Real-Time Realistic Rendering

LUGG
Lund University Graphics Group

Michael Doggett
Docent
Department of Computer Science
Lund university

30-5-2011

Visually realistic goal "… force[d] us to **completely rethink the entire rendering process.**"

Cook et al., 1987
The Reyes Image Rendering Architecture

Image courtesy and copyright Pixar

Slide courtesy Jonathan Rag n-Ke ey

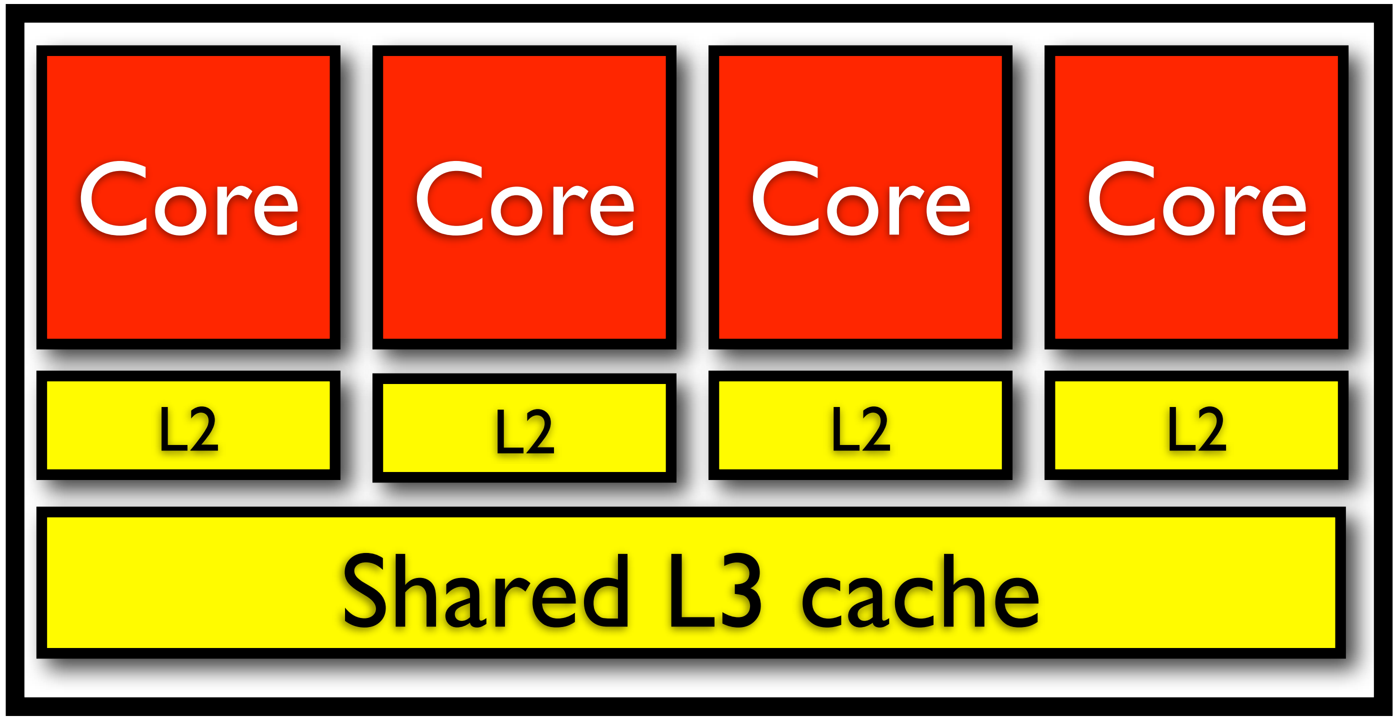
Outline

- GPU architecture
  - 2001-2009 ATI/AMD - Boston, U.S.A.
  - XBOX360, Radeon 2xxx-6xxx
- Decoupled Sampling
- Analytical Motion Blur

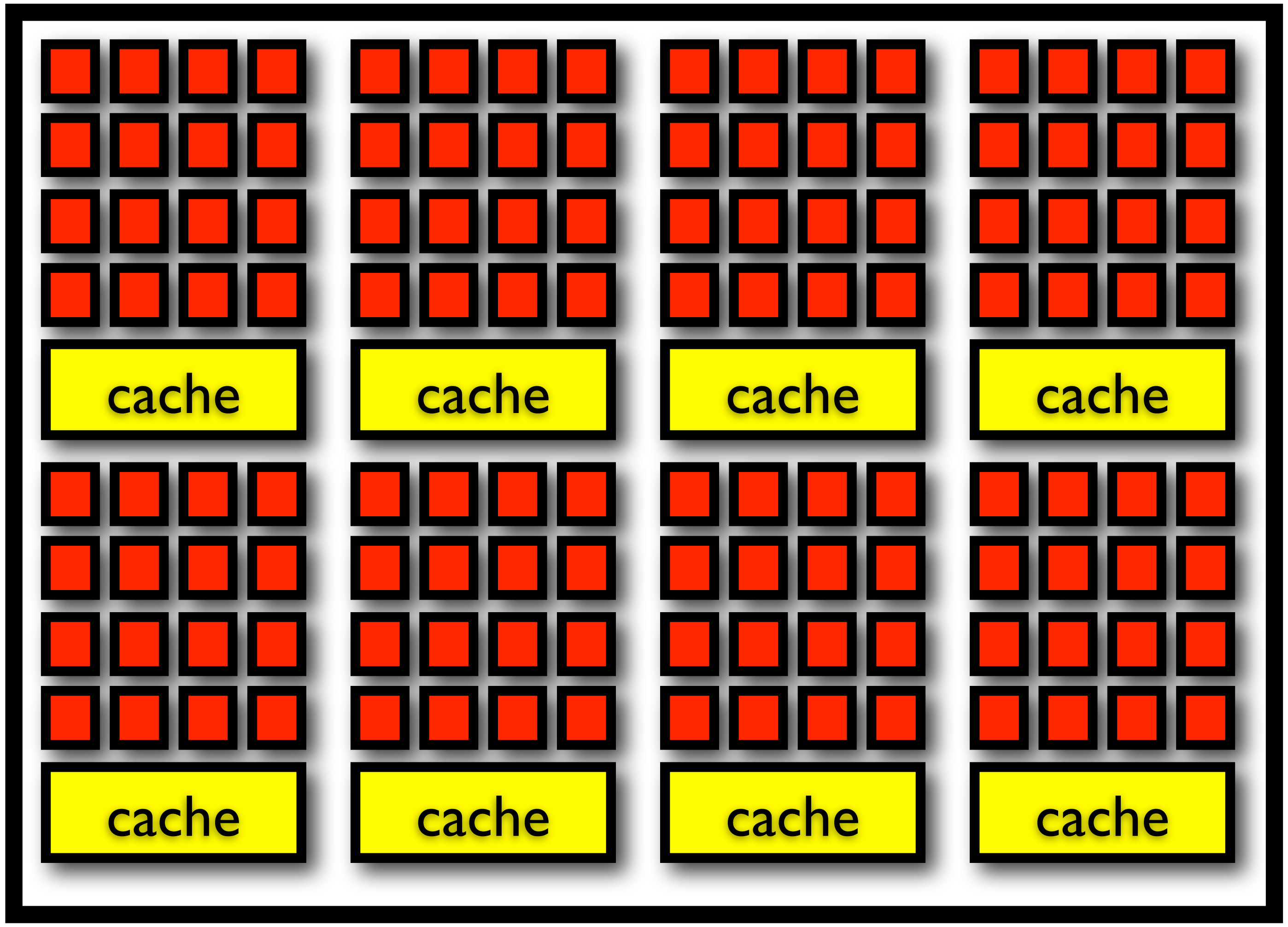
GRAPHICS GROUP

- Tomas Akenine-Möller
- Michael Doggett
- Lennart Ohlsson
- Magnus Andersson
- Rasmus Barringer
- Per Ganestam
- Carl Johan Gribel
- Björn Johnsson
- Jim Rasmusson
- Philip Buchanan

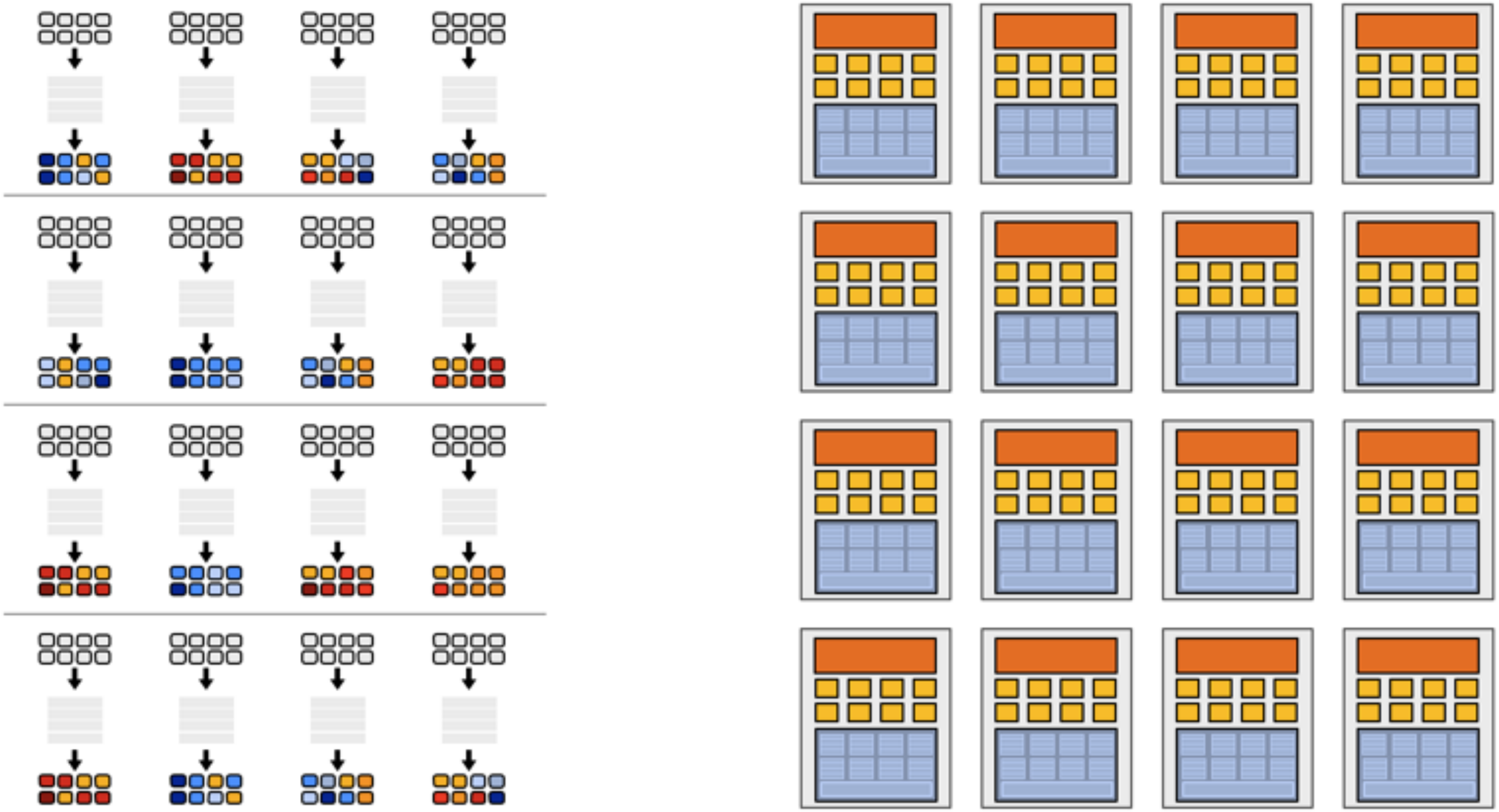
CPU


Core
Core
Core
Core
L2
L2
L2
L2
Shared L3 cache

GPU


cache
cache
cache
cache
cache
cache
cache
cache

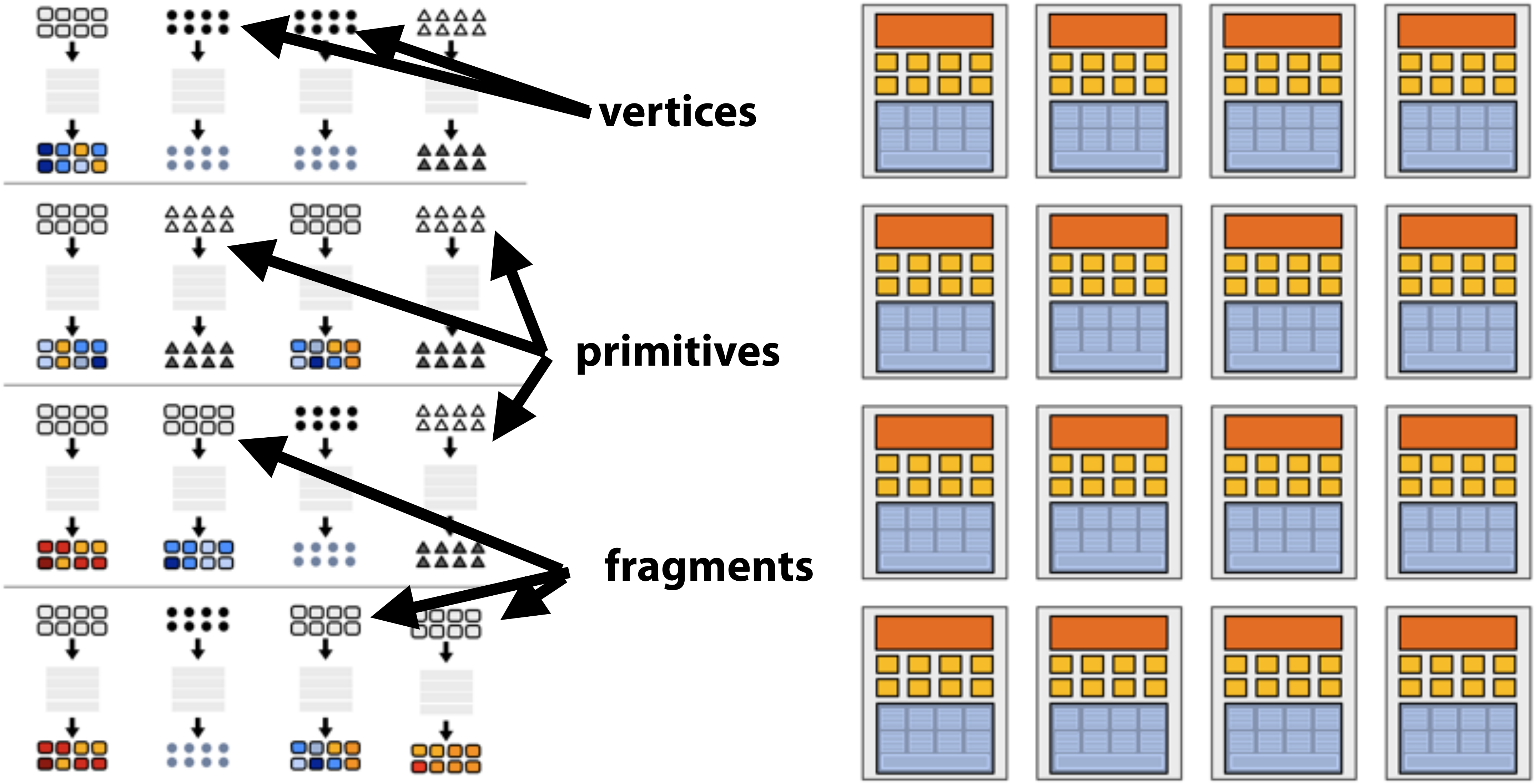
128 fragments in parallel



16 cores = 128 ALUs , 16 simultaneous instruction streams

Slide courtesy Kayvon Fatahalian

128 [vertices/fragments primitives OpenCL work items CUDA threads] in parallel



Slide courtesy Kayvon Fatahalian

GPU design parameters

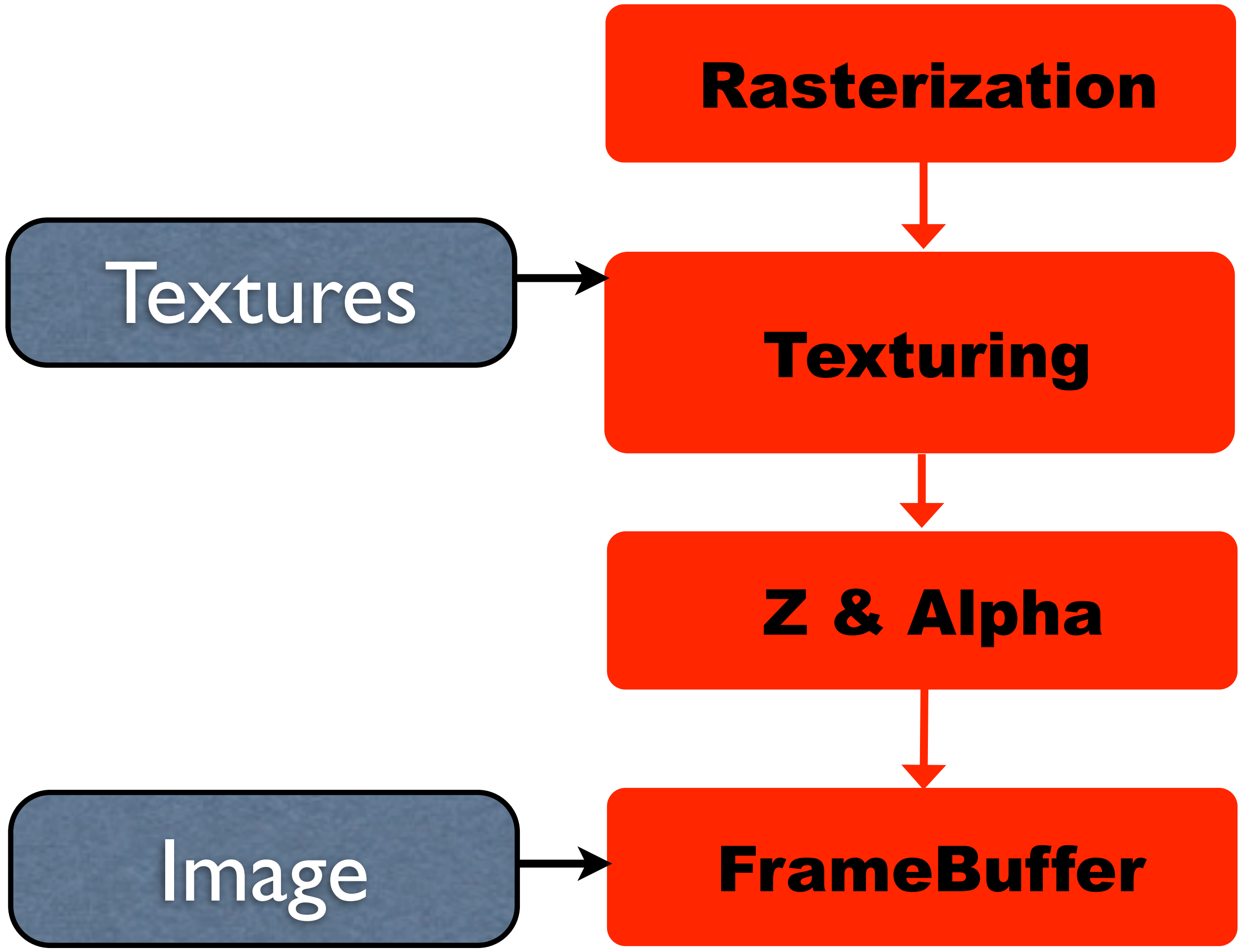
- Competition
  - Currently 2 strong competitors
    - AMD (ATI) and nVidia
  - Performance/Dollar
- Moore’s law
  - Number of transistors on a chip doubles every two years

GPU design parameters

- RTL design
  - nVidia ALUs from DX10 on are full custom
- Architecture changes hidden by API
  - Fixed function uses programmable hardware
- Many custom units
- Backwards compatible

Before programmable GPUs

- ATI
  - Founded 1985 started
- nVidia
  - Founded 1993
- DirectX 6



Rasterization

Textures

Texturing

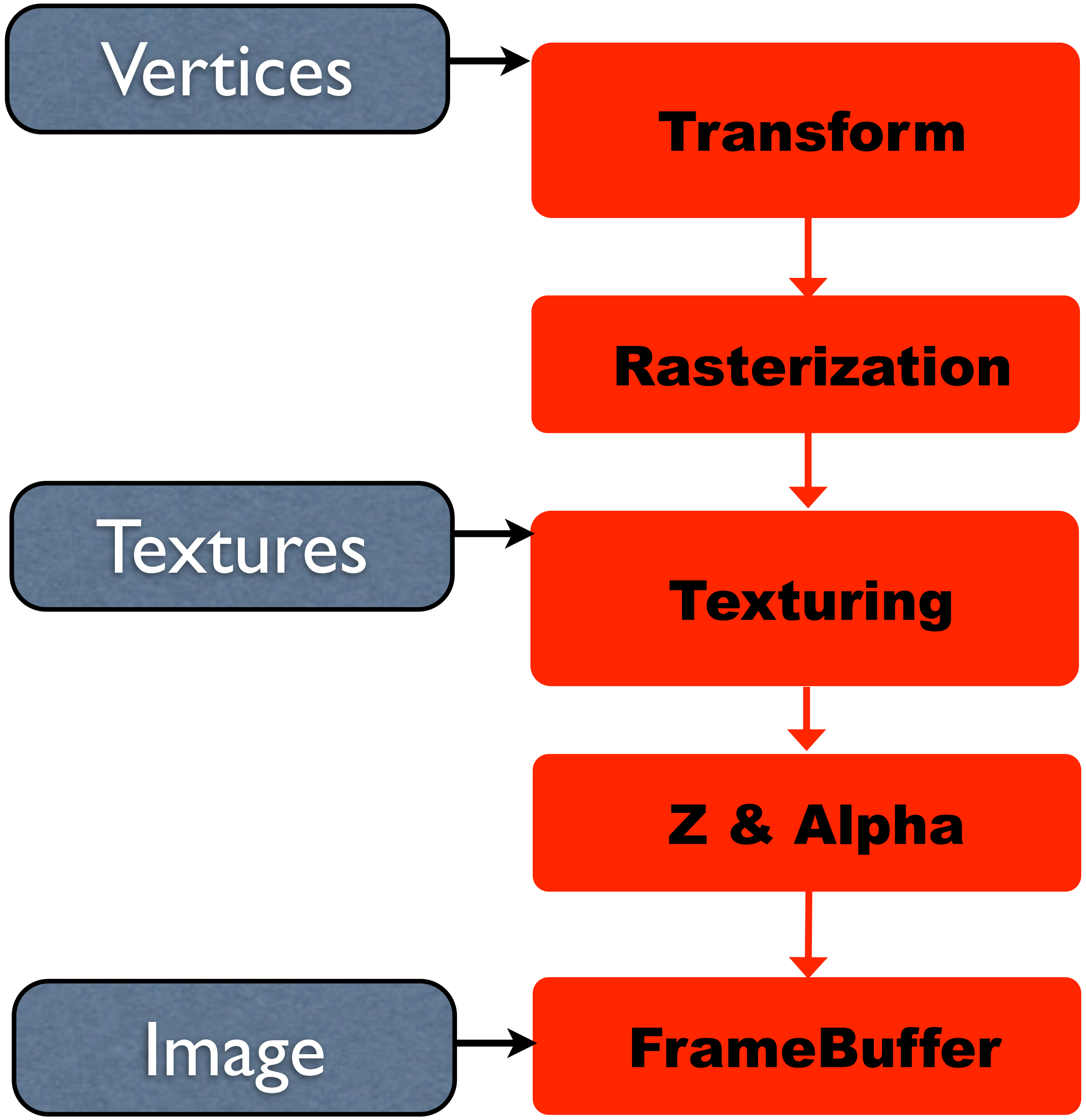
Z & Alpha

Image

FrameBuffer

Hardware Transform, Clipping and Lighting

- Transformation requires 32bit float 4x4 matrix multiplication
- Texturing for 4 component (RGBA) 8bit pixels
  - Low precision math
- DirectX 7
  - NV10 ’99 (Nvidia GeForce 256)
  - R100 ’00 (ATI Radeon 7500)



Vertices

Transform

Rasterization

Textures

Texturing

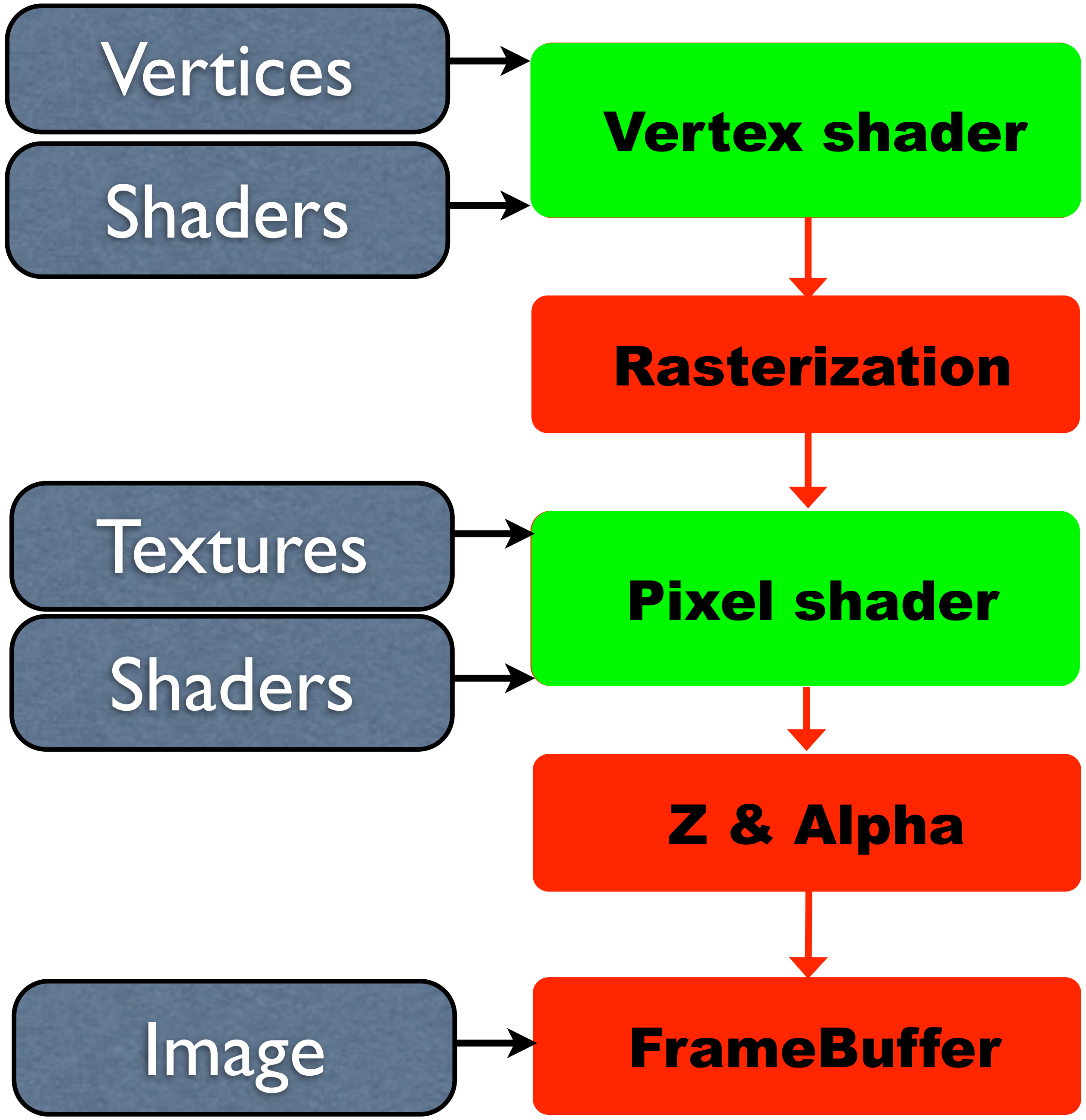
Z & Alpha

Image

FrameBuffer

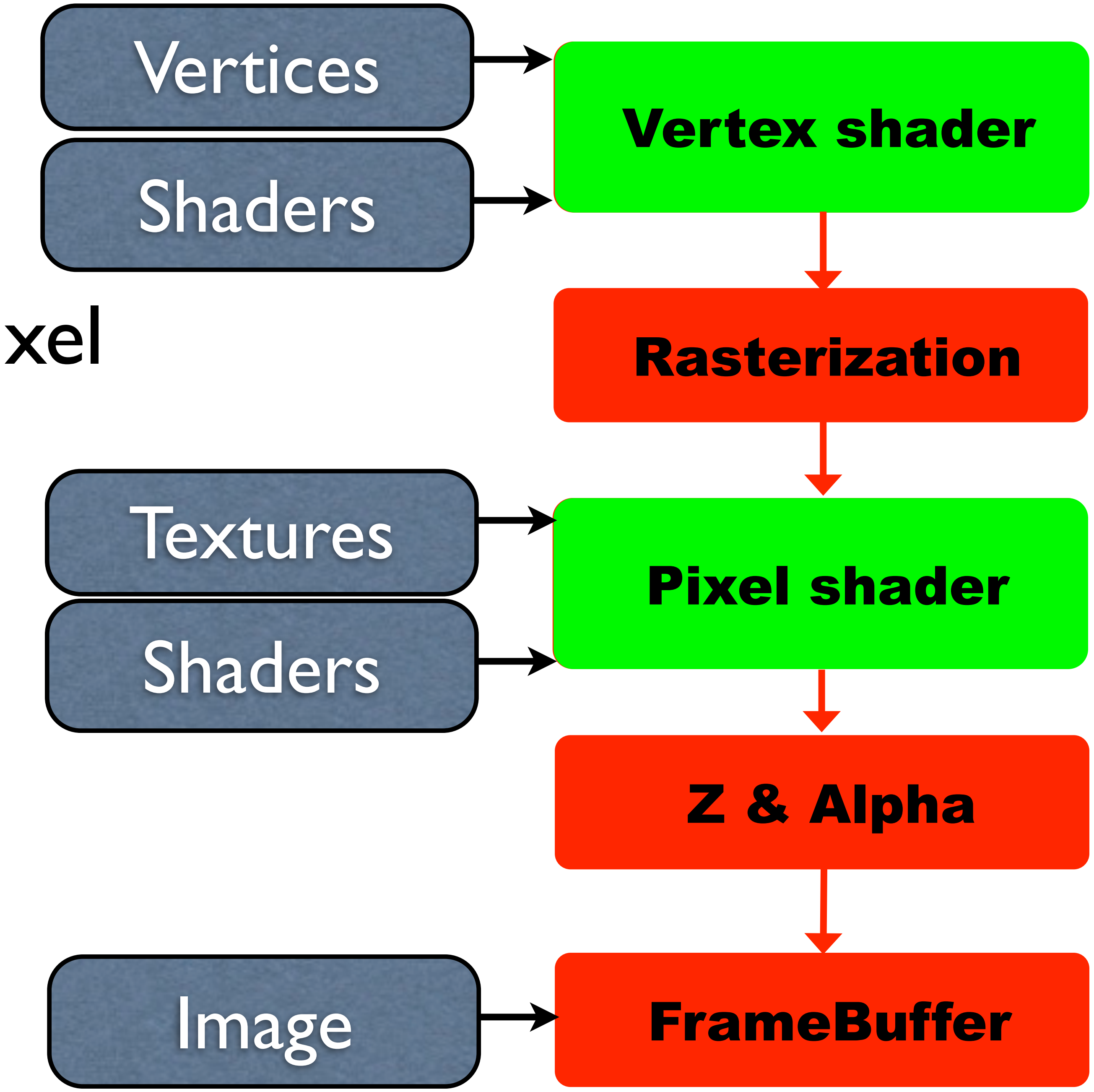
Programmable GPUs
1st Generation

- Shaders run programs that do what fixed function hardware did
- Makes GPUs simpler than CPUs



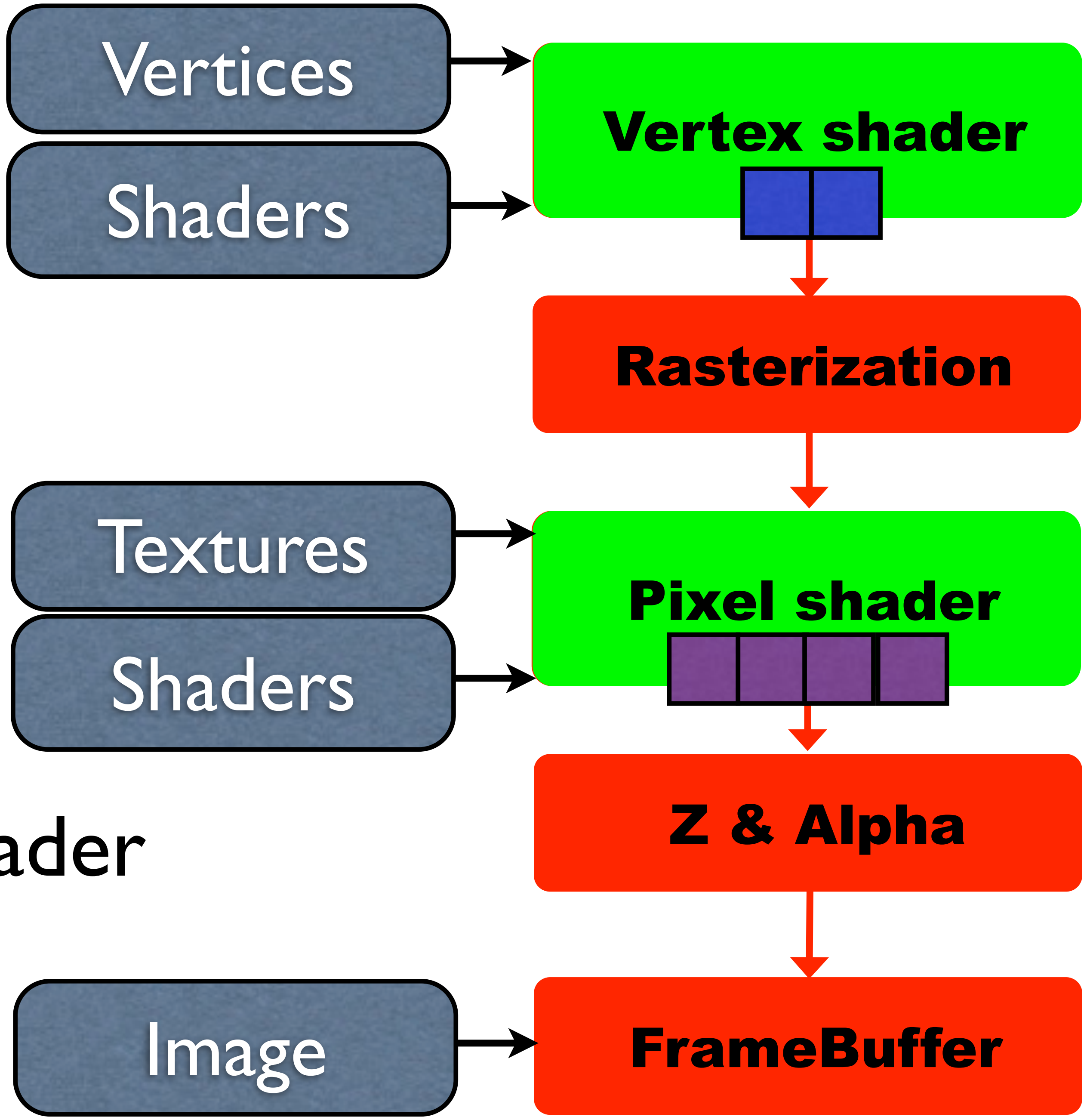
Programmable GPUs 1st Generation

- DirectX8
  - Multiple versions of Pixel shaders, 1.1, 1.3, 1.4
  - 13-22 instructions
  - assembler language



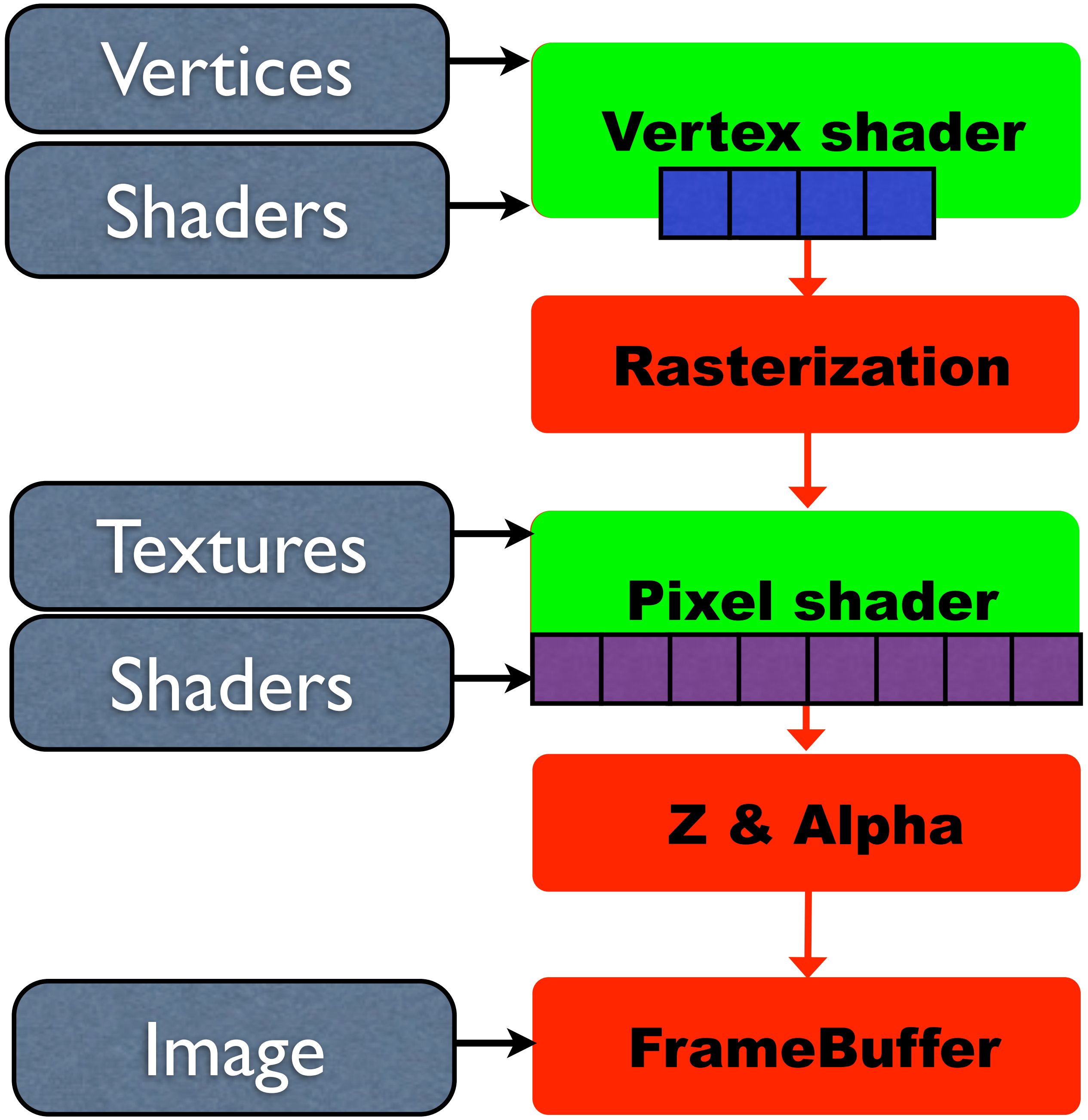
Programmable GPUs
1st Generation

- NV20 ’01
  - Nvidia GeForce 3
    - [Lindholm01]
- R200 ’01
  - ATI Radeon 8500
  - 2-wide Vertex shader
  - 4-wide SIMD Pixel shader
    - Fixed point ~16bits



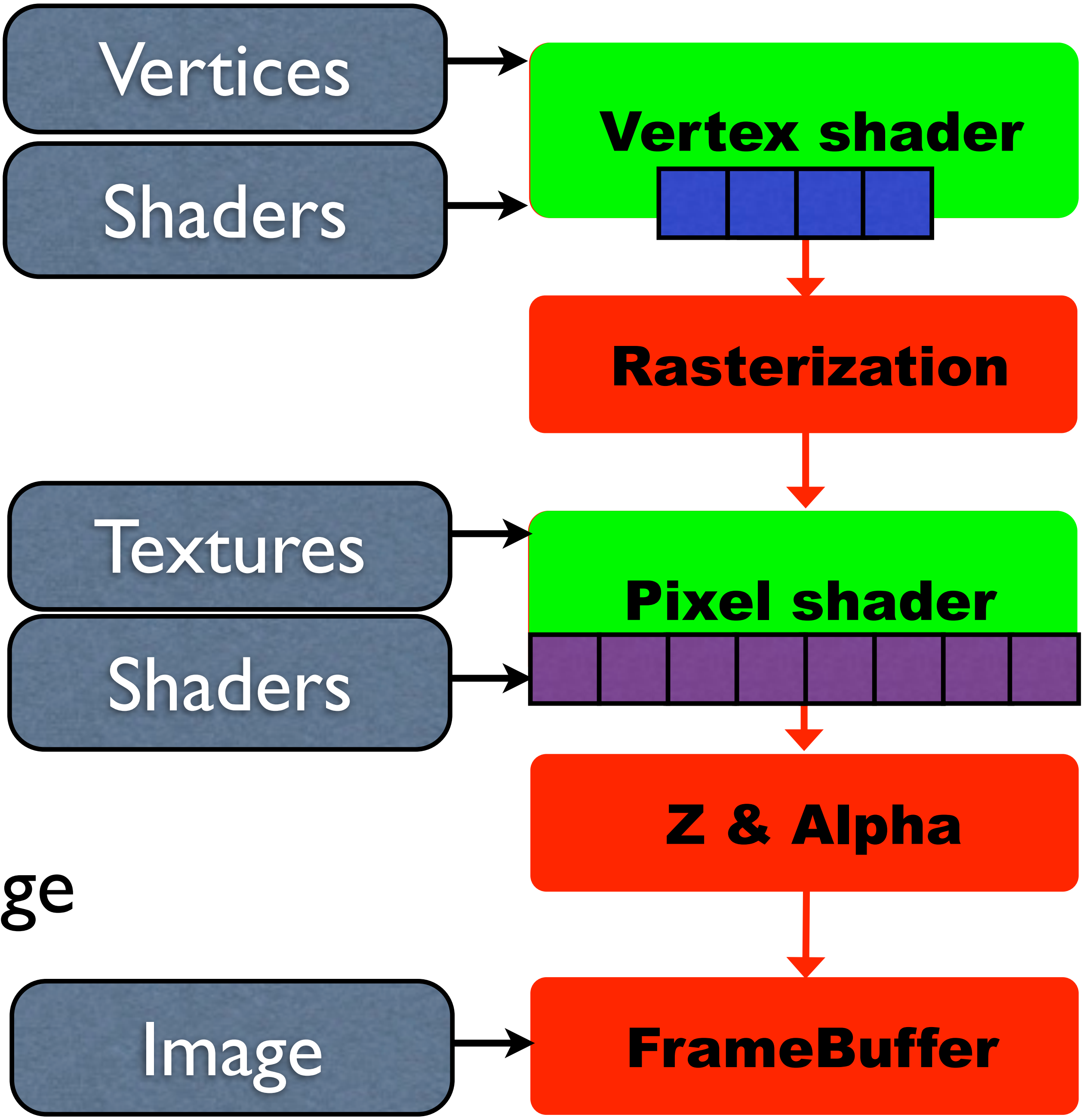
Programmable GPUs 2nd Generation

- R300 ’02
  - ATI Radeon 9700
  - 4-wide Vertex shader
  - 8-wide SIMD Pixel shader
    - 24bit floating point math

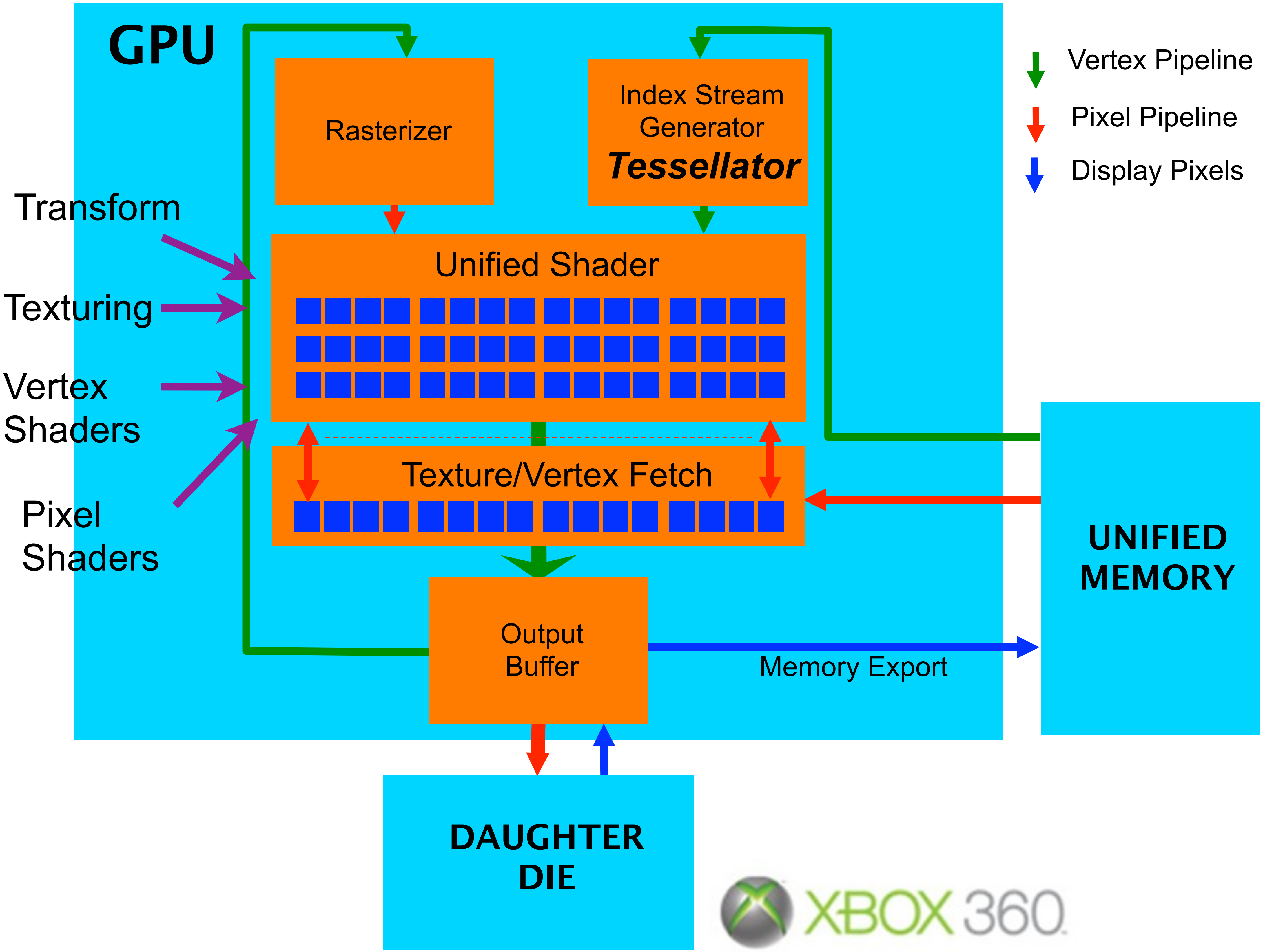


Programmable GPUs 2nd Generation

- NV30 '03
  - Nvidia GeForce FX 5800
    - 16 and 32 bit float
  - Cg (C for graphics)
- NV40 '04 GeForce 6800 [Montrym05]
- DirectX 9
  - High Level Shading Language (HLSL)



XBox360 GPU architecture - ’05



GPU

Rasterizer

Index Stream Generator
Tessellator

Unified Shader

Texture/Vertex Fetch

Output Buffer

Memory Export

Transform

Texturing

Vertex Shaders

Pixel Shaders

UNIFIED MEMORY

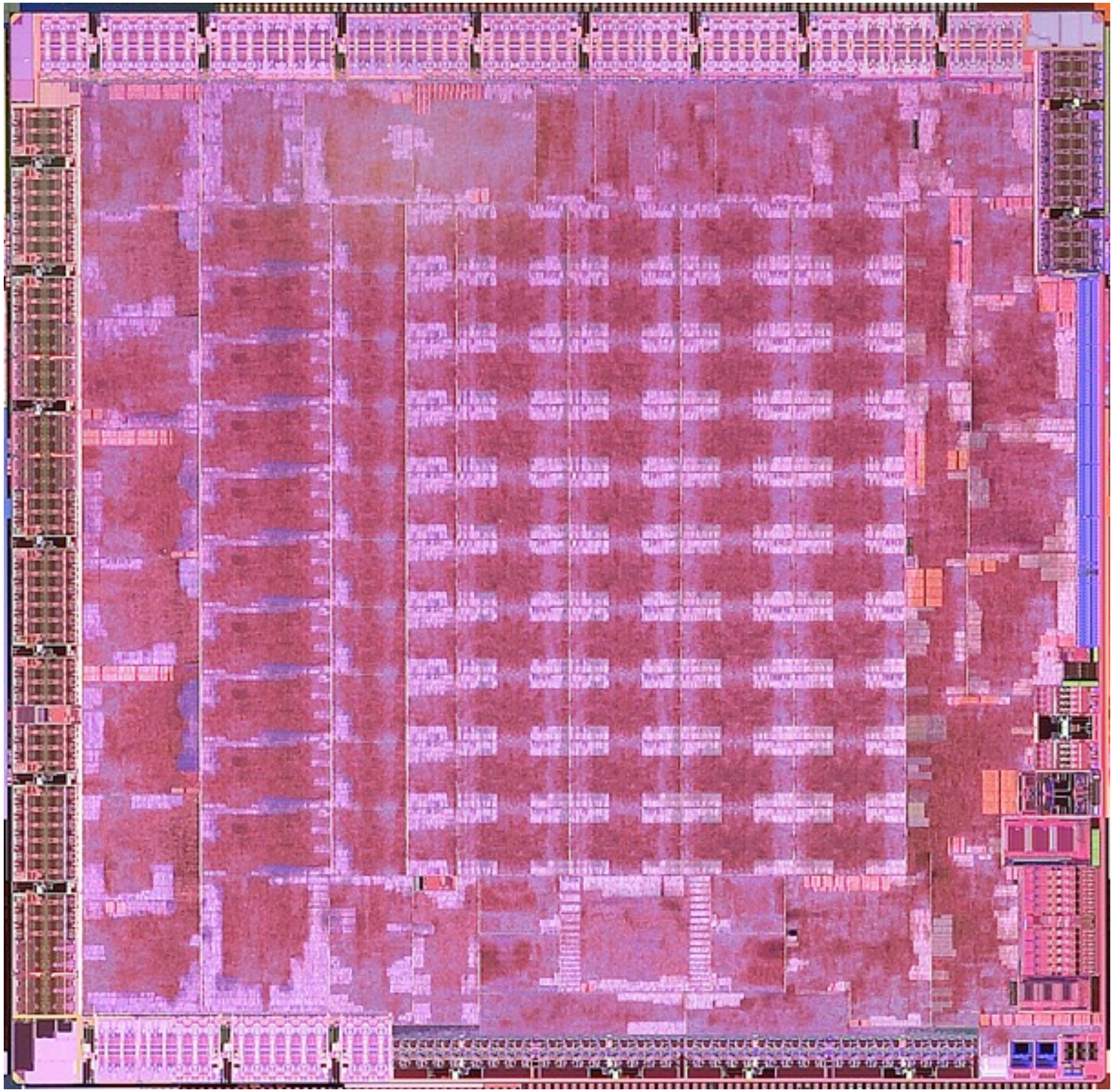
DAUGHTER DIE

↓ Vertex Pipeline
↓ Pixel Pipeline
↓ Display Pixels

XBOX 360

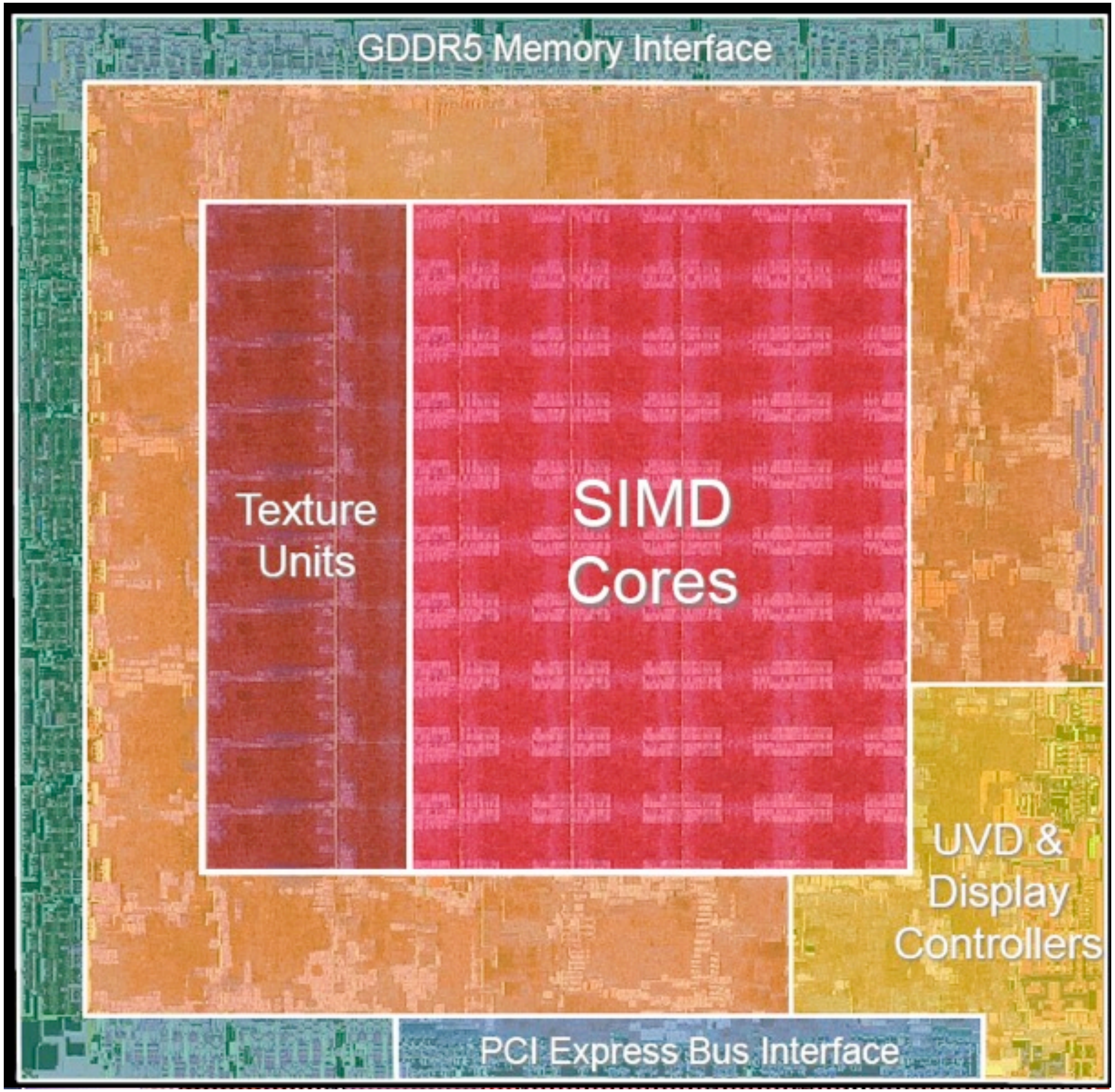
ATI Radeon 4870(R770) Die

- 2008
- 260mm2
- 956 MTransistors



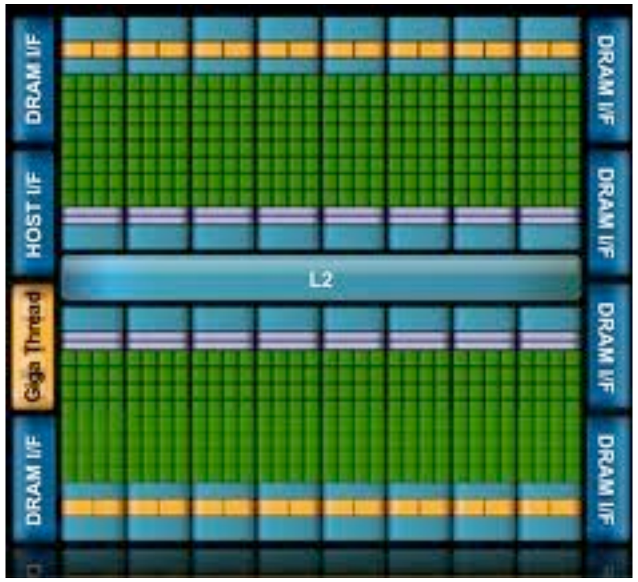
ATI Radeon 4870(R770) Die

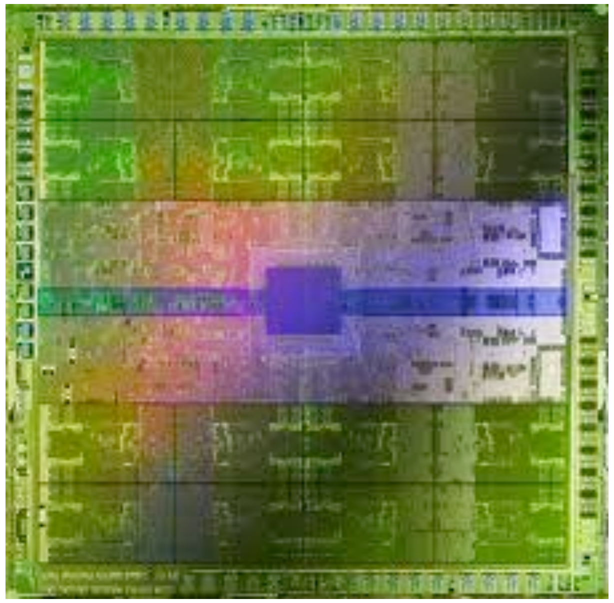
- 260mm2
- 956 MTransistors
- Red
  - 10 SIMDs
- Orange
  - 64 z/stencil
  - 40 texture



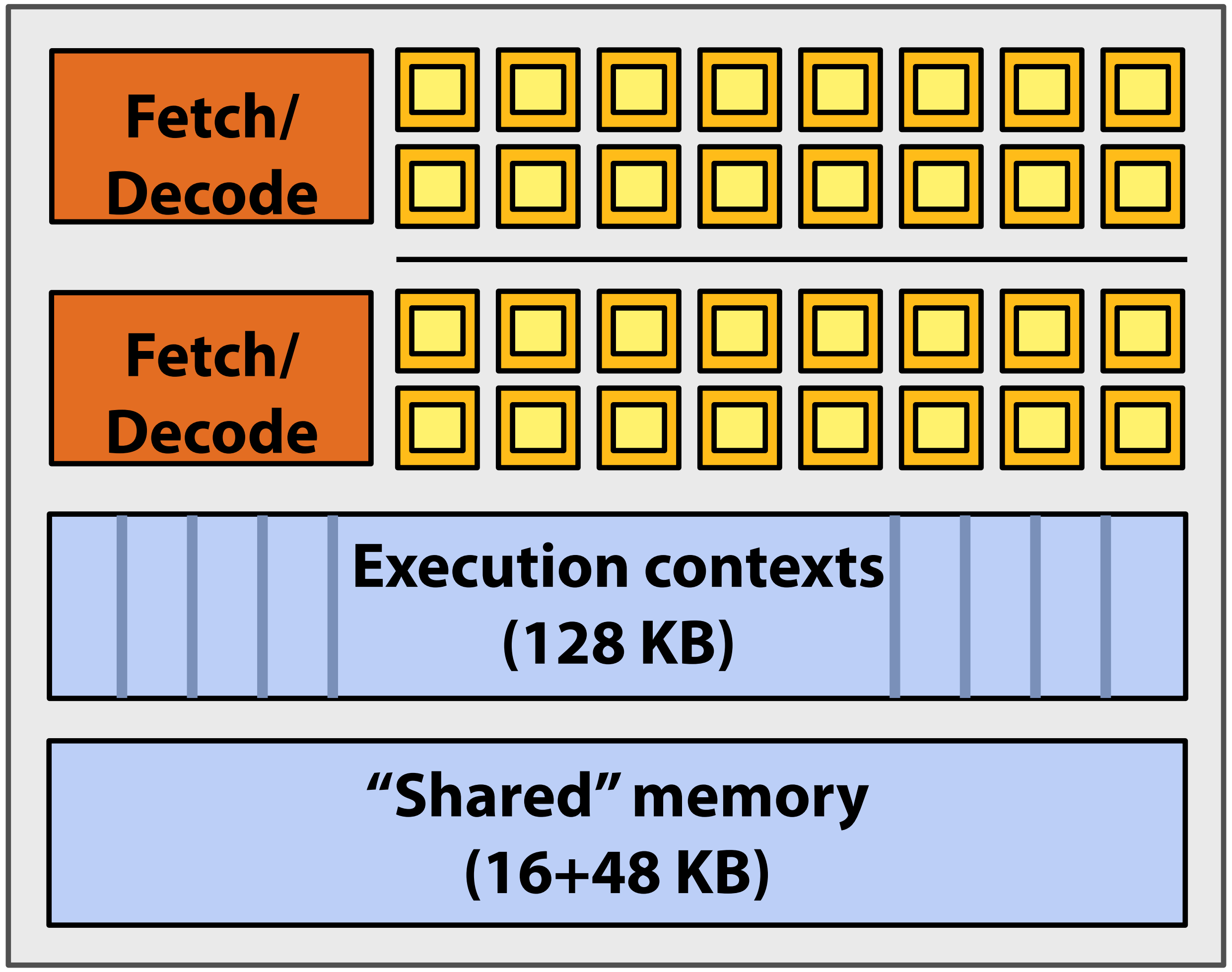
Multi-Graphics core NVIDIA Fermi

- GeForce GTX 480 (GF100)
  - Released March, 2010
- Shader Load/Store L1/L2 cache
- 4x Triangle rate
  - 4 rasterization engines
- 529mm^2, core i7 263mm^2





NVIDIA GeForce GTX 480 “SM”



Fetch/ Decode

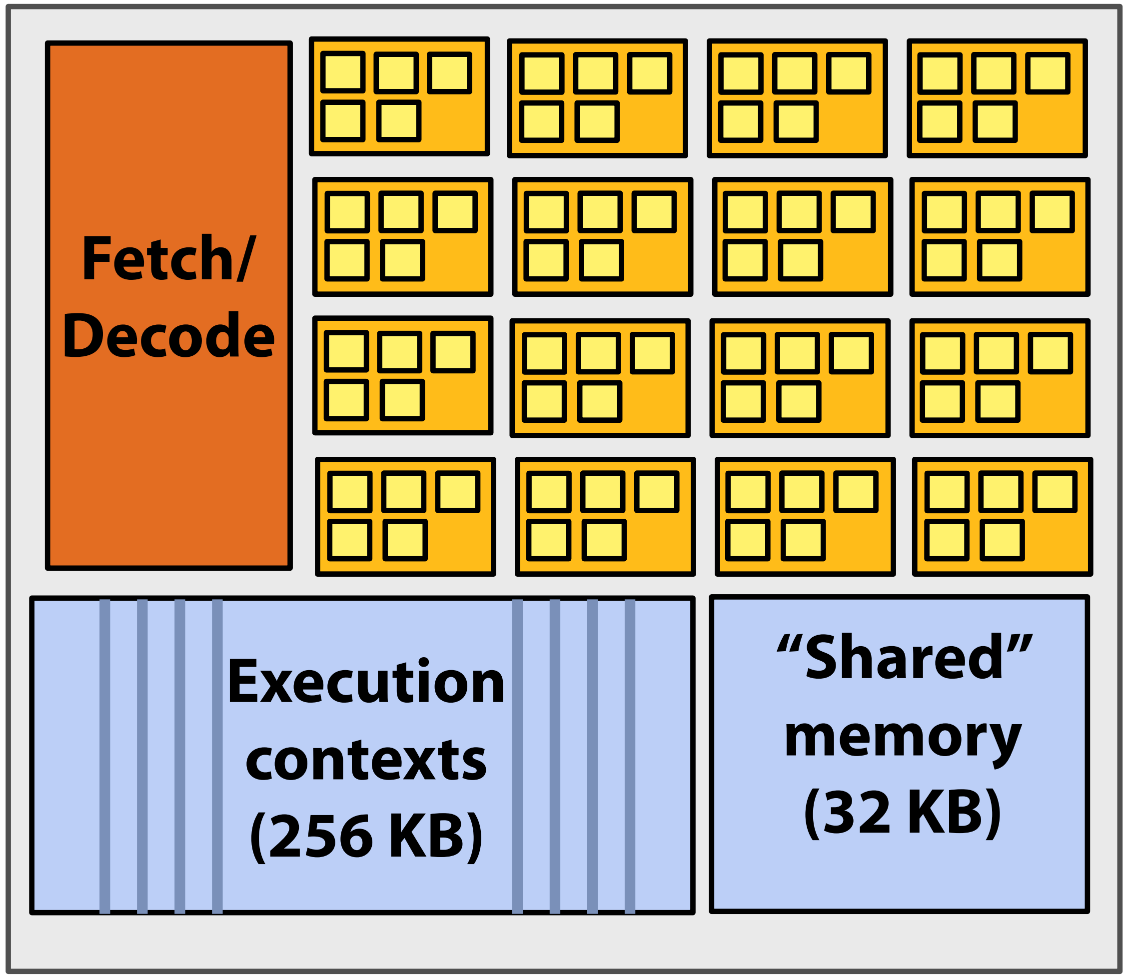
Fetch/ Decode

Execution contexts (128 KB)

“Shared” memory (16+48 KB)

15 Streaming Multiprocessors

ATI Radeon HD 5870 “SIMD-engine”



Fetch/ Decode

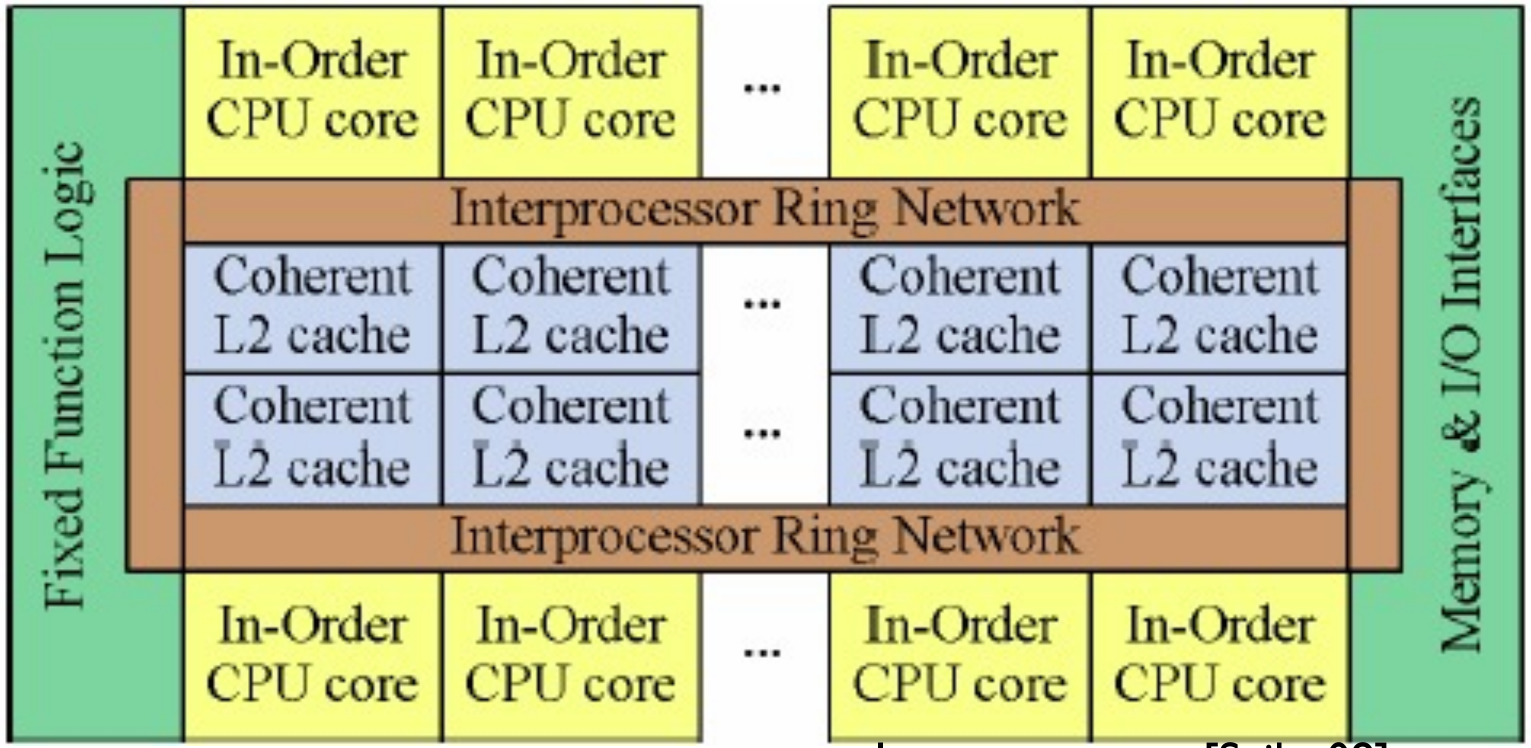
Execution contexts (256 KB)

“Shared” memory (32 KB)

20 SIMD-engines

Intel’s Knights Corner/ Ferry (Larrabee)

- 32 Pentium Cores
  - 16 wide SIMD with 32 bit floating point MAD
- Programmable and debuggable



Images courtesy [Seiler08]

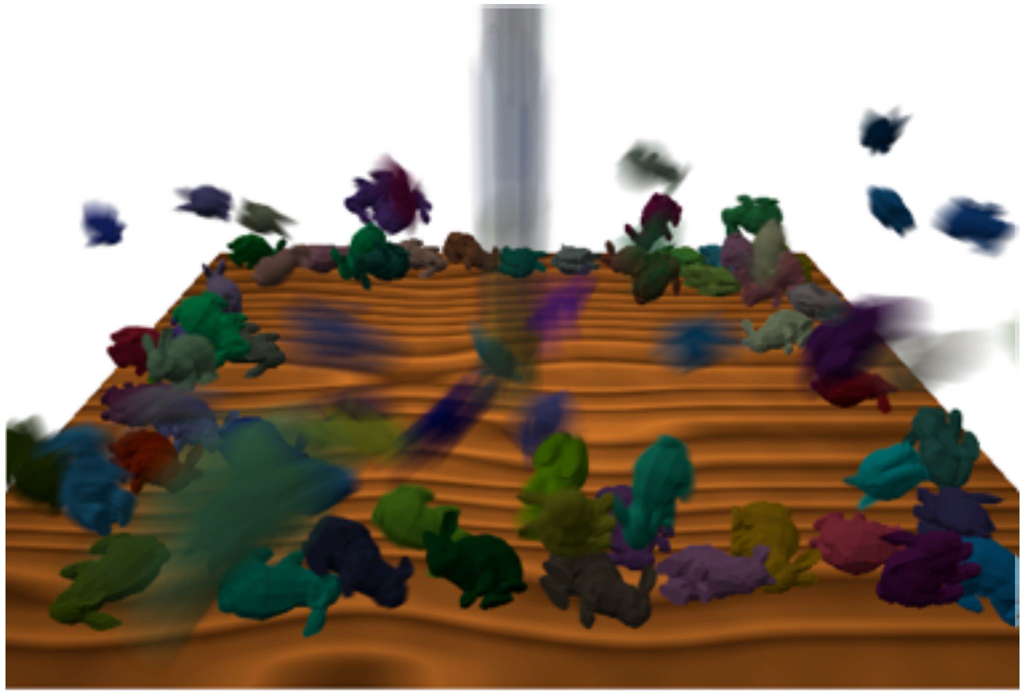
Analytical Motion Blur Rasterization with Compression

Carl Johan Gribel, Michael Doggett, Tomas Akenine-Möller

High-Performance Graphics 2010

Motion Blur Motivation

- Human visual system designed to detect motion
- This fails when presented too few images, or too much motion per image
  - motion gets jumpy
- Motion blur aids the motion detection of the visual system



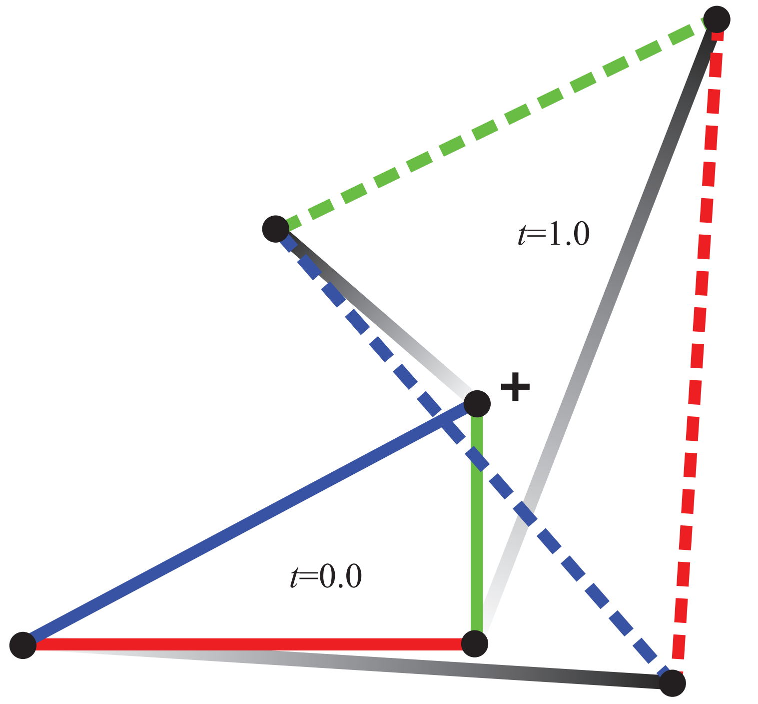
Analytical Motion Blur Rasterization

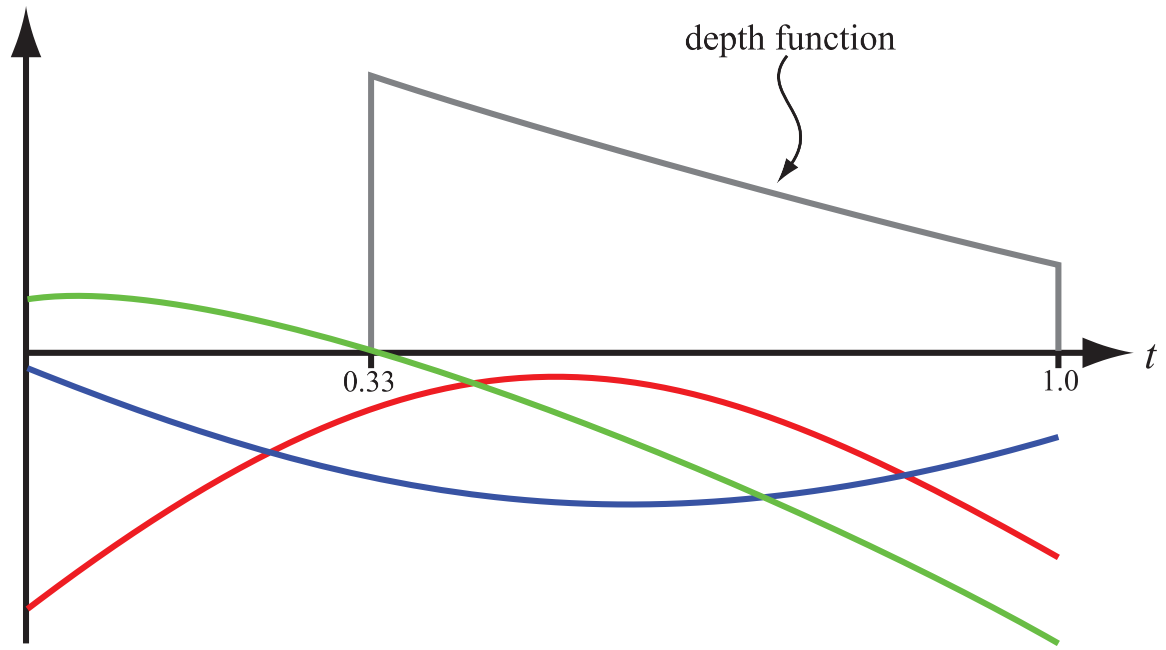
- Compute Edge Equations and exact exposure intervals
  - analytic inside-test
  - visibility management

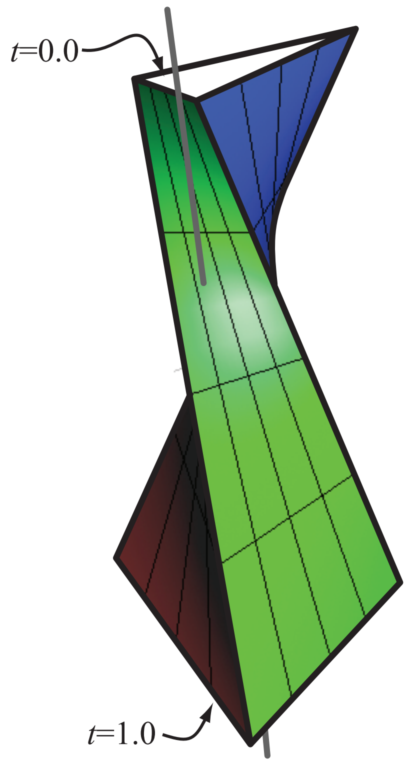
$$
\begin{aligned}
e_1(t) &= (\mathbf{p_2(t)} \times \mathbf{p_0(t)}) \cdot (x_0, y_0, 1) \\
&= (((1-t)\mathbf{q_2} + t\mathbf{r_2}) \times ((1-t)\mathbf{q_0} + t\mathbf{r_0})) \cdot (x_0, y_0, 1) \\
&= (\mathbf{f}t^2 + \mathbf{g}t + \mathbf{h}) \cdot (x_0, y_0, 1)
\end{aligned}
$$

- Compute the time integral
- Store and compress the intervals

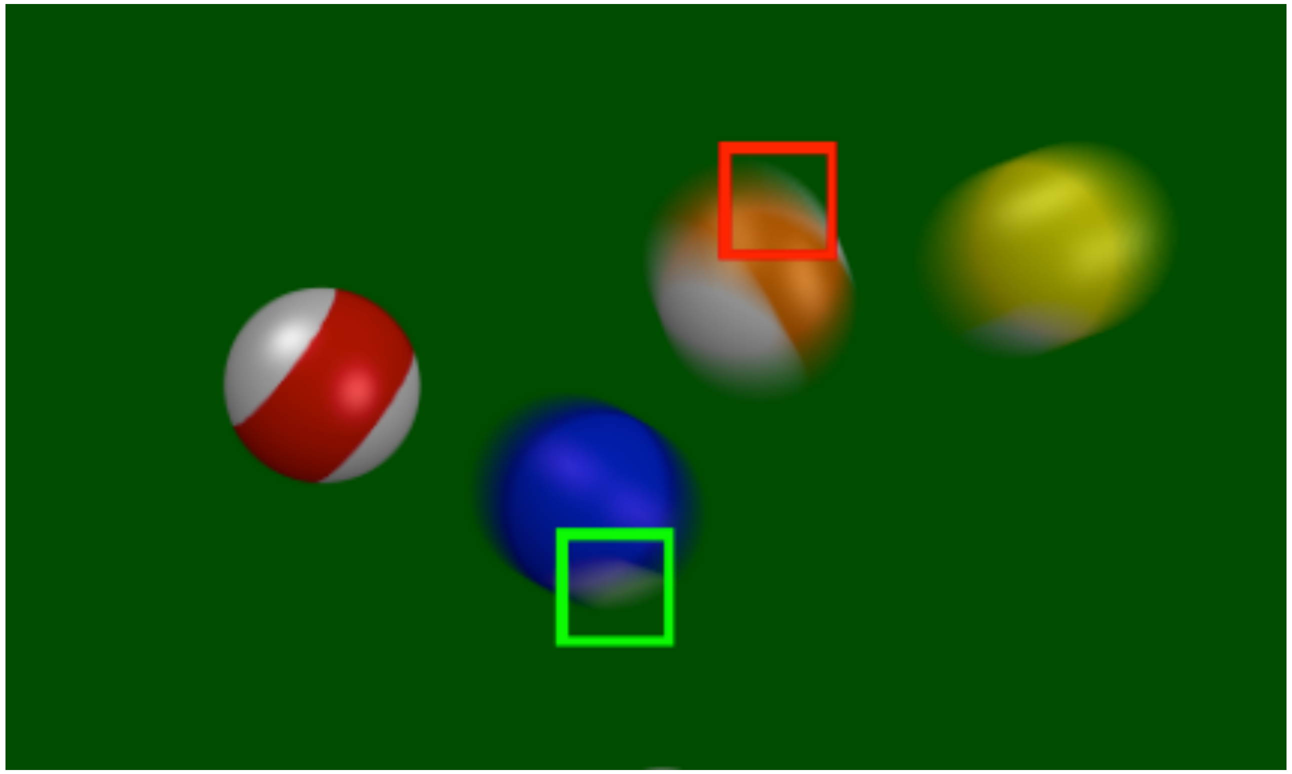
Moving triangle edge functions

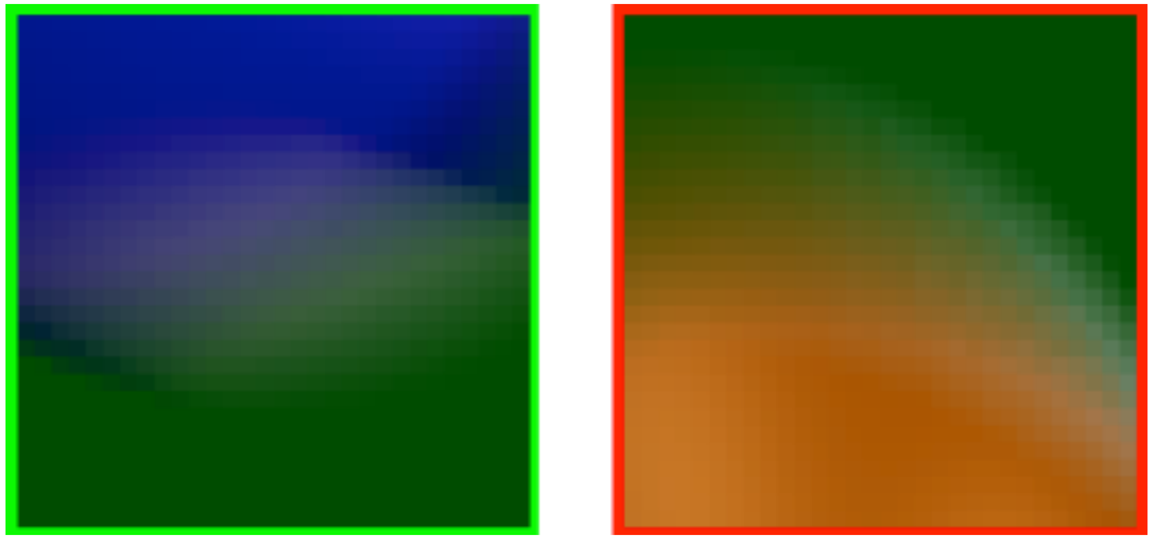




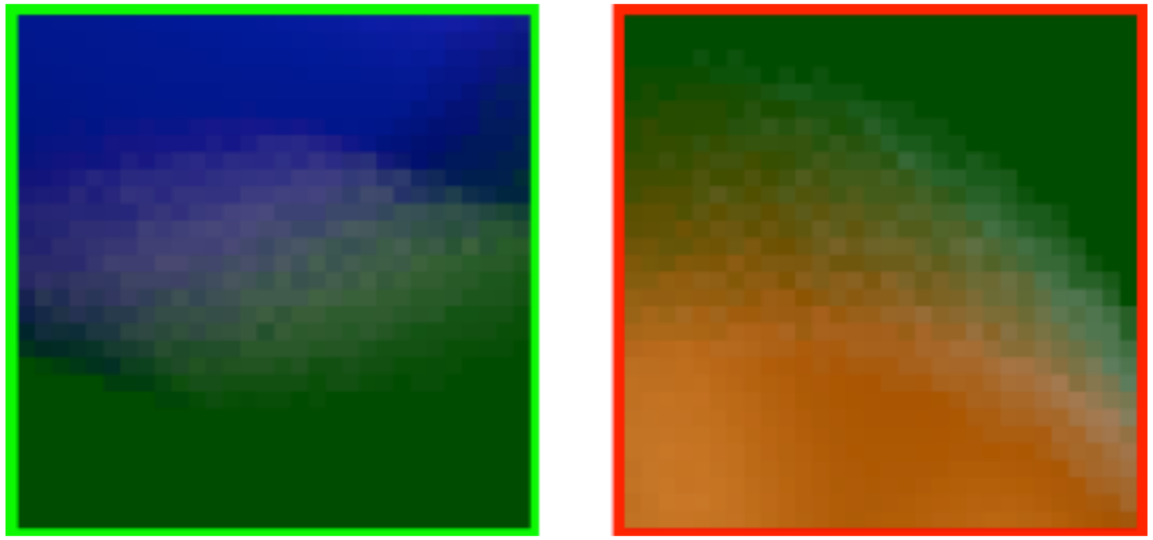


Results

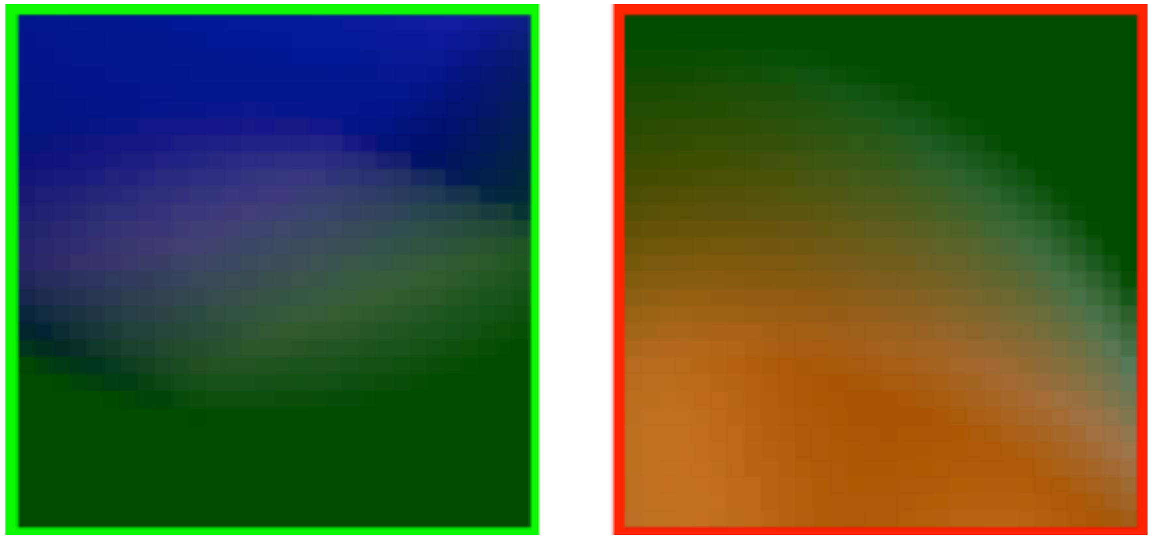




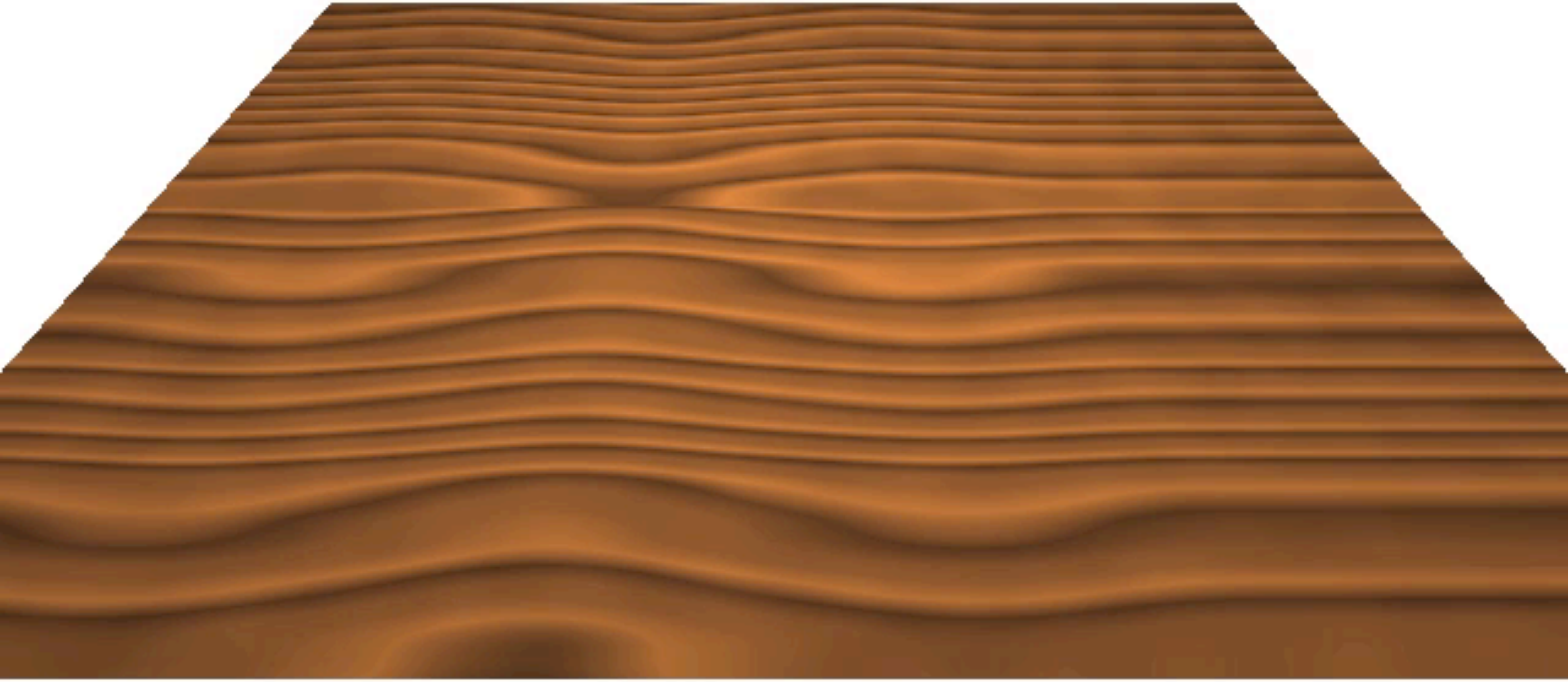
Ground Truth



Stochastic 12 spp



Analytical, compression 8



Decoupled Sampling for Real-Time Graphics Pipelines

Jonathan Ragan-Kelley, Jiawen Chen, Jaakko Lehtinen,
Michael Doggett, Fredo Durand (collab. with MIT)

ACM TOG 2011, to be presented at SIGGRAPH 2011
http://bit.ly/DecoupledSampling

Decoupled Shading

Rendering :

- Visibility - compute what is visible
- Shading - compute color for each pixel

Complex visibility

- many stochastic point samples in 5D (space, time, lens aperture)

Complex shading

- expensive evaluation can be prefiltered

Modern GPUs use multisample AA for decoupling

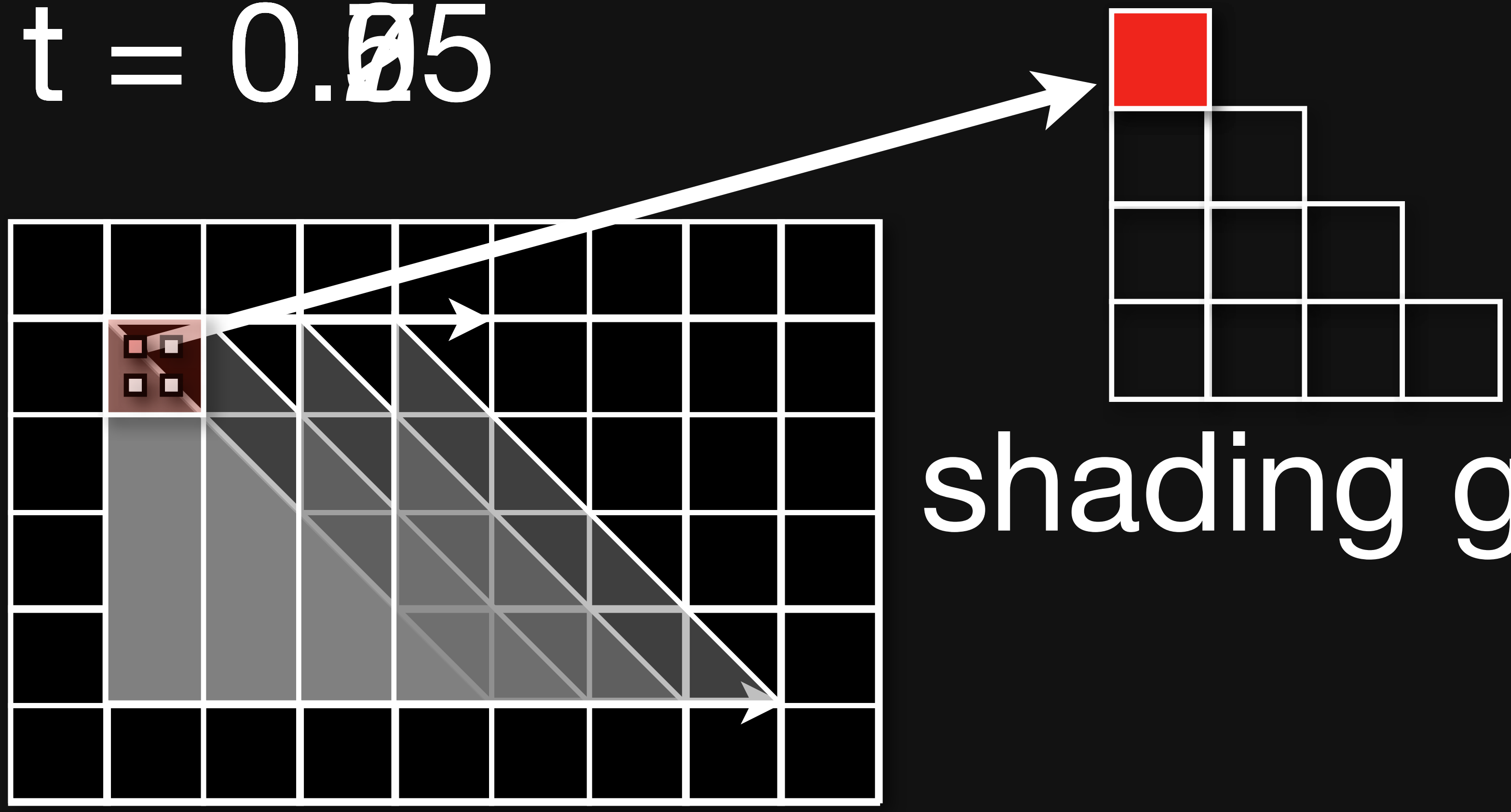
Our technique:
Post-visibility Decoupled Sampling

1. Separate *visibility* from *shading* samples.
2. Define an explicit *mapping* from visibility to shading space.
3. Use a *cache* to manage irregular shading-visibility relationships, without precomputation.

Slide courtesy Jonathan Ragan-Kelley

Decoupled Sampling with motion blur

t = 0.[illegible]5



shading grid

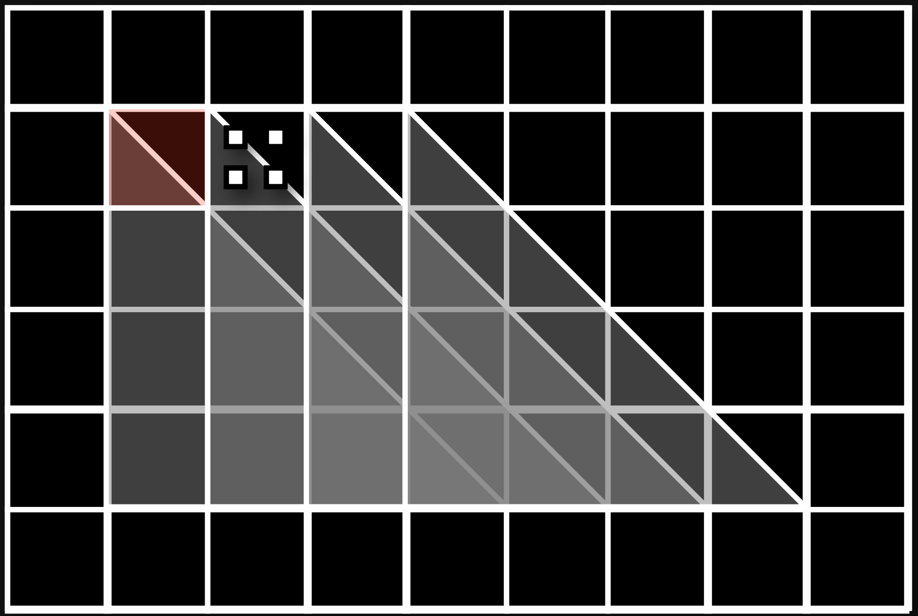
visibility samples (screen space)

```
foreach primitive:
    foreach vis sample:
        skip if not visible
        map to shading
        sample
        if not in cache:
            shade and
            cache
        else:
            use cached
            value
```

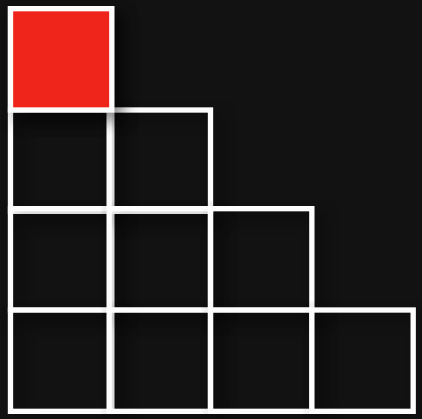
Slide courtesy Jonathan Ragan-Kelley

Decoupled Sampling with motion blur

t = 0.25



visibility samples
(screen space)



shading grid

```
foreach primitive:
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        map to shading sample
        if not in cache:
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        else:
            use cached value
```
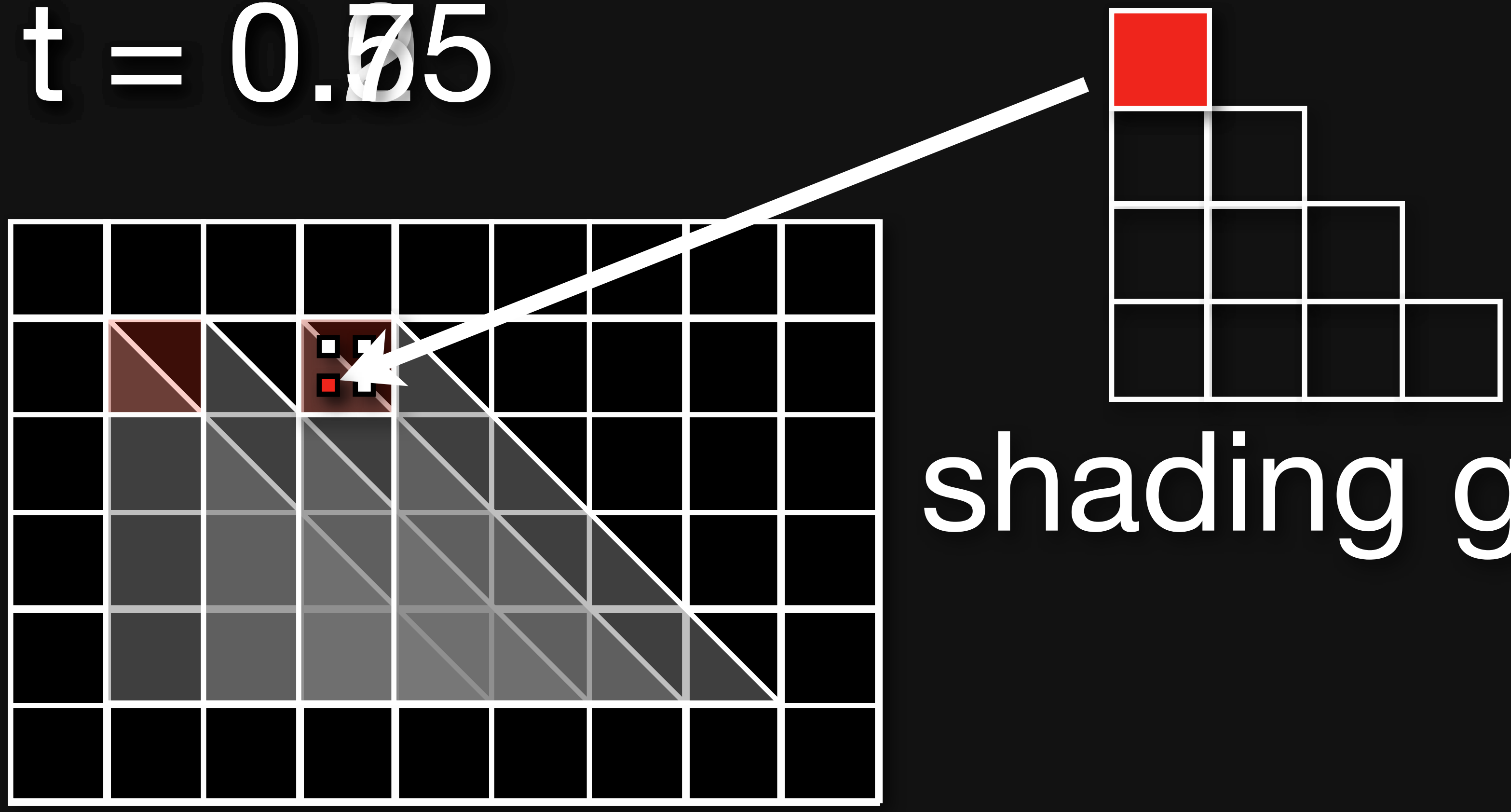

Slide courtesy Jonathan Ragan-Kelley

Decoupled Sampling with motion blur

t = 0.75



shading grid

visibility samples
(screen space)

```
foreach primitive:
    foreach vis sample:
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```
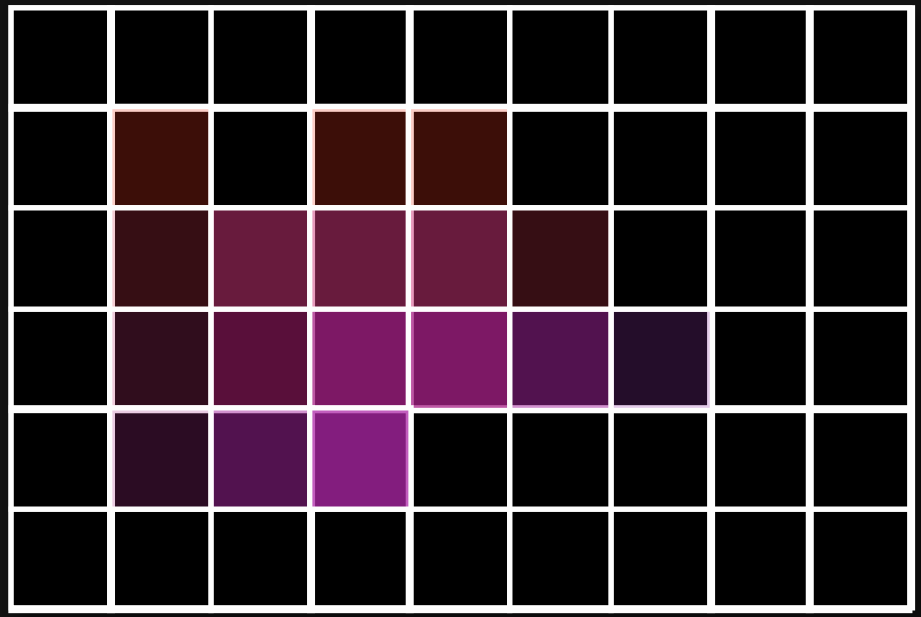
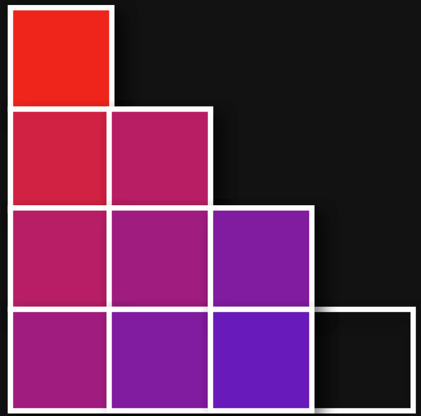

Slide courtesy Jonathan Ragan-Kelley

Decoupled Sampling with motion blur

t = …



visibility samples
(screen space)



shading grid

```
foreach primitive:
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        else:
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```
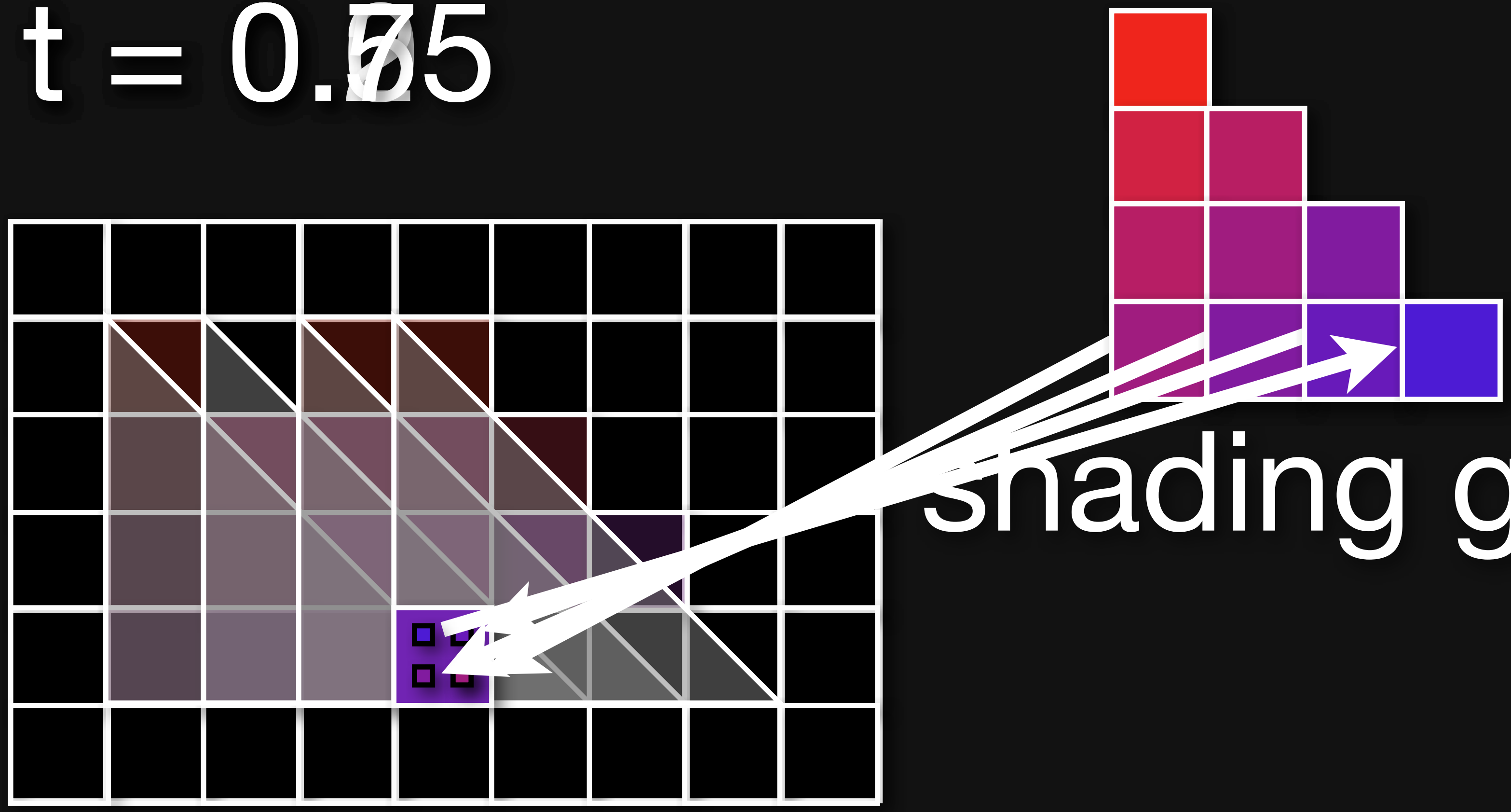

Slide courtesy Jonathan Ragan-Kelley

Decoupled Sampling with motion blur

t = 0.75



shading grid

visibility samples
(screen space)

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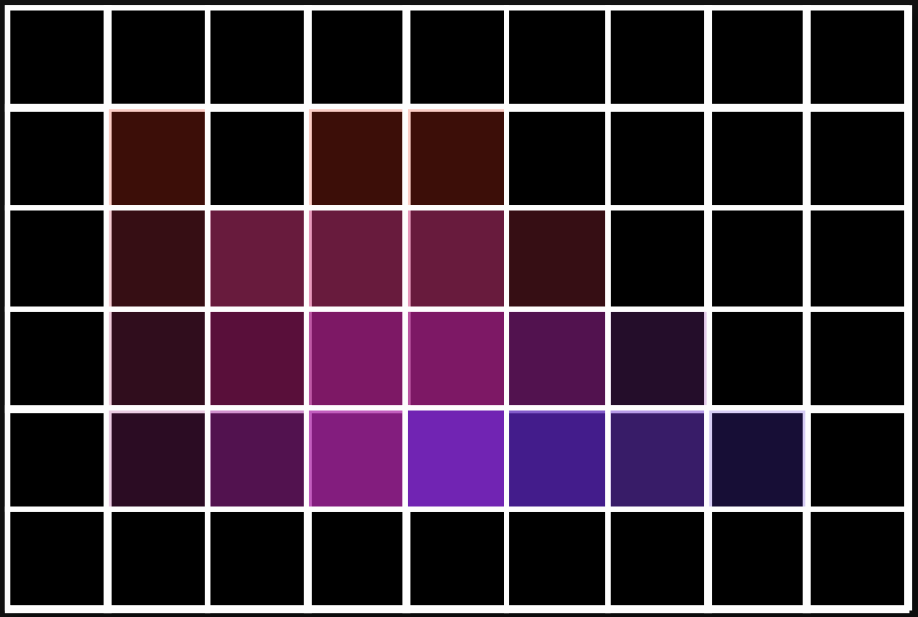
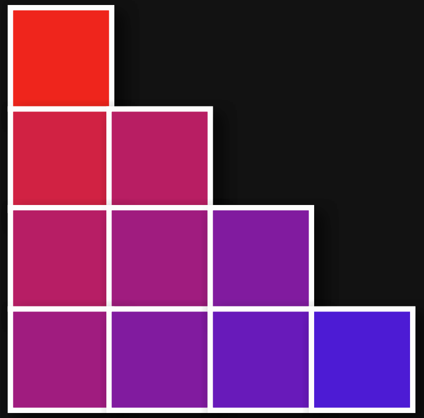
Slide courtesy Jonathan Ragan-Kelley

Decoupled Sampling with motion blur



visibility samples
(screen space)



shading grid

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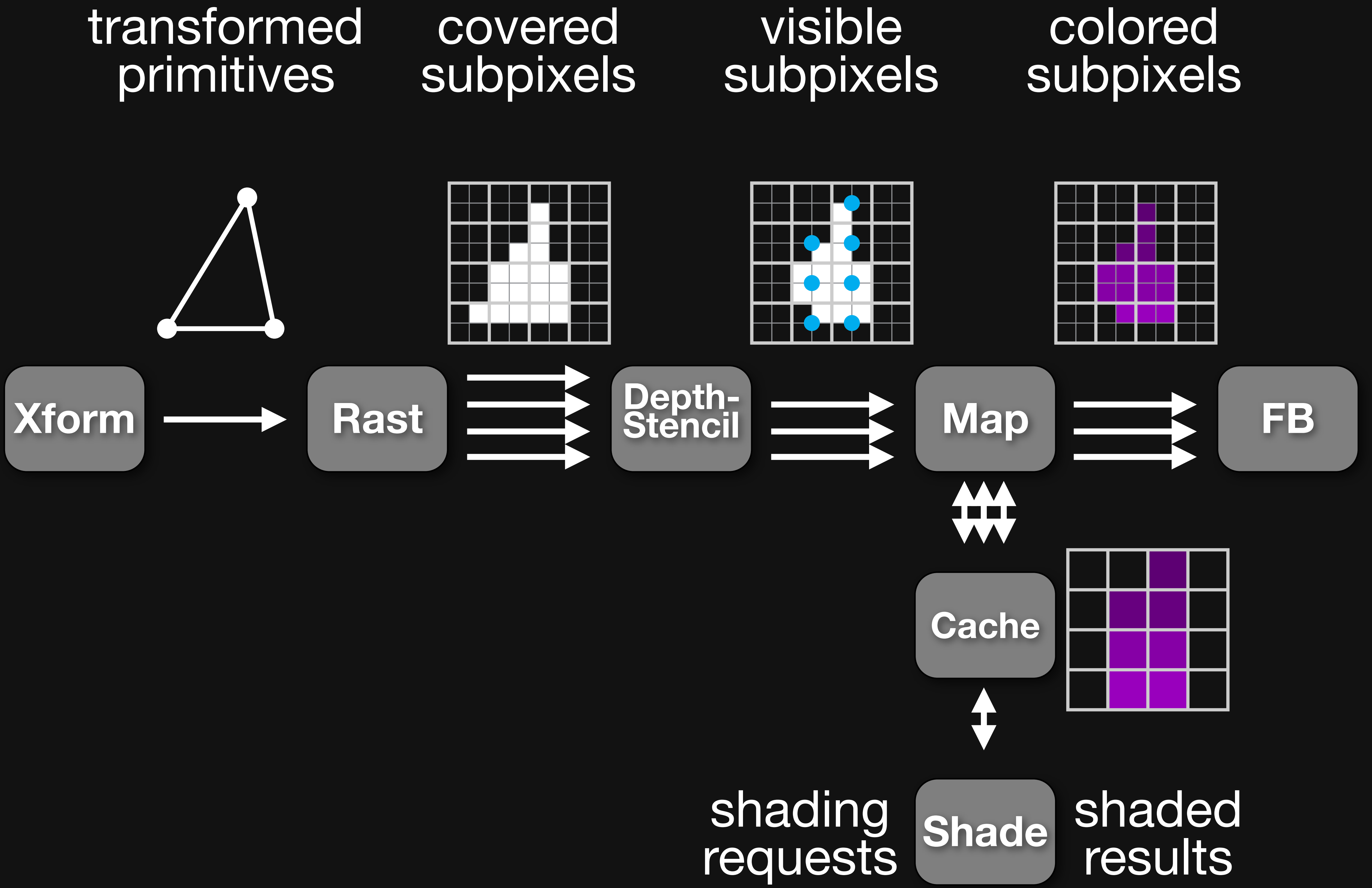
Slide courtesy Jonathan Ragan-Kelley

Decoupled Sampling



transformed primitives

covered subpixels

visible subpixels

colored subpixels

Xform

Rast

Depth-Stencil

Map

FB

Cache

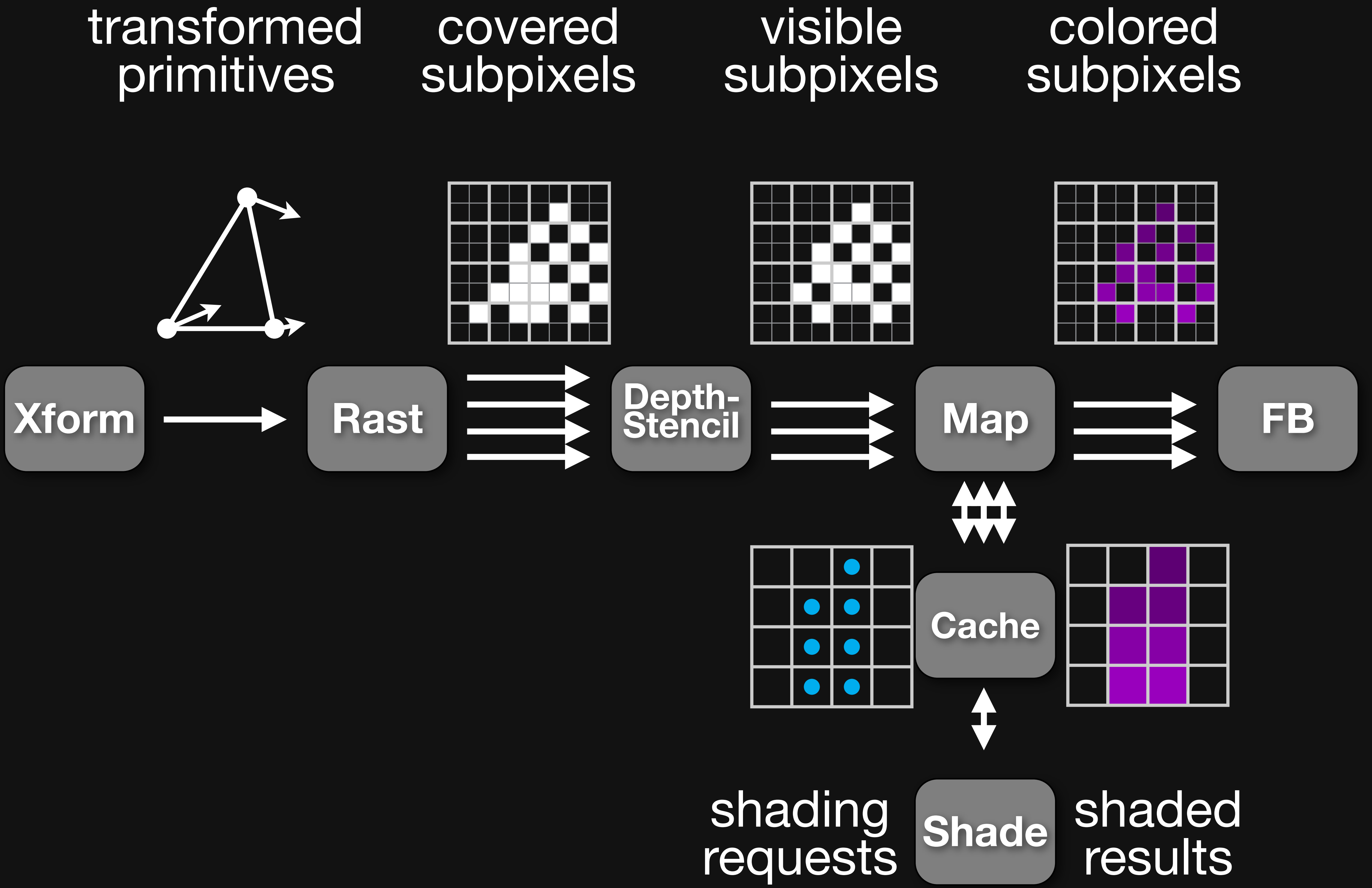
shading requests

Shade

shaded results

Slide courtesy Jonathan Ragan-Kelley

Decoupled Sampling



transformed primitives

covered subpixels

visible subpixels

colored subpixels

Xform → **Rast** → **Depth-Stencil** → **Map** → **FB**

Cache

shading requests

Shade

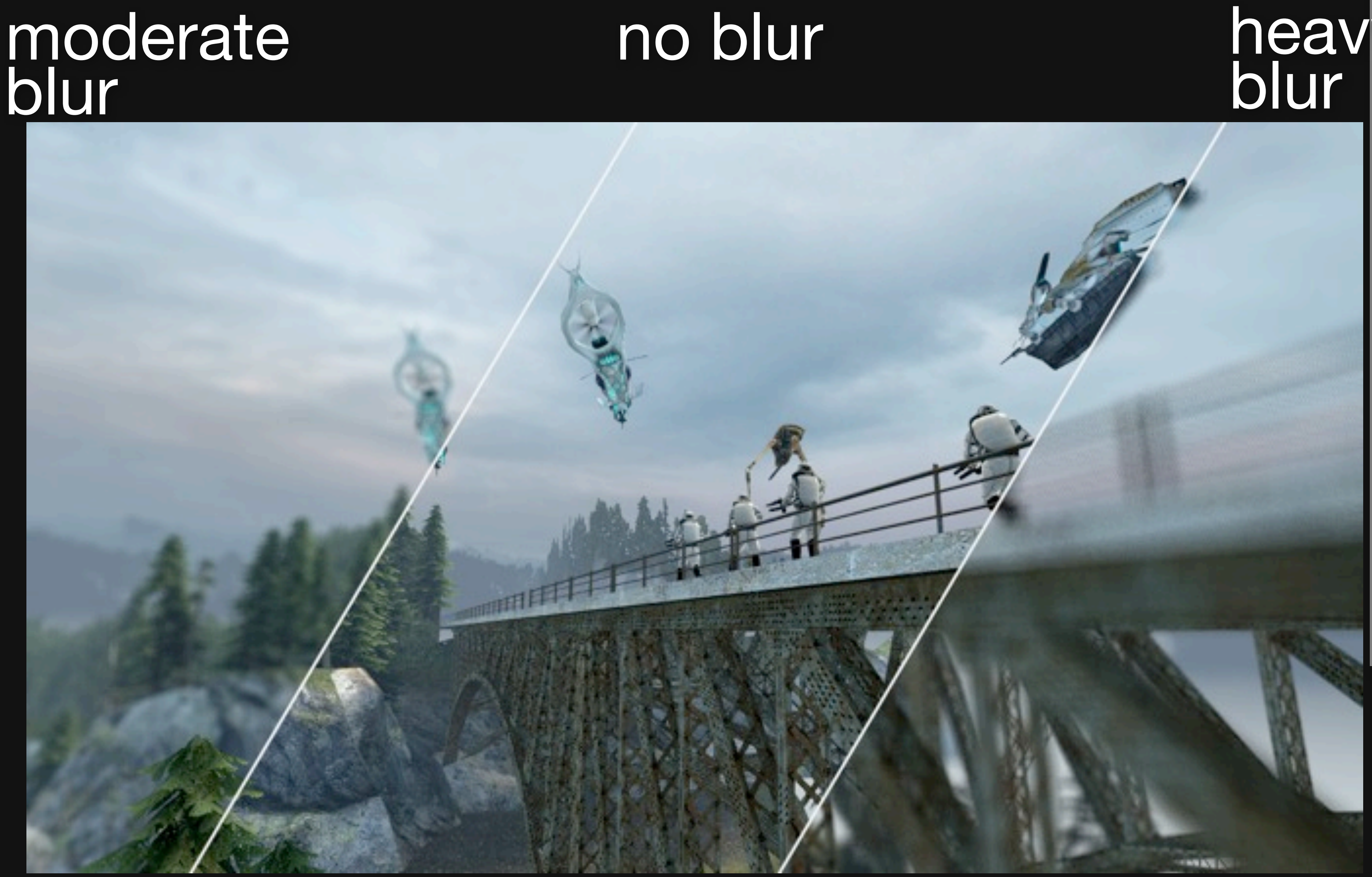
shaded results

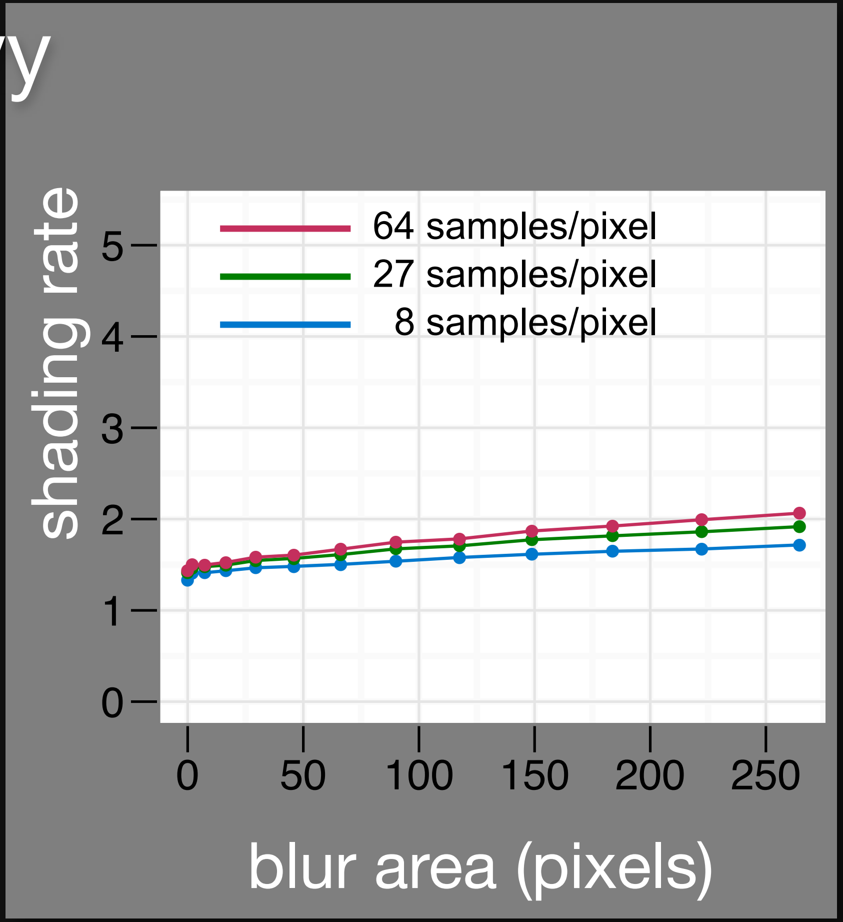
Slide courtesy Jonathan Ragan-Kelley

Results

Slide courtesy Jonathan Ragan-Kelley

Blur vs. shading rate: defocus





4.5-43x less shading than ideal supersampling

Half-Life 2, Episode 2
1280x720, 27 samples/pixel

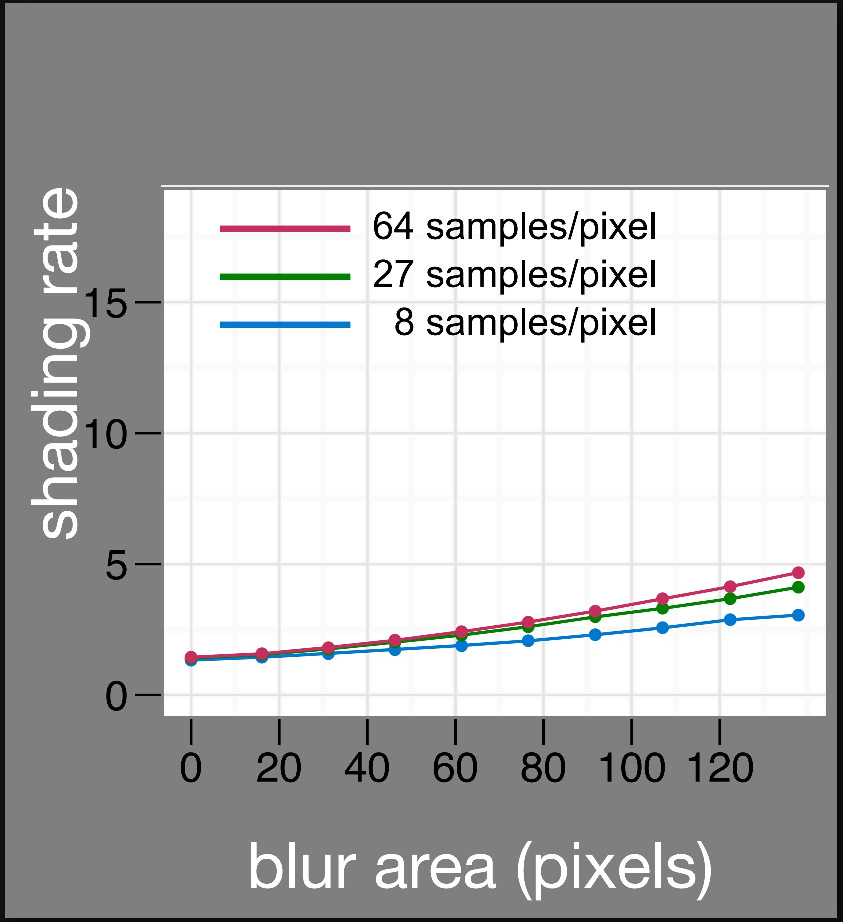
Slide courtesy Jonathan Ragan-Kelley

Blur vs. shading rate: motion

heavy blur

moderate blur

no blur

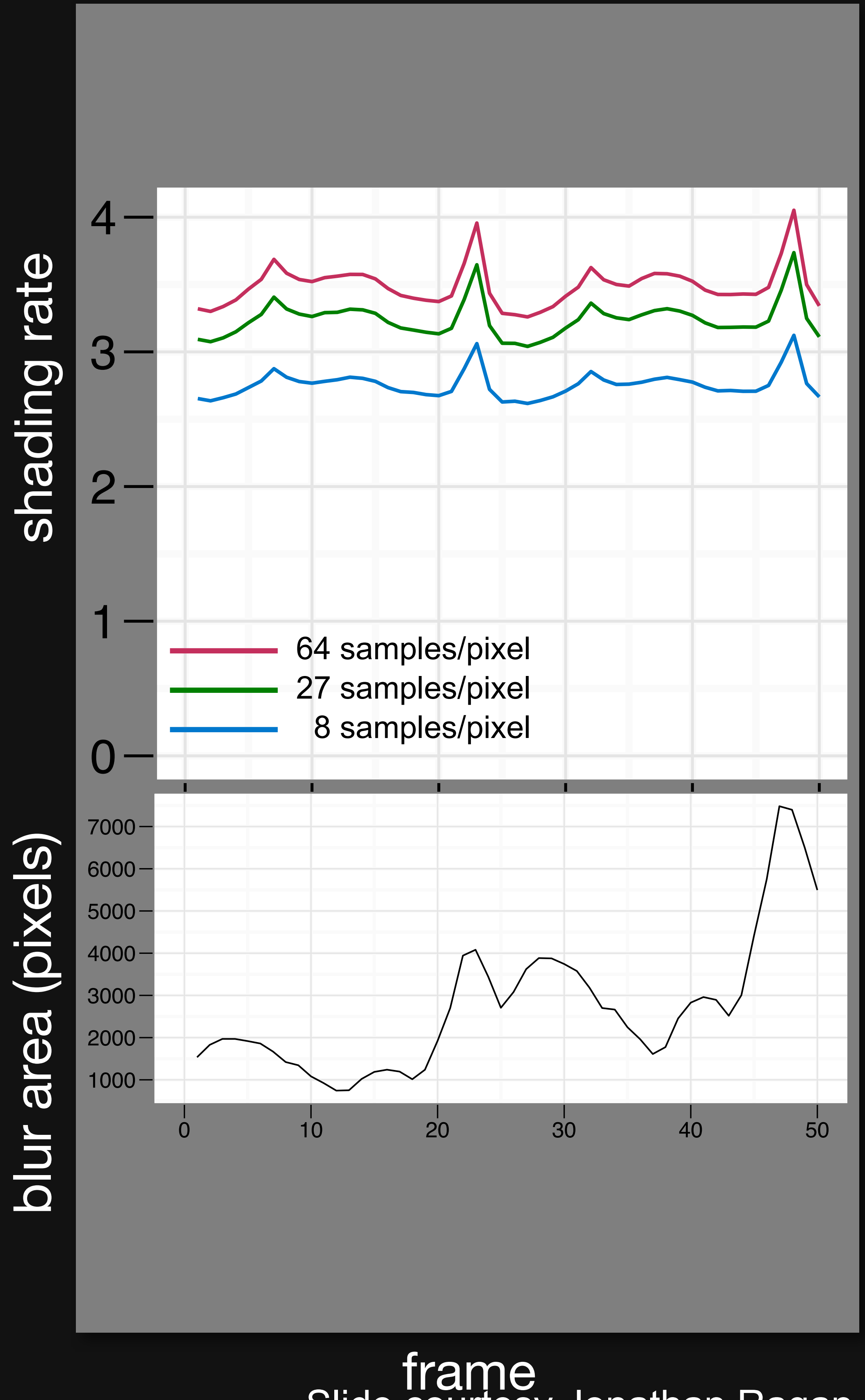


3-40x less shading than ideal supersampling

Team Fortress 2
1280x720, 27 samples/pixel

Slide courtesy Jonathan Ragan-Kelley

Blur vs. Shading Rate



Slide courtesy Jonathan Ragan-Kelley

Depth of field results

Valve’s Half-Life 2 : Episode 2

Graphics Hardware

- Hardware on which 3D graphics is created in real-time
- Traditionally custom hardware
  - Increasing programmability
  - More complex rendering algorithms
- Programmable hardware available on a wide range
  - Mobile - PowerVR, Desktop - AMD Radeon/Nvidia GeForce
  - Heterogeneous processors - CPU with integrated graphics
    - Sandy Bridge
- Create new algorithms that make use of architectural features

Device properties

- Number and type of cores
    - Task parallel
        - OOO/In-order
    - Data parallel
        - SIMD/SIMT, width, VLIW/scalar
- Caches
    - Size, bandwidths, hierarchy, coherency
- Adaptable to new varieties of architectures

Challenges

- Wide range of changing hardware
- Efficient programming and utilization
    - CUDA, OpenCL, DirectCompute
    - Fixed custom scheduling (currently)
- Quest for ever increasing realism
    - Analytical visibility
    - Decoupled sampling

Summary

- GPUs have evolved into massively parallel processors
- Analytical Motion Blur improves quality leading to more realistic images
- Decoupled shading enables real-time realistic rendering
- Need new approaches to adapt to wide variation and complex scheduling

Thanks for listening
and
Questions