Mio:
Fast Multipass Partitioning via Priority-Based Instruction Scheduling

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http://graphics.cs.ucdavis.edu/~lefohn/work/shadingLang/mio/

Programming for CPU

- Programming for CPU is easy
  - Focus on algorithm
  - Not on target hardware
- Compiler handles most complexities
  - Memory
  - Resource Allocation

Programming for GPU

- Programming for GPU is not easy
  - Focus on target hardware
  - Makes algorithm design hard
- Programmers must handle complexities
  - Instruction Counts
  - Register Usage
  - Multiplatform Programming

What happens when a shader is too big?

- Multipass rendering
  - Partition the shader into smaller shaders which do fit
  - Store intermediate results in texture memory, and then rerun the entire pipeline with the next partition
- Multipass rendering allows virtualization of programmable hardware resources
  - Virtualization allows programmers to abstract away the hardware resources

Multipass Partitioning Problem (MPP)

- Definition:

Given a shader, generate partitions that will fit within the available hardware resource.

Who needs virtualization?

- General Purpose GPU (GPGPU) users
  - GPGPU algorithms use the hardware in unanticipated ways.
  - These algorithms stress the GPU differently than shaders.
- Film studios such as Pixar
  - Very large, complex shaders exceed GPU limits
- Multiplatform shader development
  - Backwards compatibility for previous hardware.
  - Development for future hardware.
- OpenGL Implementations
  - "[Implementations] virtualize resources that are not easy to count."
    - OpenGl Shading Language Spec.

Goals

- New partitioning framework
  - Fits easily into existing compiler flows
- Fast algorithm
  - Targeting run-time compilers
  - $O(n \log n)$ time
- Robust
  - Shaders of arbitrary size
  - Support for different hardware
- Extensible

Mio

- Derived from the word meiosis
  - A process of cell division that produces child cells with half the number of chromosomes
  - Mio divides large programs into smaller partitioins

Outline

- Recursive Dominator Split (RDS)
- List Scheduling
- Mio: Algorithm Design
- Results
- Conclusions and Contributions

RDS and the MPP

- Eric Chan et al. 2002

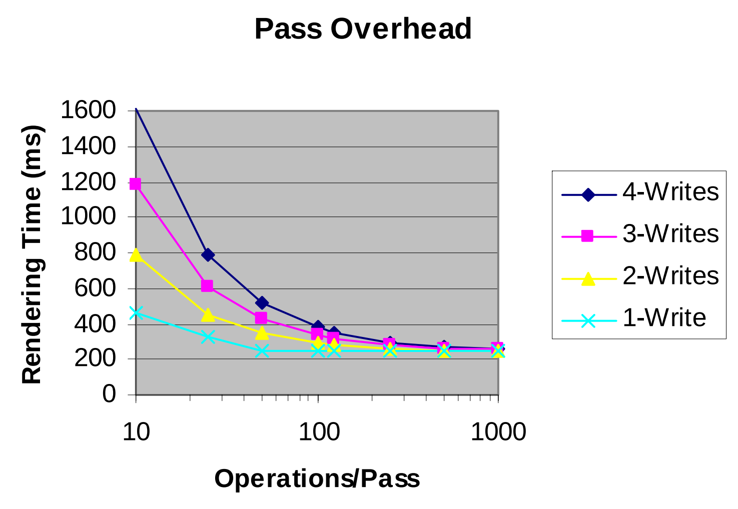
  Recursive Dominator Split (RDS)
  - $O(n^3)$ and heuristic cousin RDS_h $O(n^2)$
  - Solves MPP for hardware with differing constraints and performance characteristics

RDS limitations

- Runtime Complexity
  - $O(n^3)$ and $O(n^2)$ impractical at runtime for very large shaders
- No Support for Multiple Render Targets (MRT)
  - MRTs allow complex outputs
  - Deferred shading
  - Simplify the MPP problem
- Not very extensible
  - No control flow support

Minimization Criteria

- RDS
  - Number of passes
    - 16 instructions per pass
    - Pass overhead dominates performance
- Mio
  - Number of operations
    - 1000 instructions per pass
    - Overhead of the operations dominates performance



Runtime of a 5,000 operation shader rendered in a 512x512 quad

Save vs. Recompute

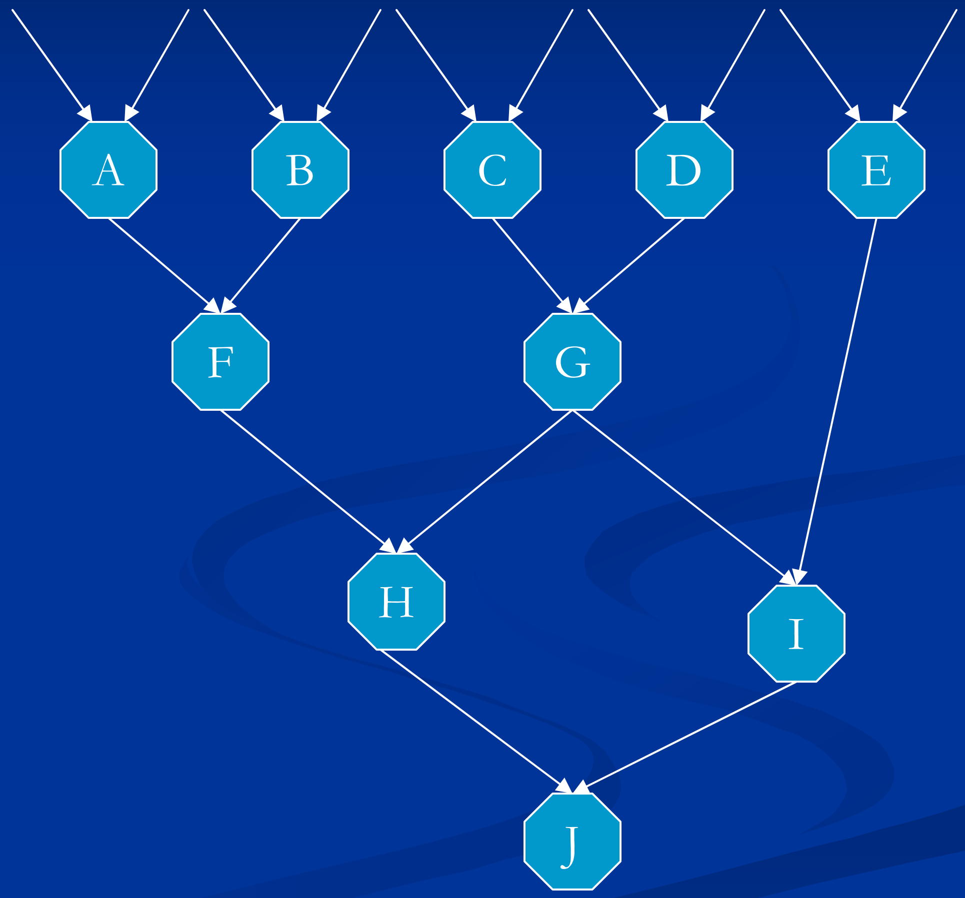
- RDS
  - Save always results in a new pass
  - Recomputation = More operations
  - Minimize passes = Recompute often
- Mio
  - Save does not always result in a new pass
  - Recomputation = More operations
  - Minimize operations = Never recompute

Multiple Render Targets

- RDS assumes a single output per pass
  - Vector or Scalar
  - Merging Recursive Dominator Split (MRDS)
    - Tim Foley et al. 2004
    - Uses MRTs to gain significant increase in shader performance
- Mio uses all available MRTs
  - Packs scalars and vectors to fill all outputs

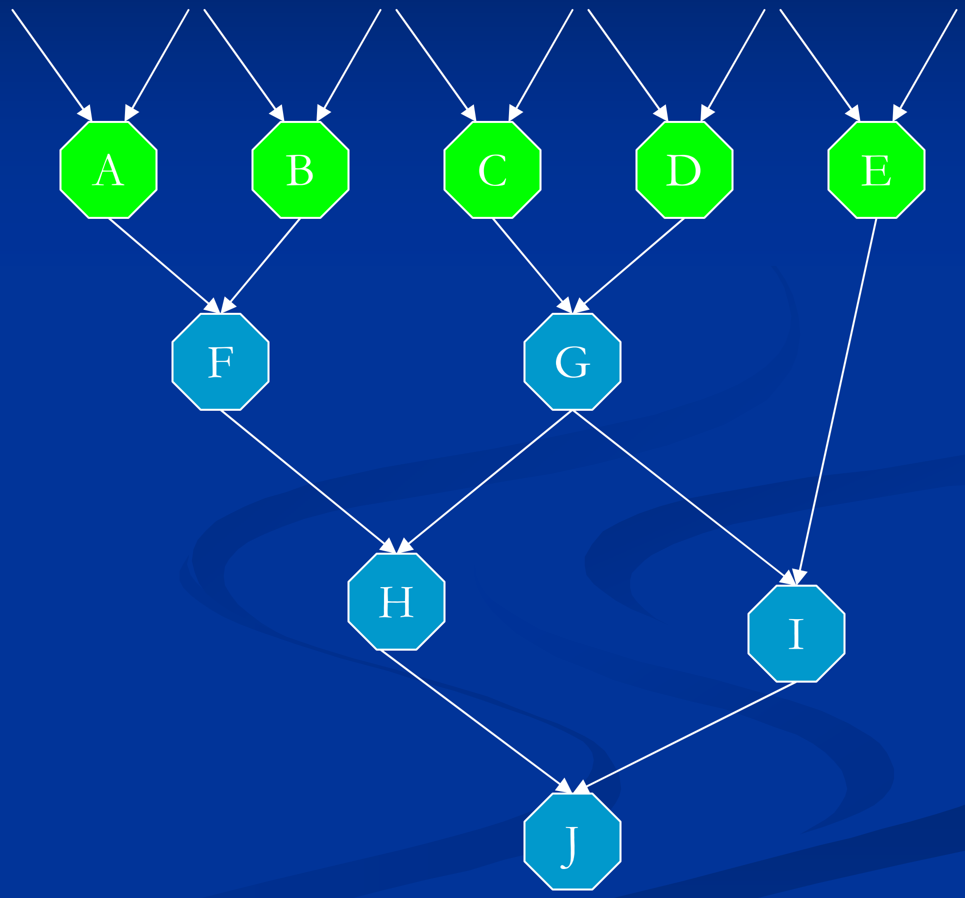
List Scheduling

- Input is a directed acyclic graph (DAG) of the dataflow within the program
- Nodes represent operations
- Edges represent ordering dependencies between operations



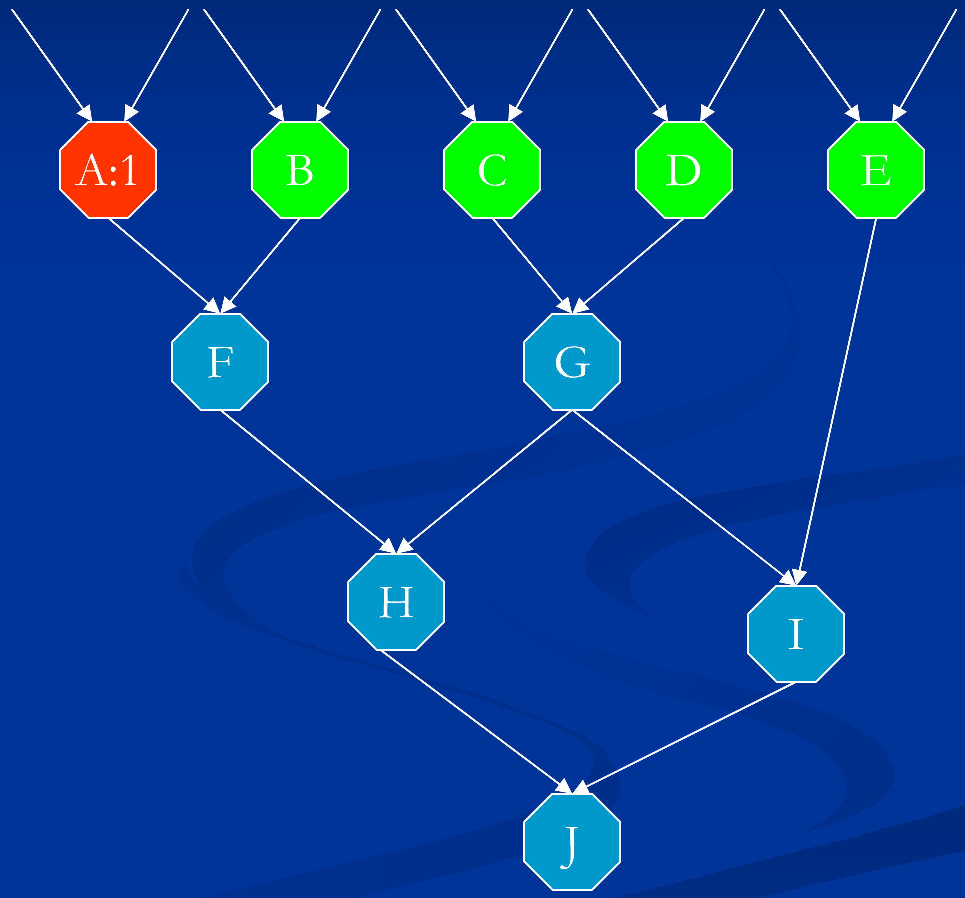
List Scheduling

- First-ready nodes are added to a ready list
- Highest priority node is selected and added to the schedule



List Scheduling

- Highest priority node is selected and added to the schedule
- Scheduled node is removed from ready list, and scheduling continues with next highest priority node



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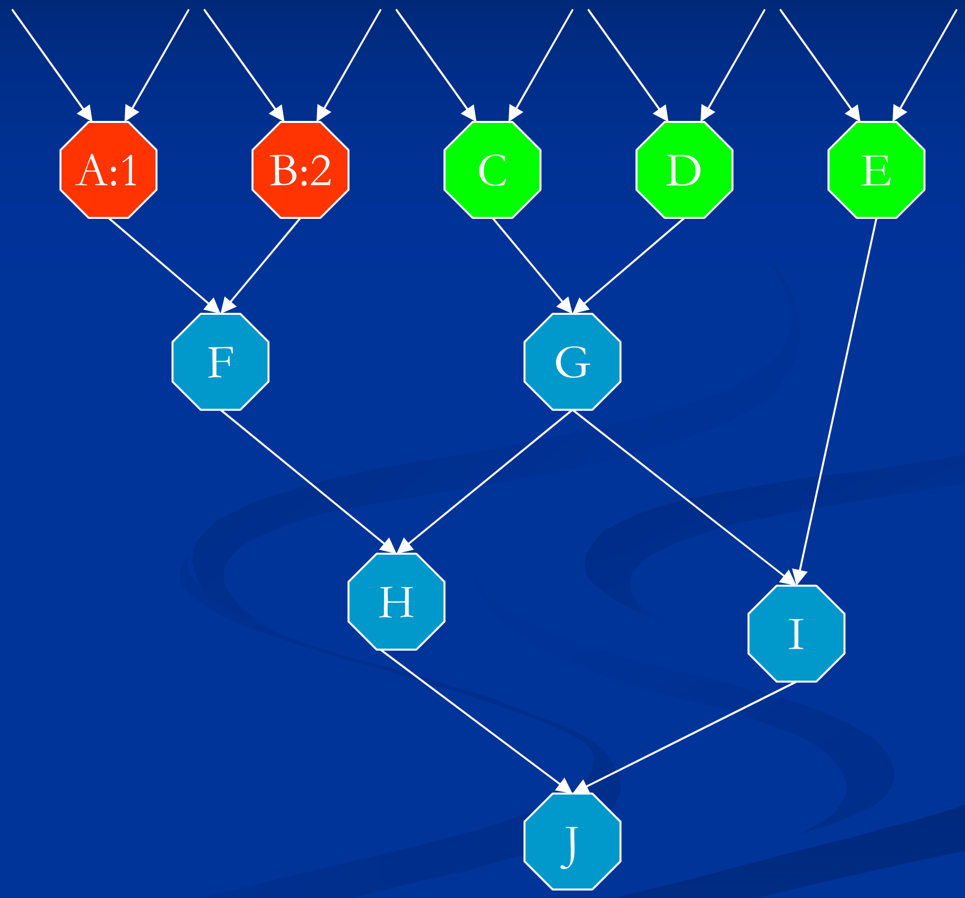
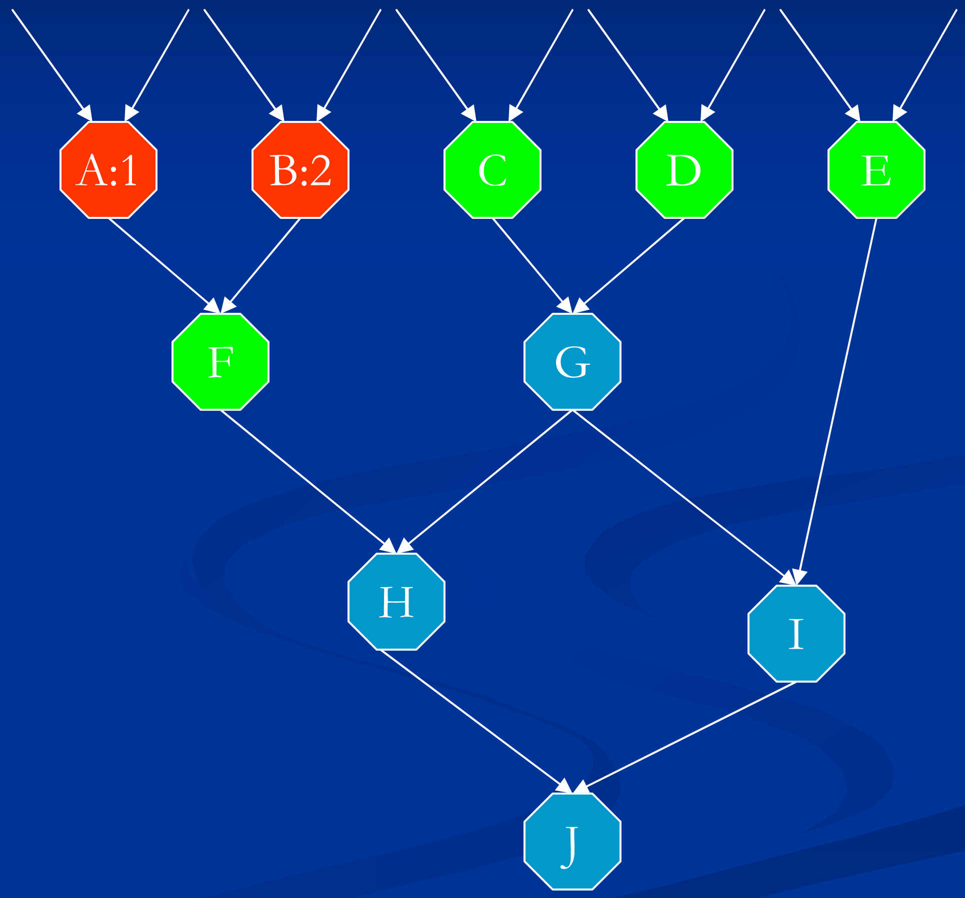


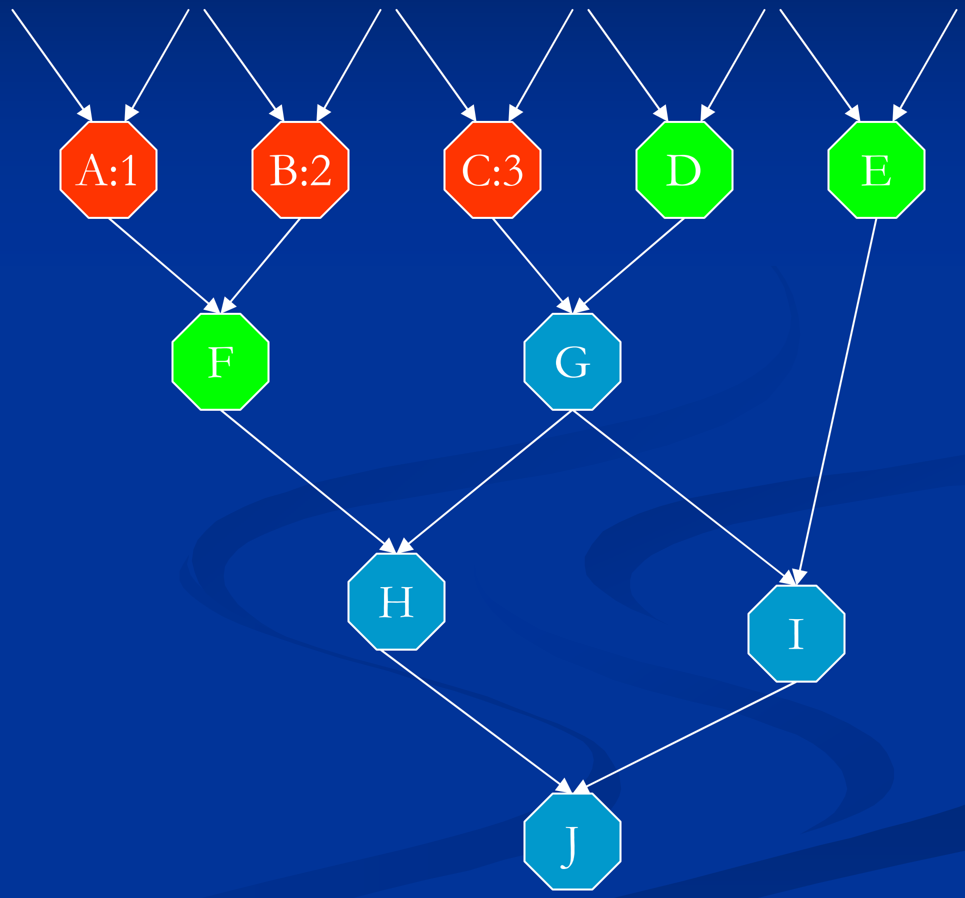
List Scheduling

- Highest priority node is selected and added to the schedule
- Scheduled node is removed from ready list, and scheduling continues with next highest priority node
- Any new ready nodes are added to ready list



List Scheduling

- Any new ready nodes are added to ready list
- Scheduling of nodes continues until all nodes are scheduled



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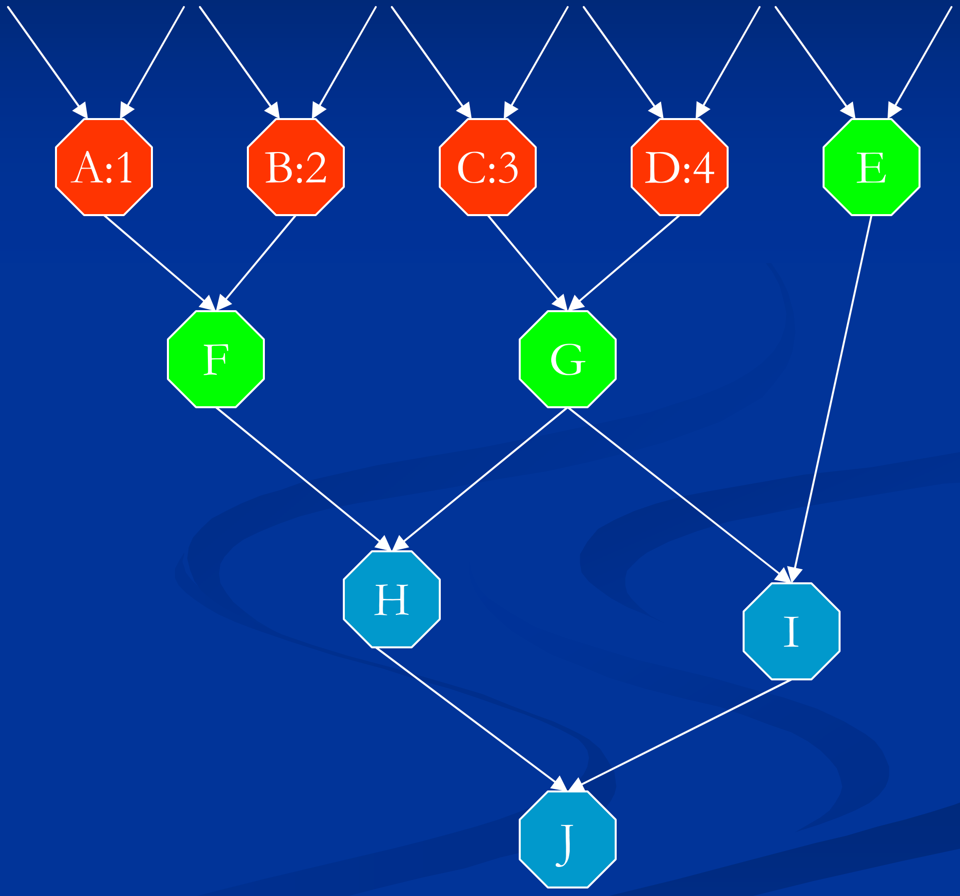

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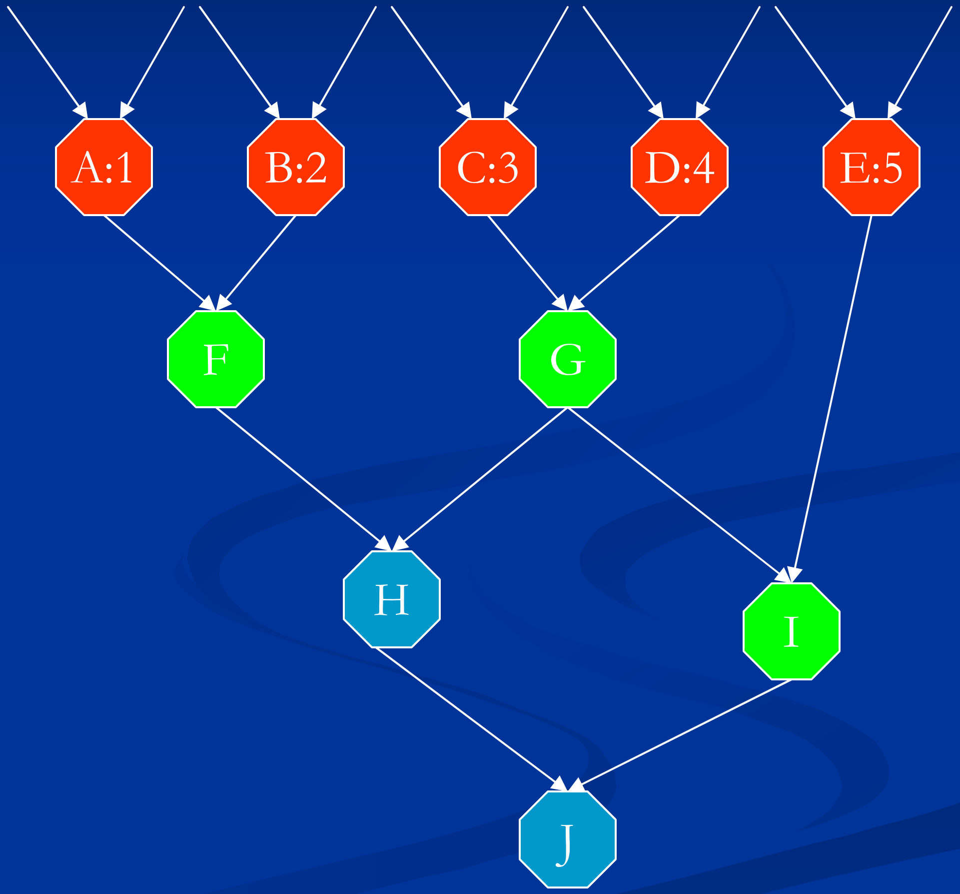

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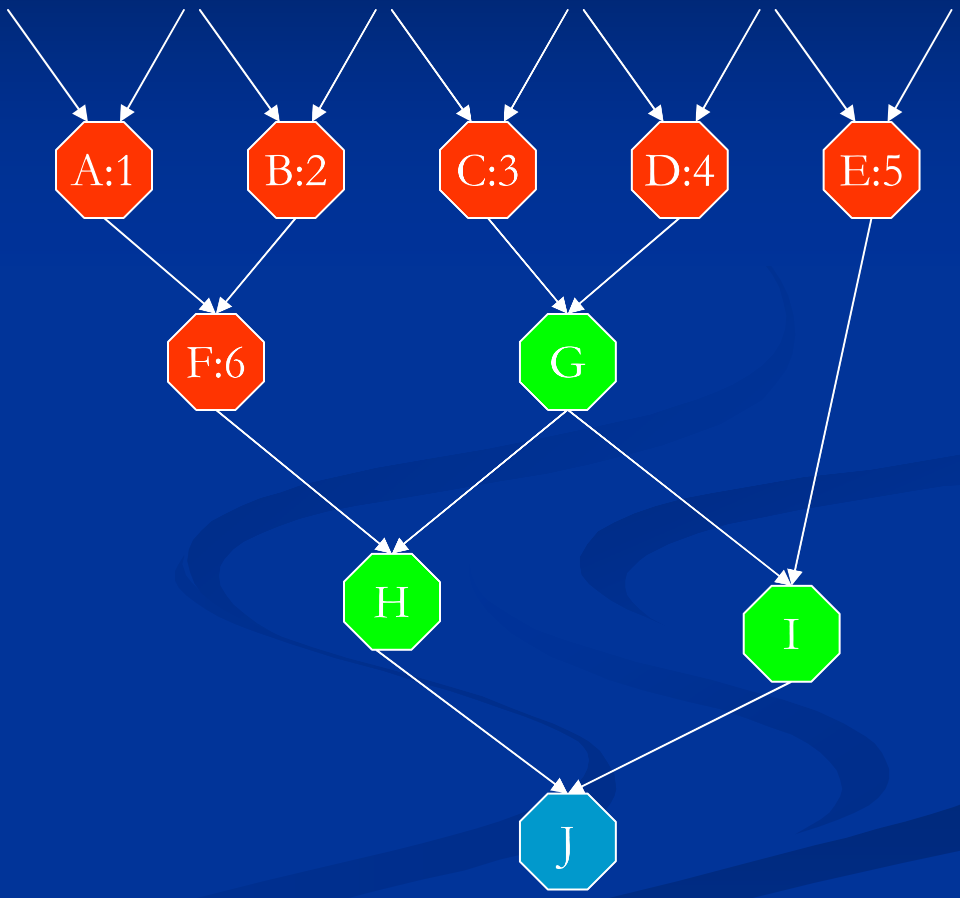

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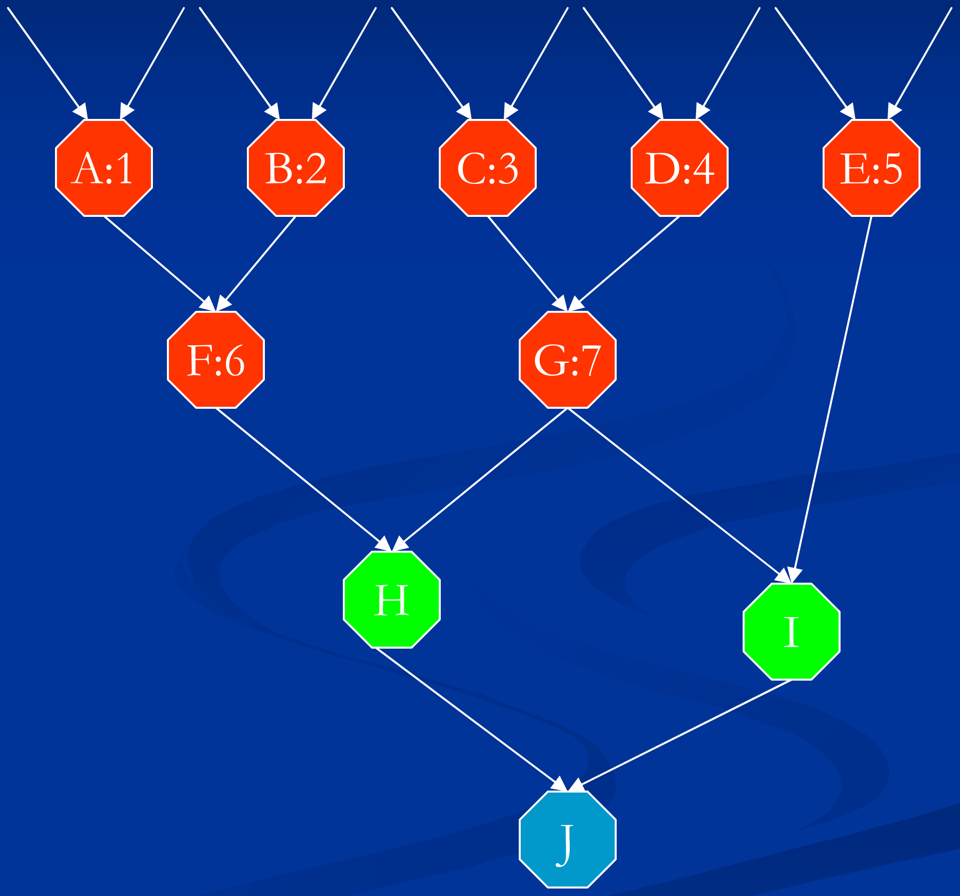

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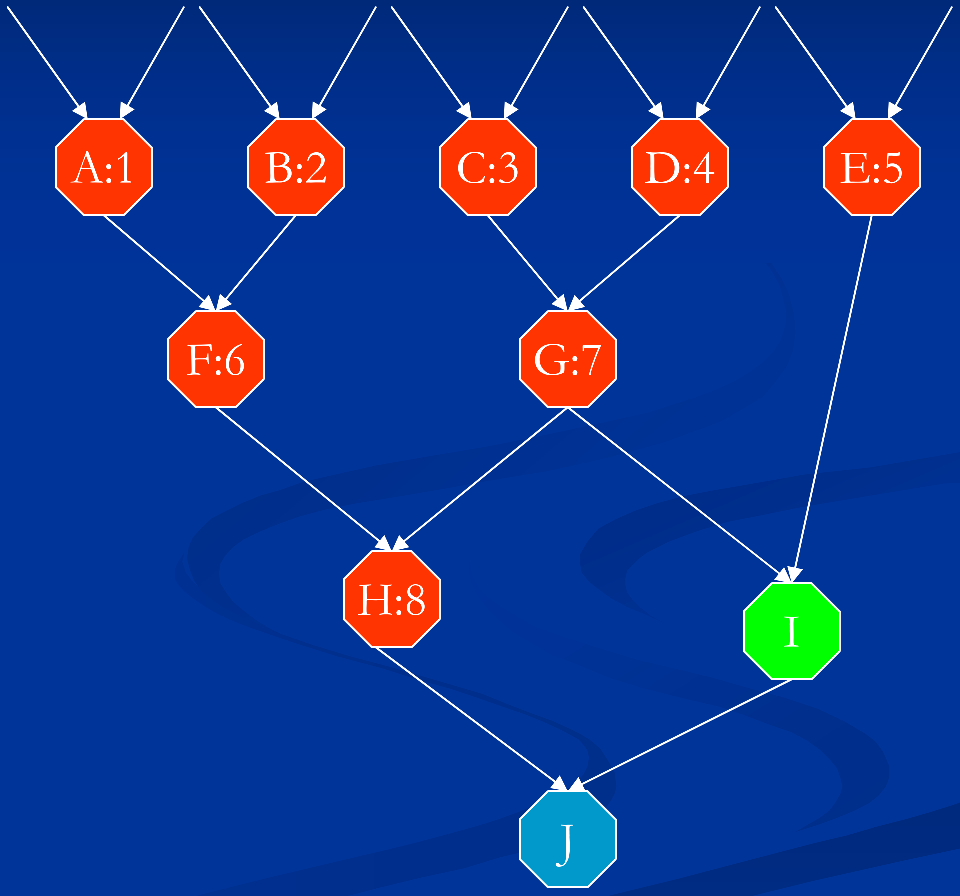

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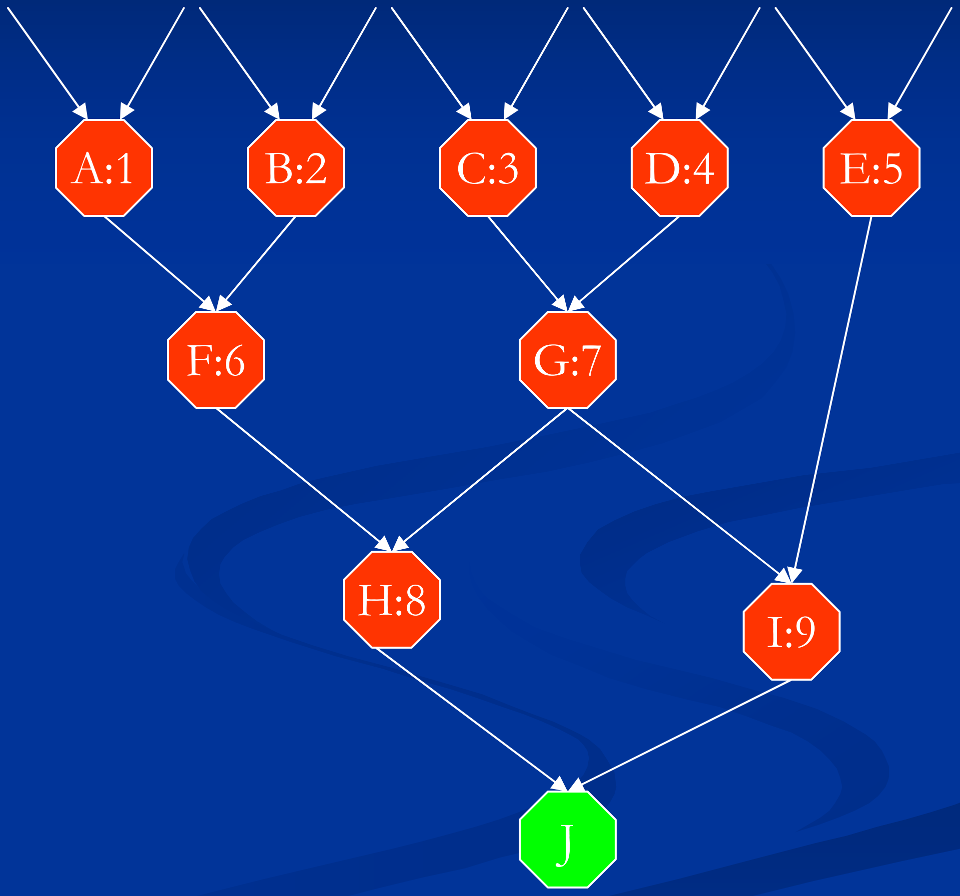

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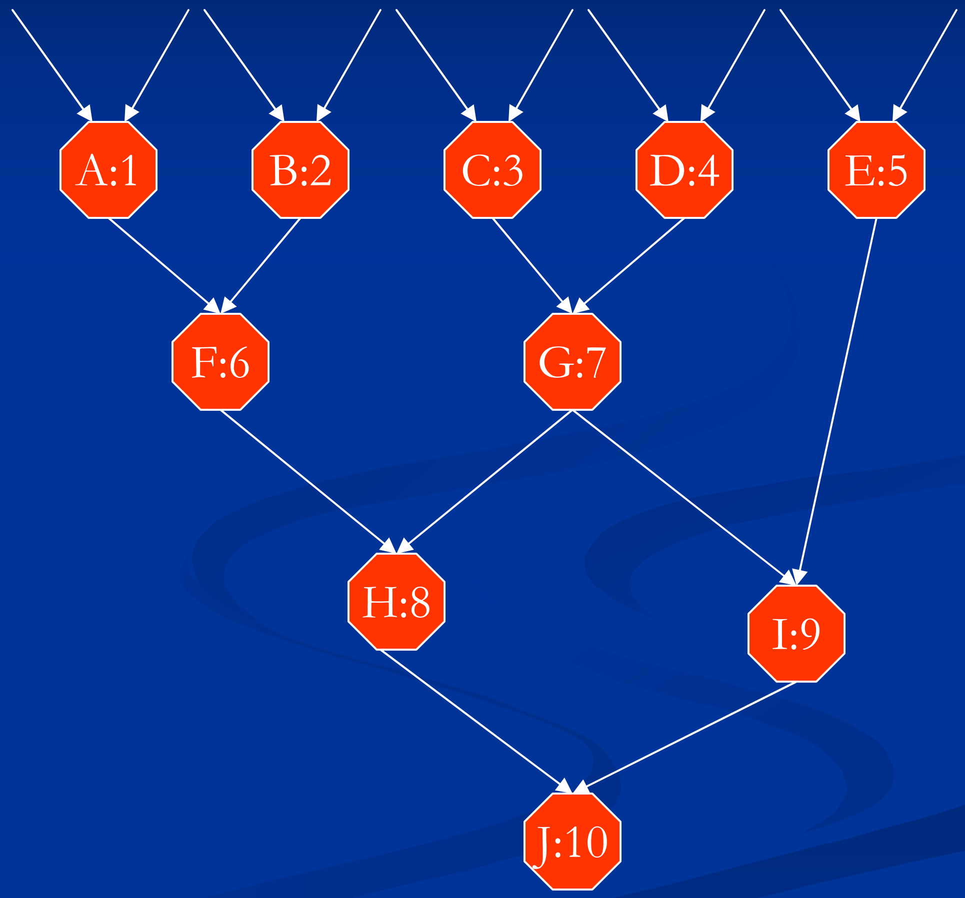


Scheduling = Partitioning

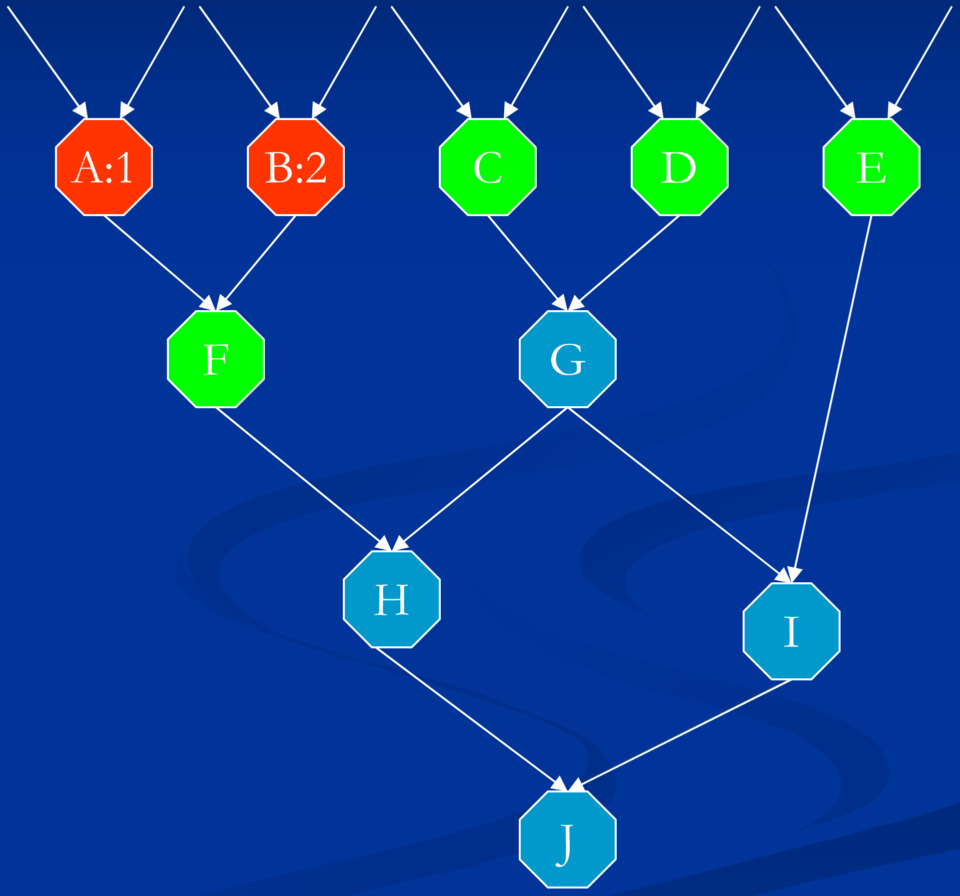
- Scheduling an operation
  - Adds that operation to the current partition
- Incremental resource estimation
  - Track resources used
  - Updated after every operation added

Mio Priorities

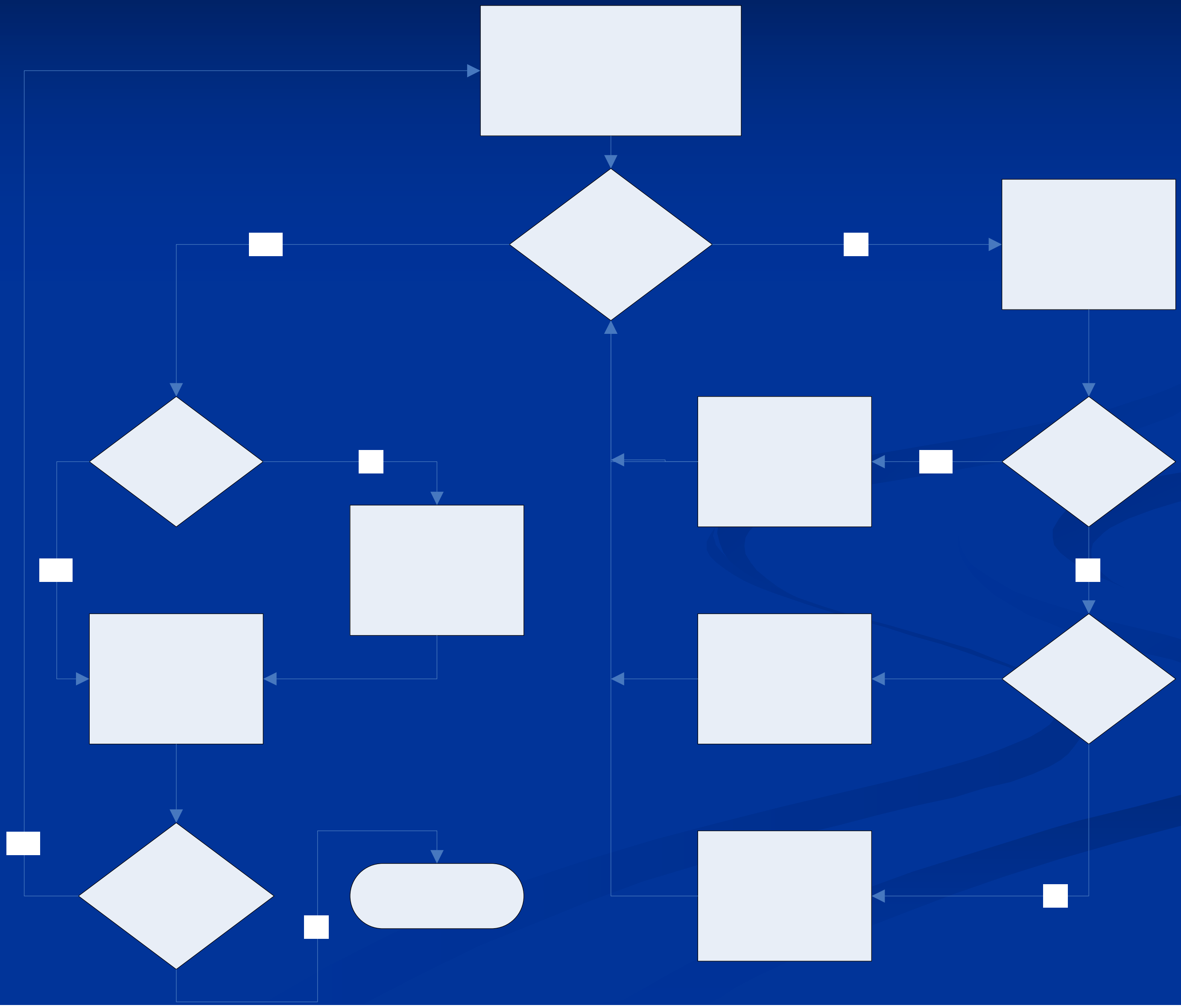
- Mio uses Sethi-Ullman Numbering
  - Produces optimal schedules for trees
    - Optimal = Minimum register pressure
    - Good Heuristic for DAGs
  - Generates deep not wide
    - Wide traversals cause extra register pressure
    - Deep traversals minimize register pressure

Deep Not Wide

- Scheduling C cause 3 intermediate results
- Scheduling F results in only 1 intermediate result
- Intermediate Results = MRTs



Mio List Scheduling



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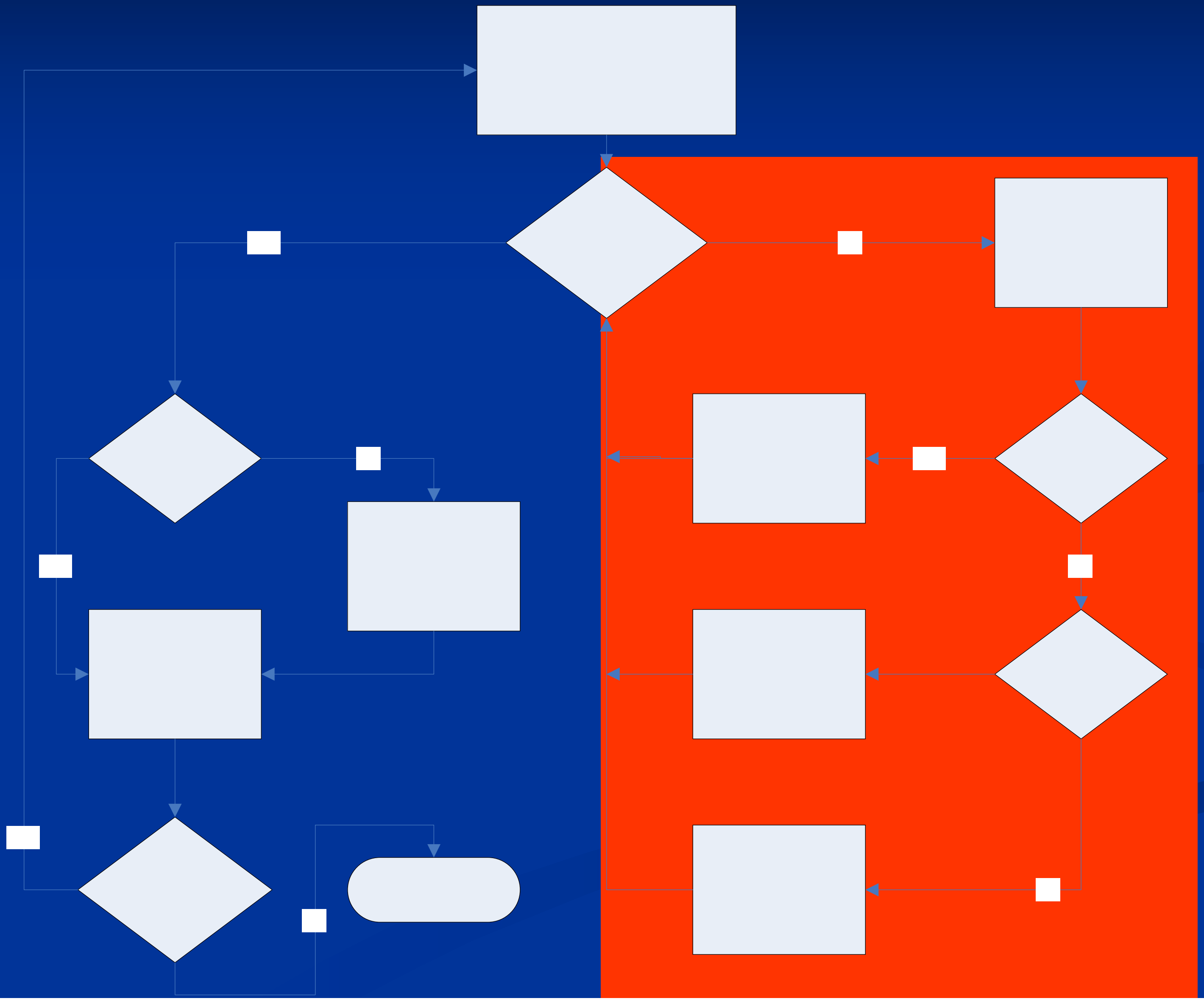

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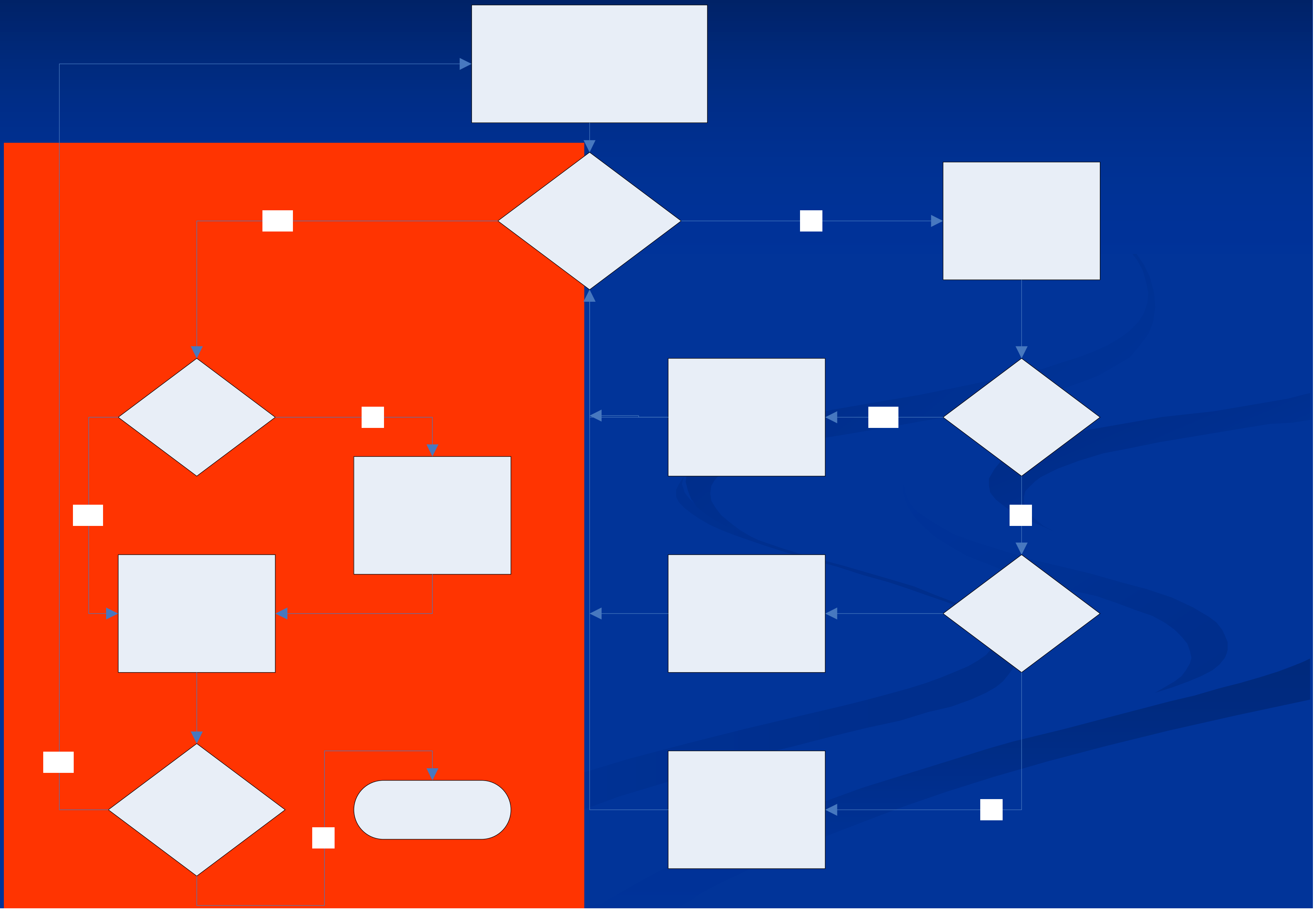
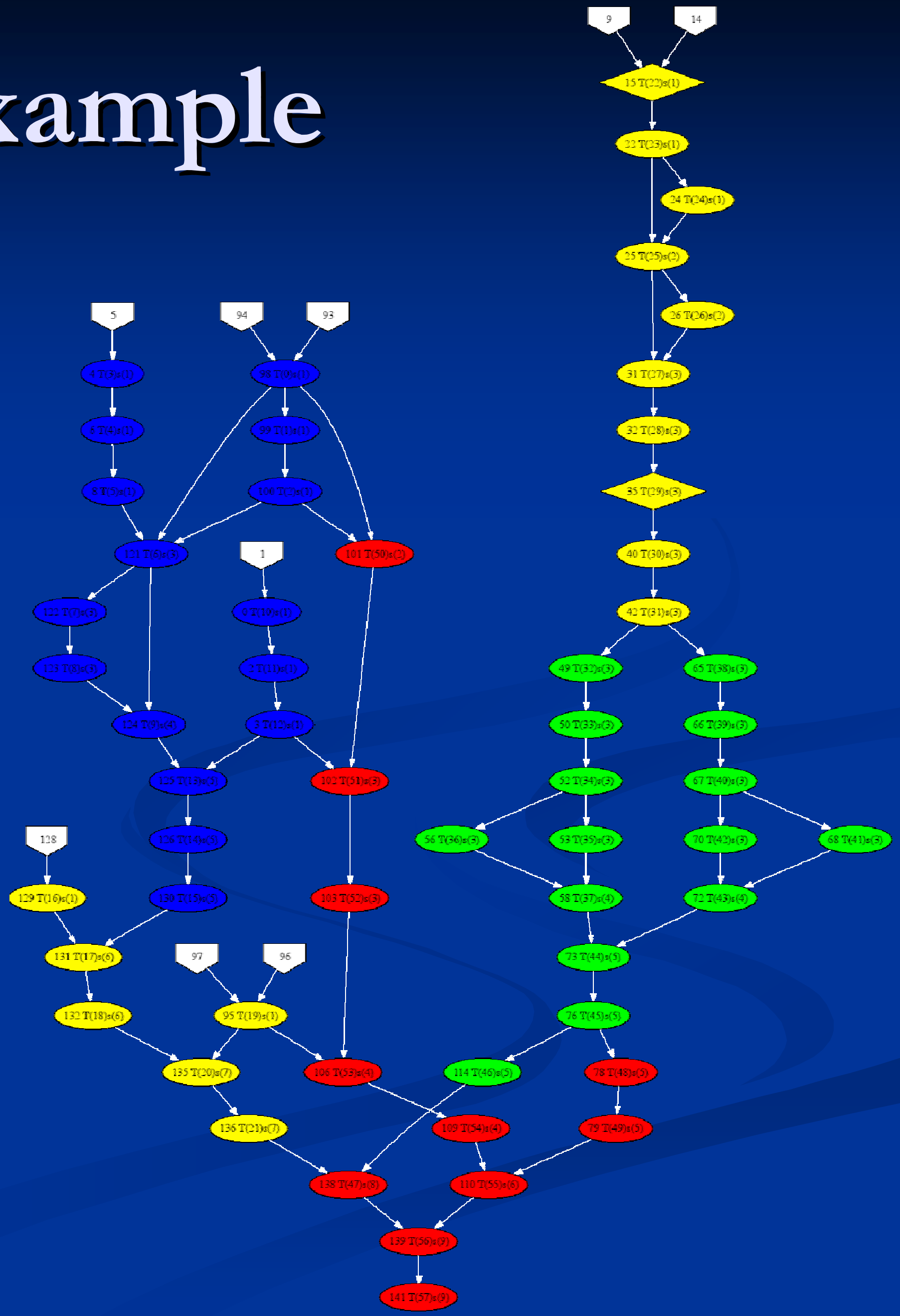


Mio Example

- Wood Shader
    - 57 Operations
    - Limited 16 operations per pass
    - 4 outputs



Experimental Setup

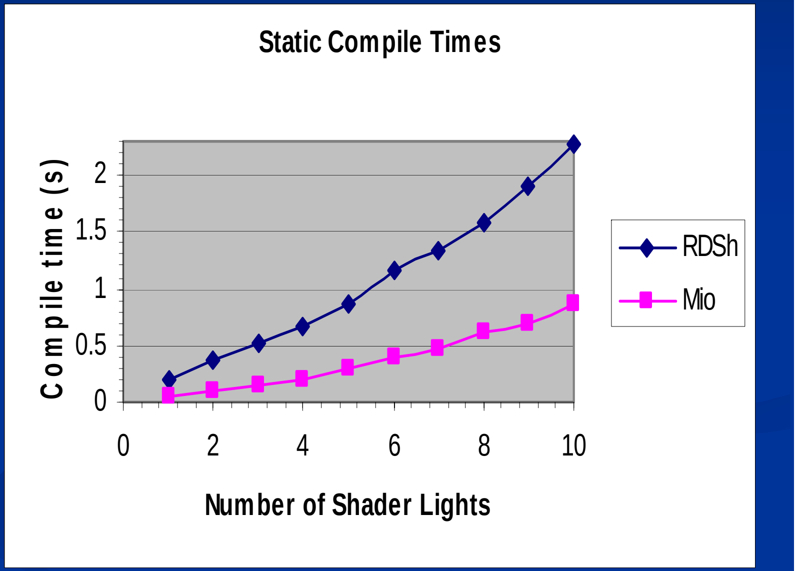
- Mio was integrated in ATI's prototype Ashli compiler. Ashli implements RDS_h which was used for comparisons.
- Measure performance with a variety of Renderman shader programs.
- The runtime tests were performed on a pre-release GeForce 6800 (NV40) graphics card.
  - Since most of the experimental shaders fit into a single pass on the NV40 we compiled the shaders with ATI 9800 limits.

Results

- Compiler Performance
- Overall Quality of the Partitions
- Shader Performance

Results

- Compiler Performance
  - Mio has superior theoretical compile-time performance.
  - Experimentation also shows that Mio has better compile-time performance scaling over a number of large shaders.
- Overall Quality of the Partitions
- Shader Performance



Results

- Compiler Performance
- Overall Quality of the Partitions
  - Fewer total operations
  - More texture operations
  - Equivalent number of passes
- Shader Performance

Results

- Compiler Performance
- Overall Quality of the Partitions
- Shader Performance
  - For small shaders with few partitions, we found equal performance between RDS and Mio.
  - However for larger shaders with more partitions, the memory footprint and texture cache thrashing caused a substantial hit to Mio performance.
    - The passes generated by Mio were not optimized to reduce intermediate buffers
    - Optimizations still needed

Future Work

- Development of open source Mio partitioner
  - Open source code will be available for academic and non-commercial use.
- Alternate priority schemes
  - Explore the tradeoffs between compile time and partition quality within Mio framework.
- Support for control flow
  - We are currently extending the Mio algorithm to handle shaders that include control flow.

Conclusion and Contributions

- Characterization of MPP in a list-scheduling frame work
  - Easily integrated into code generation
  - Supports multiple render targets
  - Well suited for more complex shaders which include flow control
- Development of an efficient priority scheme
  - Fast compile time
  - Comparable partitions to RDS

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