# 5 MAJOR CHALLENGES IN REAL-TIME RENDERING

Johan Andersson, DICE

# Overview

- What are the major challenges for us in the next 5-10 years?
  - Real-time rendering for games as well as other areas
- Which problems do we want to solve?
- What do we want to achieve & focus on?
- Based on own thoughts & feedback from people in the industry

# 25~~5~~ MAJOR CHALLENGES IN REAL-TIME RENDERING

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# Challenges 2012

Same as 2010!

1. Cinematic Image Quality
2. Illumination
3. Programmability
4. Production costs
5. Scaling

Challenge #1

# CINEMATIC IMAGE QUALITY

# Cinematic Image Quality

- Goal is to achieve Cinematic Image Quality
  - Same smooth & rich pictures that CG movies have
- Need significant improvements to GPU primary visibility
  - Antialiasing
  - Transparency
  - Defocus blur
  - Motion blur
- A future solution needs to include all *together*

# Antialiasing

- Single most visible issue to improve on
  - Aliasing breaks the illusion
  - Less aliasing = more pleasing & easier to see visuals

- Sources of aliasing:
  - Geometric aliasing
  - Proxy geometry aliasing (alpha test)
  - Shader aliasing
  - Mixed resolution rendering

# Post-process antialiasing

- Lots of developments in post-AA techniques
  - MLAA, FXAA, SMAA and more
  - Good quality / performance ratio

  - See SIGGRAPH'11 course: *"Filtering Approaches for Real-Time Anti-Aliasing"* http://iryoku.com/aacourse/

- But need solutions for the full problem

# Geometric aliasing

- Current solutions: MSAA, SSAA, temporal
  - Fixed quality techniques, not adaptive
  - Problematic to scale up to very high quality
- 16x MSAA is really good quality but expensive
  - Need high rate if using coverage masks
- MSAA + deferred
  - Massive memory usage & bandwidth
  - Want access to MSAA compression surface to avoid computing ourselves
  - See Andrew's talk in the course: *"Intersecting Lights with Pixels"*

# Geometric aliasing

- Other alternatives?
  - Analytical antialiasing
    - Would be interesting to see more research
  - Pre-filtered Sparse Voxel Octrees
    - Requires *very* high resolution / large storage
    - See Cyril's talk in the course: *"Dynamic Sparse Voxel Octrees for Next-Gen Real-time Rendering"*

# Shader aliasing

- Shader aliasing becoming more of a problem
  - High-frequency specular highlights
  - High-frequency shadows
  - Amplified by HDR Bloom & Bokeh

- What is needed to make sure shaders do not output aliased values?
  - Careful handling of derivatives when texture mapping
  - LEAN mapping, EVSM shadows
  - Wednesday: *“Rock-Solid Shading: Image Stability without Sacrificing Detail”*

# Proxy geometry aliasing

- Alpha-testing for proxy geometry results in major aliasing
  - MSAA per-sample evaluation is costly & requires many samples
- Real transparency can directly solve the aliasing
  - But we need to sort, need *order-independent transparency*

*Assets from Valve*

# Transparency

- Order-dependent transparency has always been a big limitation for content creators & developers
  - Restrictive art pipeline:
    - No glass houses
    - Even windows on cars & buildings can be painful
  - Restrictive interaction between objects & effects
    - Meshes vs particles vs volumetrics
    - Lack of sorting prevents usage of other transparent techniques
- Order-independent transparency is must going forward
  - With good performance & determinism

# Order-independent Transparency

- *Adaptive Transparency* [Salvi11] is promising
  - Currently requires multi-pass & unbounded memory
  - Need render target read/modify/write to get single-pass & bounded memory
  - Composite as you go (forward lighting)

# Motion blur


- Important for sense of speed & direction
- Velocity vectors + post-process holds up quite well

# Defocus blur

- Key visual cue to perceive depth & focus
  - Guide & emotional storytelling tool

- Sprite splatting [Igarashi08] is popular
  - Works great for out of focus background
  - Very sensitive to aliasing
  - Sharp edges on strong foreground blur

# Defocus blur – visibility issue

Incorrect visibility = hard edge

Correct visibility

# Defocus & motion blur – beyond post

- Raytrace geometry
- Stochastic rasterization
  - Lots of samples required for foreground, too little = noisy
    - Critical to have fast & temporally stable image reconstruction
  - Is defocus or motion blur the most important?
    - Leaning toward defocus due to the visibility issue
    - Though MB should not be applied after DOF, need a solution that handles both properly
- Pre-filtered Sparse Voxel Octrees


Challenge #2
ILLUMINATION

# Illumination challenges

Dynamic Global Illumination

Shadows

Reflections

# Dynamic Global Illumination

- Key visual component
- Multiple dynamic alternatives now:
  - Light Propagation Volume
  - Voxel cone tracing
  - Reflective Shadow Maps + VPLs
  - Geometry pre-compute based: Enlighten
- Major trade-offs depending on perf/memory/quality

# Dynamic GI wanted characteristics

- Static & dynamic geometry
- No pre-computation required
  - Major tradeoff with performance
- Handle large scales: indoor to large outdoor
  - With minimal light leakage
- Multiple indirect bounces
  - Single is not enough for in-door
- Indirect specular reflections

# Shadows

- General shadows continue to be a major challenge
  - *"Efficient Real-time Shadows"* course
- As a game developer, I'm tired of shadows ☹
  - Not what the graphics pipeline is built for
  - Time consuming tweaking, optimizations, compromises
  - Current techniques don't scale up
  - Are there Graphics/Compute extensions that could help?

# Shadows - wanted characteristics

**Robust:**

- Stable under object, light & camera motion
- No light leakage
- No flickering
- No magic constants

**High-quality:**

- Variable penumbra
- No aliasing
- Motion blurred

**General:**

- Works with all light types
- Supports dynamic geometry
- Supports alpha-test
- Supports transparent receivers & casters
- Scalable from small to large light sources

**Fast!**

- Sparse sampling
- Good culling

# The Many Shadow problem

- Want shadows on all lights
  - Easier to author
    - No light leaking through walls
  - Doesn't limit content creators
  - Higher quality & more interactive

- Current issues
  - Amount of geometry
  - Culling
  - Draw calls
  - Non-sparse rendering

Super simple scene, 10 spotlights

# Many Shadow – potential solutions

- Efficient rasterization
  - Smart logarithmic triangle culling with spatial data structure
  - Lazy on-demand scene culling, geometry culling & graphics dispatch
    - with CPU or GPU Compute
- Raytrace geometry
  - Render gbuffer
  - For each pixel affected by a light, cast ray to light
  - Evaluate & composite directly in pixel shader, or output to light visibility masks
- Cone trace into SVO
  - Once SVO data structure is built, easy to cone trace to query light visibility
  - Soft shadows = fast! ☺

# Reflections – categories

Glossy reflections on arbitrary surfaces

Perfect reflections on mostly-planar surfaces

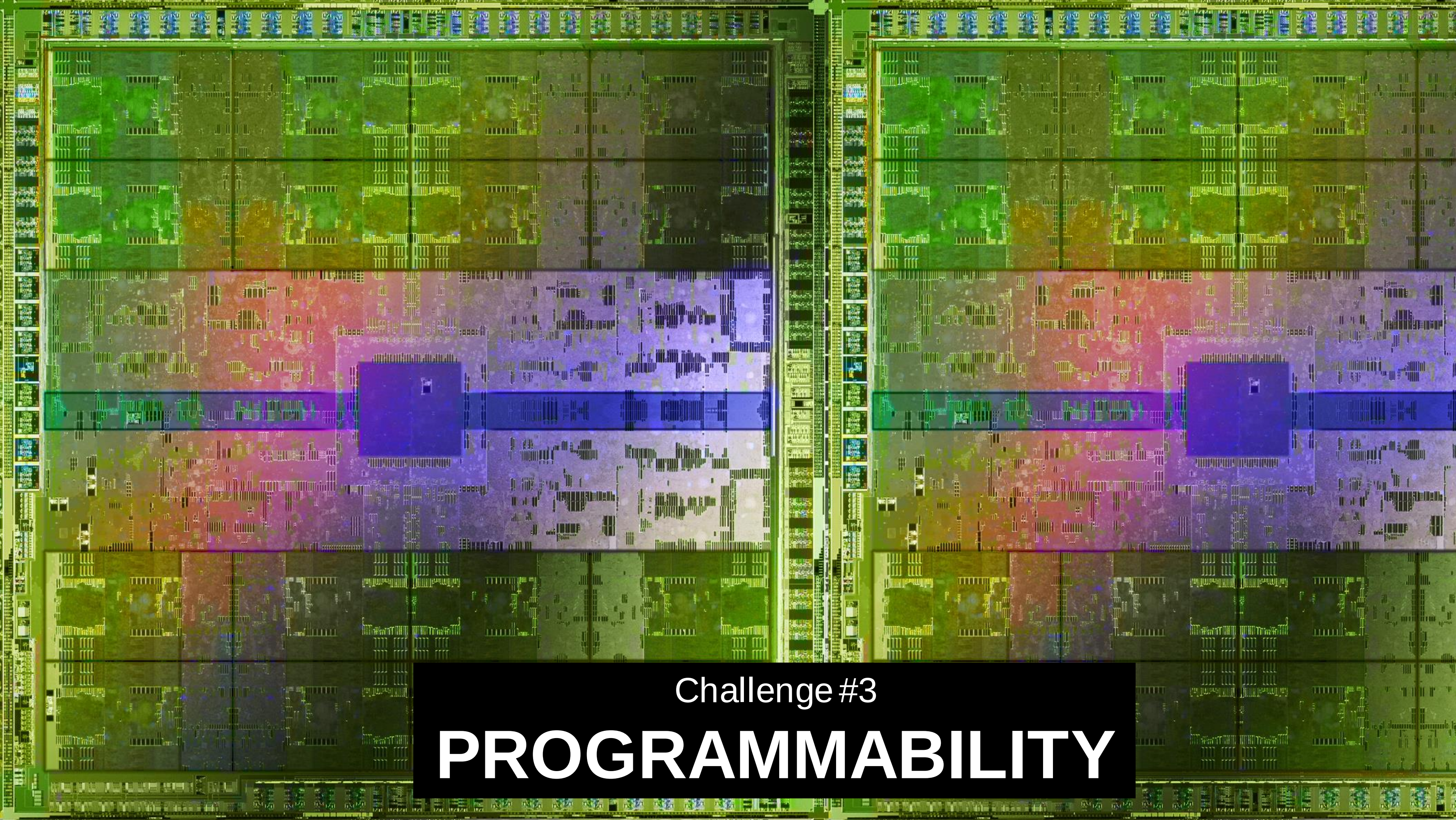
# Reflections – use cases

- Glossy reflections
  - Most surfaces, rough metal

  - Screen-space reflection
    - Fully dynamic
    - Simple & cheap
    - Visibility problems
  - Voxel Cone Tracing
    - Can be a good fit
    - Expensive to build SVO of scene

# Reflections – use cases

- Perfect reflections
  - Mostly planar surfaces: windows, water
  - Render reflected view(s)
    - Prohibitive to render scenes upfront with multiple planes
    - Want more sparse rendering
  - Raytracing is elegant, but impractical
    - Performance
    - Have to switch entire game graphics pipeline
  - Voxel Cone Tracing
    - Requires massive resolution
    - Not practical until we can use it for primary visibility



Challenge #3

# PROGRAMMABILITY

# Programmability

- Need major innovations to solve the other challenges

# Programmability - Pipelines

- Graphics pipeline is fast but fixed
  - No conservative rasterization
  - No programmable blending
  - No flexible texture filtering (min/max/derivative)

- GPU Compute can't efficiently simulate a full graphics pipeline
  - Use the graphics pipeline when possible
  - Need to enable building your own efficient GPU Compute pipelines
    - When going beyond graphics pipeline capabilities
    - Esp. important with long HW & OS lead times

# Programmability - Areas

- Need a virtual data-parallel ISA
  - Separate front-end from back-end
    - Can use same front-end (language) on all platforms (back-ends)
    - Run on all platforms and all (modern) architectures
      - Both CPU and GPU!
    - HSA with HSAIL is one promising solution
  - Most developers are multi-platform
    - Won't write serious code in platform- or vendor-specific languages

# Programmability - Areas

- Strip down the GPU SW stack & hardware abstractions
  - Only bindless access to resources
    - Need standard non-opaque texture layouts
  - Virtual memory
  - Both CPU or GPU Compute can generate GPU work
  - Layer existing fat APIs on top of it (DirectX & OpenGL)

# Programmability - Areas

- GPU Compute spawning fine-grained tasks for itself
  - Build your own pipelines, independently of CPU
  - Kepler GK110 'Dynamic Parallelism' on all chips, platforms and compute languages
- Need mechanisms to build SIMD coherency
  - Not ideal to write out giant sample lists to memory and sort
  - *Queues* as a language & HW abstraction primitive

# Programmability - Areas

- Low-latency CPU/GPU collaboration
  - Balance work, run where most efficient
    - Frostbite uses it on consoles [Coffin11] [Brisebois11]
  - GPU spawning work for CPU
  - CPU inserting more work for GPU *within* the frame
  - Simple use case for Sample Distribution Shadow Maps:
    1. Render z+gbuffer
    2. Analyze zbuffer to determine ideal shadowmap distribution
    3. Kick of CPU to cull & create shadowmap graphics display list
    4. GPU renders something else while waiting for CPU

# Programmability - Areas

- Render target read/modify/write
  - A must have base operation
  - OIT & programmable blending


Challenge #4

# PRODUCTION COSTS

# Production costs

- Games are getting bigger & more complex
  - More content
  - More variation
  - Higher quality/detail
  - More complex content production process

- What are the next big step forward for content production?
  - Quick iteration times = quality

# Production costs

- If we had the ultimate real-time renderer that solves primary visibility and illumination, how much artist time would we save?
  - Probably not that much overall unfortunately (but increase quality)
    - Having shadows everywhere and dynamic GI saves some artist time
    - Will save engineering time & support
  - Content creation is the biggest time sink
- What can save significant amount of time?
  - Scalable geometry representation
  - Procedural texturing
  - Procedural geometry
  - Content acquisition

Challenge #5

# SCALING

# Scaling

- Games & rendering use cases are needing more and more scaling. Both up and down!
  - Detail: mm to km
  - Resolution: 320x480 (IPhone3) to 5760x1200 (Eyefinity). 45x
  - Power: 1W to 300W. 300x
- Requires significant scaling in performance
- Which techniques, algorithms & pipelines are scalable?

# Scaling: Detail

- How can we increase detail while building even larger interactive worlds?
  - Scalable geometry is difficult, discrete LODs suck
    - Want an inherently scalable & filterable primary data representation. Dynamic SVOs?
  - Can’t author everything
    - Use procedural detail up close

# Scaling: Resolution

- Some of the lowest powered devices have the highest resolution screens
  - Consumers ☺
  - Developers ☹
- Graphics pipeline need a more flexible decoupling of *shading rate* vs *visibility rate*!
  - MSAA and fixed upsampling is not enough

# Scaling: Power

- Marketplace is shifting from 100+ W to 1-45 W
  - Phones (1 W), Tablets (3 W), Ultrabooks (17 W), Laptops (45 W)
- Developers typically don't care about power usage
  - But hardware/device manufacturers and consumers do
  - With cloud rendering, power is a direct cost for developer
- Need power efficient algorithms, techniques & pipelines
  - Grand challenge for the next 10 years: photo-realistic rendering at 1W

# Questions?

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# Thanks for the feedback!

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Marco Salvi
Andrew Lauritzen
Colin Barré-Brisebois
Ivan van Assen
Matt Collins
Charles de Rousiers
Stephen Hill
Nathan Reed
Timothy Lottes

Sebastien Lagarde
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Jim Vaughn
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Aras Pranckevičius
Julien Guertault
Sam Martin
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,

Pål-Kristian Engstad
Jonathan Ragan-Kelly
Matthijs De Smedt
Doug Binks
Morgan McGuire
Andrew Richards
Daniel Wexler
Eric Smolikowski
David Möllerstedt

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