SIGGRAPH2009 NEW ORLEANS

GRAMPS: A Programming Model For Graphics Pipelines

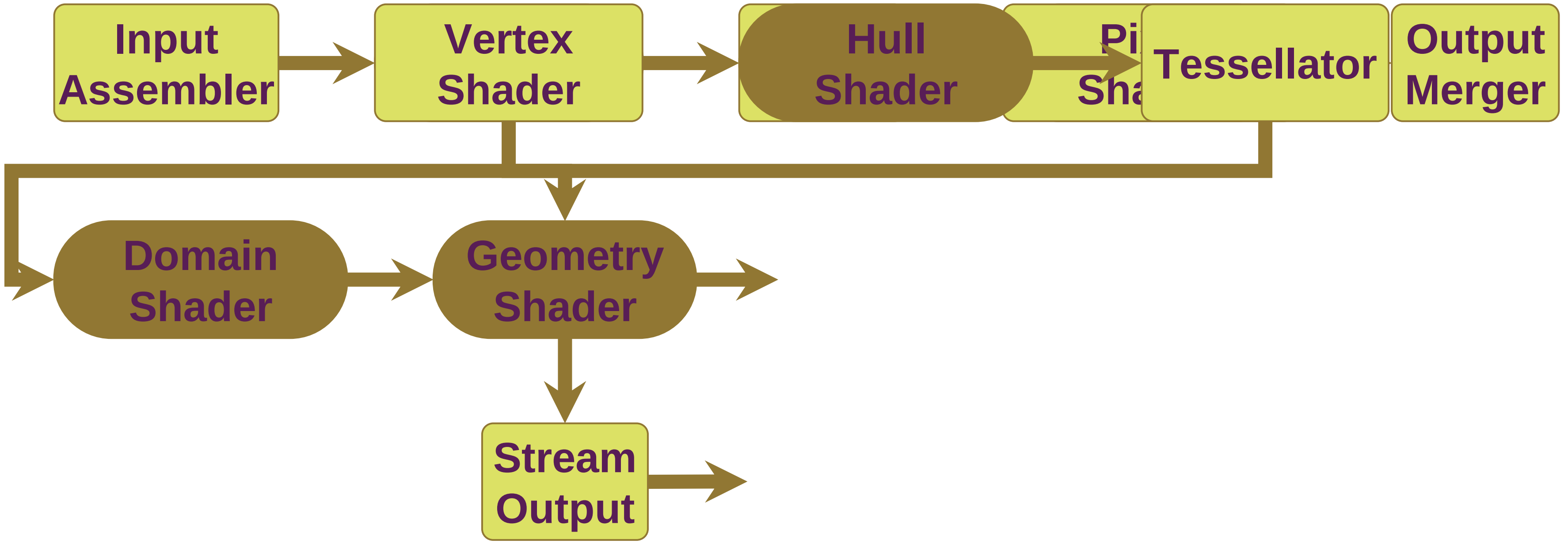
Jeremy Sugerman,
Kayvon Fatahalian, Solomon Boulos,
Kurt Akeley, Pat Hanrahan

"The Graphics Pipeline"

- Central to the rise of 3D hardware and software.
- A stable and universal abstraction
- Shaped the evolution of the field…
- … while leaving enormous room for innovation.

The Graphics Pipeline is evolving

Direct3D 11 ›le Shading



“GPU” is evolving, too

- Continued drive for algorithmic innovation and advanced rendering techniques
- First class programming models for compute:
  – OpenCL, compute shaders, vendor specific, …
- New / different hardware implementations:
  – E.g., Larrabee, CPU-GPU combinations / hybrids
  – Even NVIDIA and AMD GPUs are very different

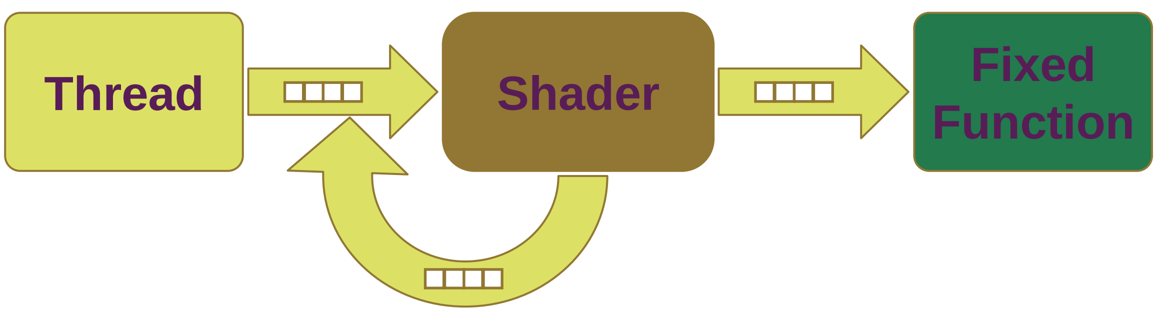
From fixed to programmable (again)

Idea: Evolve the pipeline itself from preset configurations to a programmable entity

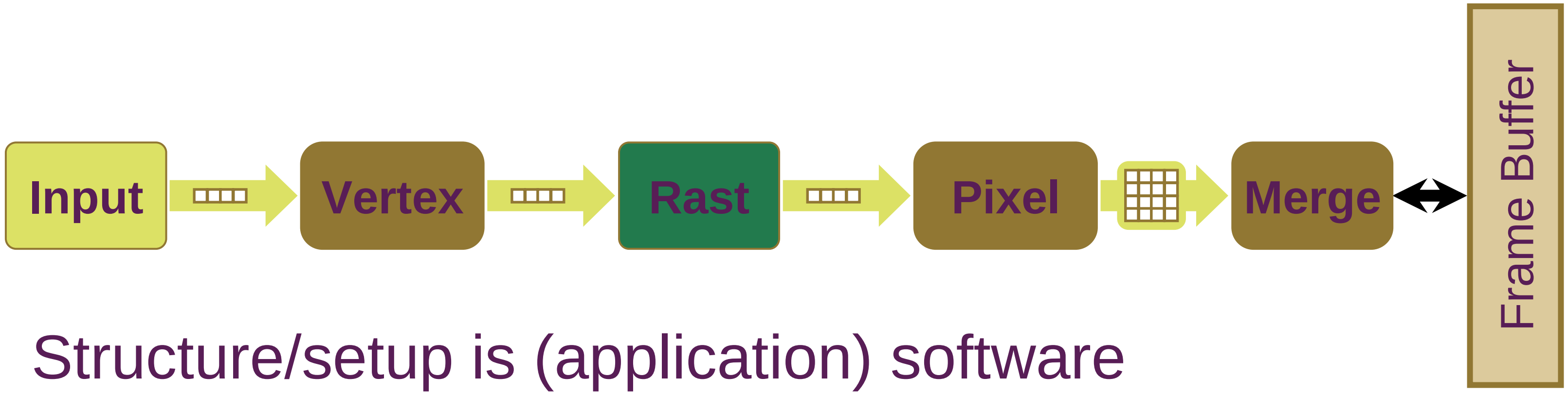
GRAMPS

- Programming model and run-time for parallel hardware
- **Graphs** of stages and queues
- GRAMPS handles scheduling, parallelism, data-flow

Example: Simple GRAMPS Graph



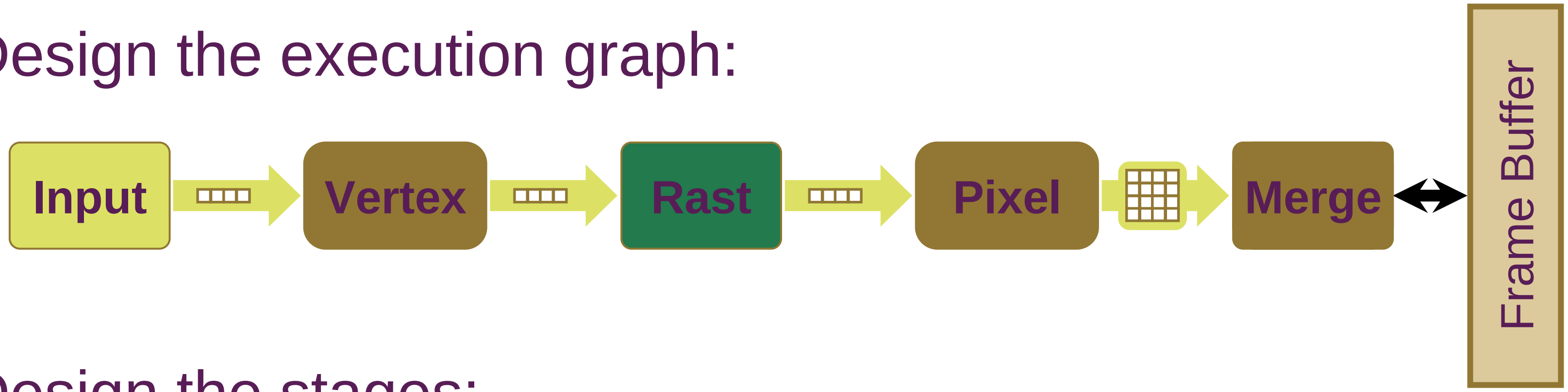
The Graphics Pipeline becomes an app!



- Structure/setup is (application) software
  – Customized or completely novel renderers
- Reuses current hardware: FIFOs, shader cores, rast, …
- Analogous to the transition to programmable shading
  – Proliferation of new use cases and parameters
  – Not (unthinkably) radical

Writing a GRAMPS application

Design the execution graph:

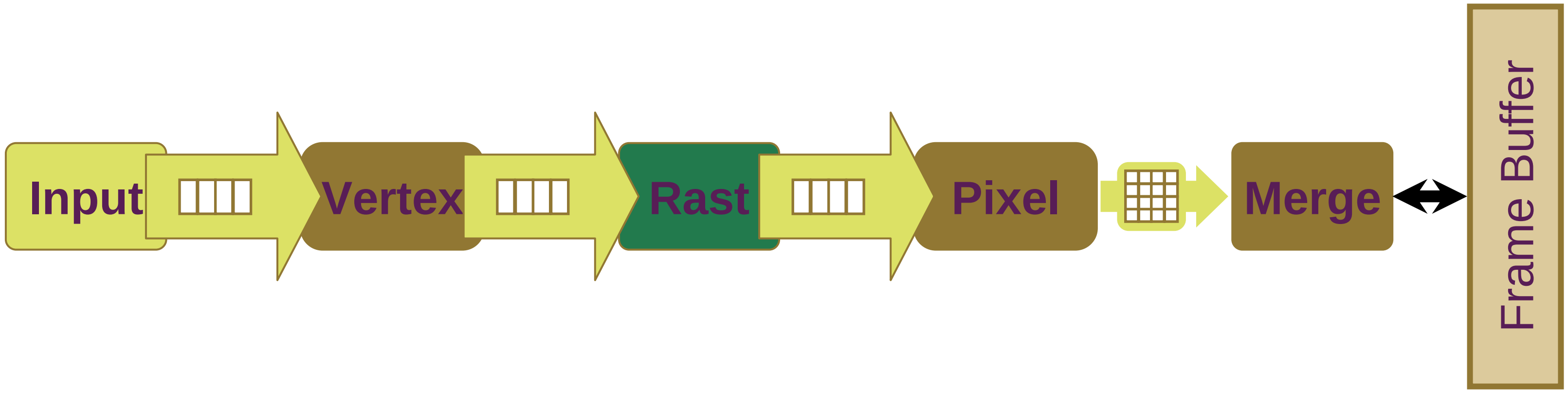


Design the stages:

- Shaders
- Threads (and Fixed Function stages)

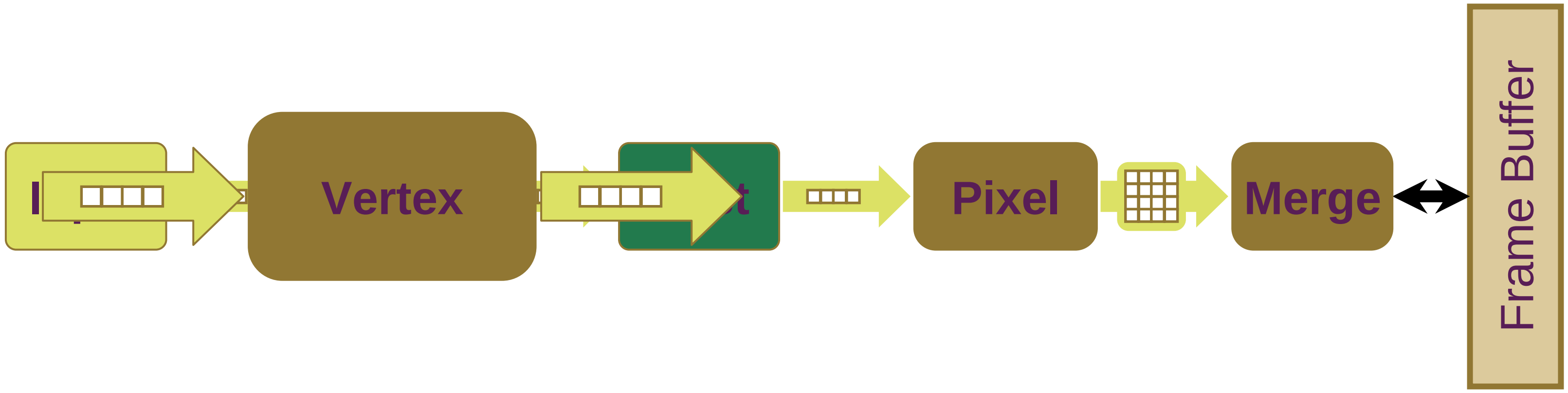
Instantiate and launch.

More Detail – Queues



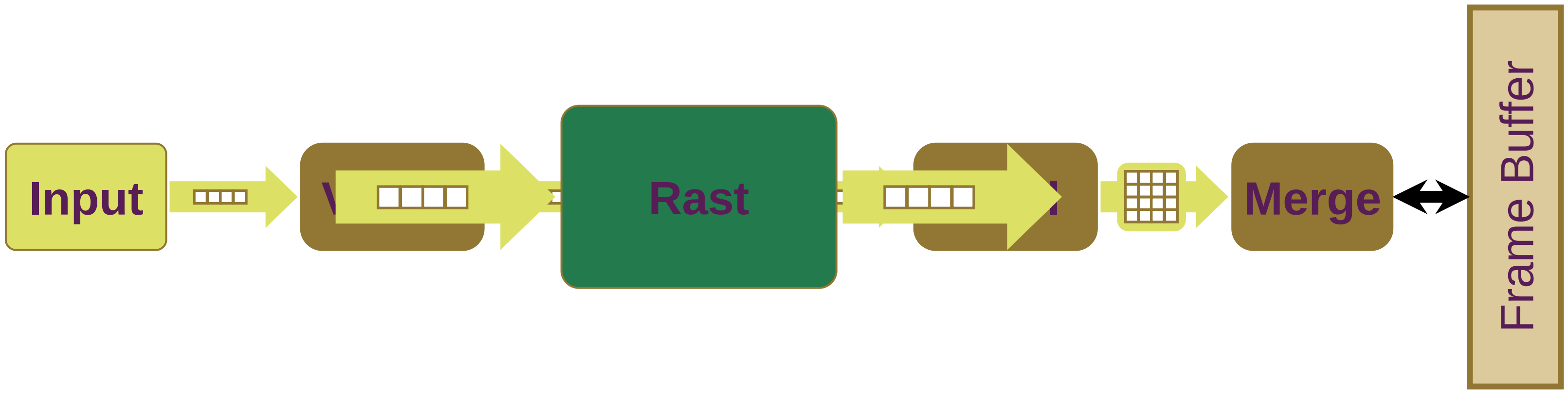
- Queues operate at a "packet" granularity
  - "**Large** bundles of **coherent** work"
- GRAMPS can optionally enforce ordering
  - Required for some workloads, adds overhead

More Detail – Shaders



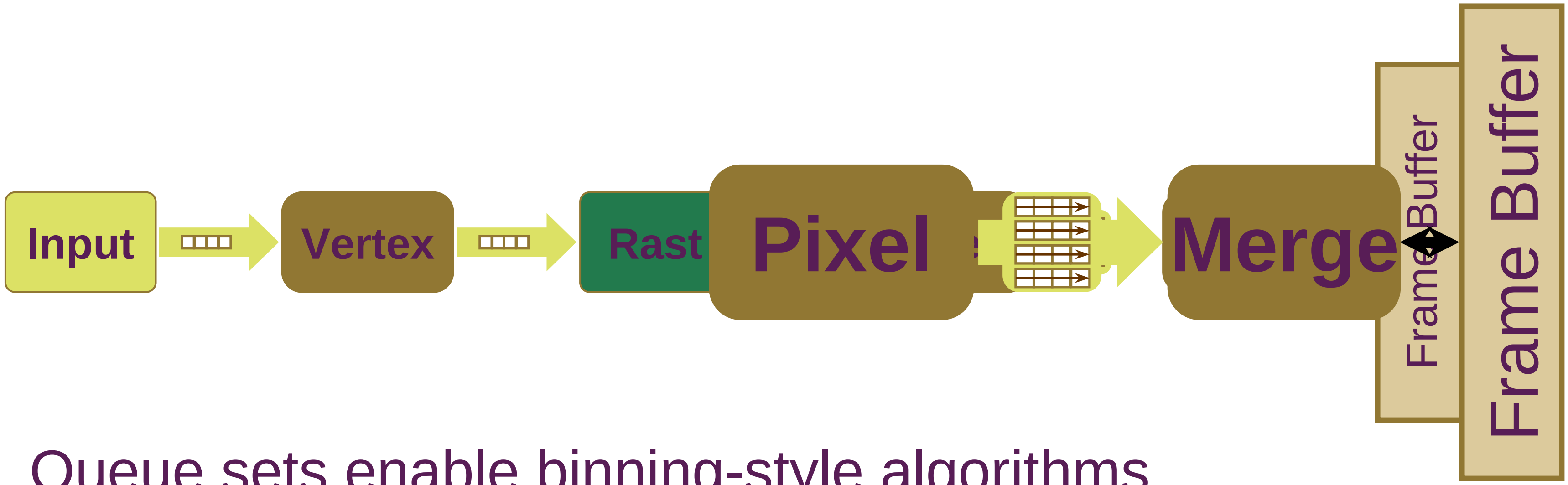
- Shaders: Like pixel (or compute) shaders, stateless
  - Automatic instancing, pre-reserve/post-commit
- “Collection” packets: shared header and N elements
- **New**: “Push” operation to coalesce variable outputs

More Detail – Thread/Fixed Function



- Threads: Like POSIX threads, stateful
  - Explicit reserve/commit on queues
- Fixed Function: Effectively non-programmable Threads

More Detail – Queue Sets



- Queue sets enable binning-style algorithms
- One logical queue with multiple lanes (or bins)
  - One consumer at a time **per lane**
  - Many lanes with data allows many parallel consumers

Quick Comparison to “Streaming”

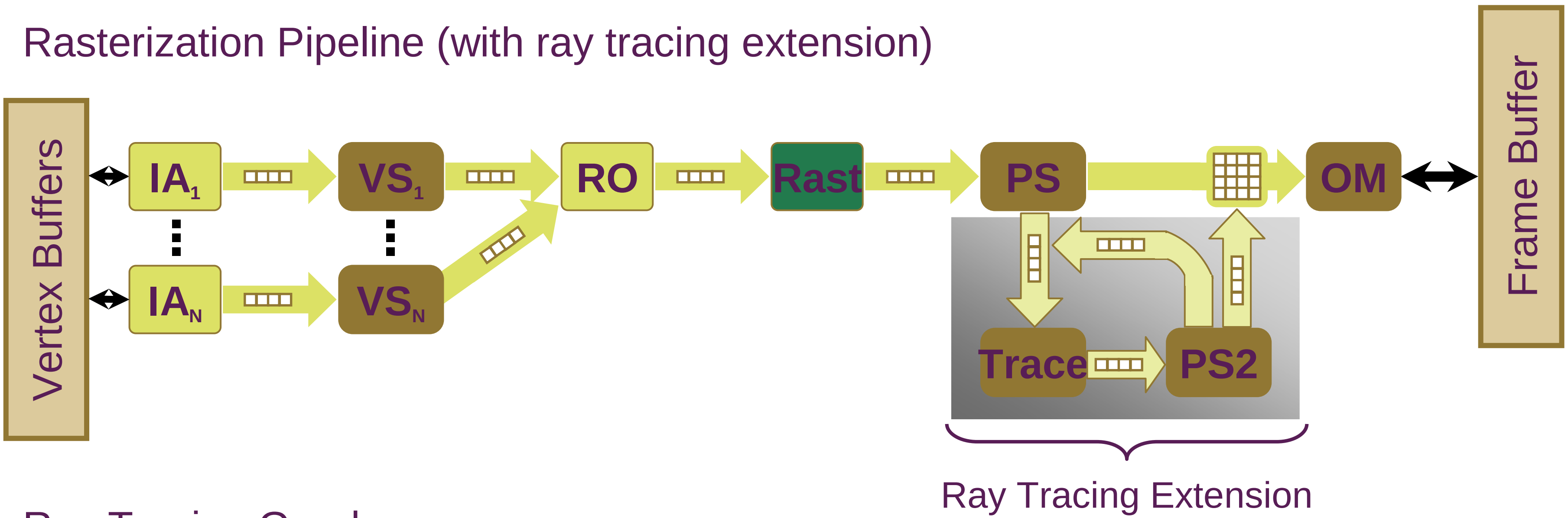
- Streaming: “squeeze out every FLOP”
  - Goals: throughput, bulk transfer, arithmetic intensity
  - Intensive static analysis, program transformation
  - Bound space, data access, execution time
- GRAMPS: “interesting applications are irregular”
  - Goals: throughput, dynamic, data-dependent code
  - Aggregate work at run-time, heterogeneous hardware
  - Streaming apps **are** GRAMPS apps

Evaluation: Design Goals

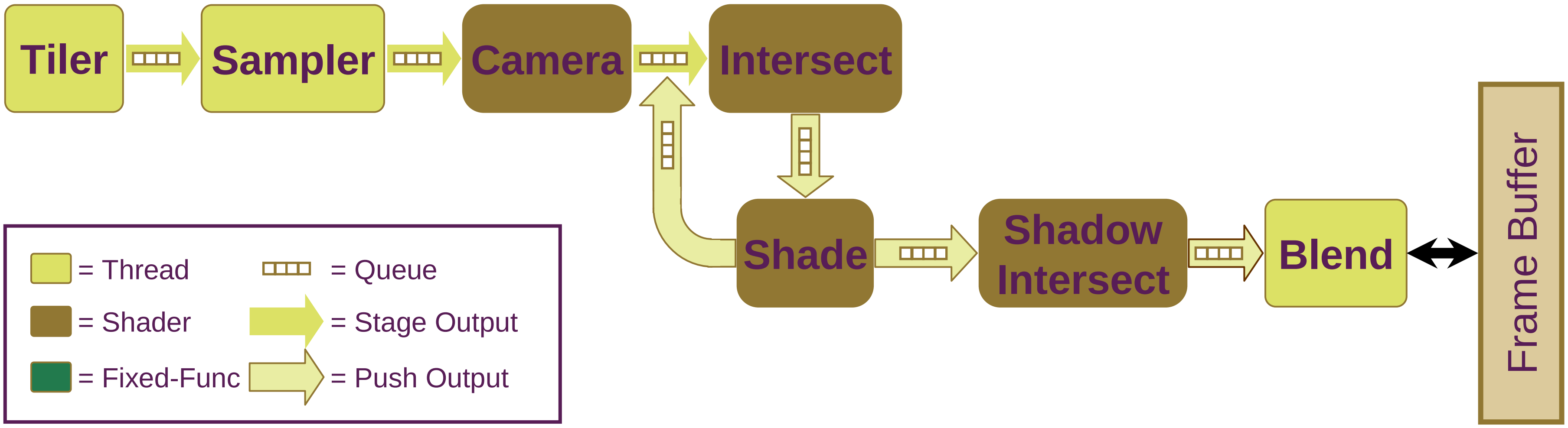
- Broad application scope: preferable to roll-your-own
- Multi-platform: suits many hardware configurations
- High performance: competitive with roll-your-own
- Tunable: expert users can optimize their apps
- Optimized Implementations: inform, and are informed by, hardware

Broad Application Scope

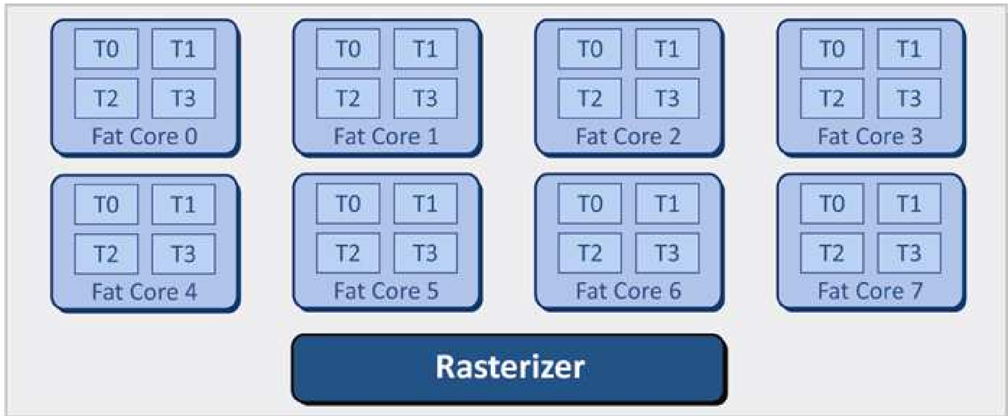
Rasterization Pipeline (with ray tracing extension)



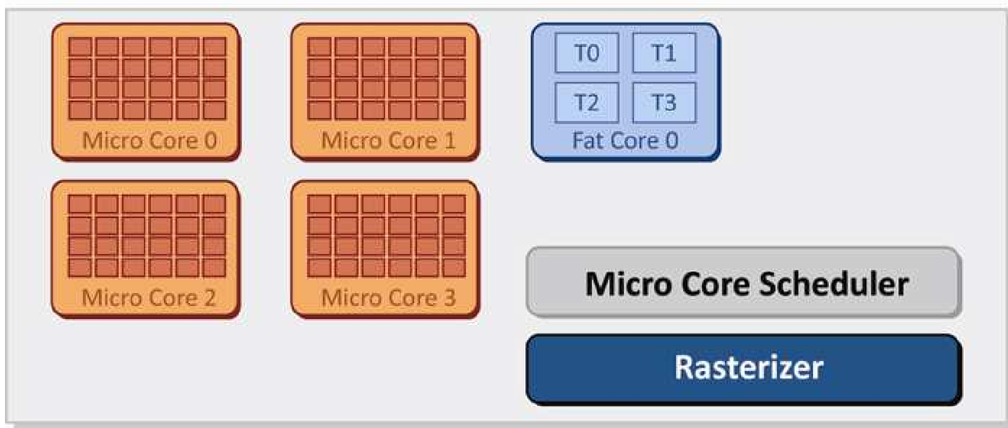
Ray Tracing Graph



Multi-Platform: Two (Simulated) Machines



CPU-Like: 8 Fat Cores, Rast



GPU-Like: 1 Fat Core, 4 Micro Cores, Rast, Sched

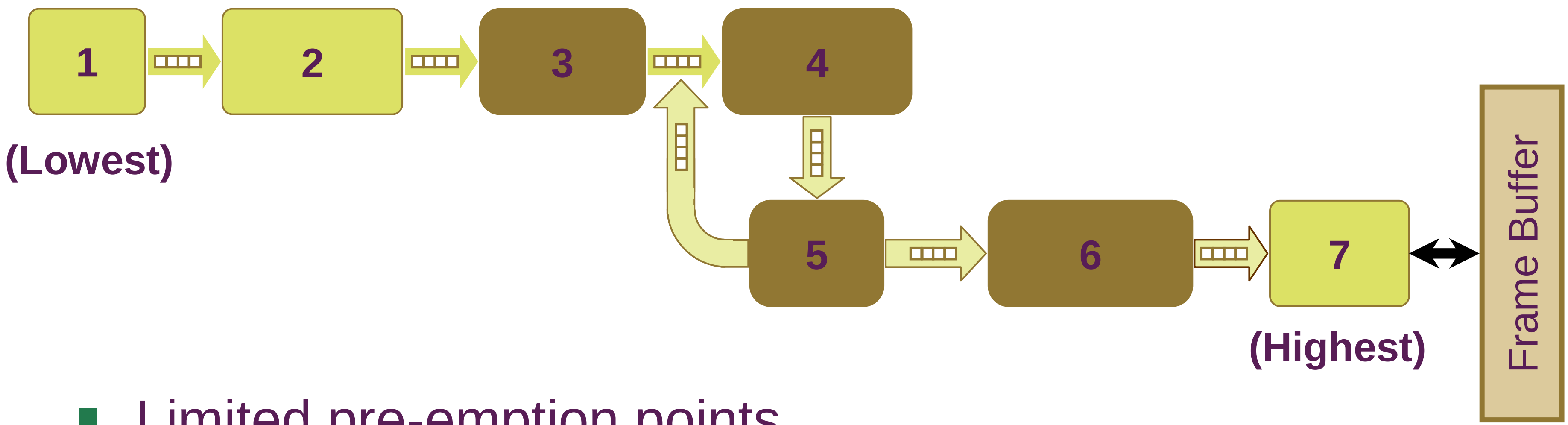
High Performance – Metrics

- Priority #1: Show scale out parallelism
  - Can GRAMPS exploit the application parallelism and fill the machine?
- Priority #2: Show ‘reasonable’ bandwidth / storage requirements for queueing
  - What is the worst case total footprint of all queues?
  - A scheduling problem: trade-off with possible parallelism

High Performance – Scheduling

Very simple static prototype scheduler (both platforms):

- Static stage priorities:



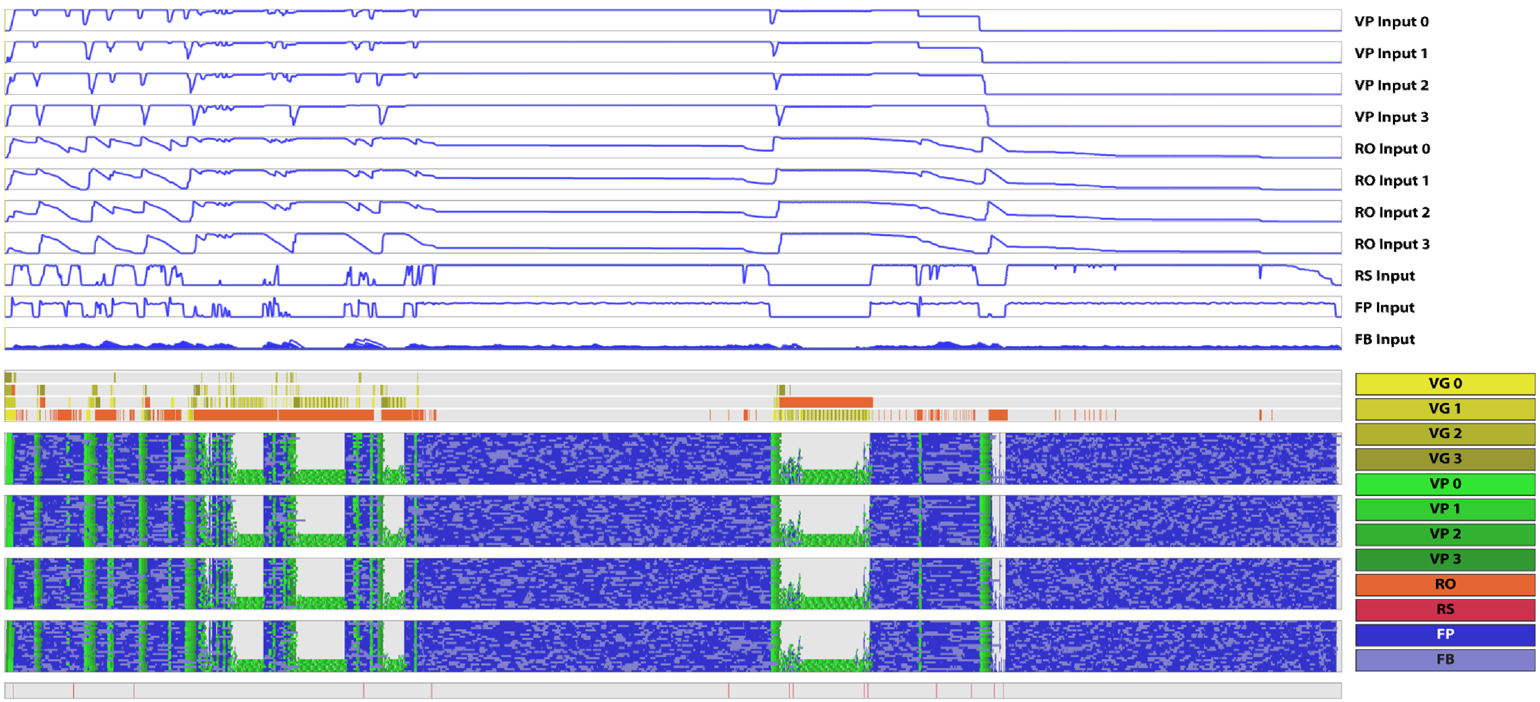
- Limited pre-emption points
- **No** dynamic weighting of current queue depths

High Performance – Results

- Three scenes x { Rasterization, Ray Tracer, Hybrid }
- Parallelism is 95+% for all but rasterized fairy (~80%).
- Queues are small: < 600KB CPU-like, < 1.5MB GPU-like
- Order costs footprint

Tunability – Understanding Performance

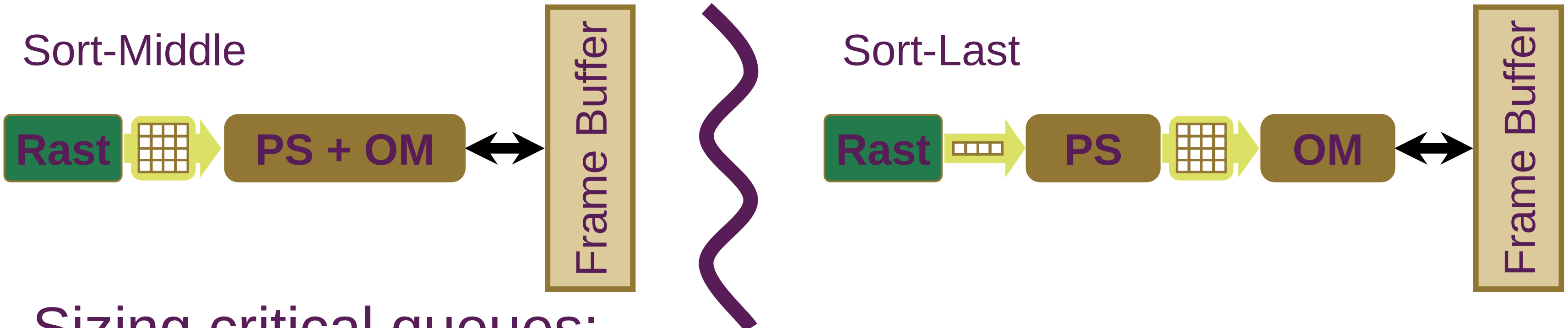
- GRAMPSviz:



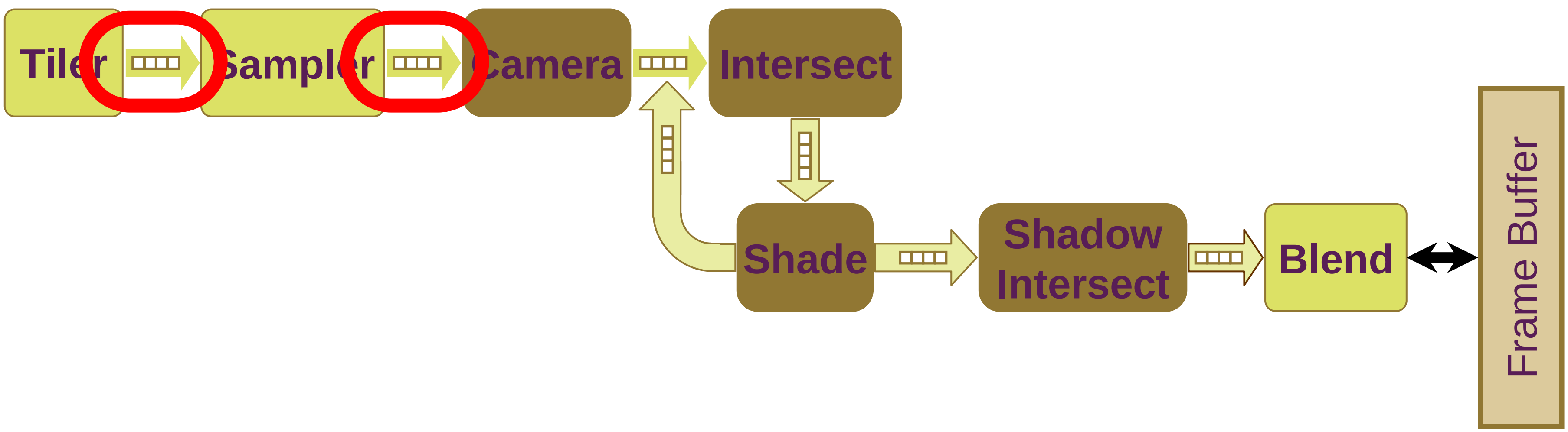
- Also: raw counters, statistics, text log of run-time activity

Tunability – Lessons Learned

- Execution Graph topology / design:



- Sizing critical queues:



Summary

- After a long era of stability, the Graphics Pipeline is undergoing rapid change.

- GRAMPS enables software-defined custom pipelines.
  - The Graphics Pipeline becomes an app
  - Prototypes show plausible performance, resource needs
  - Handles heterogeneous parallelism well
  - Applicable beyond rendering and beyond GPUs

Thank You

- Our funding agencies:
  - Stanford Pervasive Parallelism Lab
  - Department of the Army Research
  - Intel Corporation
  - Rambus Stanford Graduate Fellowship
  - Intel PhD Fellowship
  - NSF Graduate Research Fellowship
- http://graphics.stanford.edu/papers/gramps-tog/