bandwidth (e.g., 300Mpixels/s)

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Parallel Planned Work

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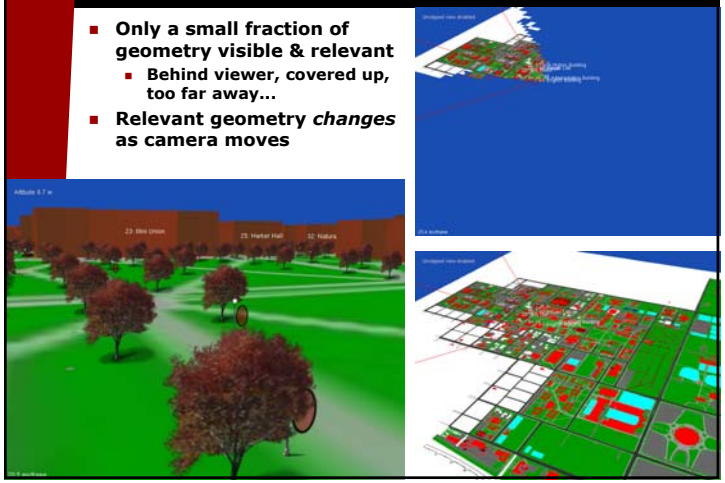
Complicated, Dynamic Problem

- Only a small fraction of geometry visible & relevant
  - Behind viewer, covered up, too far away…
- Relevant geometry *changes* as camera moves



Prioritized Load Balancing

- Parallelism only provides a benefit *if* problem speedup is good
  - Poor prioritization can destroy speedup
  - Speedup does not mean "all processors are busy"
    - That's easy, but work must be *relevant* [Kale et al 93]
  - Must keep all processors and the network busy on relevant work
- Goal: generate most image improvement for least effort
- Priority for rendering or shipping impostor based on
  - Visible error in the current impostor (pixels)
  - Visible screen area (pixels)
  - Visual/perceptual "importance" (scaling factor)
  - Effort required to render or ship impostor (seconds)
- All of these are estimates!

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Graphics Planned Work

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New Graphics Opportunities

- Impostors cuts the rendering bandwidth needed
- Parallelism provides extra rendering power
- Together, these allow
  - Soft Shadows
  - Global Illumination
  - Procedural Detail Generation
  - Huge models

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Quality: Soft Shadows

- Extended light sources cast fuzzy shadows
  - E.g., the sun
- Prior work
  - Ignore fuzziness
  - Point sample area source
  - New faster methods [Hasenfratz 03 survey]

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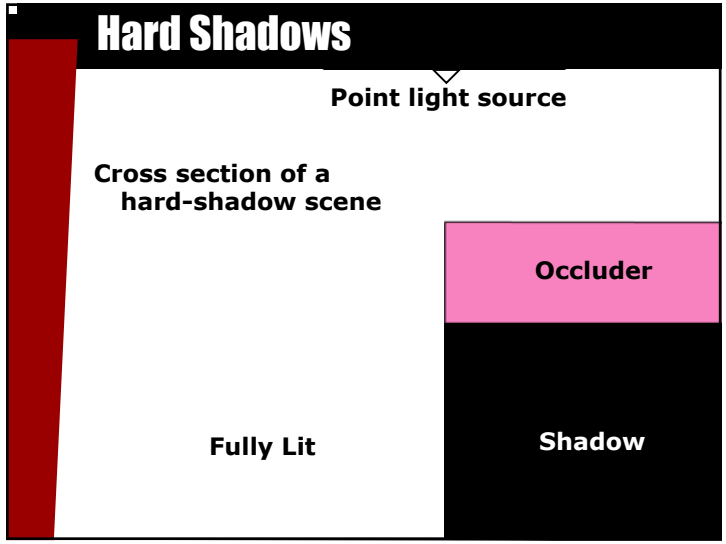
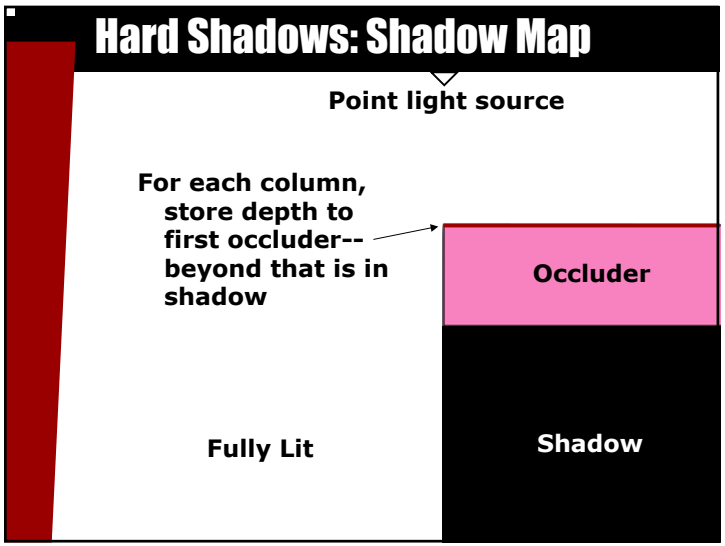
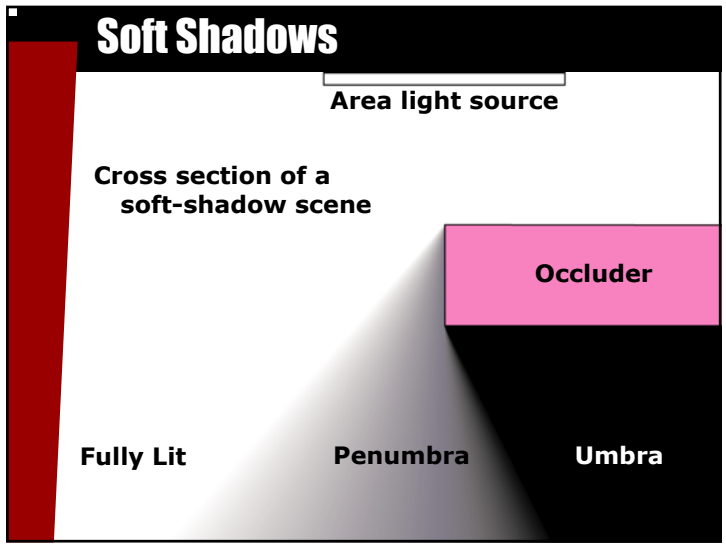
Hard Shadows

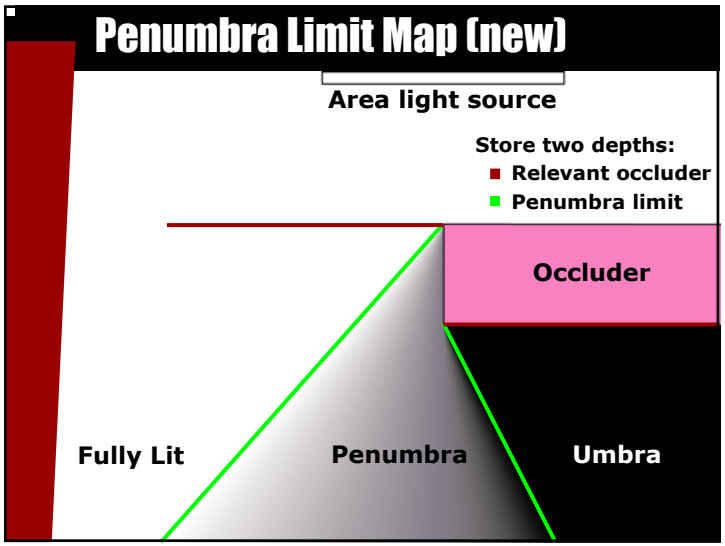


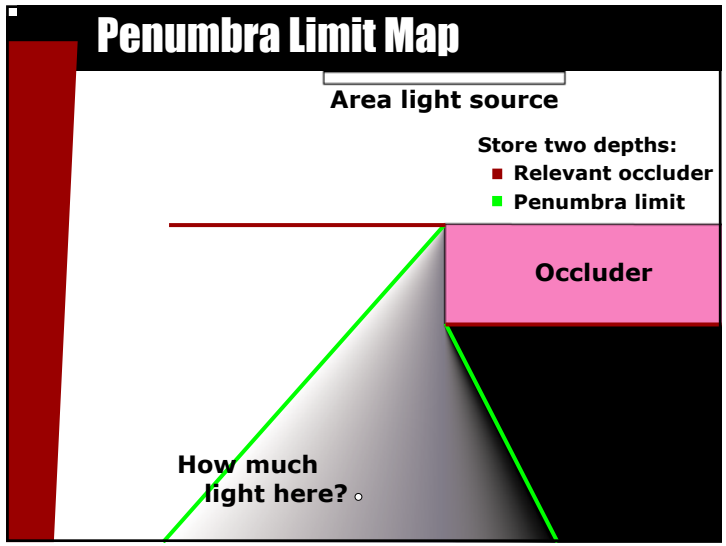
Hard Shadows: Shadow Map

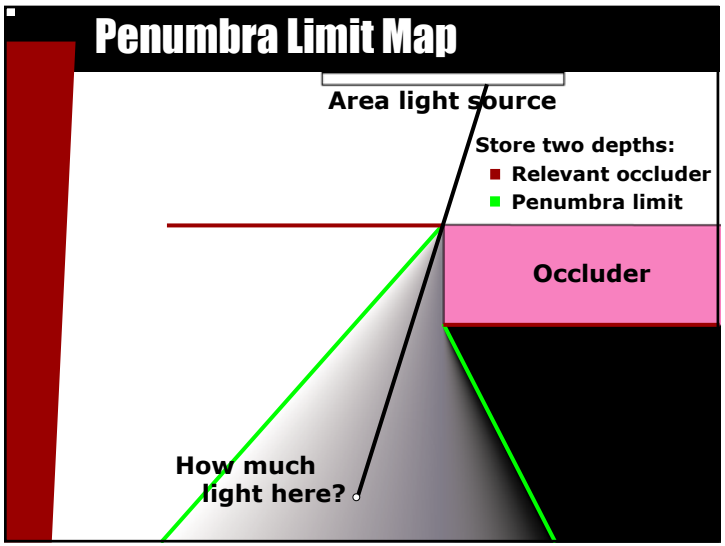


Soft Shadows




Penumbra Limit Map (new)
Area light source
Store two depths:
Relevant occluder
Penumbra limit
Occluder
Fully Lit
Penumbra
Umbra


Penumbra Limit Map
Area light source
Store two depths:
Relevant occluder
Penumbra limit
Occluder
How much
light here?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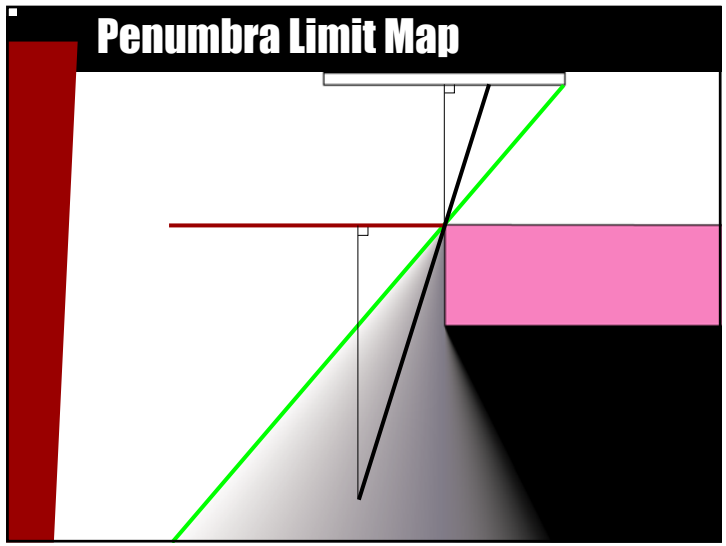
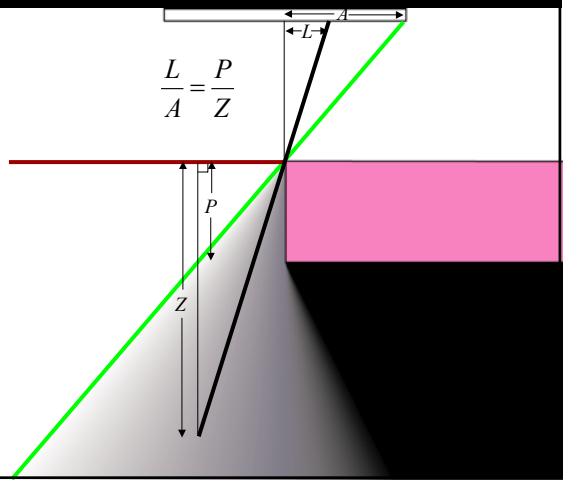
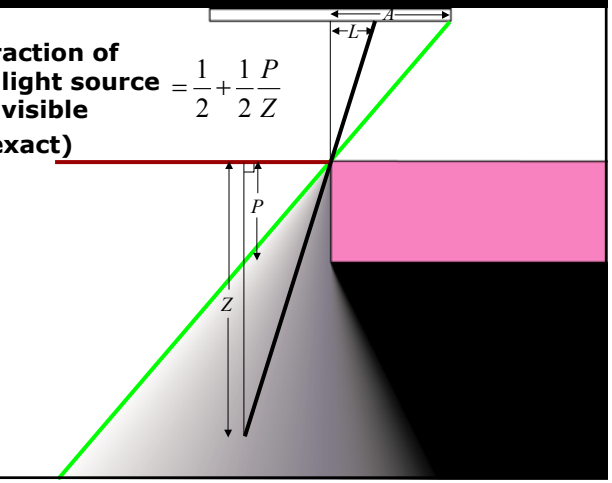

Penumbra Limit Map

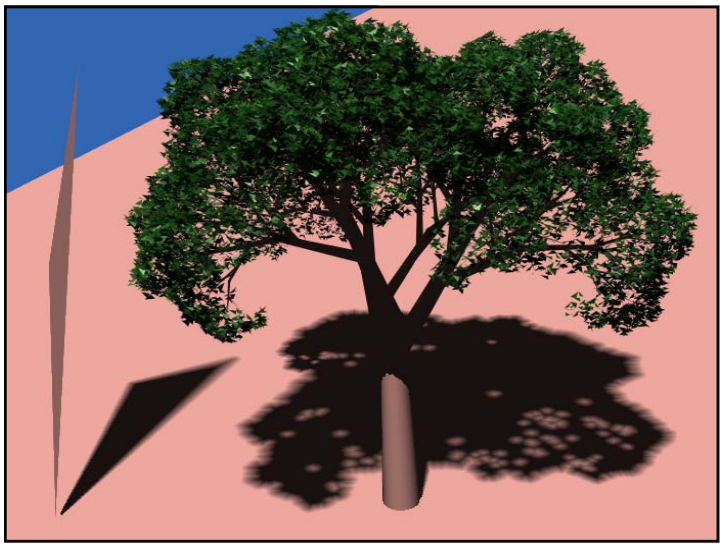
Penumbra Limit Map



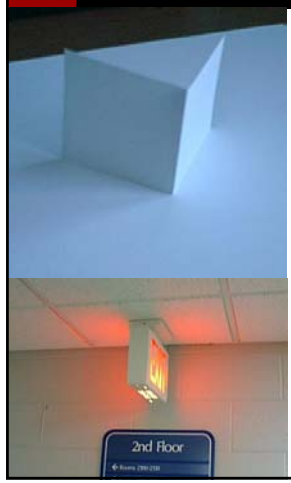
Penumbra Limit Map

Fraction of light source visible (exact) $= \frac{1}{2} + \frac{1}{2}\frac{P}{Z}$





Quality: Global Illumination



- Light bounces between objects (color bleeding)
  - *Everything* is a distributed light source!
- Prior work
  - Ignore extra light
    - "Flat" look
  - Radiosity
  - Photon Mapping
  - Irradiance volume [Greger 98]
  - Spherical harmonic transfer functions

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Detail: Complicated Texture

- World's colors are complicated
- But can be described by simple programs
  - Randomness
  - Cellular generation
    [Legakis & Dorsey & Gortler 01]
  - Texture state machine
    [Zelinka & Garland 02]
- Many are expensive to compute per-pixel, but cheap per-impostor
  - Multiscale noise:
    - $O(\text{octaves})$ for separate pixels
    - $O(1)$ for impostor pixels

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Detail: Complicated Geometry

- World's shape is complicated
- But lots of repetition
- So use subroutines to capture repetition

[Prusinkiewicz, Hart]

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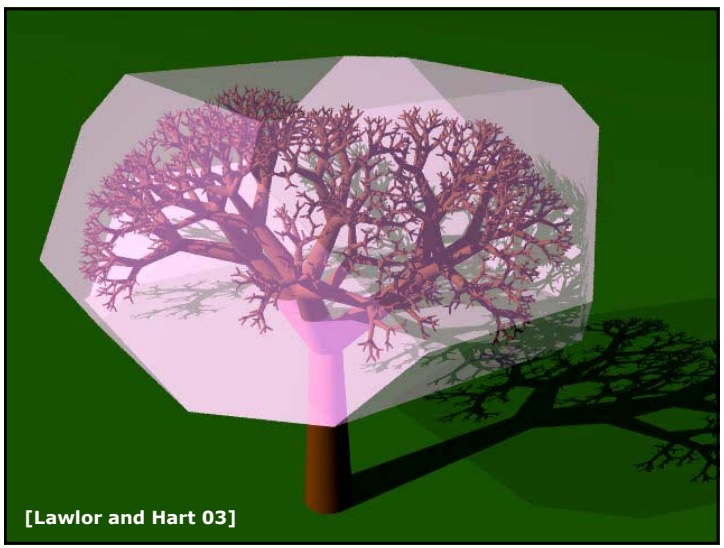

Scale: Kilometers

- World is really big
  - Modeling it by hand is painful!
- But databases exist
  - USGS Elevation
  - GIS Maps
  - Aerial photos
- So *extract* detail from existing sources
  - Leverage huge prior work
- Gives *reality*, which is useful

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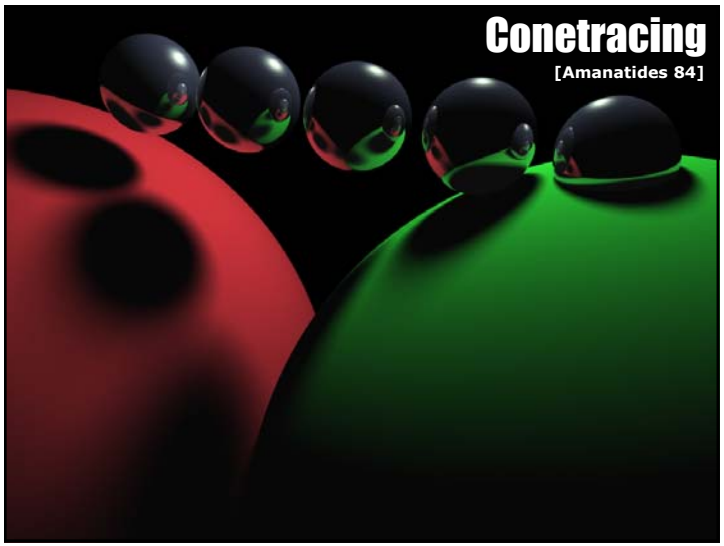

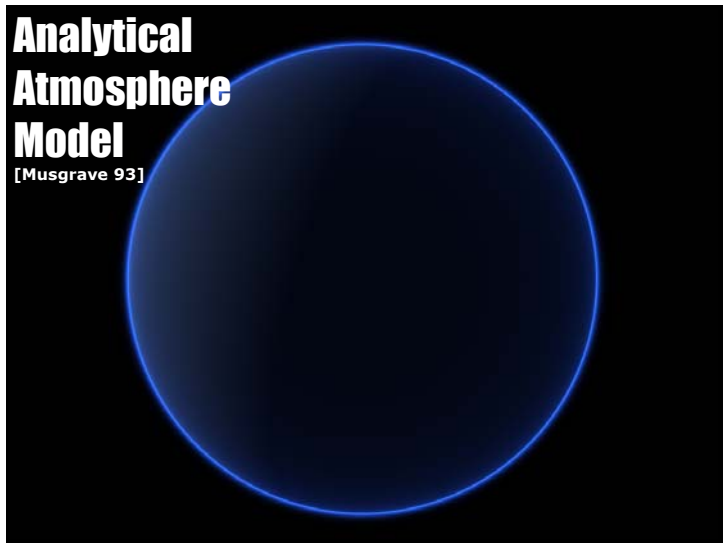

Conclusions

- **Parallel Impostors**
  - **Benefit from parallelism and benefit from impostors are *multiplied* together**
- **Enables quantum leap in rendering detail and accuracy**
  - **Detail: procedural texture and geometry, large-scale worlds**
  - **Accuracy: antialiasing, soft shadows, motion blur**

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