Lecture 11: Interactive Rendering

Chapters 7 in Advanced GI

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Kavita Bala

Computer Science

Cornell University

HW 1

- Questions?

Interactive Software Rendering

- Interactive
  - User-driven, not pre-scripted animation
  - At least a few frames per second (fps)
- Software
  - Major shading done in software
    - Can use hardware to help
- Rendering
  - Online, not pre-computed or captured
    - Eg, lightfields are pre-computed

An Oxymoron?

- Why not just use hardware?
  - The games all use it
  - It has lots of cool effects
  - Isn’t software too slow?

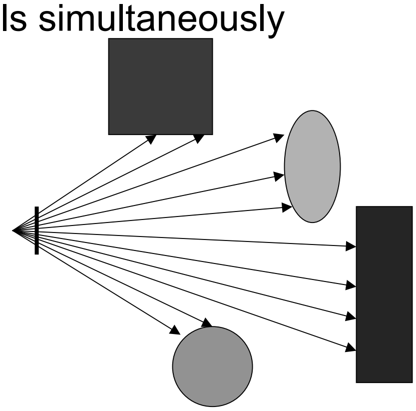
Fast interpolation from vertices

- Specify properties at vertices
  – Color
  – Texture coordinates
  – Surface normals, etc.
- Interpolate at each pixel in triangle

- But: average triangle size is decreasing
  – Many more visible triangles than pixels, therefore, interpolation less valuable

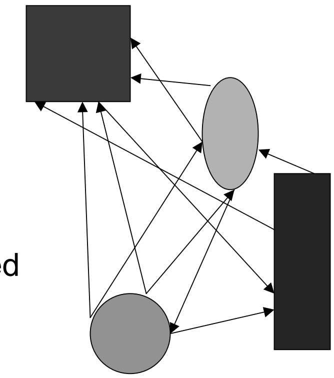
Fast Visibility Determination

- z-buffer: Amortized performance
  – One rendering determines visible surfaces for all pixels simultaneously



Fast Visibility Determination

- Great for some visibility queries types
  - Primary (eye) rays
  - Shadow rays (point sources)
- Not so good for other types
  - Shadow rays (area light sources)
  - Many lights
  - Reflection & refraction from curved surfaces
  - Indirect illumination
  - Adaptive sampling



Fast Shading

- Latest boards can do per-pixel shading
- Programmable
- Local shading only
  - All inputs must be provided ahead of time
  - Non-local shading can only be approximated
    - Shadows, reflections, indirect, etc

Why Software Rendering?

- Global Illumination: Non-local information
- Extremely high complexity
- Arbitrary shading models
- Portability
  - No tweaking: just works
  - No scene dependent optimizations

Hardware Vs. Software

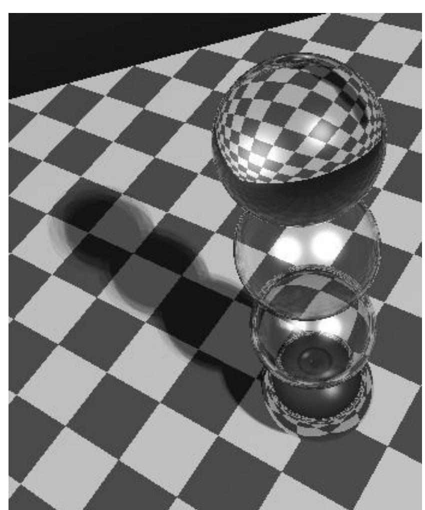
- Hardware still has the edge due to its dedicated pipeline
- Software attractive for its scalability and flexiblility
  - If it can be made “fast enough” for interactive use
  - And handle scene and/or effects the hardware cannot handle

Ray Tracing (or Ray Casting)

- Common visibility tool for software
- Flexible
- Efficient for large models
  - Using an acceleration structure (grids, bsp, etc)
- Usually the largest computational bottleneck
- Easily parallelizable: each pixel in parallel

Interactive RT (Parker et. al.)

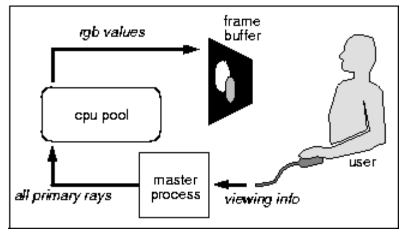
- SGI Origin 2000
  - 64 processors
  - Shared memory
- Whitted-style ray tracing
  - Shadow, reflection, and refraction rays
- Non-polygonal primitives
  - Spheres and splines

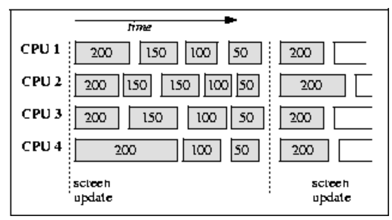


15 fps

Interactive RT: (Parker et al.)

- Dynamic load balancing
  - Tasks divided by screen region
  - Sequence of larger to smaller tasks
  - Found near ideal parallel speedup





Coherent Ray Tracing (Wald et. al.)

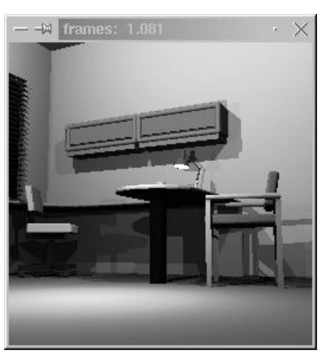
- Highly optimized ray tracing engine for Intel-based PCs
- Carefully profiled their ray tracer
  - Discovered it was often memory bound
- Hand-crafted and tuned their code
  - Both C and assembly versions
  - Compact, cache-friendly data structures
  - Optimized for SIMD (SSE)
  - Reordered computations for better coherence

Coherent Ray Tracing (Wald et. al.)

- Optimizations
  - Separated data based on use
    - Data needed for intersection stored separately
  - Used compact axis-aligned BSP structure
  - Cache aligned data
  - Works on groups of four rays at a time
    - Allows for efficient use of SIMD (SSE)
- Limitations
  - Restricted to triangles only
  - Optimized for Phong shading specifically

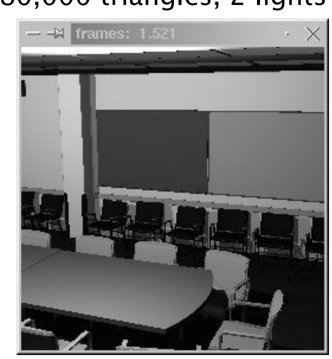
Test Scenes I

- Test scenes: 800 triangles to >8 million



Office:
34,000 triangles, 3 lights

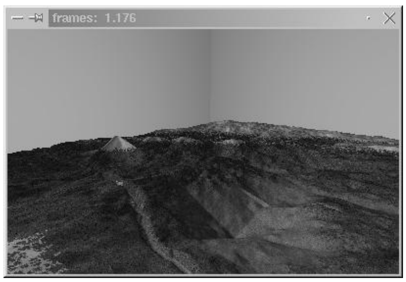
Conference Room:
280,000 triangles, 2 lights

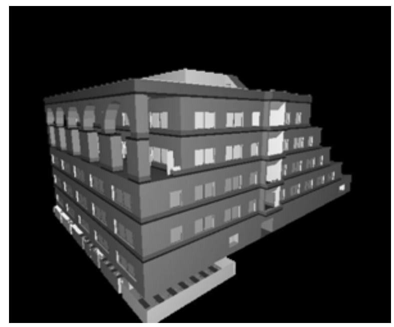


Test Scenes II

- Test scenes: 800 triangles to >8 million

Berkeley Soda Hall:
1.5 to 8 million triangles





Terrain:
1 million triangles (textured)

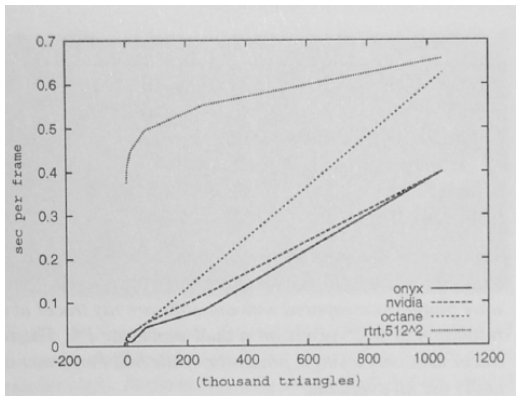
Performance Results I

- Comparison to Rasterization-Hardware
  - Rasterization : IRIS Performer
  - RTRT: 512x512 Pixel, 1 CPU (PIII-800MHz)

Scene (triangles)	Octane	Onyx3	NVidia	RTRT
Office (40k)	>24fps	>36fps	12.7fps	1.8fps
Theatre (680k)	0.4fps	6-12fps	1.5fps	1.1fps
Library (907k)	1.5fps	4fps	1.6fps	1.1fps
5^{th} floor (2.5M)	0.5fps	1.5fps	0.6fps	1.5fps
Soda Hall (8M)	-	-	-	0.8fps

Performance Results II

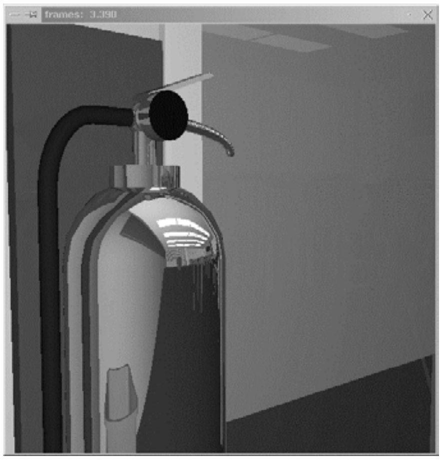
- Comparison to Rasterization-Hardware
  – Ray tracing scales well for large environments

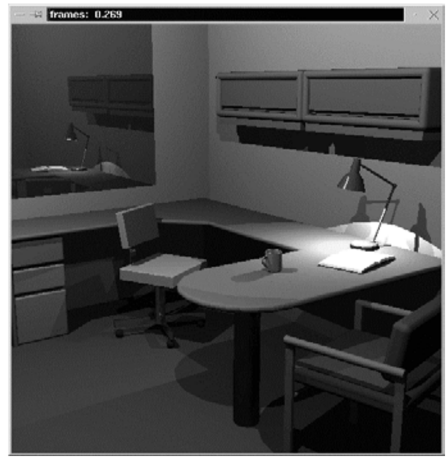


Optimizations (Wald et. al.)

- Also parallelized for more speed
  – Demonstrated on five dual processor PIIIs
- Times are for primary rays only
  – Adding shadows, reflections, etc. adds costs
- Considerable speedup
  – But, more is needed, especially for more complex shading such as:
    - soft shadows, glossy reflections, and indirect illumination

Sample Images





Upshot

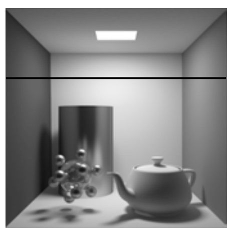
- Software Interactive Rendering is possible now with current machines
  - Good scaling with scene complexity
  - Greater shading flexibility

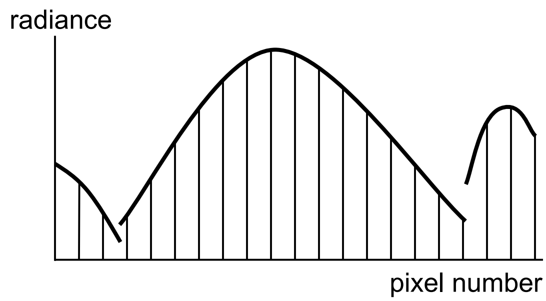
- Many more challenges still remain
  - Higher resolutions
  - Anti-aliasing
  - Fully dynamic environments
  - Global Illumination
  - Complex lighting

Interactive Global Illumination

Rendering as Sampling

- Ray tracers compute radiance at each pixel

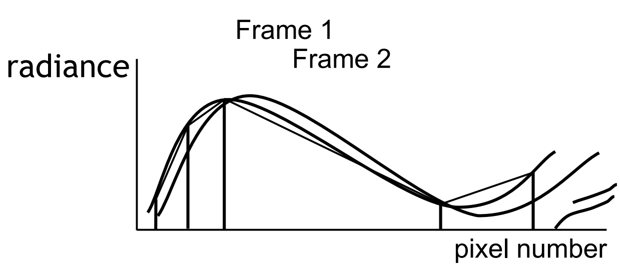




- Rendering = Sampling radiance

Coherence

- Within one frame: spatial coherence



- Across many frames: temporal coherence

Interactive Global Illumination

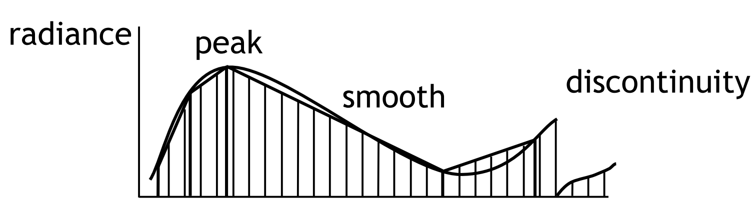
- Need to render every pixel of every frame?

Frame 10 Frame 20 Frame 30

- Exploit coherence in radiance
  - object space, image space, temporal

Strategy

- Insight: radiance is mostly smooth -- use sparse sampling and reconstruction



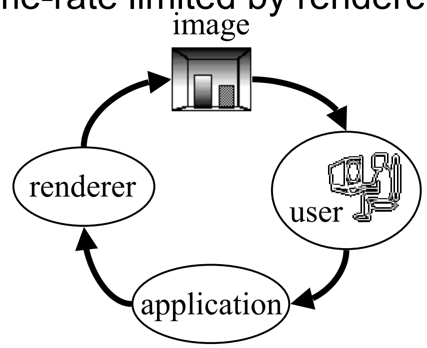
- Radiance samples are very expensive
- Goal: reconstruct most pixels by interpolation
- Issues: discontinuities, non-linear variations

Interactive Global Illumination

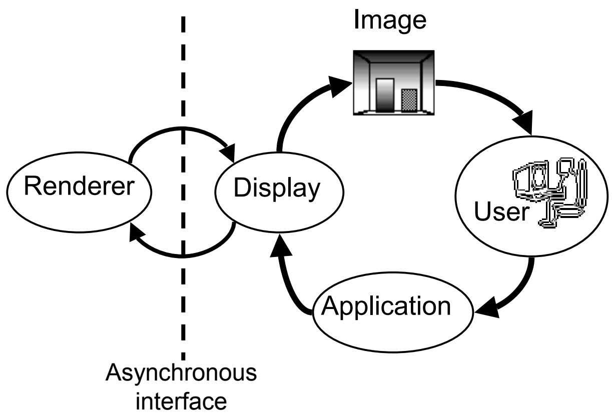
- Fast feedback
- Must bridge gap in framerate
- Interactive requirements
  - Image quality
  - Responsiveness
    - Don’t make the user wait
    - Provide rapid user feedback
  - Consistency
    - Don’t surprise or distract the user
    - Avoid sudden changes if possible
      - Eg, in quality, frame rate, popping, etc.

Visual Feedback Loop

- Standard visual feedback loop
  - Entirely synchronous
  - Frame-rate limited by renderer



Modified Visual Feedback Loop



Display Process

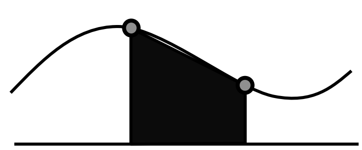
- Automatically exploit spatial and temporal coherence
- Layered on top of an existing (slow) global illumination renderer
- Provide interactive performance

Sparse Sampling Approaches

- 4D:
  - Radiance Interpolants
  - Holodeck
- 2D: Image based
  - Post-rendering Warp
  - Render Cache
  - Edge and Point Rendering

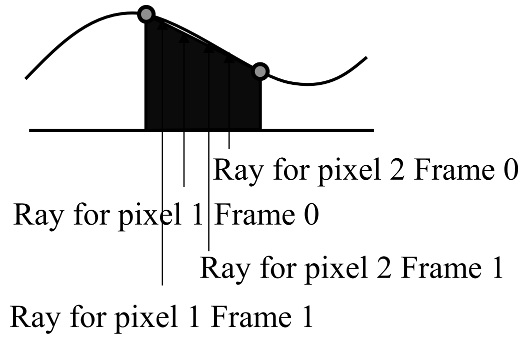
Radiance Interpolants Bala(96,97,99)

- Radiance interpolant:
  - set of sparse samples of radiance function that allow accurate reconstruction



- Note x-axis is the axis of rays

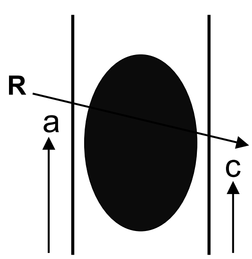
Interpolant for Approximation

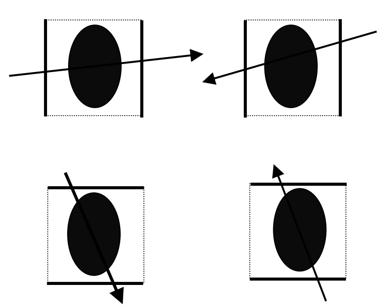


- Approximate radiance with conservative error bounds: accelerate ray tracing
  - Exploits spatial and temporal coherence
  - On-line: no preprocessing

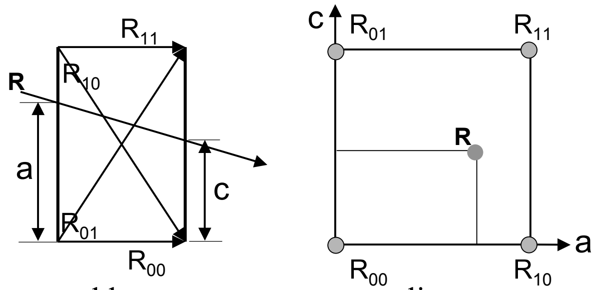
Ray Parameterization

- Radiance is computed along a ray
- In 2D, ray can be parameterized by (a,c)





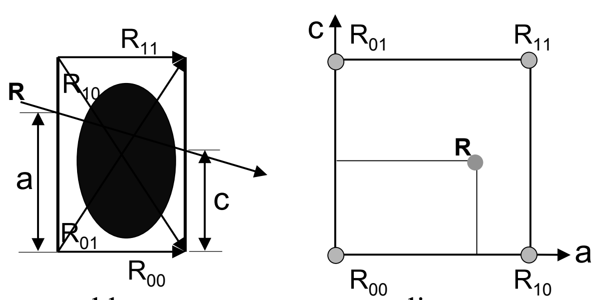
Dual Space



world space a-c line space

- Space of rays is called line space
- It is a dual space
- Every ray in world space is a point in line space
- And vice-versa

Linespace and Interpolants



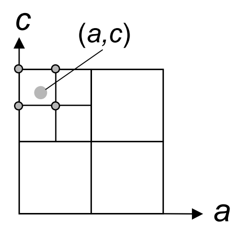
world space a-c line space

- Bilinear interpolation

  $R = (1-a)(1-c)\, R_{00} + a\,(1-c)\, R_{10} + c\,(1-a)\, R_{01} + a\,c\, R_{11}$
- Radiance interpolant: set of four radiance samples for region of line space

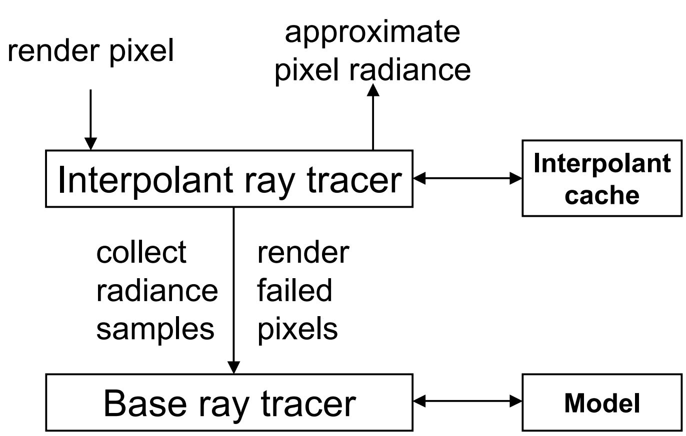
Data structure: Linetree

- Linetree stores interpolants for each object
- Hierarchical tree over line space
  - in 2D, quadtree
- Indexed by ray coordinates
  - Given (*a,c*), find linetree leaf and its interpolant



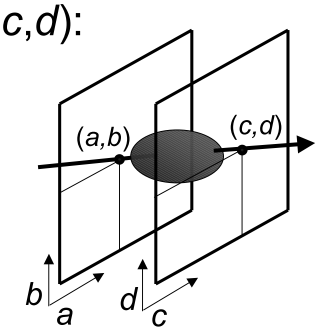
a-*c* line space

System Overview



3D Rays: 4D Parameterization

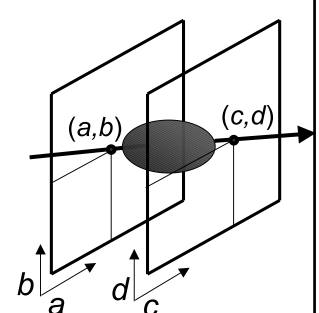
- Ray parameterized by (*a*,*b*,*c*,*d*):
- 6 such pairs of faces



- Linespace is 4D
  – Every ray is point in 4D linespace
  – A box in 4D linespace corresponds to a bundle of 3D rays

4D Radiance Interpolants

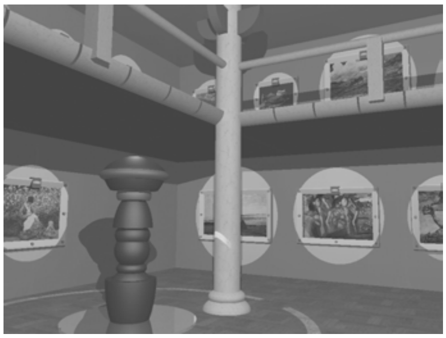
- Interpolant associated with 4D hypercube in line space
  – Sixteen radiance samples
  – Quadrilinear interpolation

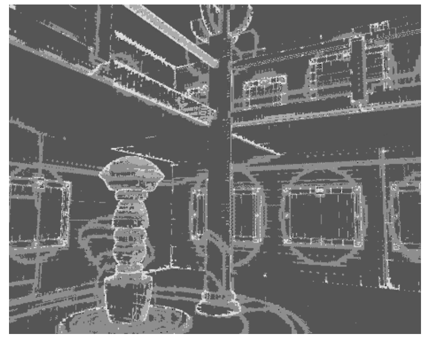


- Samples stored in 4D linetree
- Error-driven subdivision

Results: Museum Scene

1000+ ray-tracing primitives (100k-500k polygons)
195 MHz R10000





gray: interpolation success
yellow: silhouettes; green: shadows; cyan: non-linear radiance

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