Hardware Shading: State-of-the-Art and Future Challenges

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Graphics Hardware

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Hardware is now fast enough

- for complex geometry
- for multipass rendering

Multipass rendering:

- render objects multiple times with different shading parameters and textures to achieve complex shading
- hardware treated as a SIMD processor
- graphics pipeline becomes complex instruction set
- e.g. Quake 3: sometimes 5 passes and more

Graphics Hardware

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New hardware features

- speeding up rendering by reducing number of passes
  - *e.g. multitexturing reduces total bandwidth*
  - *make complex algorithms feasible: e.g. extensions for bump mapping*
- sometimes completely new possibilities
  - *e.g. dependent textures/pixel textures for environment mapped bump mapping*

Applications of Complex, Interactive Shading

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Engineering and design

- light planing, interior design, luminary design

Marketing and (e-)commerce

- product and material catalogs, online shops

Entertainment

- movie special effects, games

Visualization

- medical imaging, scientific visualization

Questions

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What features are <u>necessary</u>?

- what does it take to support the typical rendering algorithms?

What features are <u>useful</u>?

- significant performance improvements for a variety of algorithms

Programming support

- make it easy to develop for graphics hardware

Overview

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Hardware shading algorithms

- materials, shadows, bump maps, volume rendering
- discussion of shading algorithms

Recent hardware developments

- increased flexibility for geometry and fragment processing

Shading languages for graphics hardware

- motivation, required features, open problems

Hardware support for shading languages

Hardware Shading Algorithms

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Examples for multipass rendering:

- realistic materials for local and global illumination
- shadow maps
- volume rendering and participating media
- bump mapping

Rendering of Realistic Materials

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Local illumination (Heidrich '99, Kautz'99):

- use textures to store sampled BRDFs and reflection models
- break down high-dimensional tables to lower-dimensional terms (textures)
- make sure texture coordinates are easy to compute

Example: Torrance-Sparrow Model

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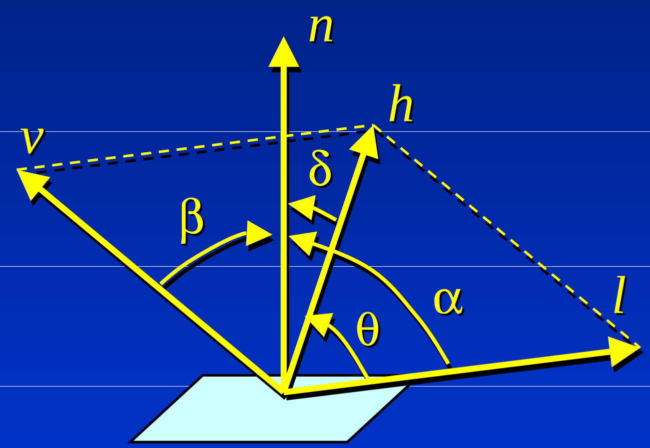
Torrance-Sparrow ('67):

- $f_r = F(\theta)D(\delta) \bullet G(\alpha,\beta)/(\pi \cos\alpha \cos\beta)$



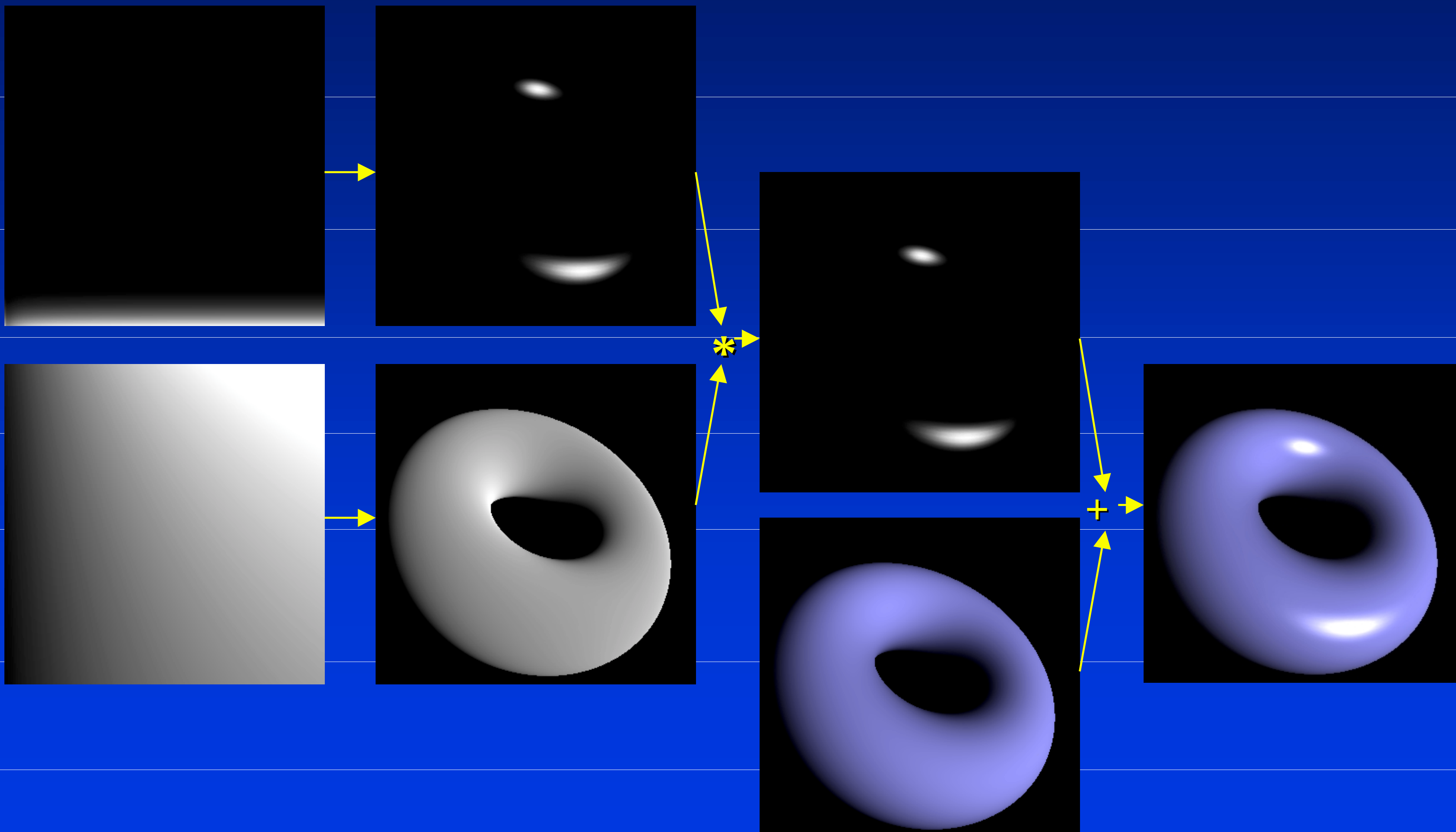
Sample factors

- store as 2D textures

Texture coordinates:

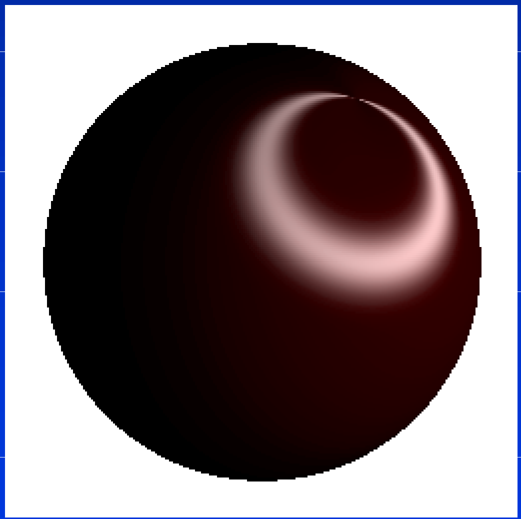
- reparameterize terms over cosines of angles
- allows for hardware-based texture coordinate generation

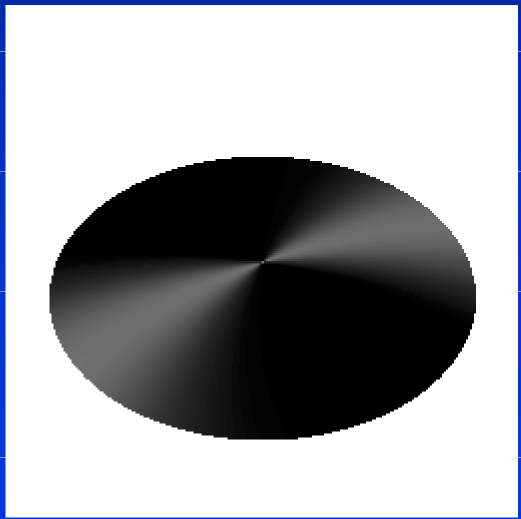
Torrance-Sparrow Model



Banks Model

Anisotropic model (Banks '94, Heidrich '98)

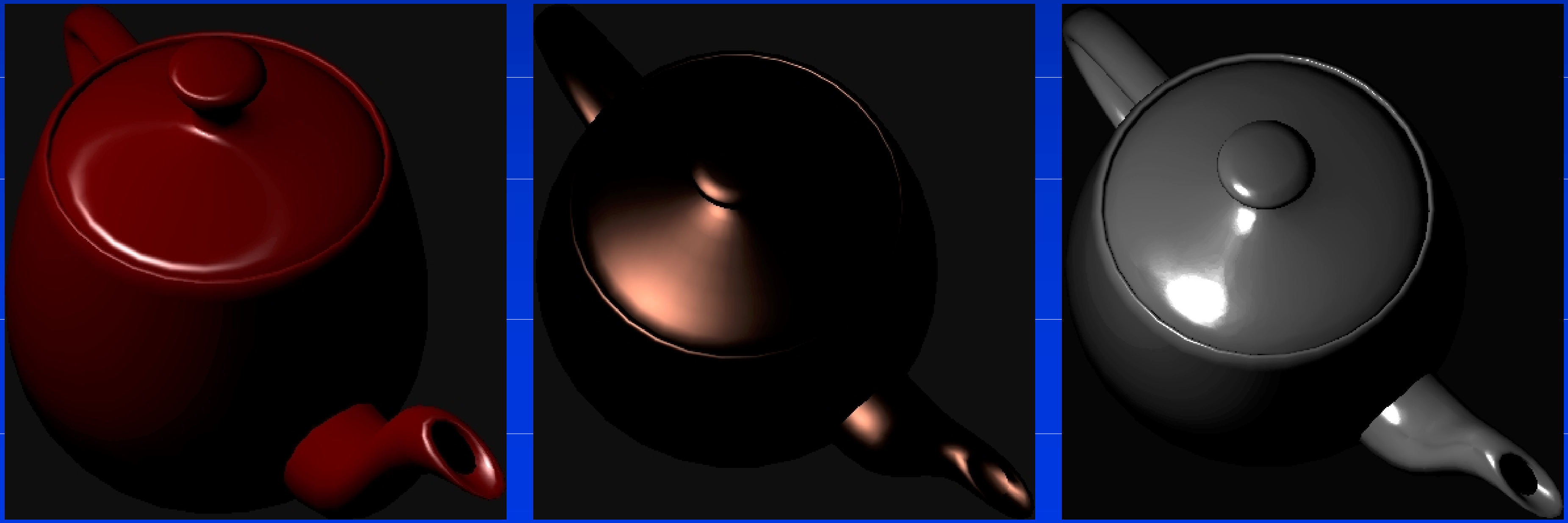




Sampled BRDFs

Factorization of sampled BRDFs (Kautz ´99)

- measured/simulated BRDF data
- rendering similar to analytic models



Sampled BRDFs With Textures

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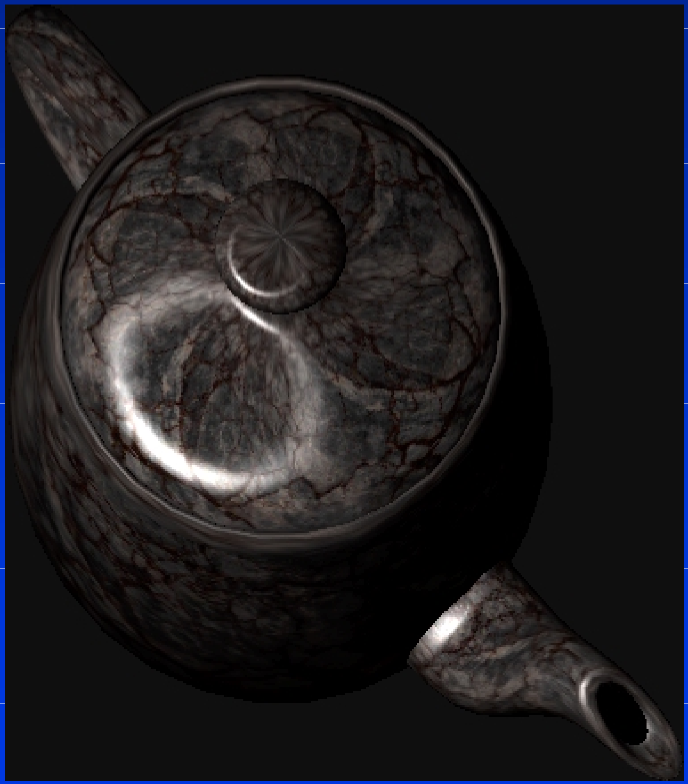
Combining BRDFs with diffuse textures



Environment Maps With Complex Materials:

Hardware Shading Algorithms

Examples for multipass rendering:

- realistic materials for local and global illumination
- shadow maps
- volume rendering and participating media
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Shadow Maps

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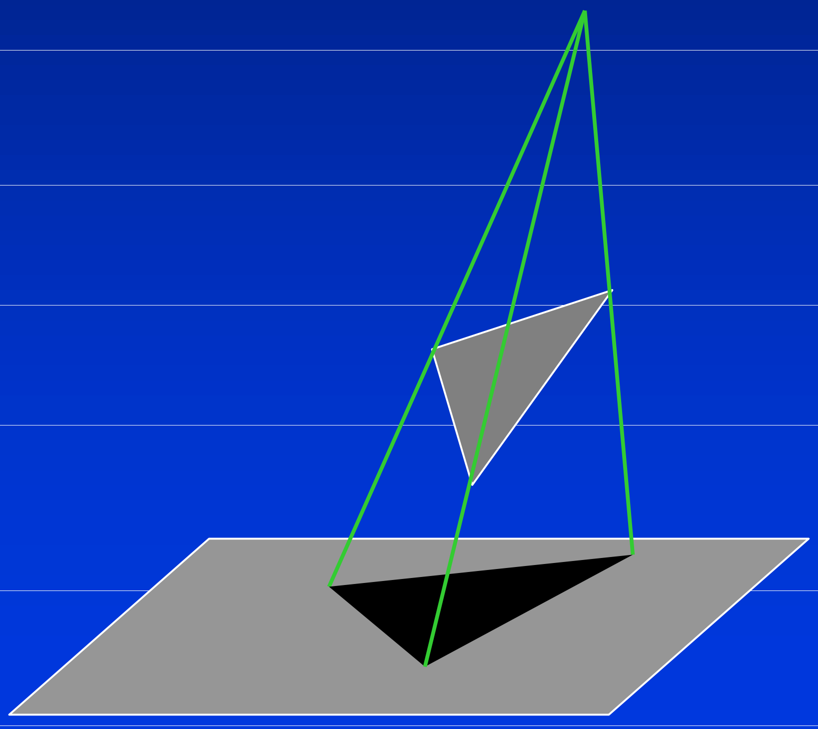
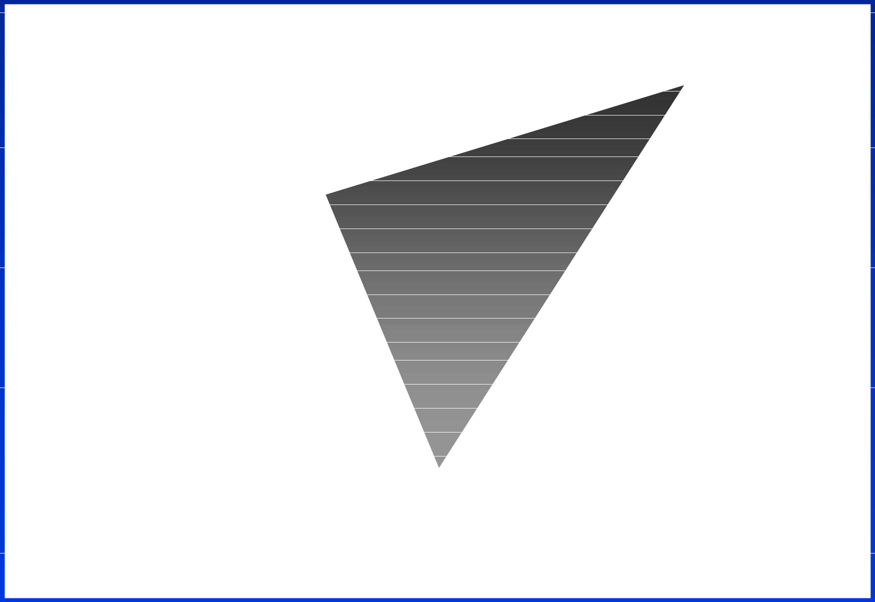
Shadow maps using the alpha test



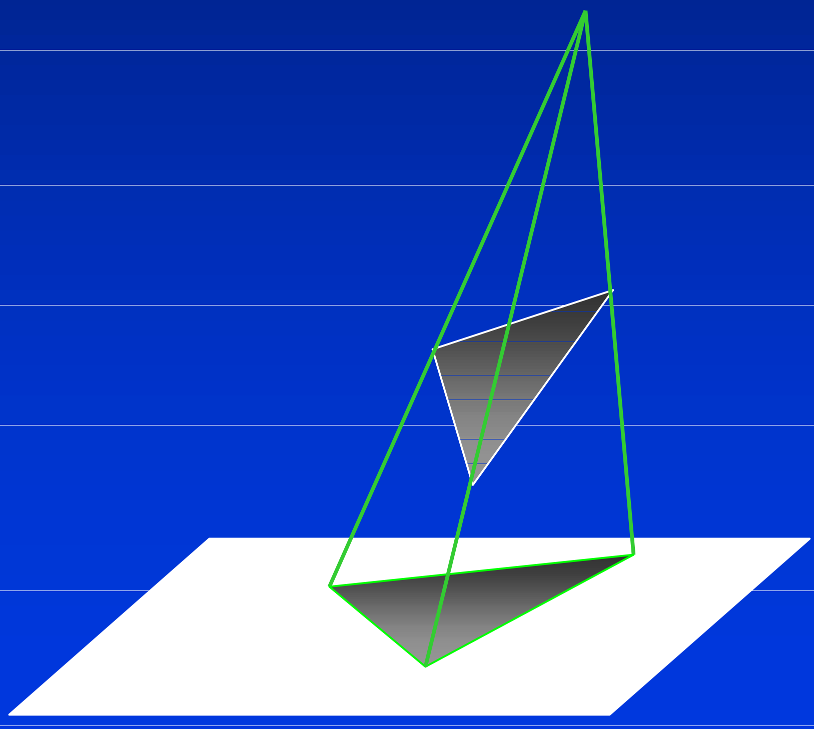
Shadow Maps

Alpha shadow map:



Shadow Maps

Shadow map applied as projective texture



Shadow Maps

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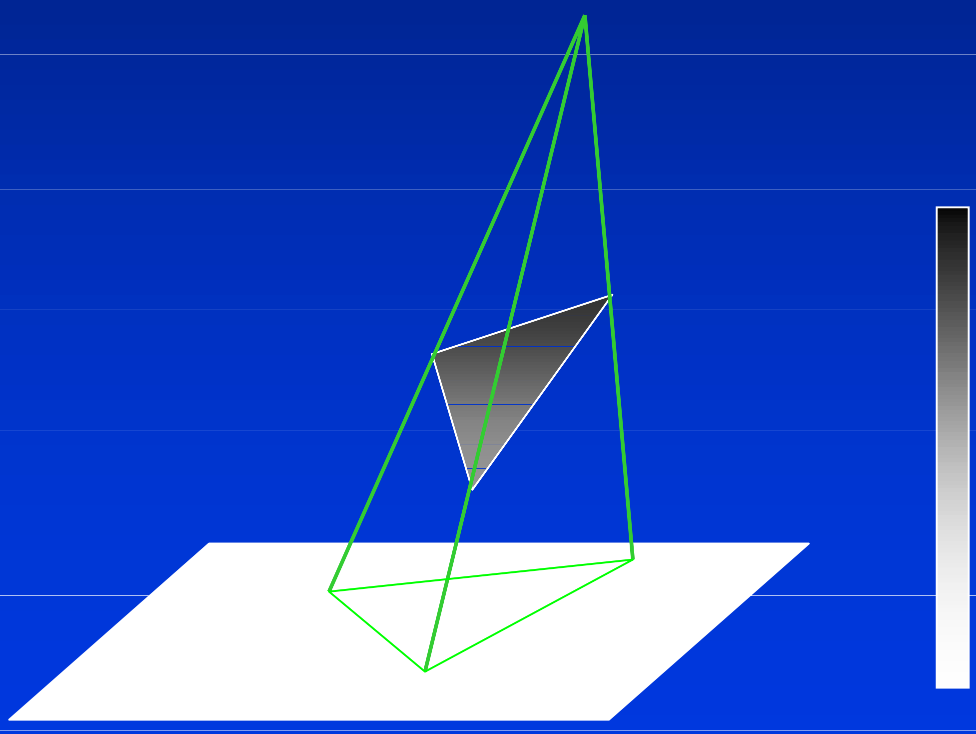
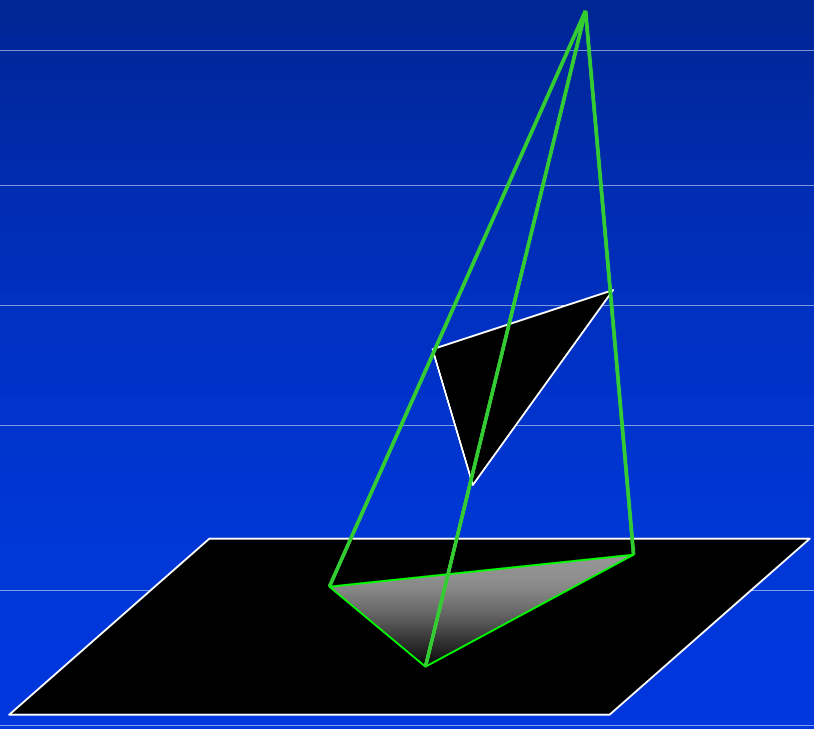
Light source z as 1D alpha texture



Shadow Maps

Subtract projective texture image from 1D texture image



Hardware Shading Algorithms

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Examples for multipass rendering:

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Volume Rendering

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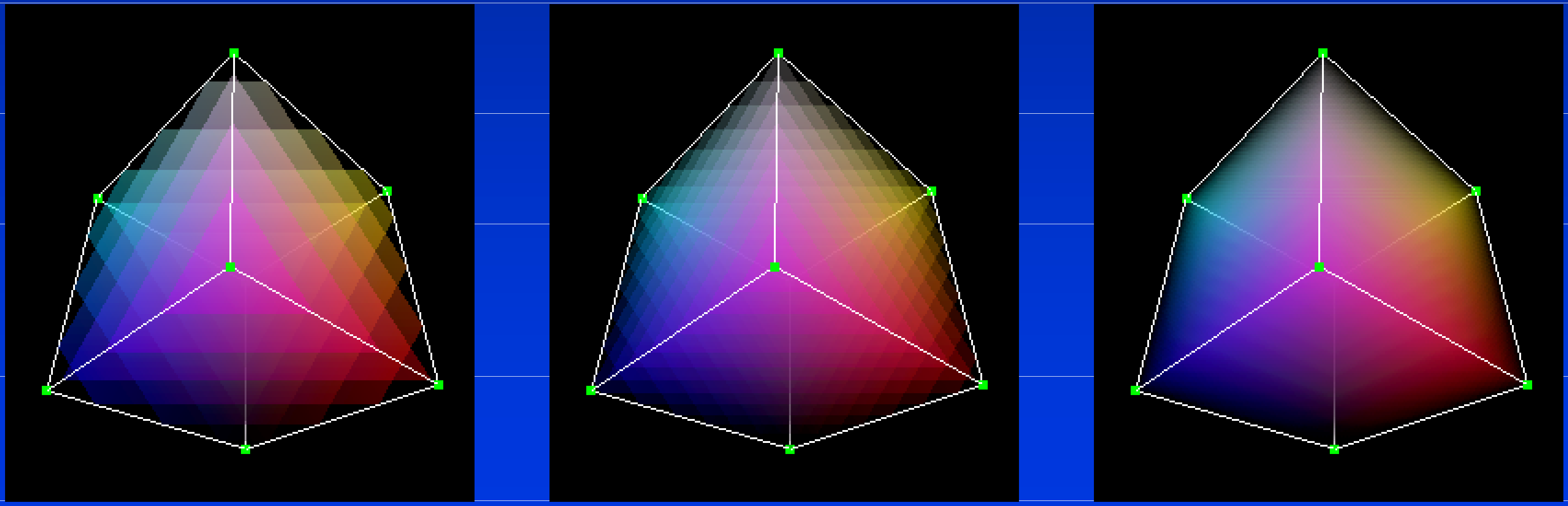
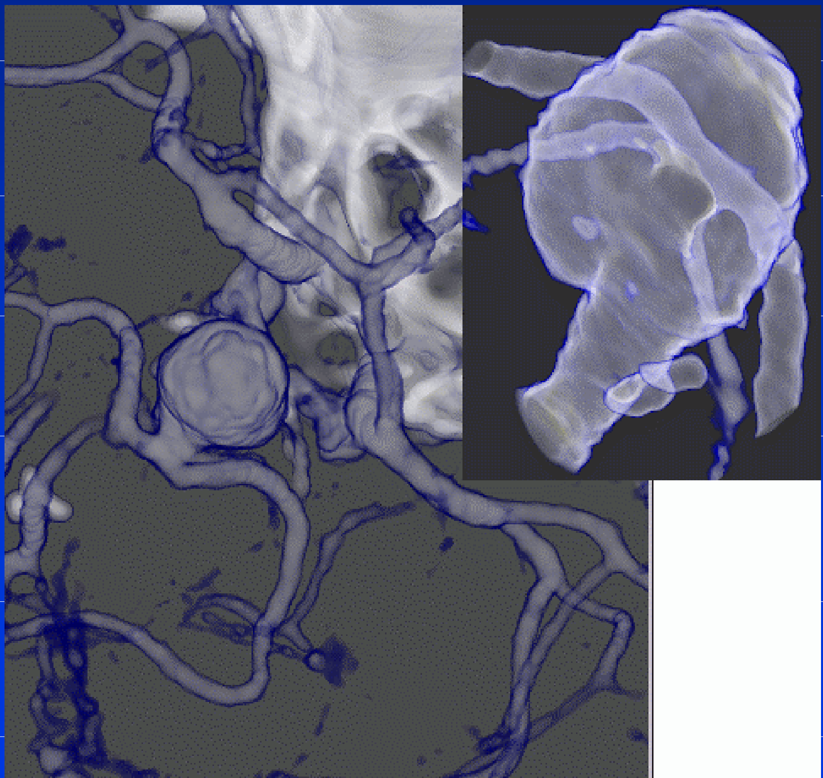
Texture-based volume rendering (Cabral '94, Westermann '98, Salama'00)

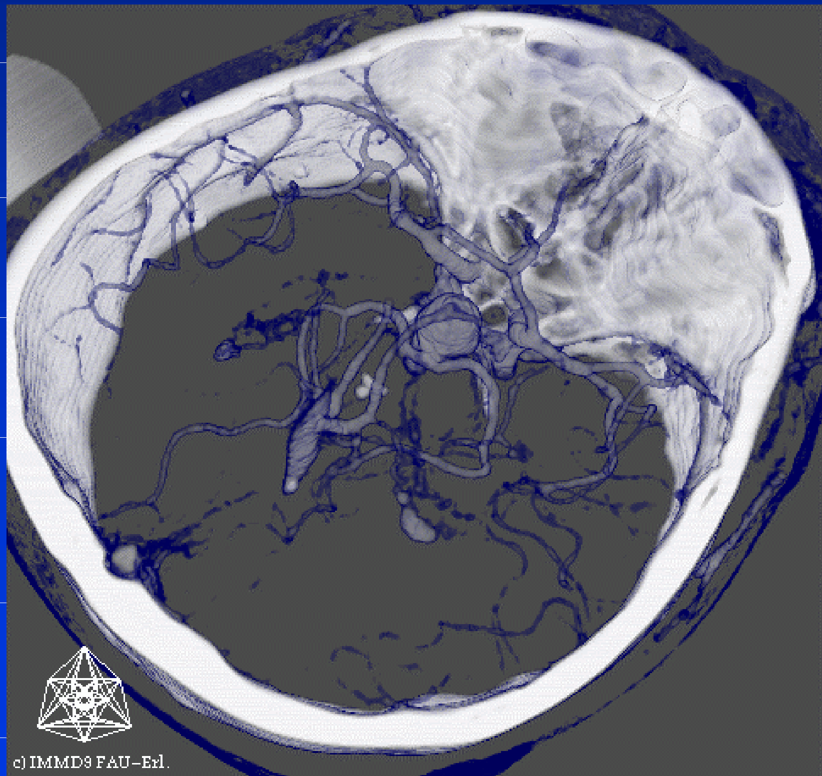
- back-to-front rendering of textured volume slices



Volume Rendering

Texture-based volume rendering (Cabral '94, Westermann '98, Salama'00)





Images: Hastreiter '98

Participating Media

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Volume rendering for streaks of light (Everitt '00, Dobashi '00)

Image: Everitt '00

Image: Dobashi '00

Hardware Shading Algorithms

Examples for multipass rendering:

- realistic materials for local and global illumination
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Bump Mapping

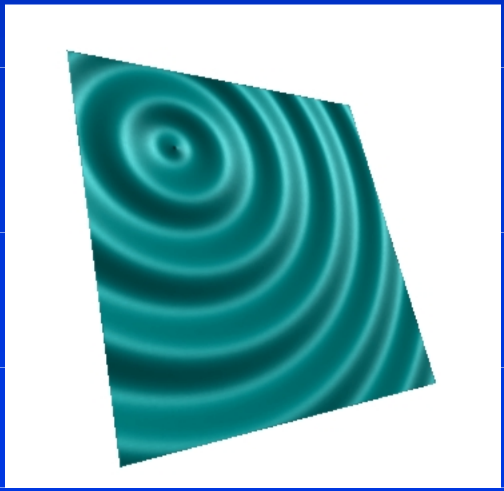
Tangent space bump mapping (Peercy ’97):

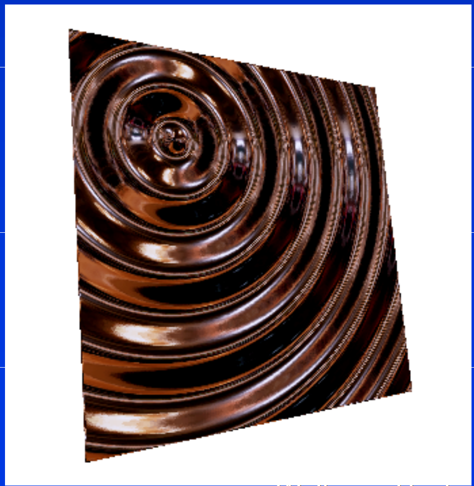
- store normal textures
- use with interpolated local coordinate frame (Schilling '97)
- illumination is function of dot products

Environment mapped bump mapping

- needs dependent texture lookups

Space-varying BRDFs (Kautz ’00)





Bump Map Shadows

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Horizon maps (Max '88)

- pre compute and store horizon for each point in a height field

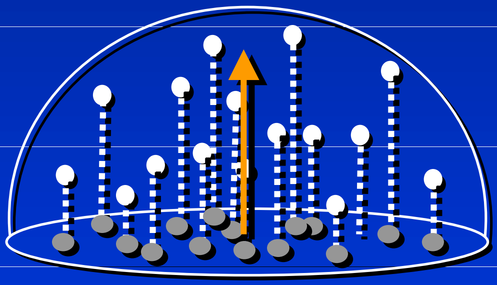
Hardware implementation (Sloan '00)

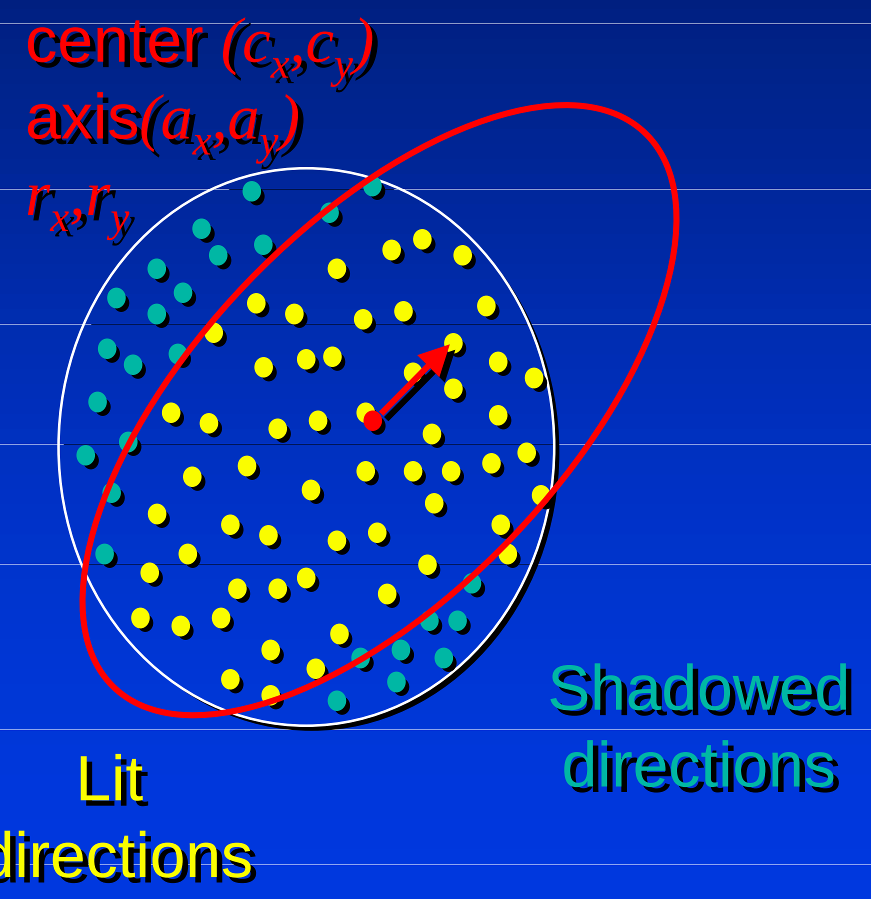
- original horizon map data structure
- several rendering passes

Single pass multi-texturing (Heidrich '00)

- using different horizon representation (ellipse)

Bump Map Shadows





Bump Map Shadows

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Project light direction into tangent plane

Transform projected point into new coordinate system

- given by center and main axes of ellipse (l_x', l_y')

Shadow test:

$$1 - \frac{(l_x')^2}{r_x^2} - \frac{(l_y')^2}{r_y^2} \geq 0$$

Discussion

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Common theme: multipass rendering

- for texture generation
  - *e.g. generating shadow or environment maps*
  - *typically: simulation of global effects*
- for texture application
  - *combining results of different textures and shading algorithms in the frame buffer*
  - *typically: complex local effects*

Discussion - Implications

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Bandwidth

- multiple transmission of geometry
- multiple read/writes to framebuffer
- sometimes read back of framebuffer

Geometry

- different passes require different per-vertex params.
  – *color, texture coordinate, normal...*
- require flexible way of generating these parameters

Recent Hardware Development

Increased flexibility of rendering pipeline

- mostly to reduce number of passes

Rasterization stage: multi-texturing

- reduces total required bandwidth for most algorithms requiring multiple textures
- but becomes bottleneck for fragment processing stage of rendering pipeline if many textures are used
- texture shaders (McCool '99), register combiner (NVIDIA '99): use the available time to perform more complex operations with the looked up values

Recent Hardware Development

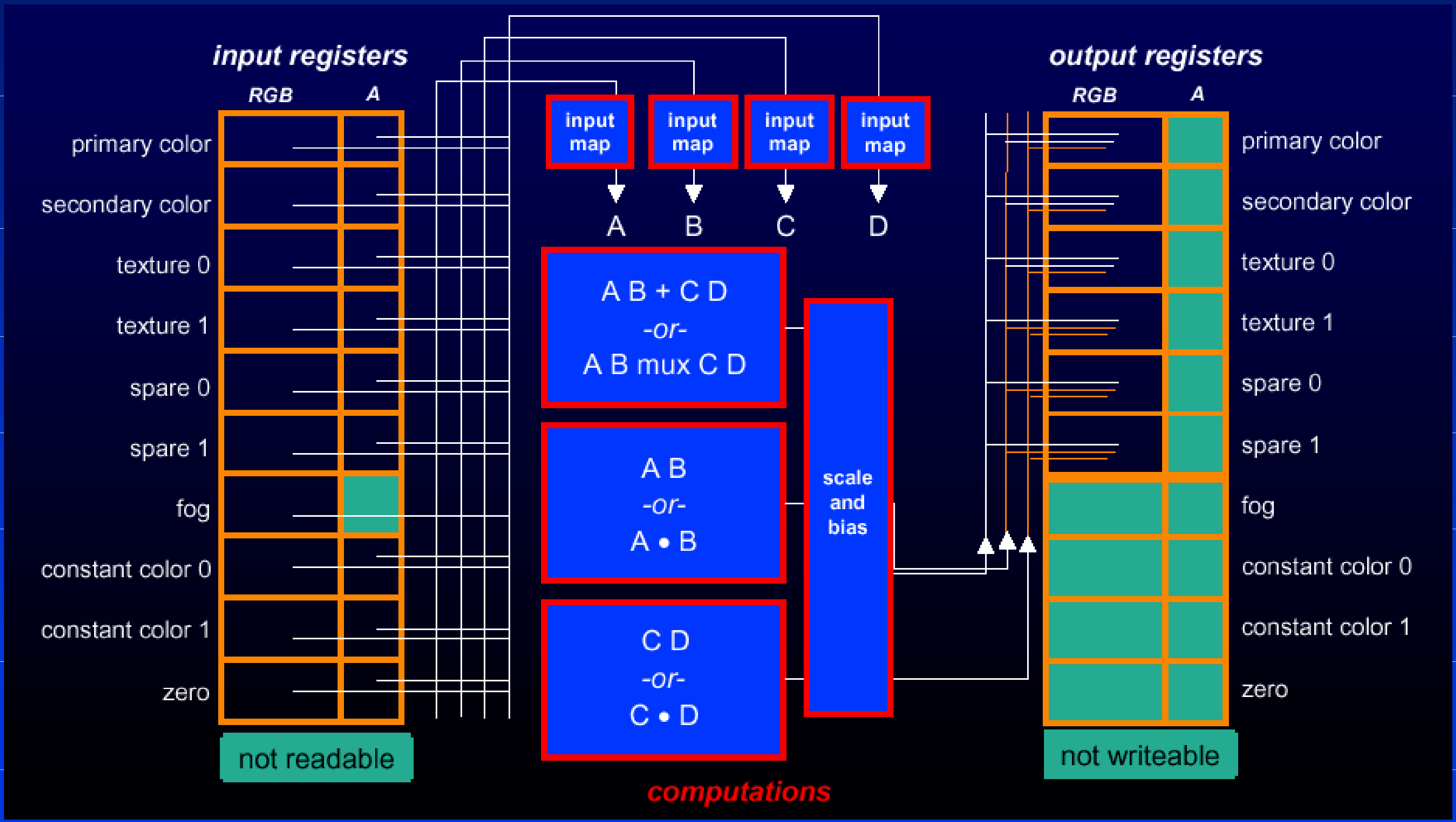

Diagram: NVIDIA

Recent
Hardware Development

Geometry stage

- texture coordinate generation
- programmable geometry (DirectX 8)
  - *http://www.gamasutra.com/features/index_gdc.htm*

Dependent Texture Lookups

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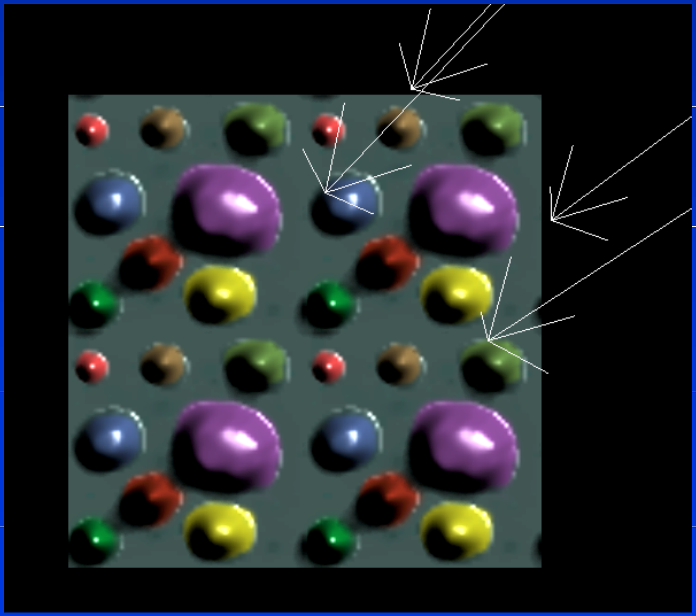
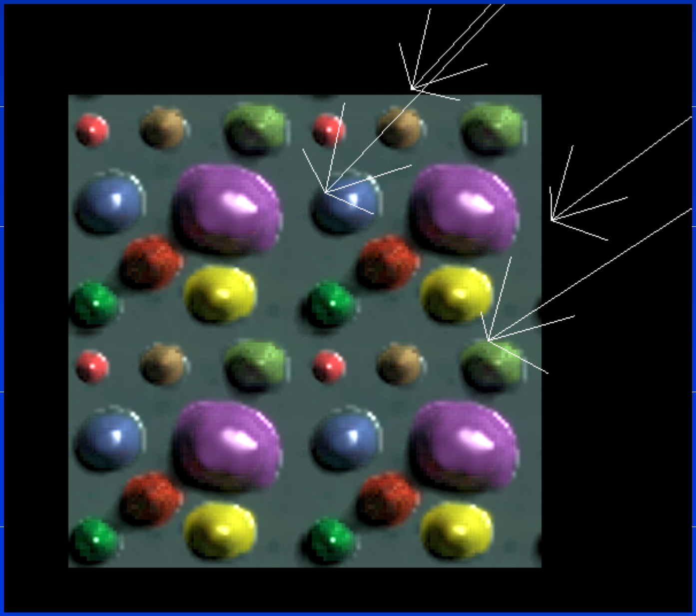
Useful for:

- environment mapped bump mapping
- light transport for indirect illumination (Heidrich '00)
- line integral convolution (LIC, Heidrich '99)
- ...





Problems With New Hardware Features

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Problem:

- extensions hard to program for
- no debugging support
- non-standard: capabilities vary with specific hardware
  - *have to adapt algorithms to individual graphics boards*

Solution: high-level shading language

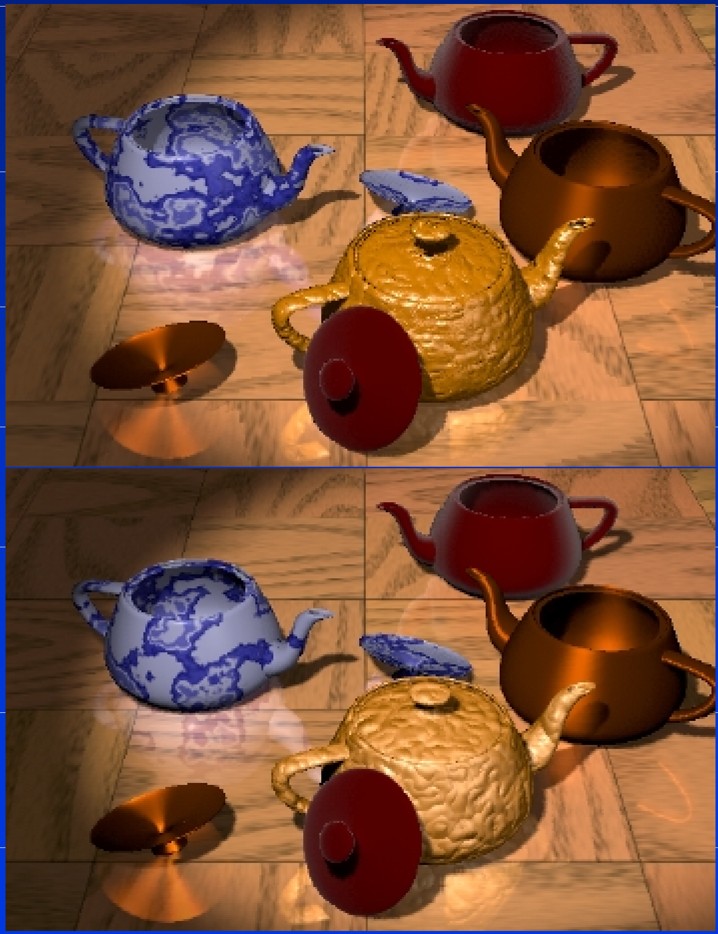
Shading Languages: RenderMan

RenderMan shading language (Hanrahan '90)

- standard in offline applications
- e.g. Toy Story

RenderMan on OpenGL (Peercy '00)

- RenderMan shading language with standard OpenGL+ pixel textures* floating point framebuffer



Images: Peercy '00

Feasible Languages

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For hardware shading:

- use sampled representations of complex functions
- shading languages for combining textures

Existing systems:

- Quake 3 shading language
- Stanford programmable shading project
  - *http://graphics.stanford.edu/projects/shading*
- SGI interactive shading language (ISL)
  - *http://www.sgi.com/software/shader*

Research Issues

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Immediate mode vs. scene graph

- problem: no widely accepted scene graphs available

Compiler technology

- code generation for very complex instruction sets

Working around the brick wall

- managing partial results and multiple passes

Beyond RenderMan?

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Management of texture generation passes

- language for describing generation of environment maps, shadow maps, light maps...

New kinds of interesting shaders

- cellular automata (e.g. clouds)
- reaction-diffusion shaders (e.g. animal skin)
- require side effects (textures evolving over time)
- desirable: hardware convolution

Hardware Support for Procedural Shading

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What can hardware developers do?

- orthogonal feature sets
- cost/precision models for hardware operations
- avoiding the brick wall
  - *managing intermediate results*
  - *micro-threading (Mark '00, McCool '00)*

Summary

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Complex hardware shading is now possible

- multi-pass algorithms and new hardware features

Recent hardware developments

- reduce number of passes, increase performance
- hard to program

Shading languages for graphics hardware

- make programming easier
- a lot of research to be done
- need hardware support

Acknowledgments

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MPI rendering group:

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SGI procedural shading group:

- Marc Olano, Marc Peercy

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