Comparing Reyes and OpenGL on a Stream Architecture

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Motivation

Frame from *Quake III Arena*
© id Software, 1999

Frame from *3DMark2001*
© madonion.com, 2001

Frame from *A Bug's Life*
© Pixar Animation Studios, 2000

- Special-purpose processors: great performance
- General-purpose processors: great flexibility
- As graphics architects, how do we get both?

OpenGL and Reyes

- **OpenGL: Prevalent in real-time graphics systems today**
  - Designed for high-performance real-time implementations
- **Reyes: Architecture to implement RenderMan**
  - Designed for high-quality, non-real-time rendering
- **Streaming framework for rendering enables implementation and comparison of both pipelines**

Frame from *Monsters Inc.*

Summary

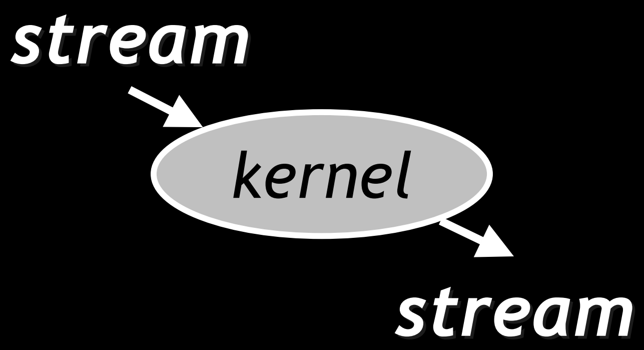
- **Rendering in streaming framework provides flexibility and performance**
- **OpenGL and Reyes are both streaming apps**
  - Focus of paper: comparison between two
- **Contributions of paper:**
  - Streaming framework for rendering
    - Enables multiple pipelines / hybrid pipelines
  - Algorithms for streaming implementation
  - Quantitative comparison between OpenGL and Reyes

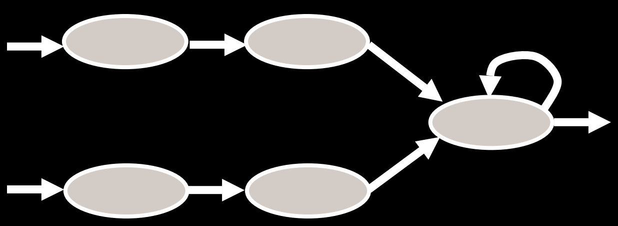
Previous Work

- **OpenGL: Segal and Akeley ’99**
- **Reyes: Cook/Carpenter/Catmull ’87**
  - RenderMan: Upstill ’90, Apodaca and Gritz ’00
- **Programmability and rendering:**
  - Shade trees: Cook ’84
  - Programmable pipeline: Olano ’98 (dissertation)
  - RenderMan on OpenGL: Peercy et al. ’00
  - OpenGL with streams: Owens et al. ’00
  - Real-Time Shading Language: Proudfoot et al. ’01
  - Smash: McCool ’01

The Stream Programming Model

- Streams
  - Ordered sets of data elements of the same datatype
  - Datatype can be compound
- Kernels
  - Perform computation
  - Inputs/outputs are streams
  - Typical operation: apply function to each element in stream
  - Can be chained together
  - Expose parallelism





Programming Model Details

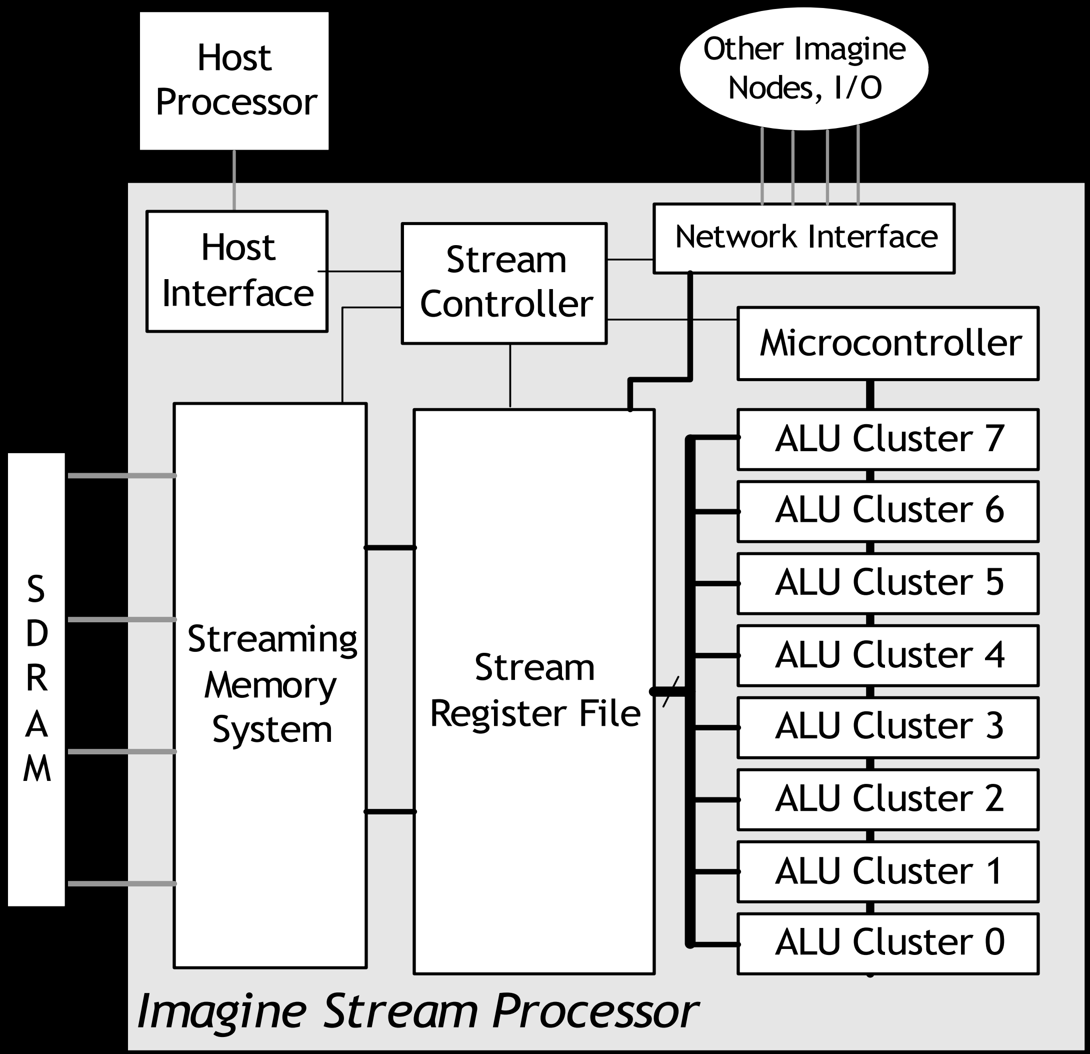
Limited control flow

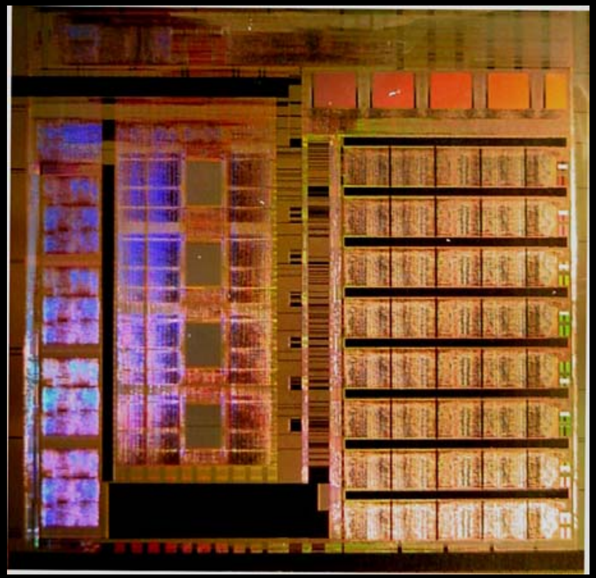
- Goal: Exploit data-level parallelism
  - SIMD (single-instruction, multiple-data)
- Requirement: Simple control
  - Primary control structure: loop
  - No branches
- Conditional streams allow data-dependent operation

Kernels operate only on local data

- Goal: Fast kernel execution
- Requirement: Data must be close to functional units
  - Must structure program to avoid global accesses within kernels
  - No pointers, no global arrays within kernels

The Imagine Stream Processor

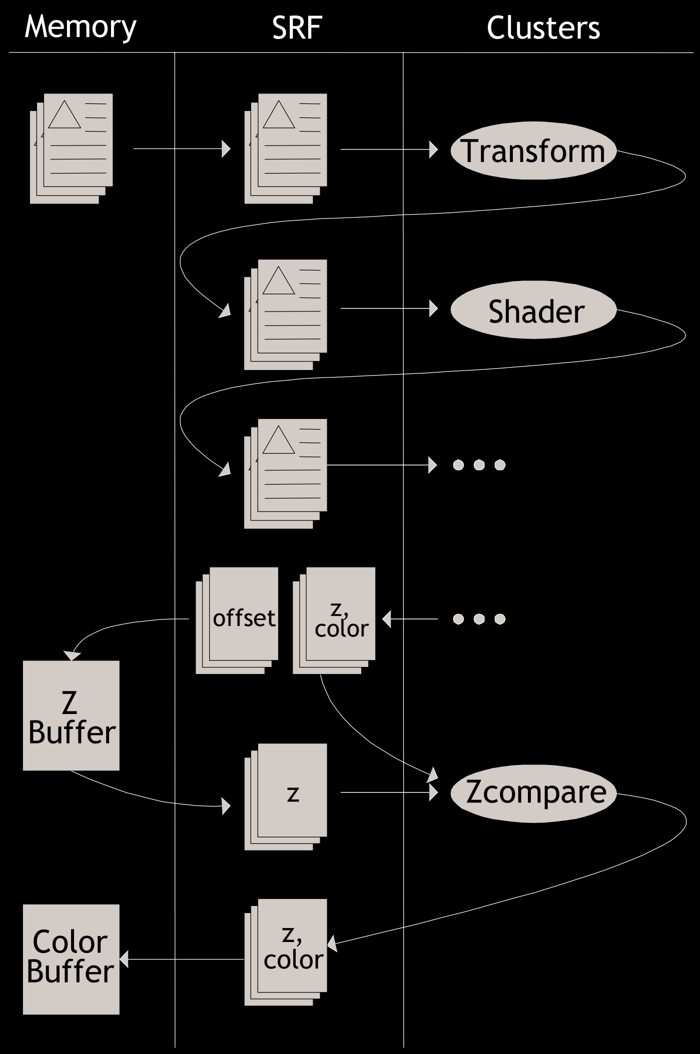




[Khailany et al., IEEE Micro Mar/Apr '01]

Implementation

- Input stream divided into "batches"
- Batch loaded from memory to SRF
- Series of kernels run on input batch
- Output written back to memory

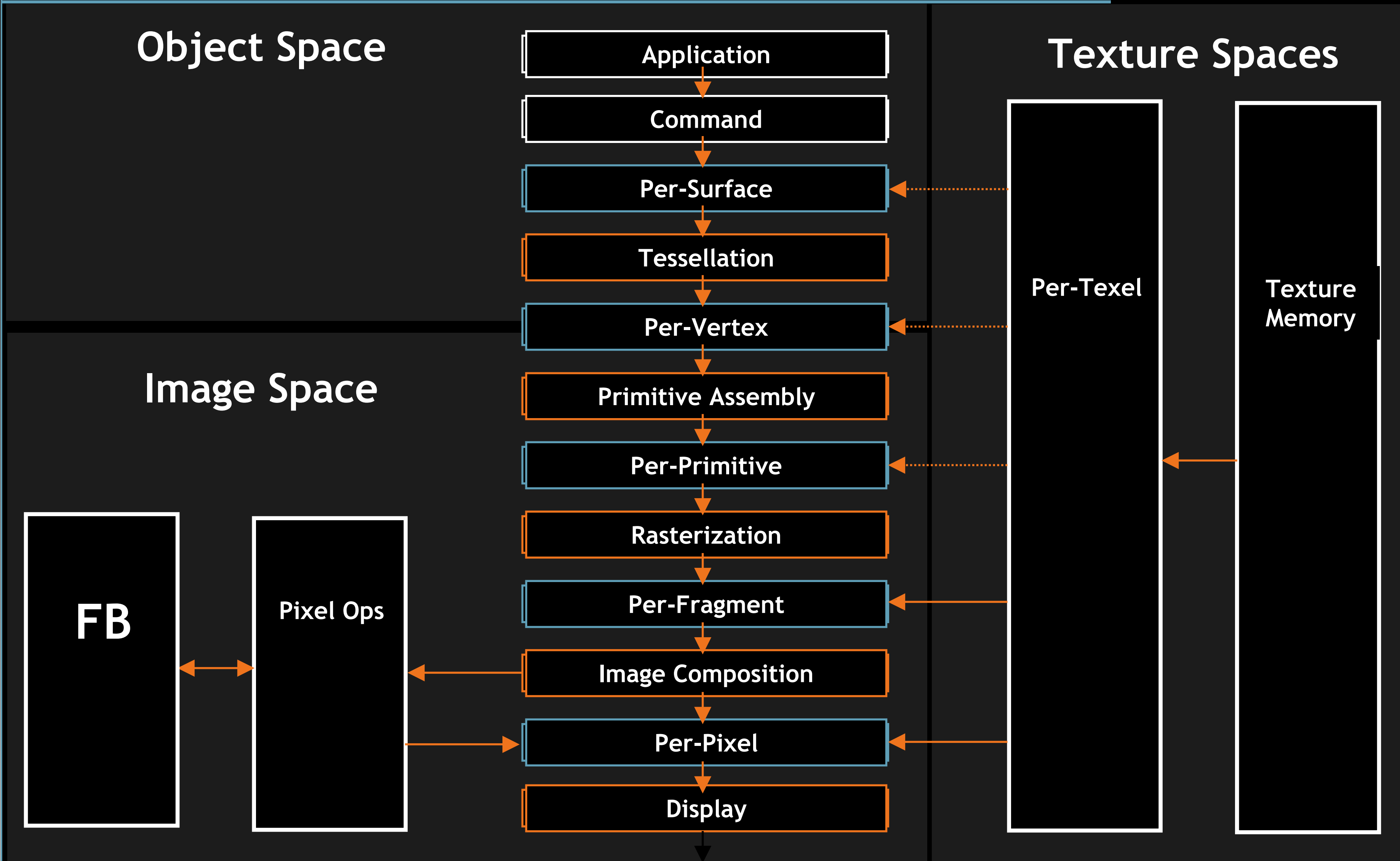


[Owens et al., Graphics Hardware '00]

Why Stream Processing?

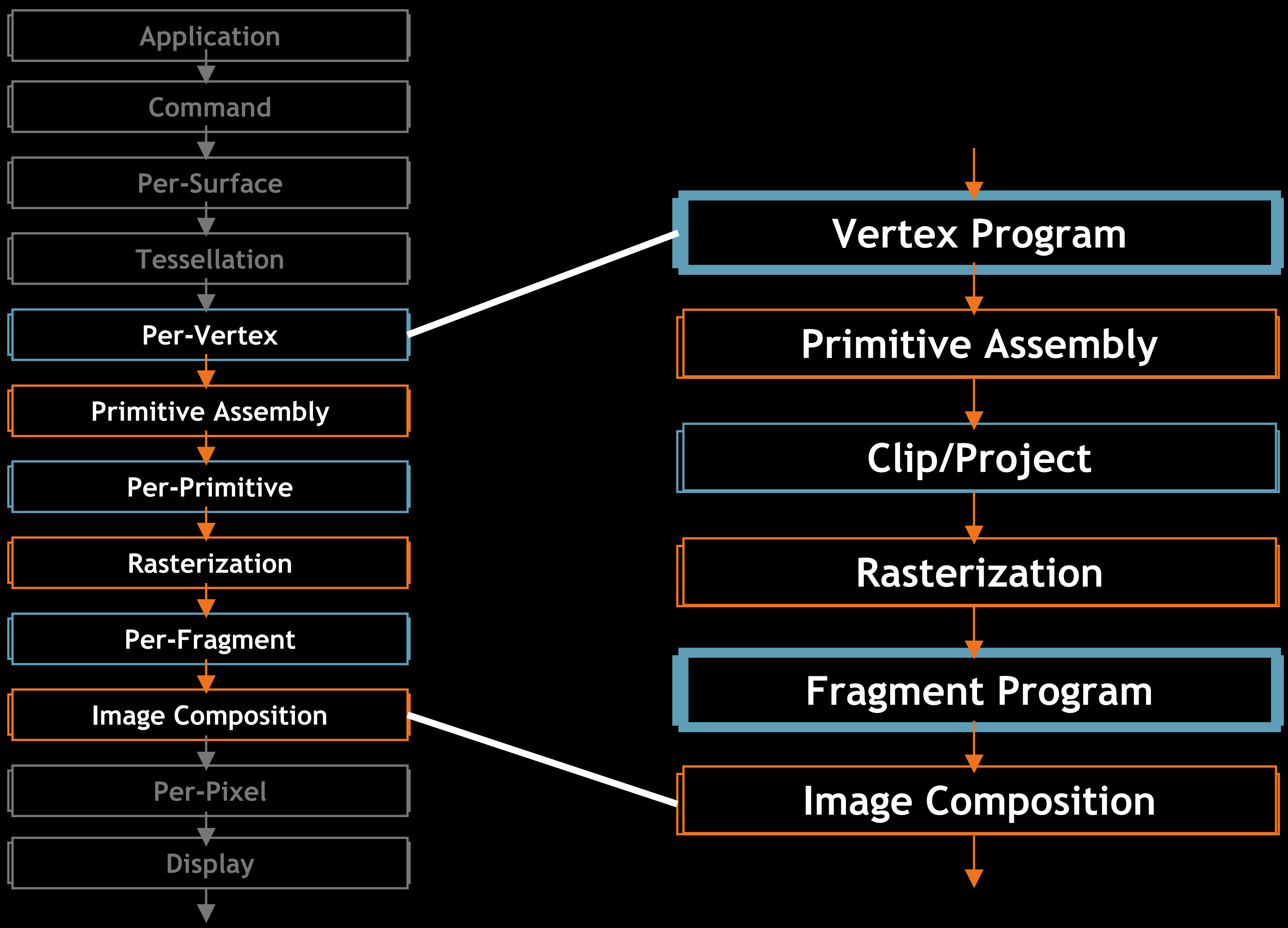
- **Graphics tasks are stream tasks**
  - Exploit parallelism, producer-consumer locality
  - Stream hardware is designed to:
    - Support lots of computation
    - Deliver high data bandwidth
  - SIMD nature of Imagine matches OpenGL/DirectX and Reyes shading models
- **Goal: Design of efficient algorithms for the stream model results in efficient implementations in special-purpose hw**

Stream Framework for Rendering

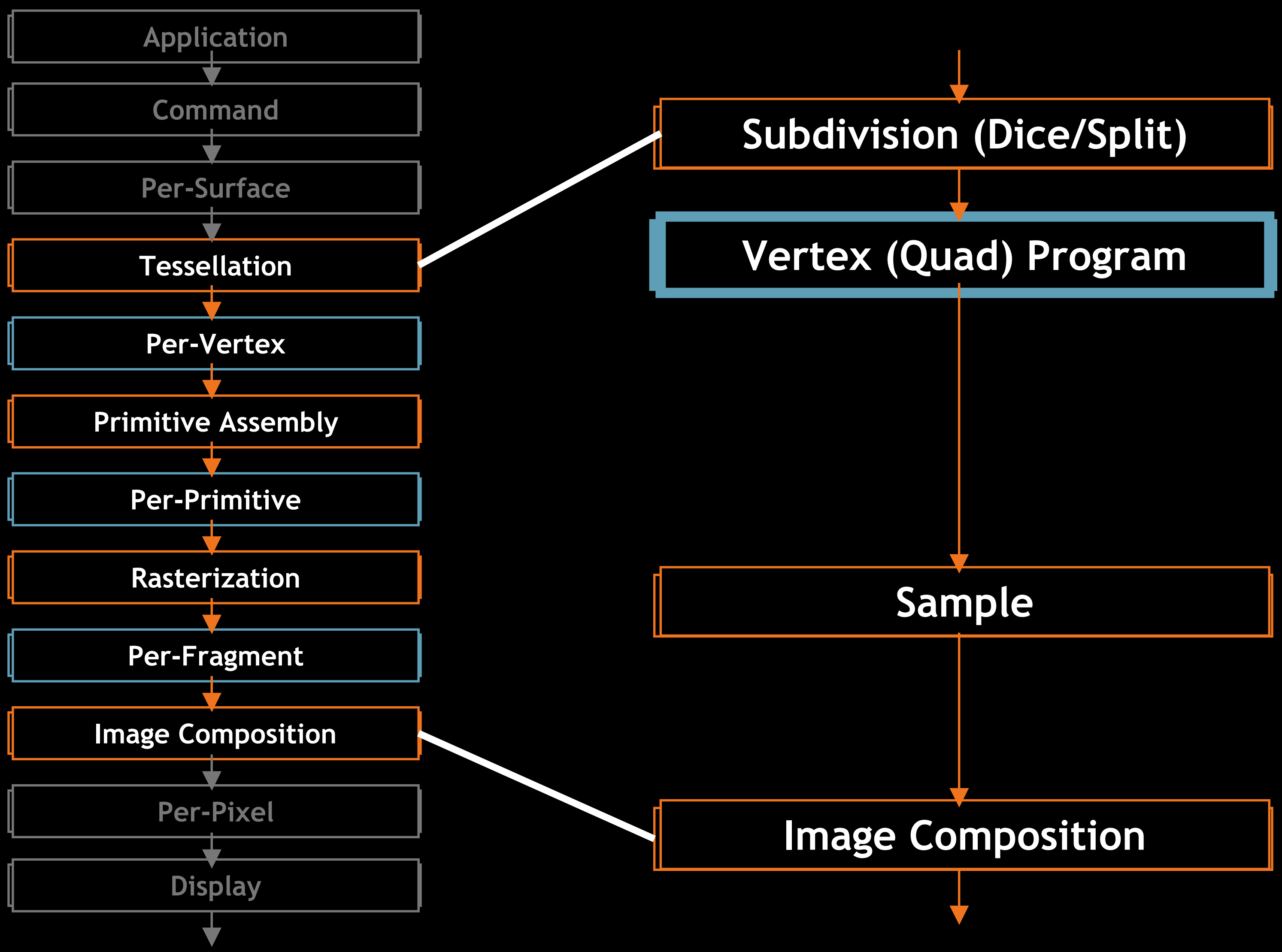


From Akeley and Hanrahan, *Real-Time Graphics Architectures*

OpenGL in Streaming Model



Reyes in Streaming Model



Summary of Pipeline Differences

- **Shading and texturing**
  - OpenGL: 2 shaders, 2 coordinate spaces
  - Reyes: Single shader, single coordinate space
- **Sampling vs. rasterization**
  - OpenGL: rasterizes arbitrary-sized triangles
  - Reyes: samples bounded-sized quads
- **Tessellation**
  - OpenGL: tessellates in host or at compile time
  - Reyes: tessellates dynamically as part of pipeline

Shading and Texturing

- OpenGL
  - Vertex shading: eye space
  - Fragment shading: screen space
    - Textures require filtering (mipmapping, 8 samples/access)
    - Imagine OpenGL: mipmapped scenes are > 2x slower than point-sampled
  - Factoring advantageous for large triangles, but must support two shading units
- Reyes
  - Vertex/quad shading: eye space
    - Coherent access textures: samples are properly filtered
  - Gain ability to shade before pixel coverage calculation: motion blur, depth of field

Sampling vs. Rasterization

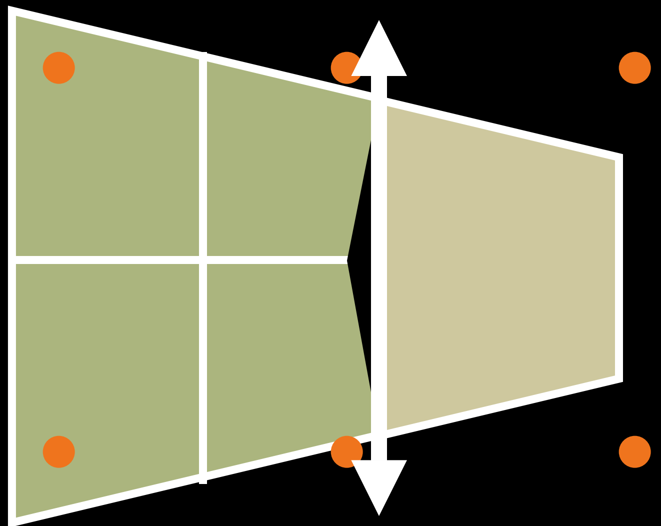
- **Sampling quads is simpler than rasterizing triangles**
  - Quads have bounded size
  - Triangles can have arbitrary size
- **Imagine implementations:**
  - 8 Gouraud shaded primitives w/ identical coverage
  - Reyes sample: 100 cycles, 548 ops
  - OpenGL rasterize: 565 cycles, 2276 ops
    - More complex shaders need lots of interpolants

Tessellation

- **OpenGL: compile time, or on host**
- **Reyes: runtime**
  - Adaptive subdivision
  - Catmull-Clark subdivision surfaces
  - Goals
    - Keep data structure on-chip
    - No global knowledge (i.e. binary dicing)
    - *O*(log *n*) storage for *n* quads (depth first traversal)
  - Most traditional subdivision algorithms inapplicable
    - Typically limit subdivision differences between levels
  - Biggest problem: Ensuring no holes in surface

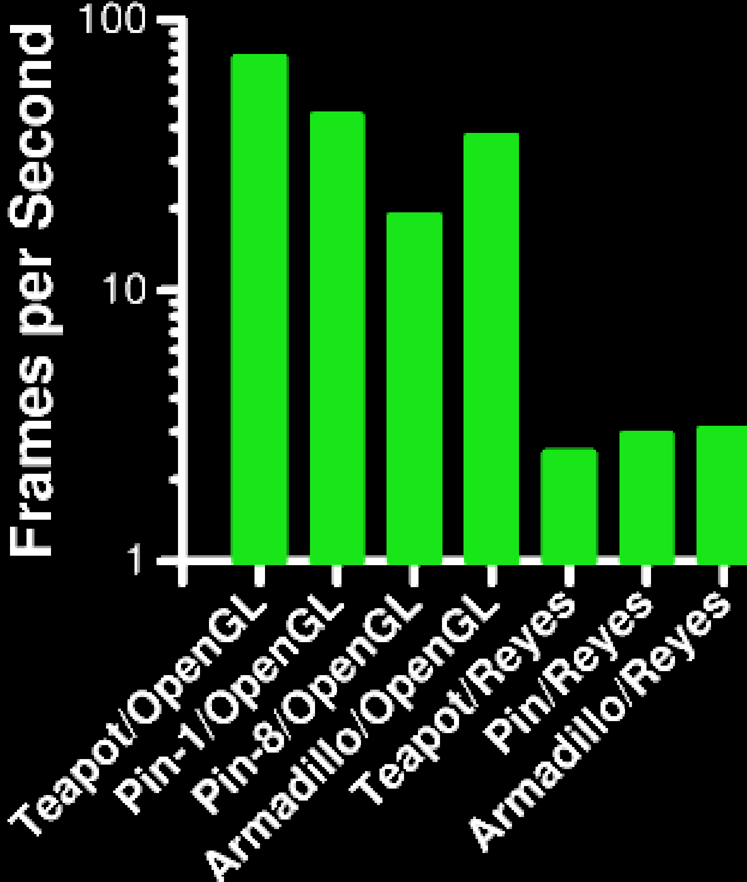
Ensuring Hole-Free Subdivision

- Quad on right: complete, and output
- Quad on left: must be subdivided
- Potential crack?
- Freeze edges once they fall beneath threshold
- Edges represented as edge equations



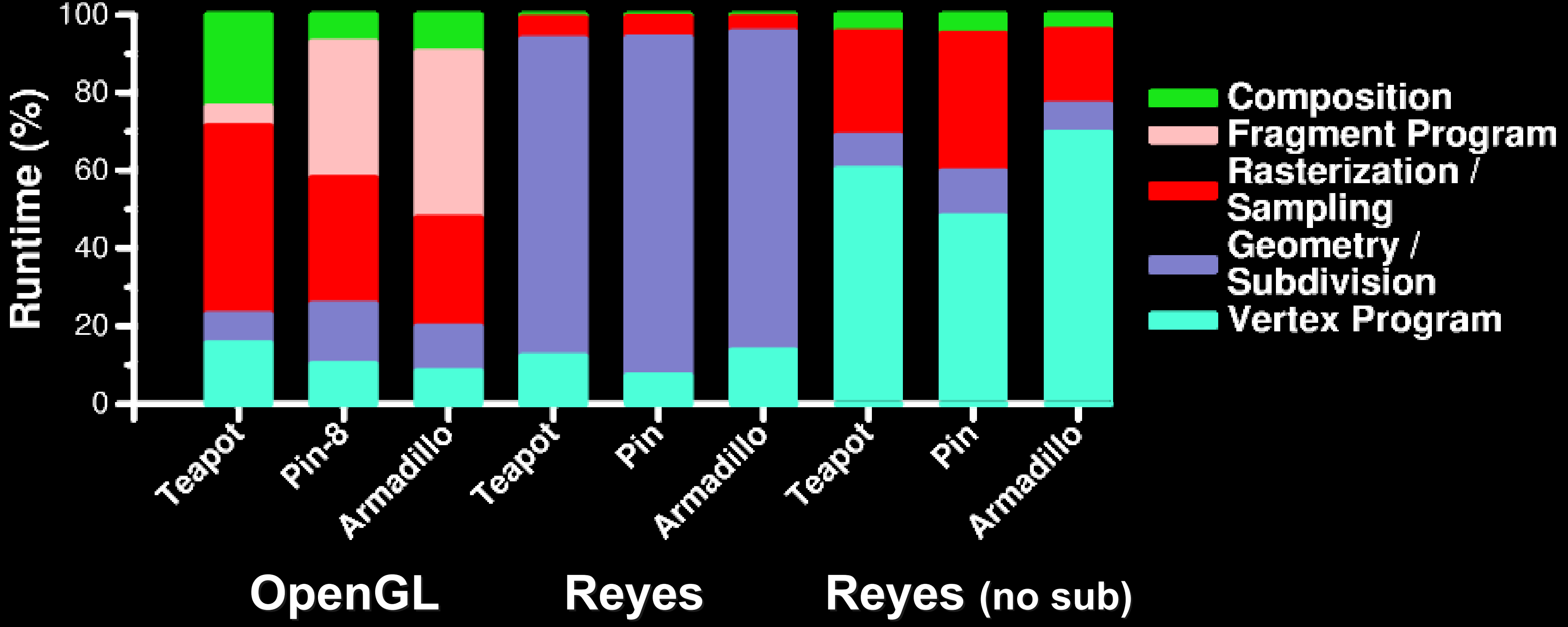
Performance

- **Reyes scenes order of magnitude slower than OpenGL scenes**
- **OpenGL scenes:**
  - Triangle sizes 2-12 pixels/triangle
- **Why?**



Runtime Results

- Avg. of 82% of Reyes runtime in subdivision
- Of remainder, about half in shading
- Subdivision produces many zero-frag quads



Reyes: Refining Subdivision

- **Possible improvements**
  - High-level backface culling
  - Intelligent splitting (x or y, not both)
  - Early quad kill
- **Subdivision spectrum - adaptive to fixed**
  - Our algorithm: fully adaptive
  - Non-adaptive “oracle” subdivision test:
    - Subdivision takes 10% of runtime
  - Ideal algorithm?

Conclusions

- **Streaming is a natural way to describe programmable pipeline**
  - Matches pipeline flow
  - Exploits concurrency and locality
- **OpenGL and Reyes both fit into streaming framework**
  - Framework supports either pipeline, or hybrid
- **Reyes has several algorithmic advantages …**
  - Bounded size primitives, single shader, coherent textures, potential for more sophisticated effects …
- **… but subdivision remains a challenge**

Thanks to …

- Stanford Flash Graphics group
- NVIDIA architecture group
- Kurt Akeley and Pat Hanrahan
- Kekoa Proudfoot and Bill Mark
- Matt Pharr
- Funding agencies: DARPA, Intel Foundation, MARCO