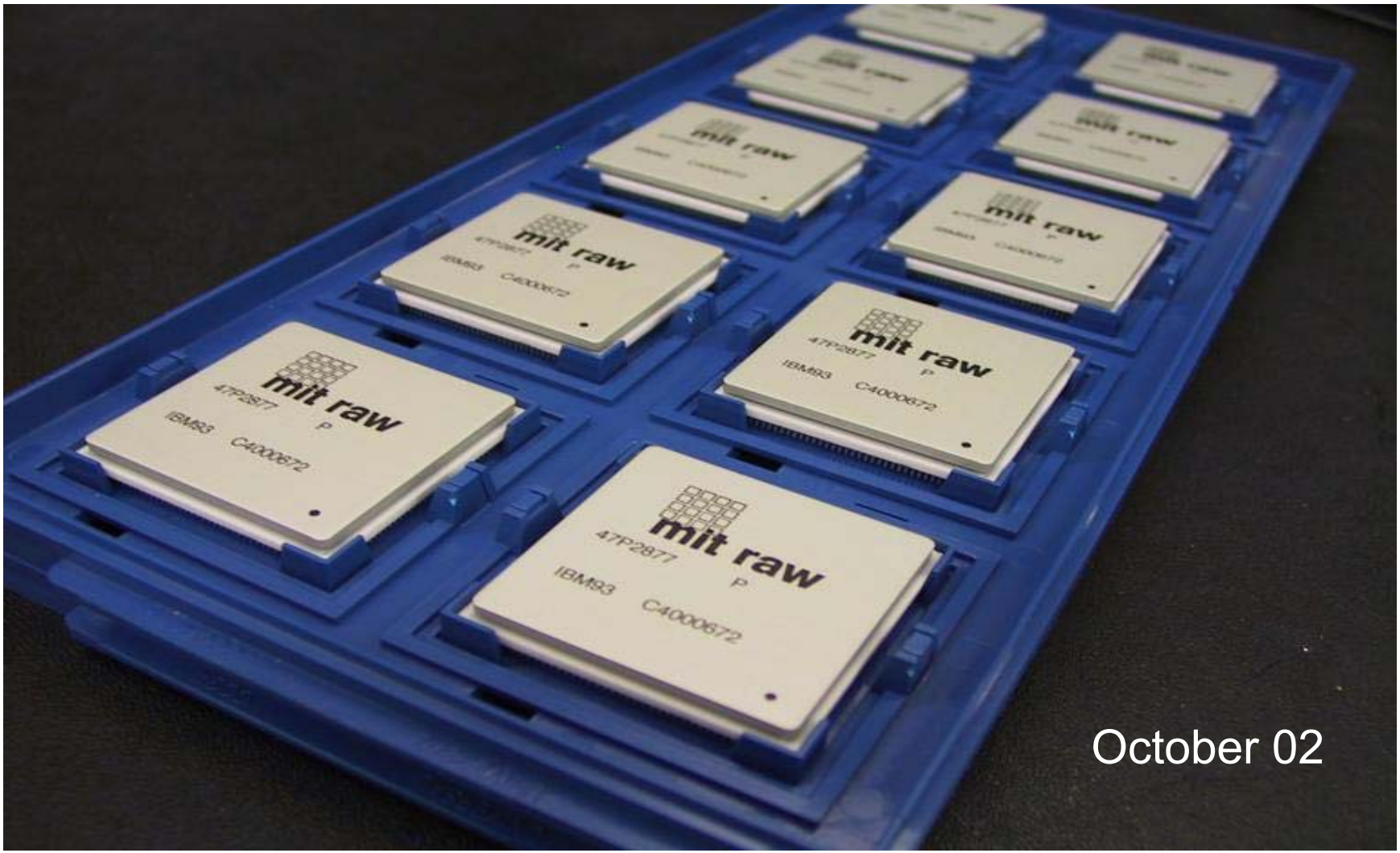
6.189 Multicore Programming Primer, January (IAP) 2007

6.189 IAP 2007

Lecture 17

The Raw Experience

Raw Chips



Raw Microprocessor

- Tiled microprocessor with point-to-point pipelined scalar operand network
- Each tiles is 4 mm x 4mm
  - MIPS-style compute processor
    - Single-issue 8-stage pipe
    - 32b FPU
    - 32K D Cache, I Cache
- 4 on-chip mesh networks
  - Two for operands
  - One for cache misses, I/O
  - One for message passing

Raw Microprocessor

- 16 tiles (16 issue)
- 180 nm ASIC (IBM SA-27E)
- ~100 million transistors
- 1 million gates

- 3-4 years of development
- 1.5 years of testing
- 200K lines of test code

- Core Frequency:
  - 425 MHz @ 1.8 V
  - 500 MHz @ 2.2 V

- Frequency competitive with IBM-implemented PowerPCs in same process

- 18W average power

One Cycle in the Life of a Tiled Processor

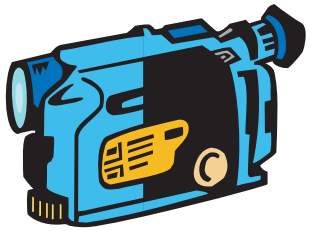
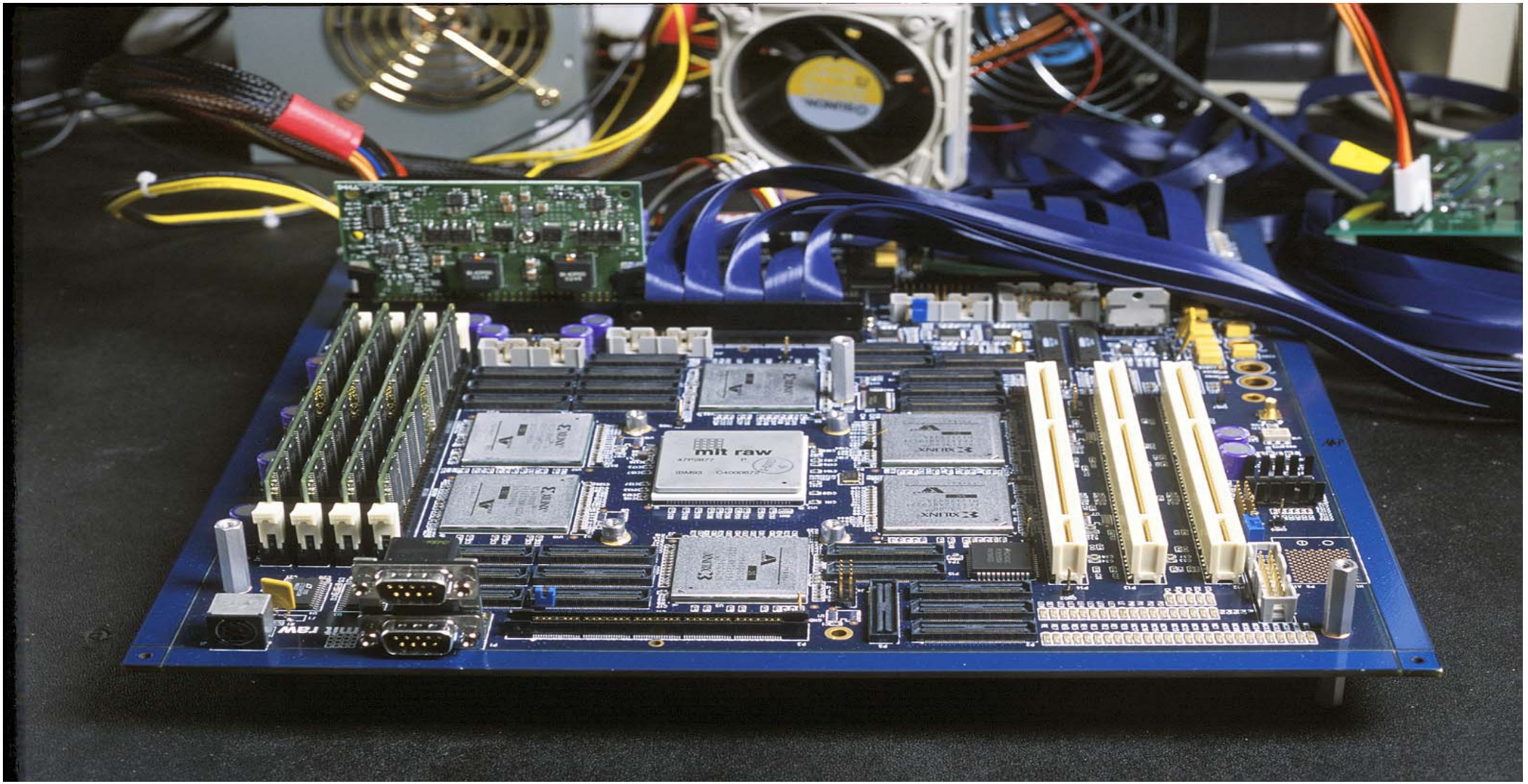


Image by MIT OCW.

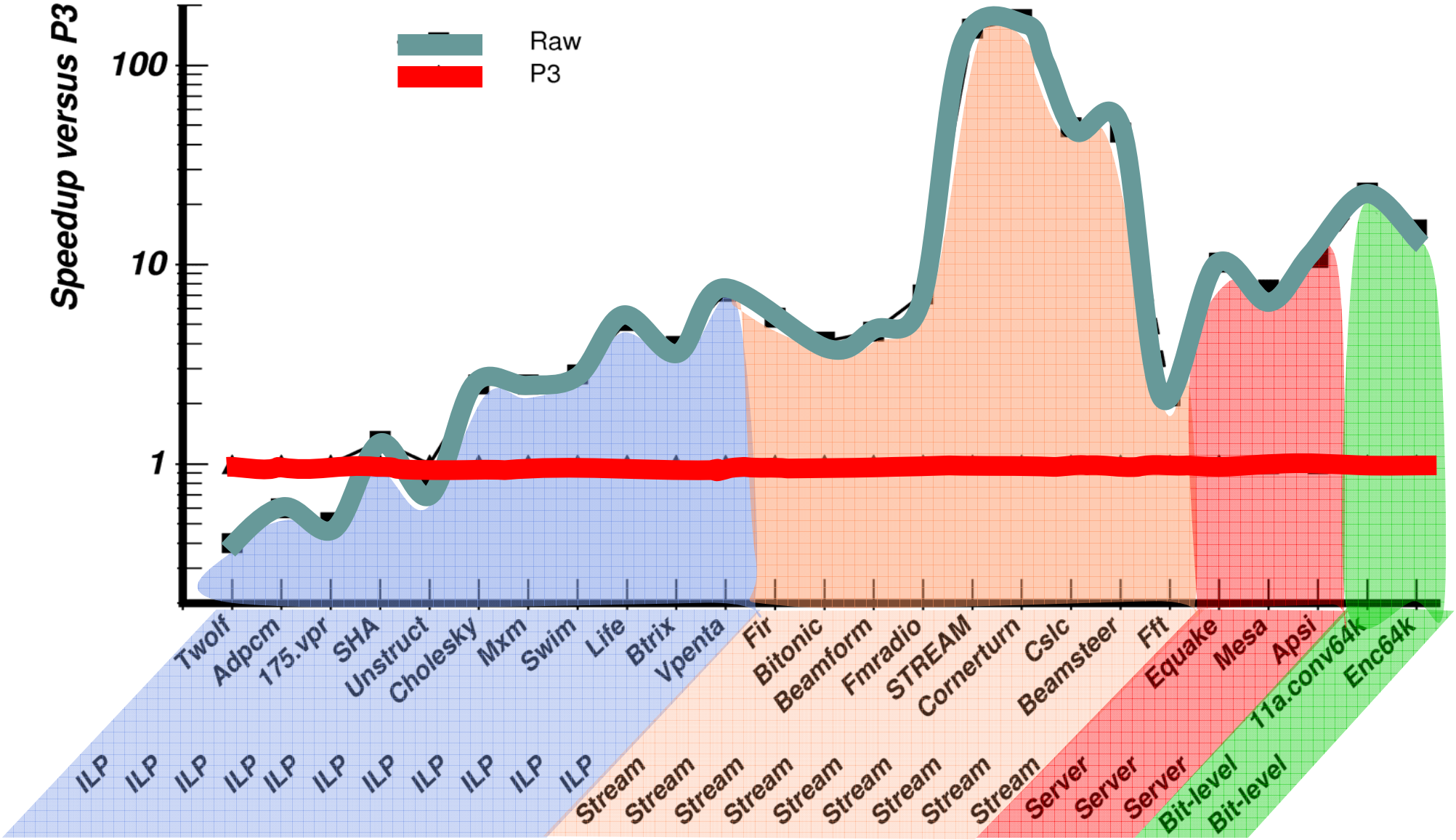
Image by MIT OCW.

- Application uses as many tiles as needed to exploit its parallelism

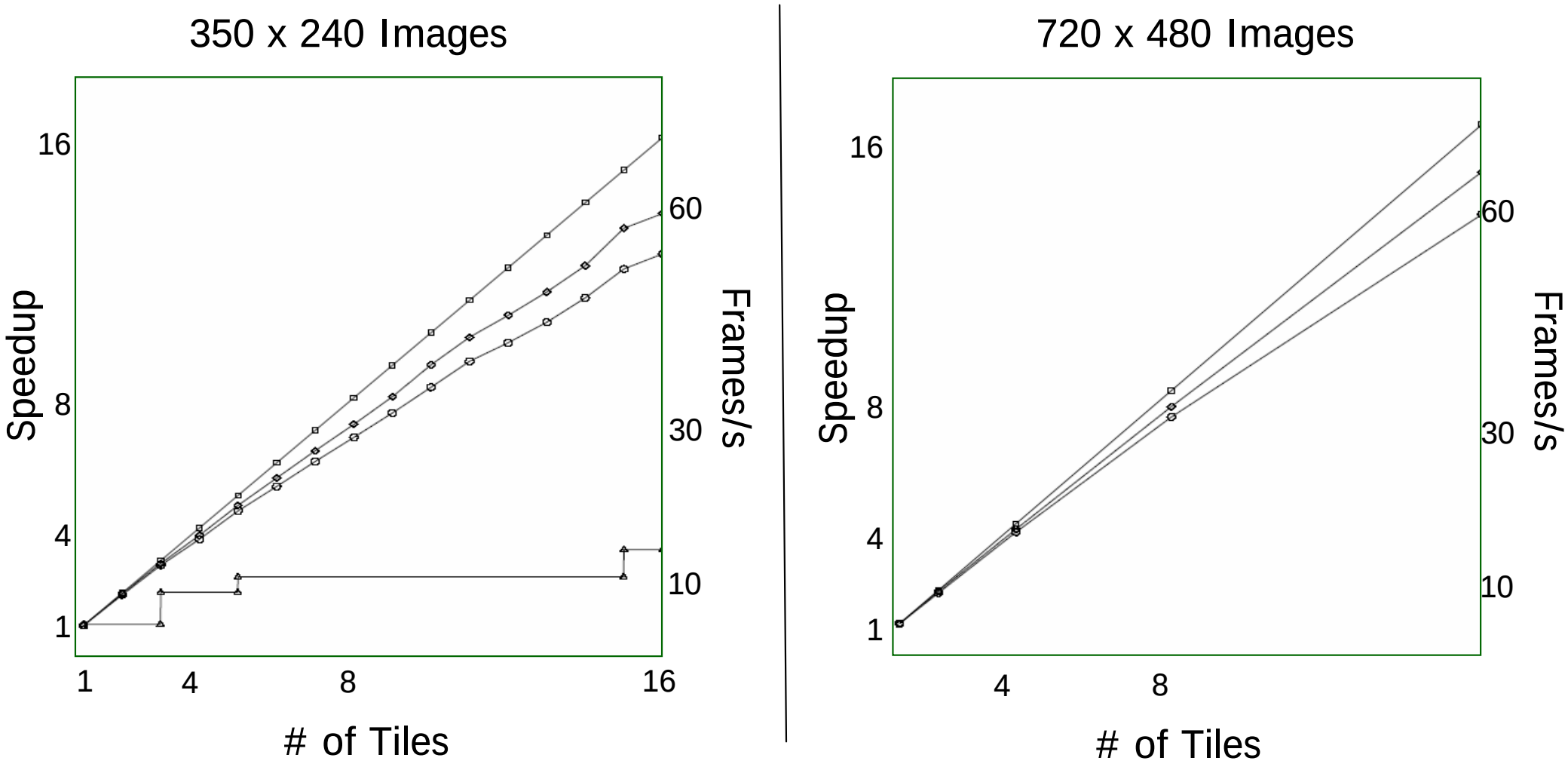
Raw Motherboard



Raw in Action



MPEG-2 Encoder Performance



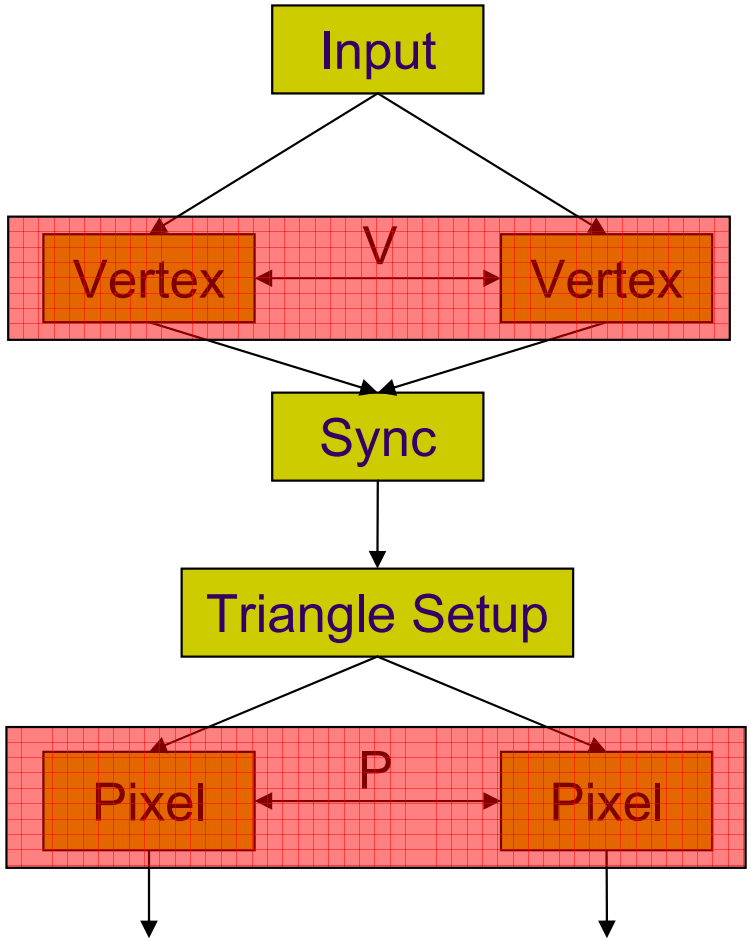
- Square – Linear speedup
- Diamond – Hand-optimized, slice parallel implementation
- Circle – Slice parallel implementation
- Triangle – Baseline macroblock parallel implementation

MPEG-2 Encoder Performance

# Tiles	Encoding Rate (frames/s) 352 x 240	640 x 480	720 x 480
1	4.30	1.14	1.00
2	8.48	2.24	1.97
4	16.18	4.45	3.84
8	30.82	8.69	7.52
16	58.65	16.74	14.57
32	103*		30*
64	158*		51.90

* Estimated data rates

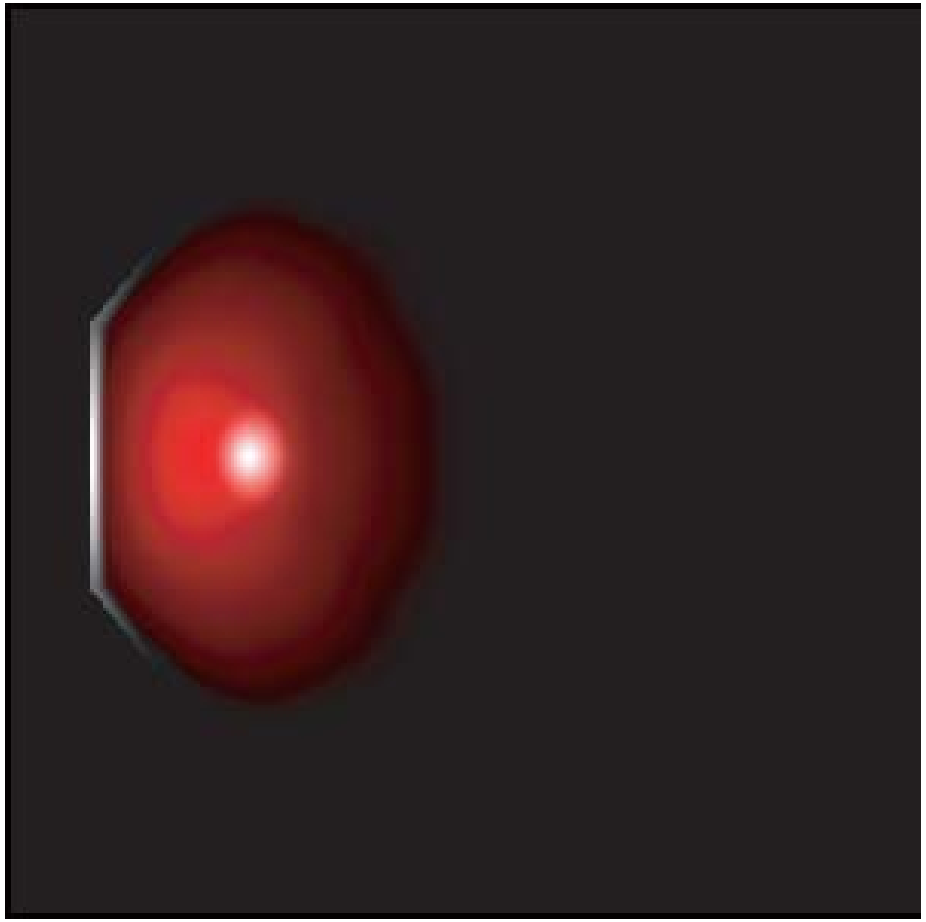
Programmable Graphics Pipeline



simplified graphics pipeline

Phong Shading

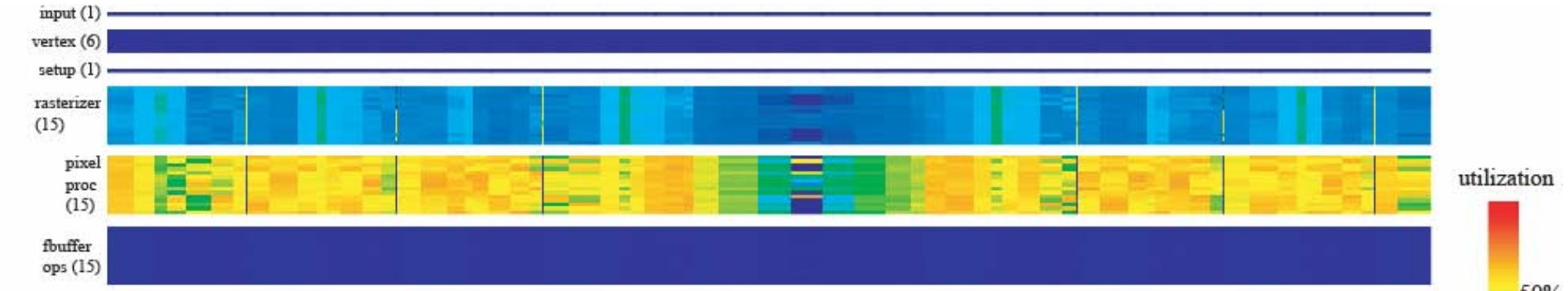
- Per-pixel phong-shaded polyhedron
- 162 vertices, 1 light



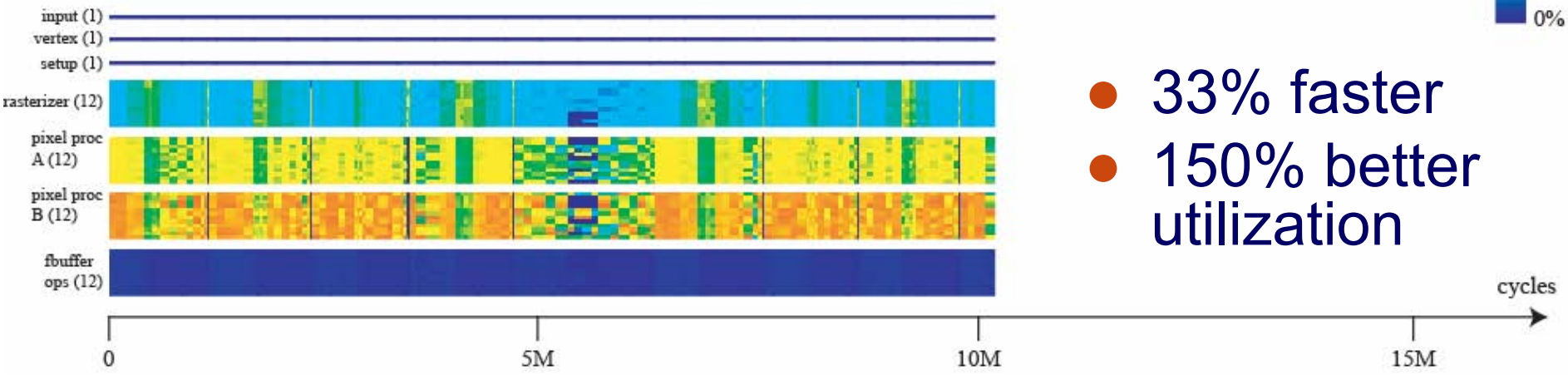
Output, rendered using Raw simulator

Phong Shading (64-tiles)

Fixed pipeline



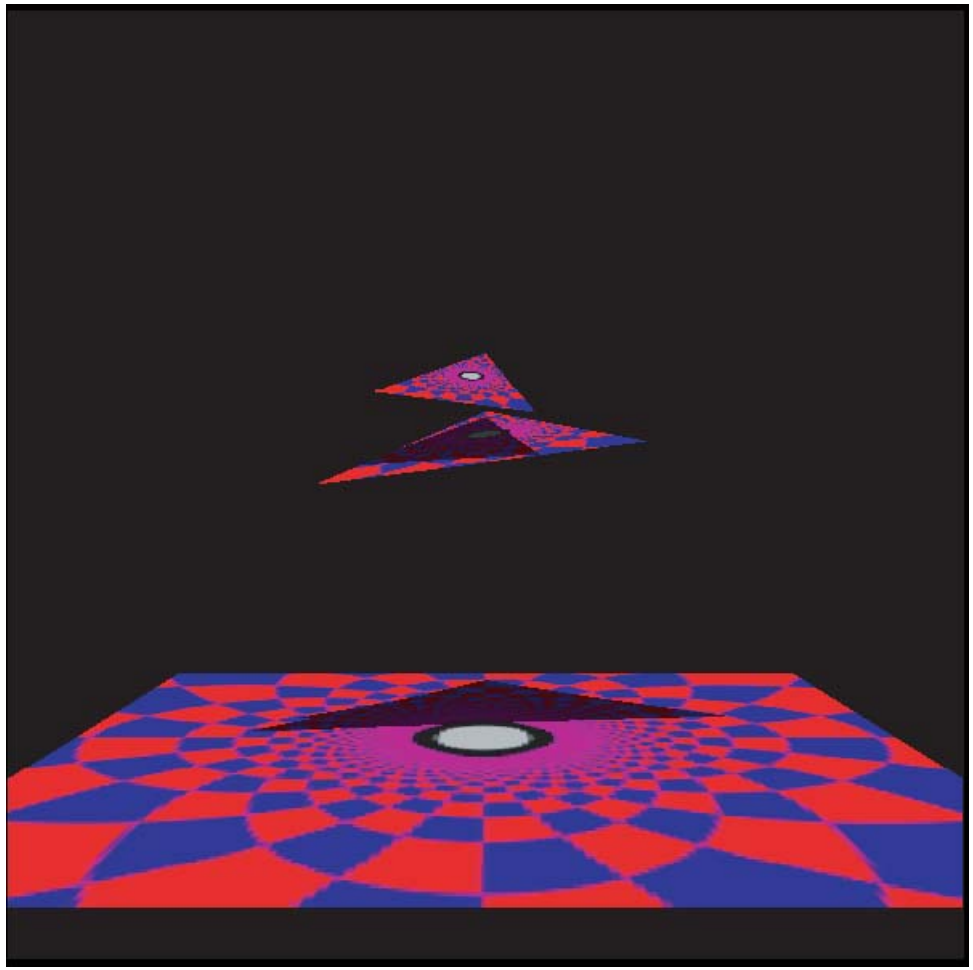
Reconfigurable pipeline



- 33% faster
- 150% better utilization

Shadow Volumes

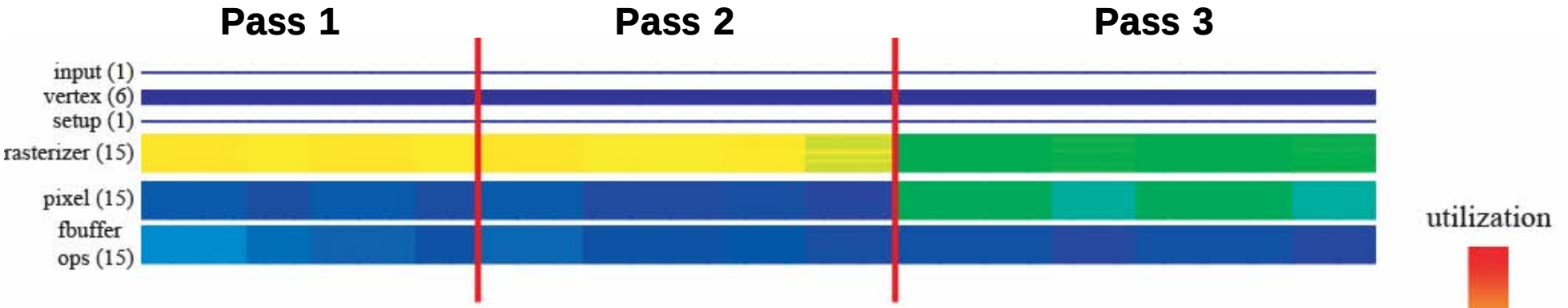
- 4 textured triangles
- 1 point light
- Rendered in 3 passes



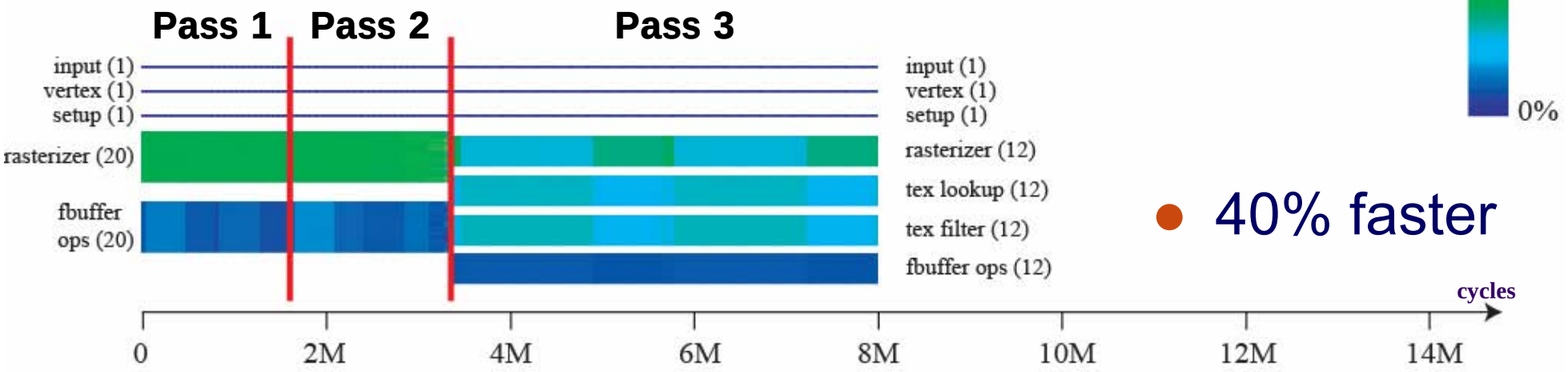
Output, rendered using Raw simulator

Shadow Volumes (64-tiles)

Fixed pipeline

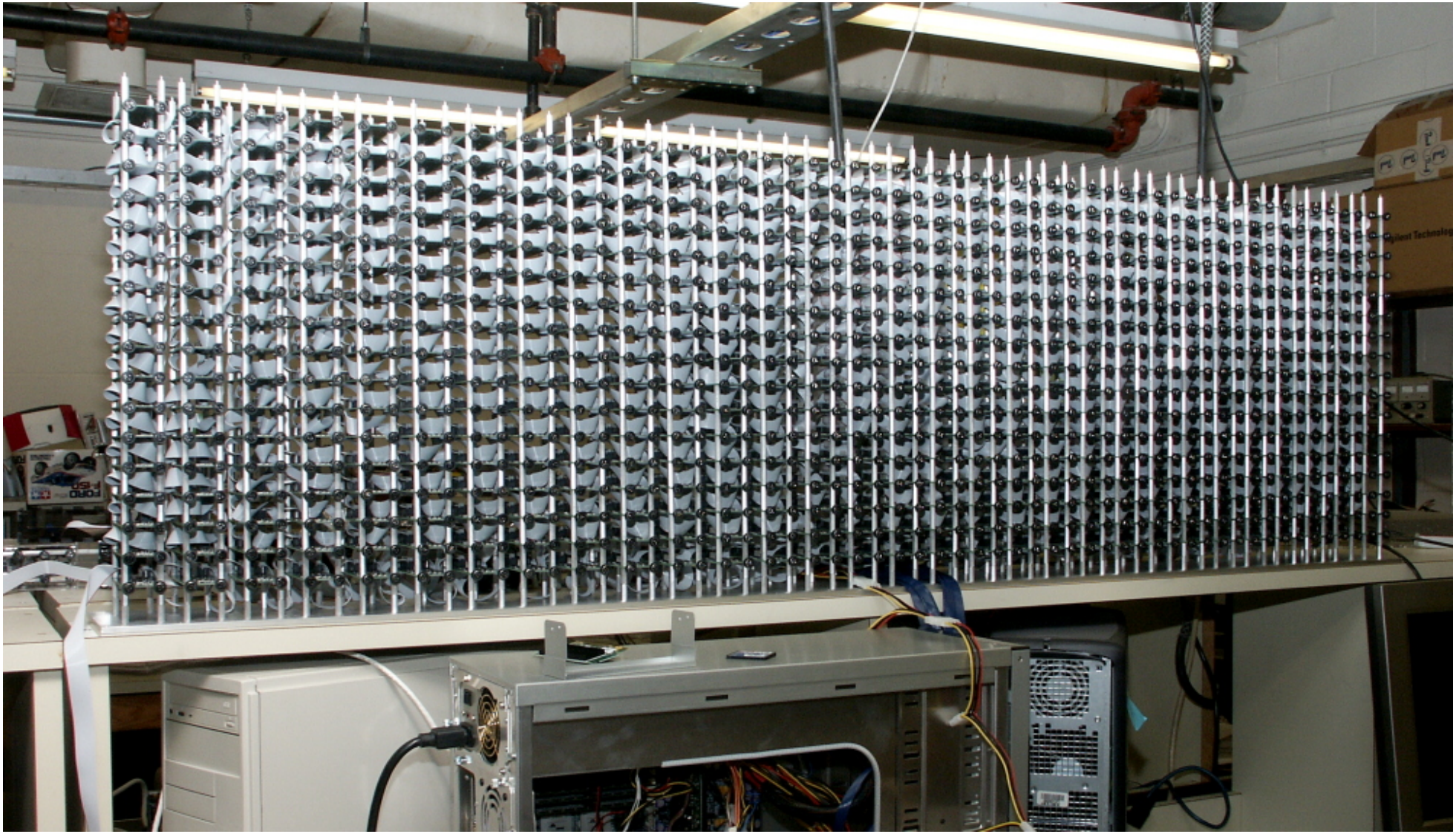


Reconfigurable pipeline

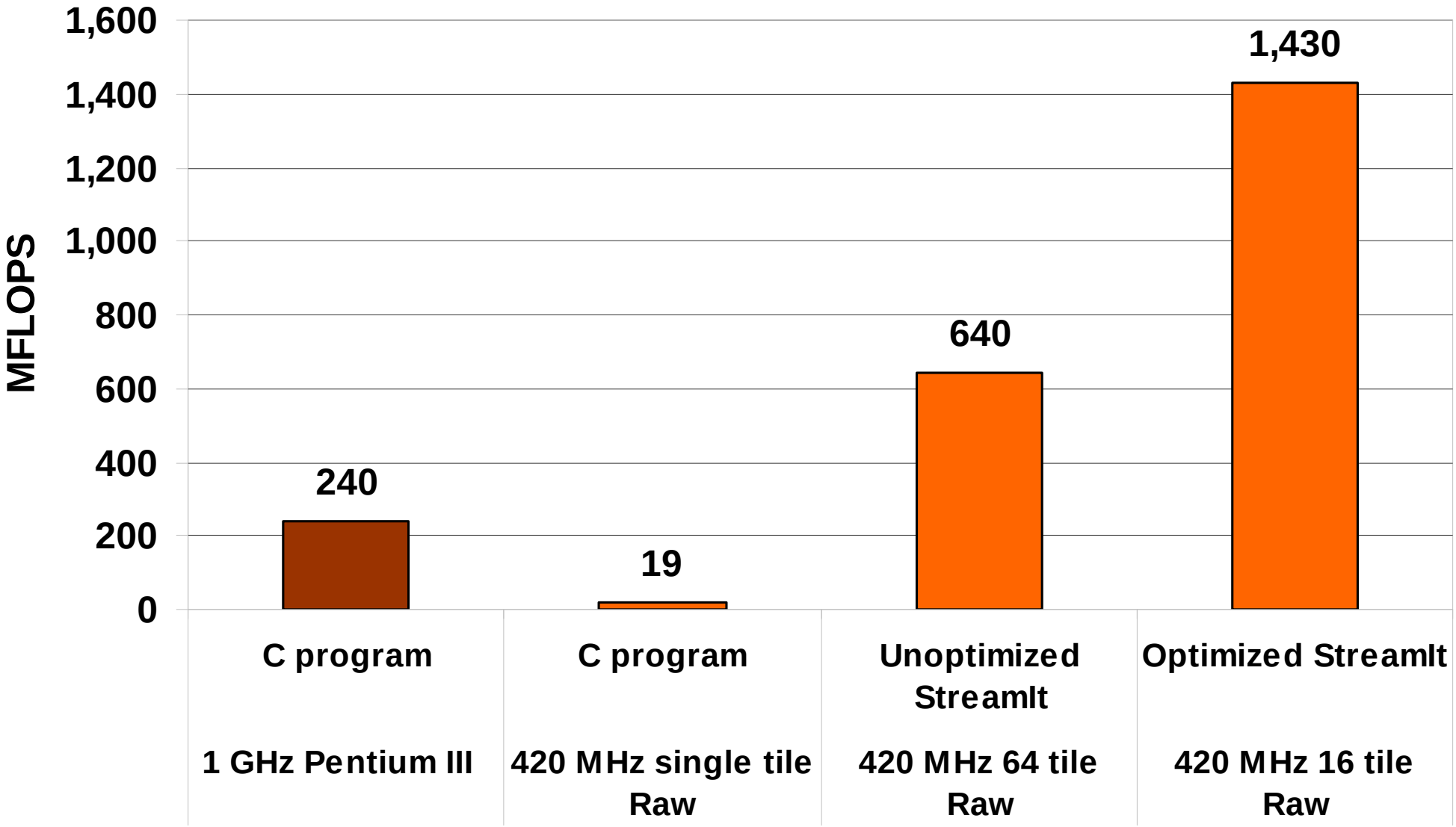


- 40% faster

1020 Element Microphone Array



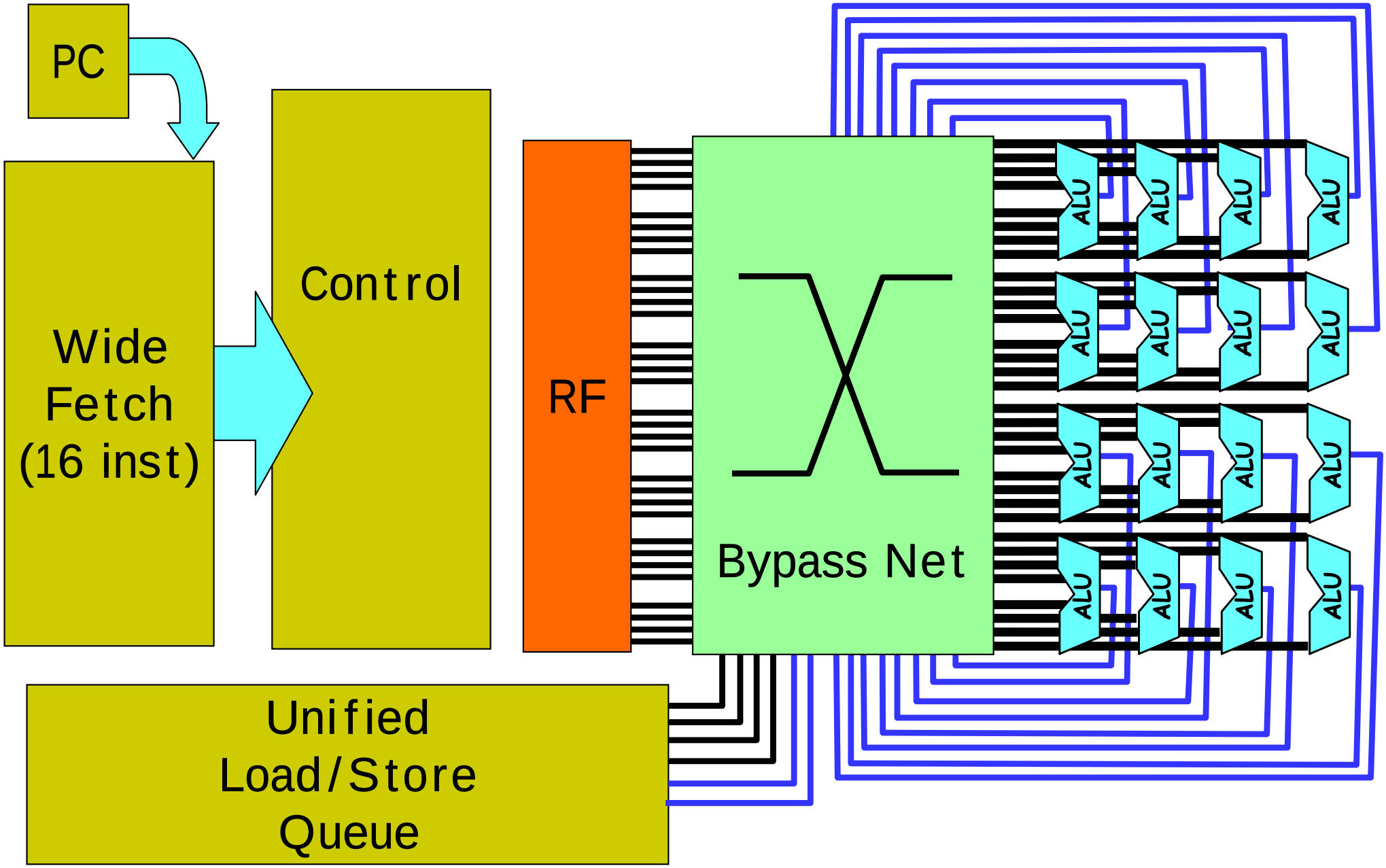
Case Study: Beamformer



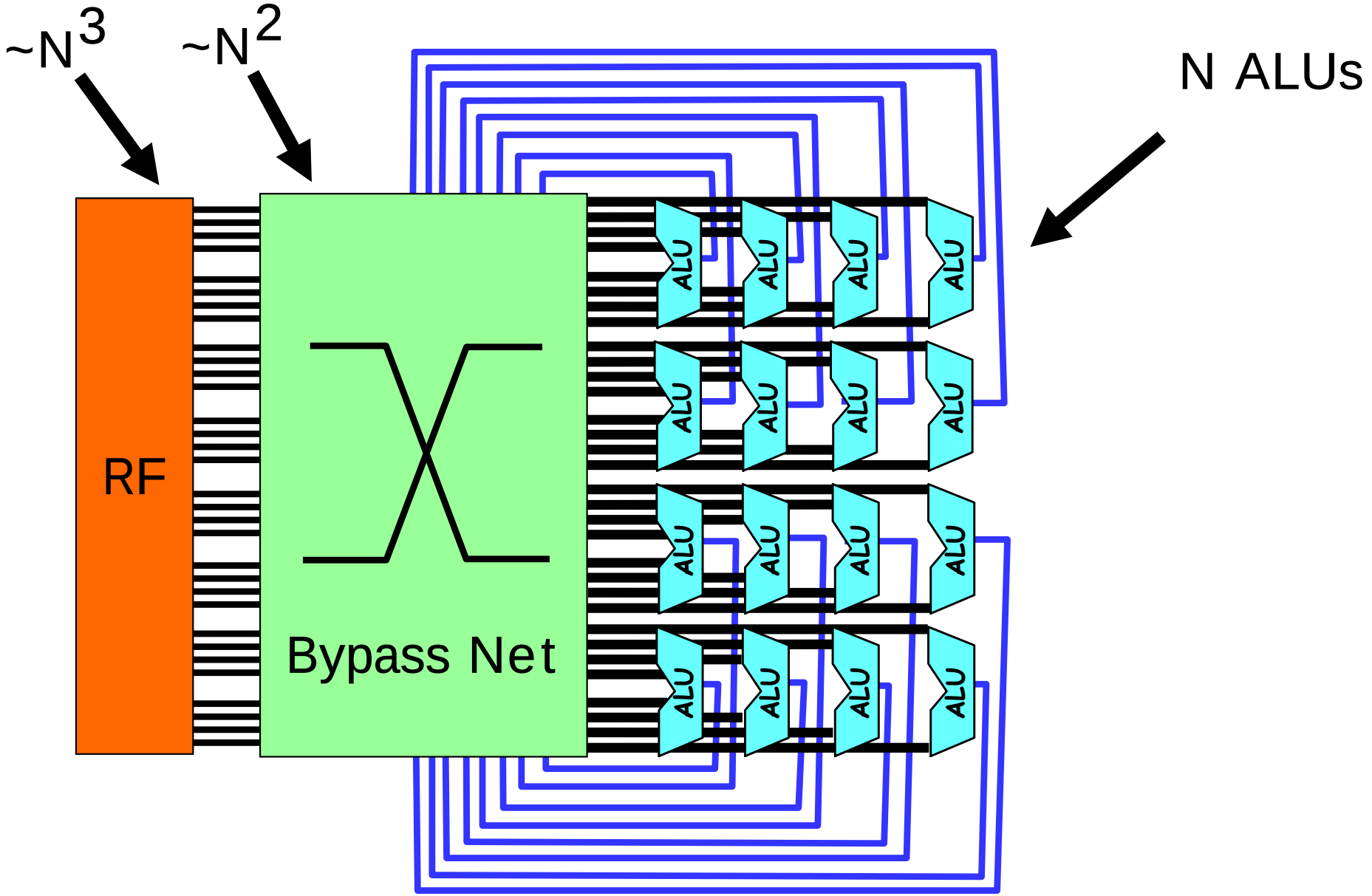
The Raw Experience

- Insights into the design Raw architecture
- Raw parallelizing compiler
- StreamIt language and Compiler

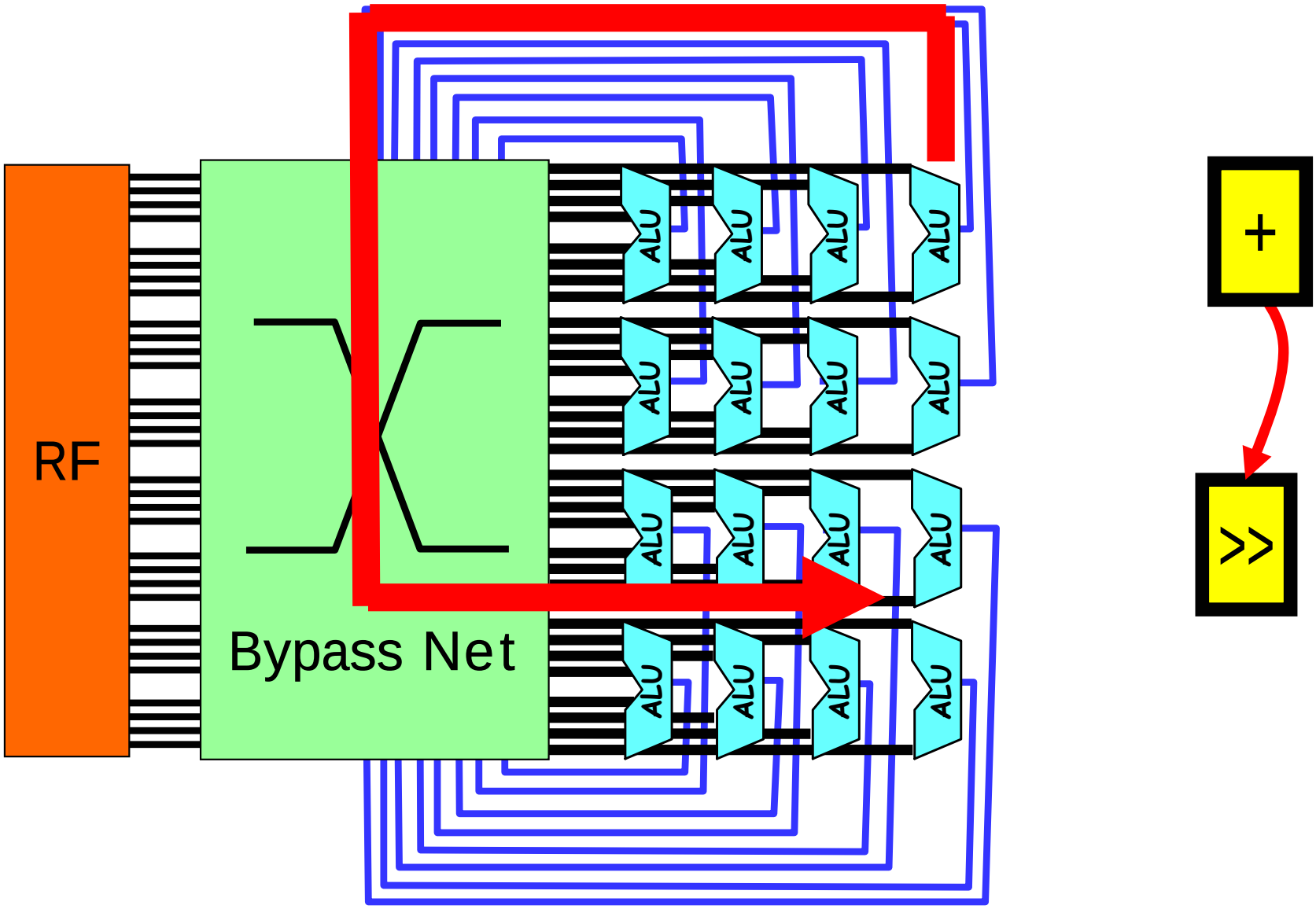
Scalability Problems in Wide Issue Processors



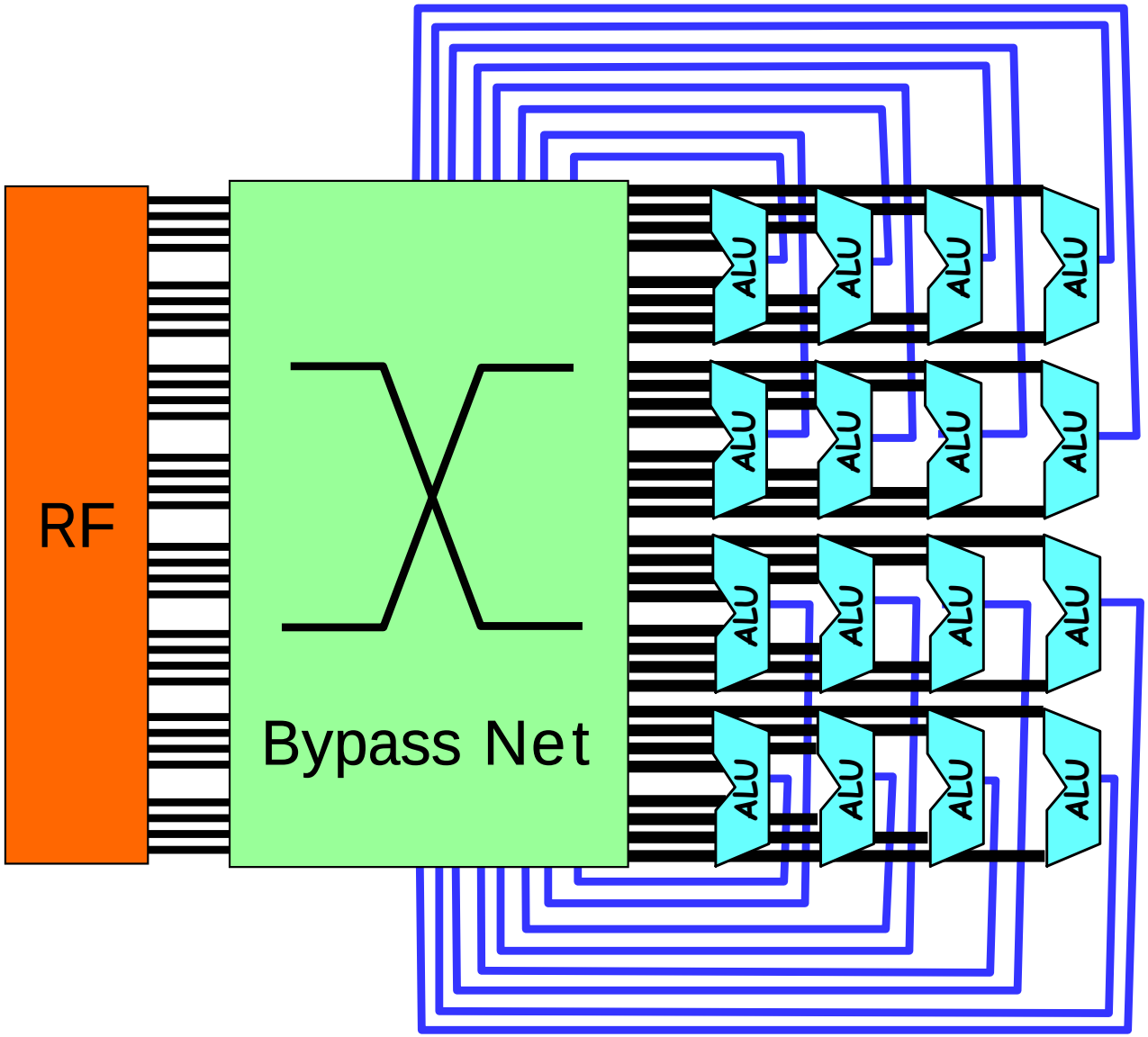
Area and Frequency Scalability Problems



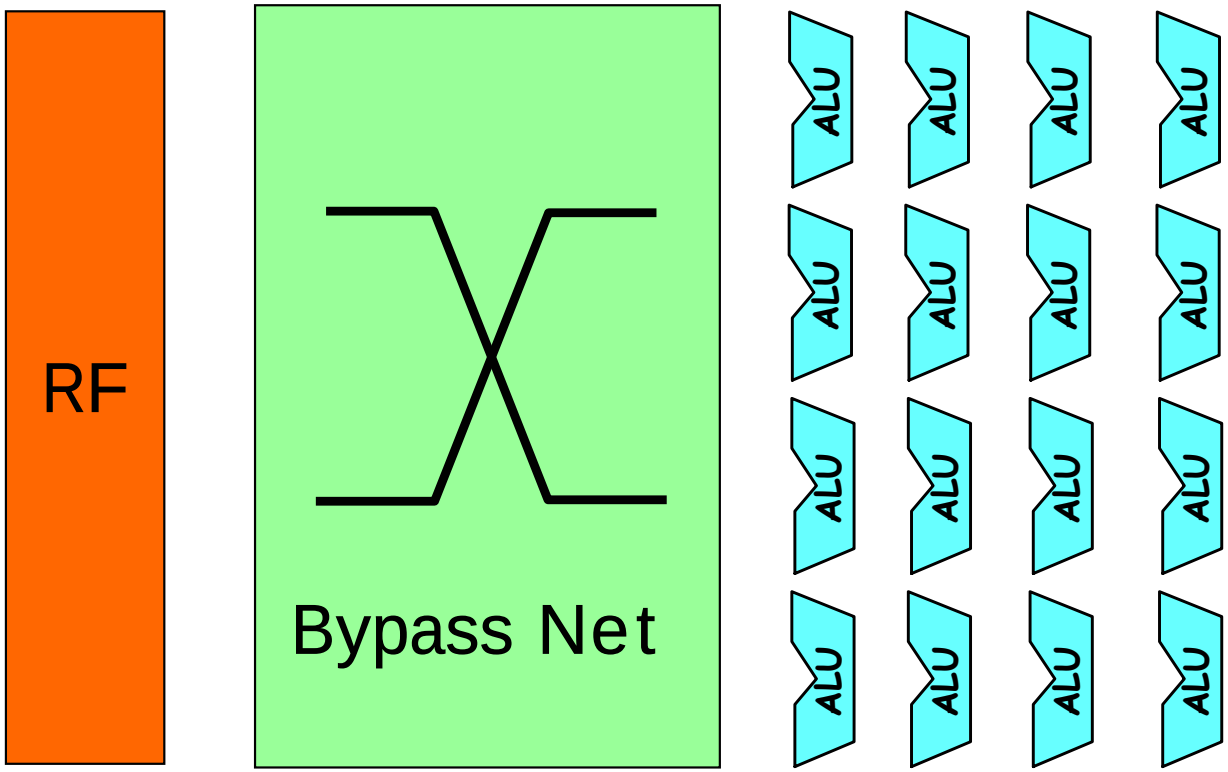
Operand Routing is Global



Idea: Make Operand Routing Local

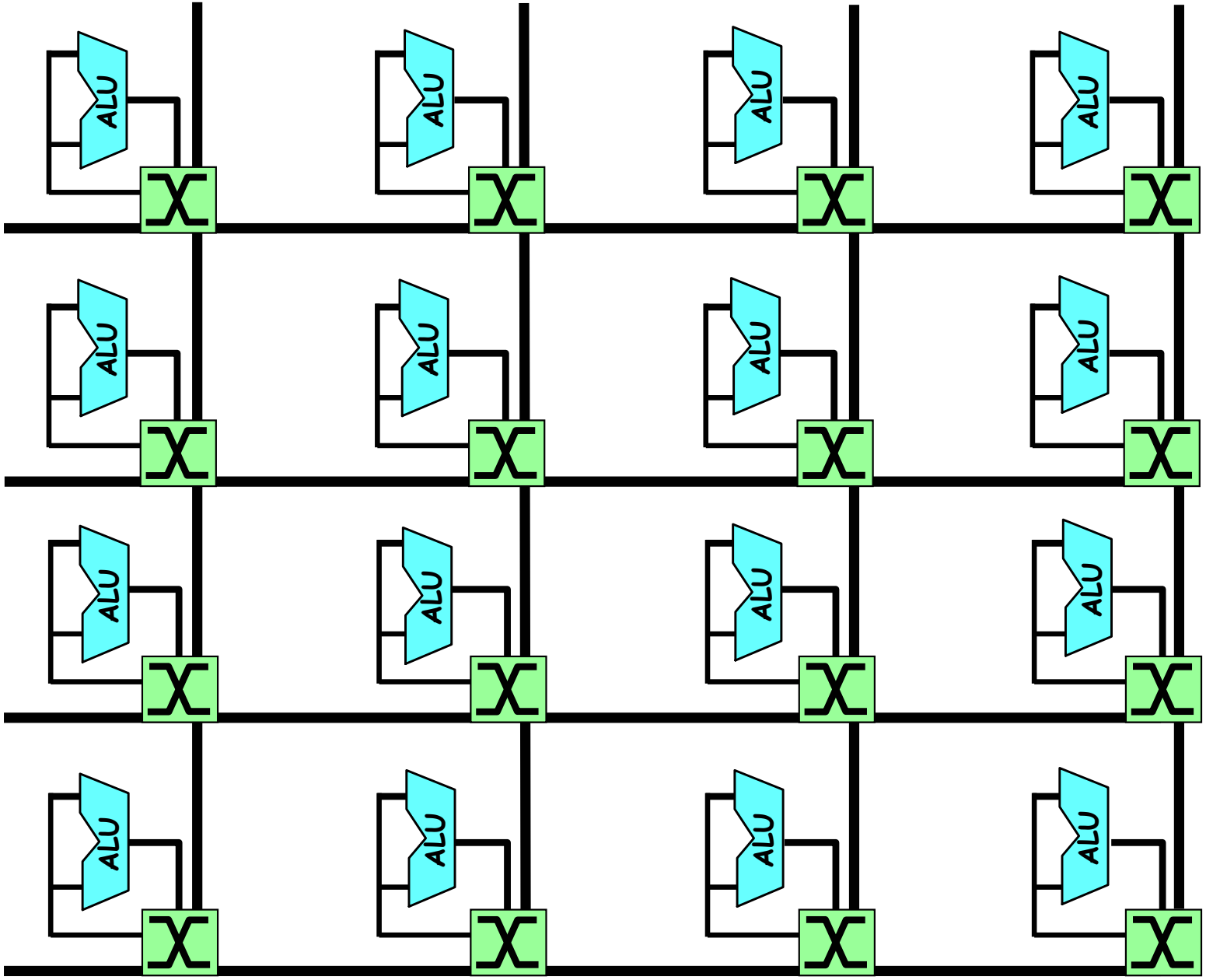


Idea: Exploit Locality

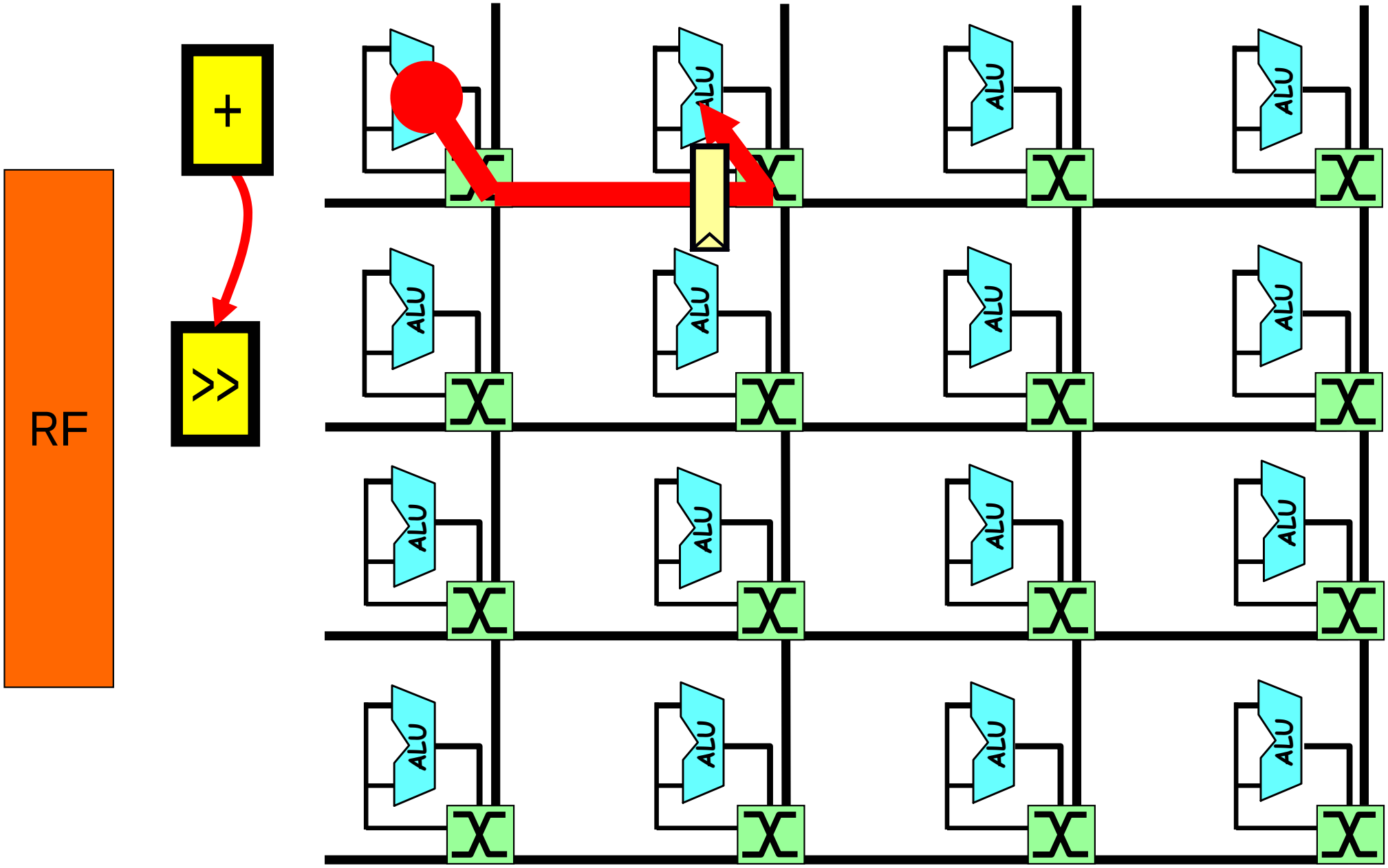


Replace Crossbar with Point-To-Point Network

RF



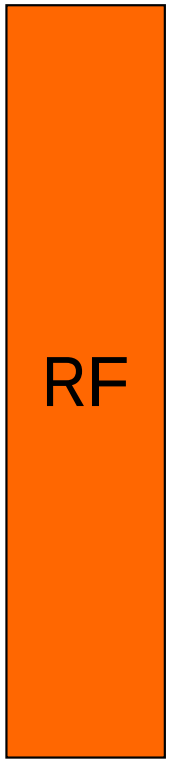
Replace Crossbar with Point-To-Point Network

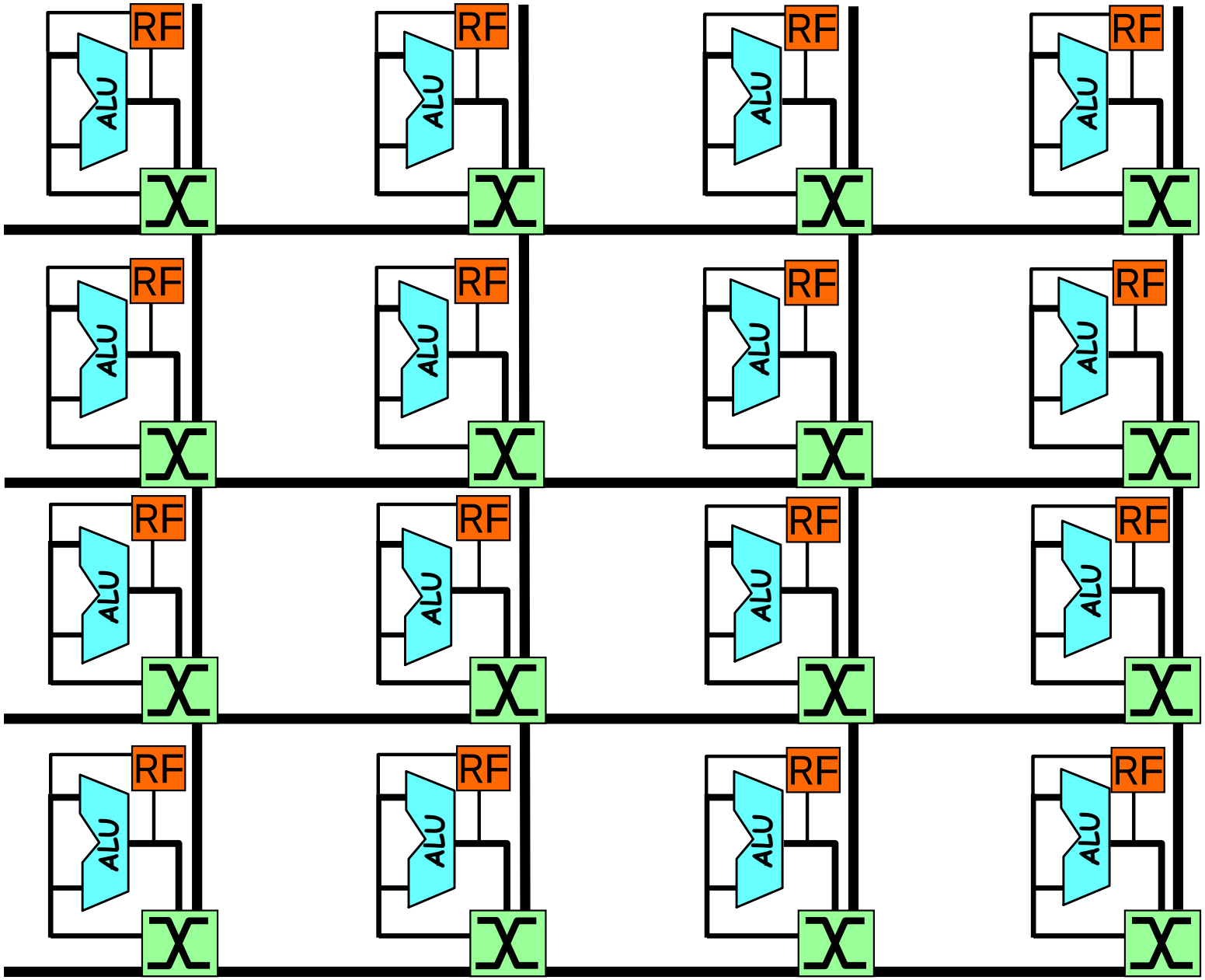


Operand Transport Latency

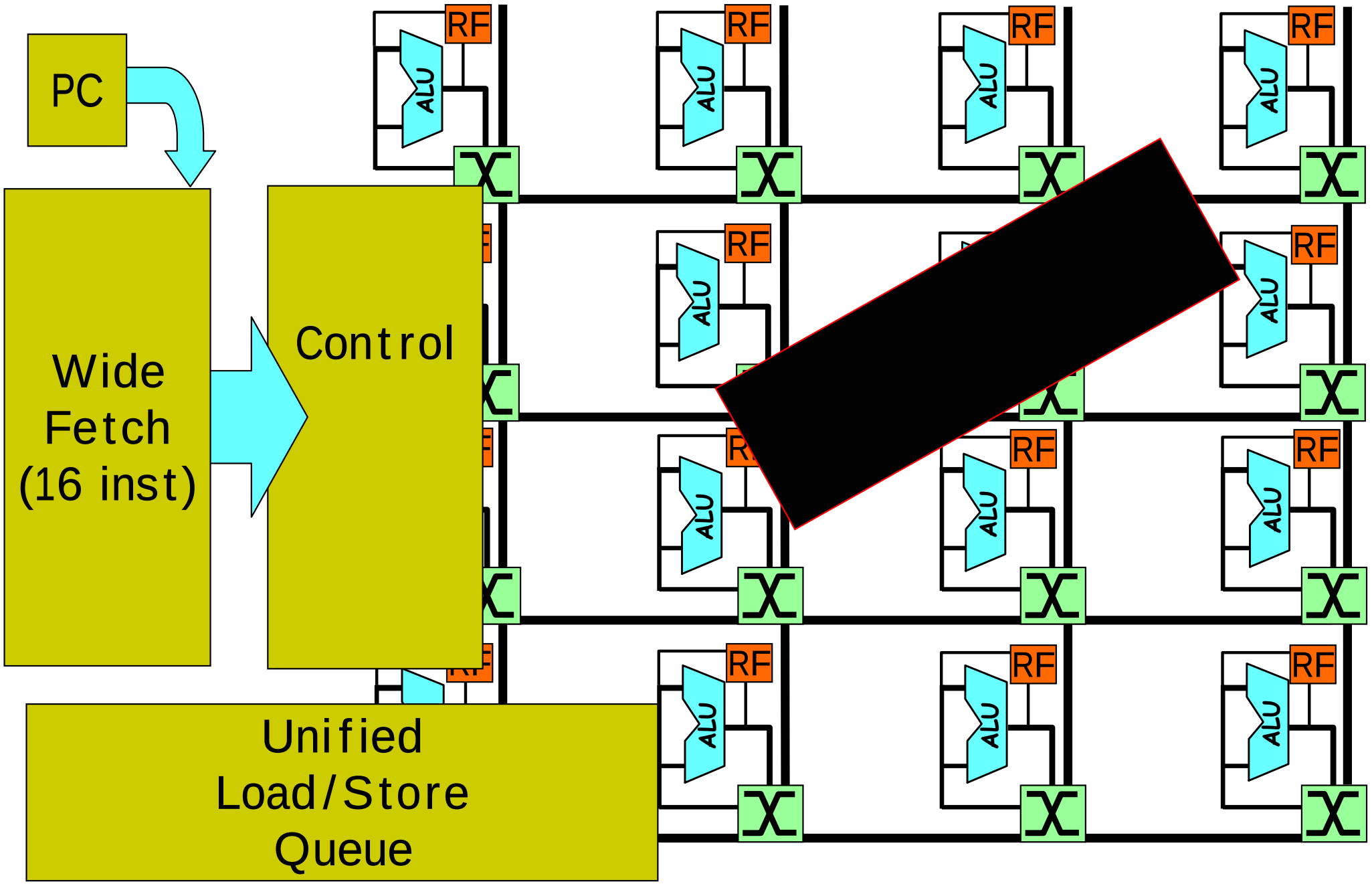
	Crossbar	Point-to-Point Network
Non-local Placement	~ N	~ $N^{1/2}$
Locality-driven Placement	~ N	~ 1

Distribute the Register File

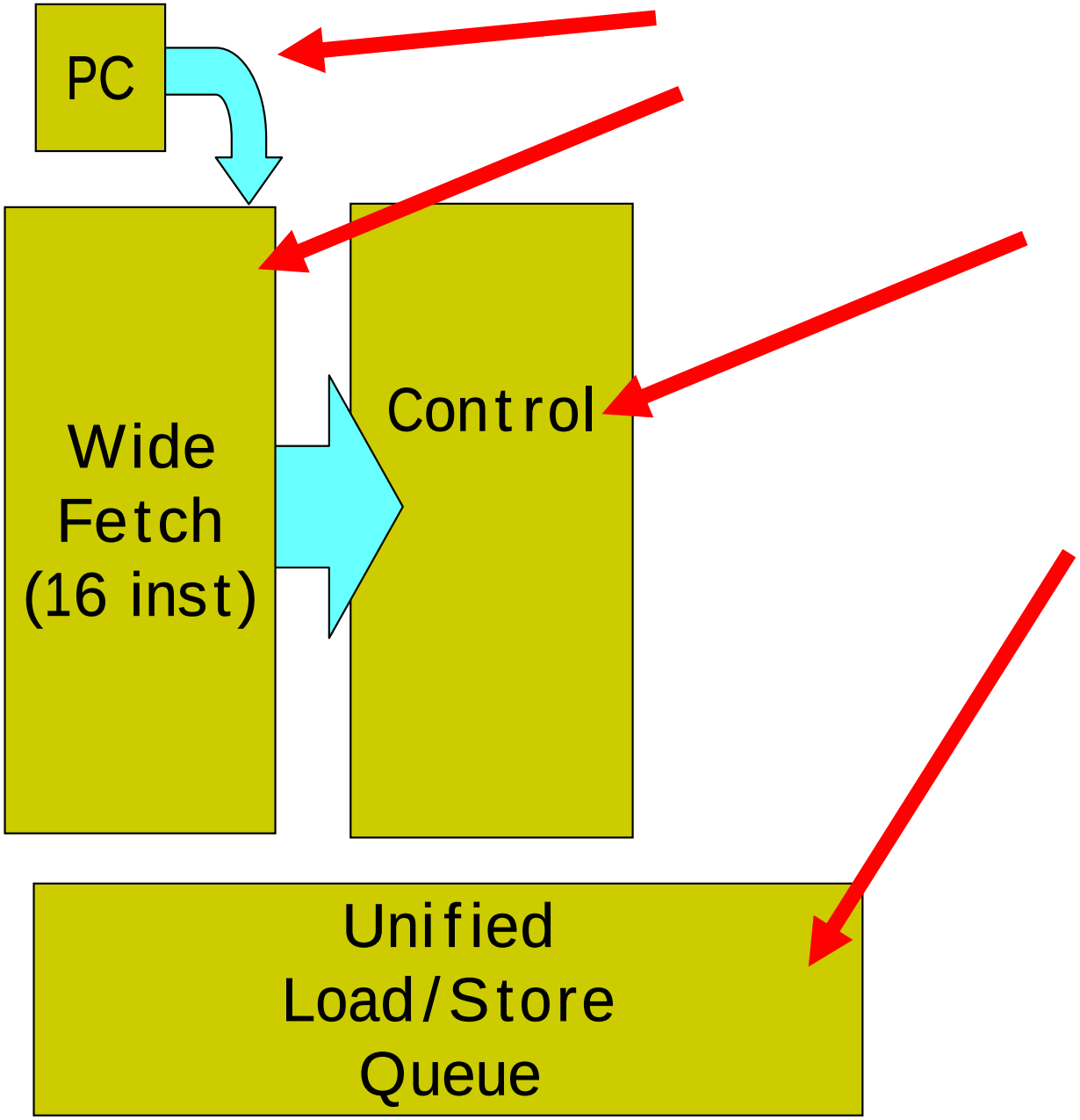




More Scalability Problems



More Scalability Problems



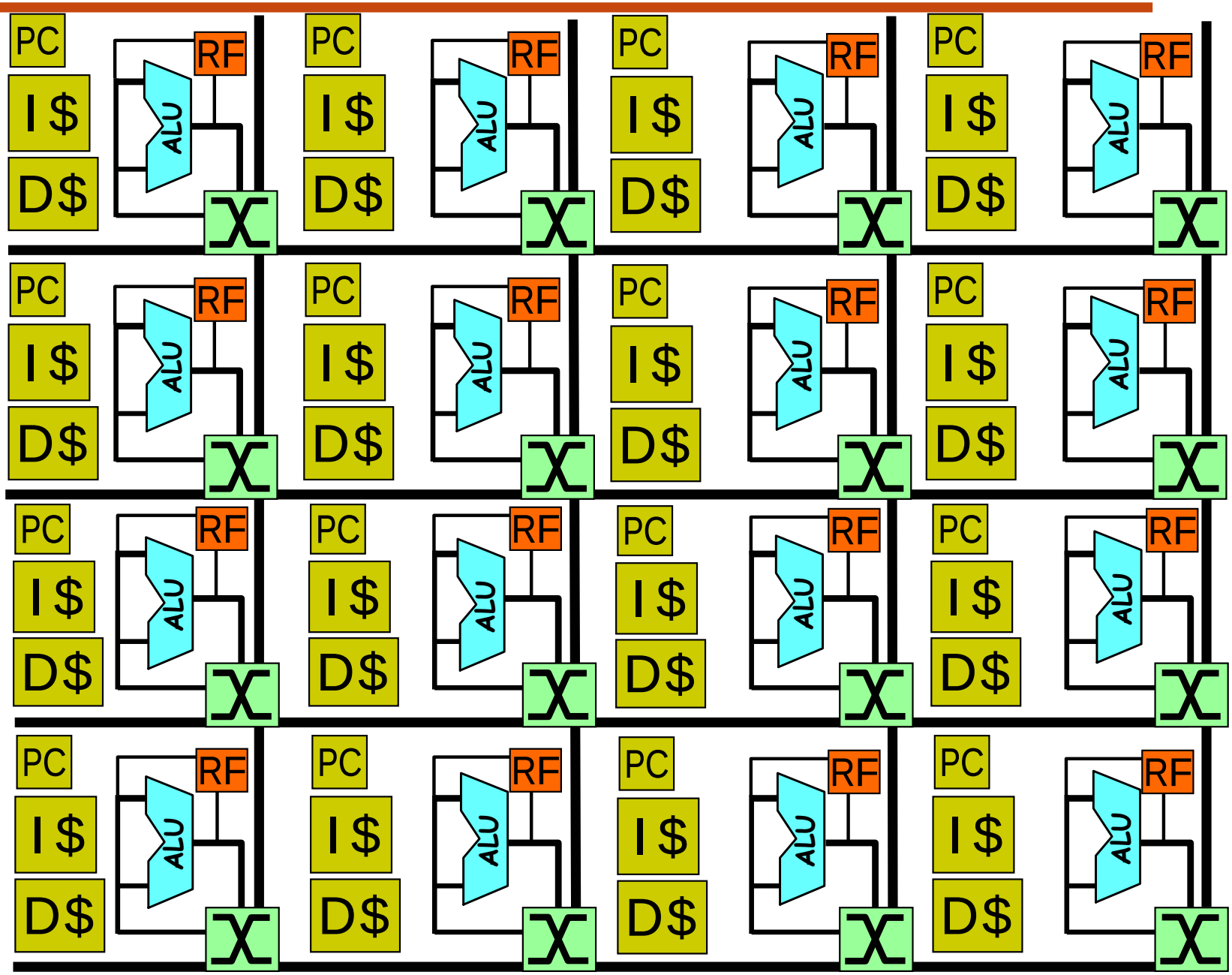
Distribute Everything

PC

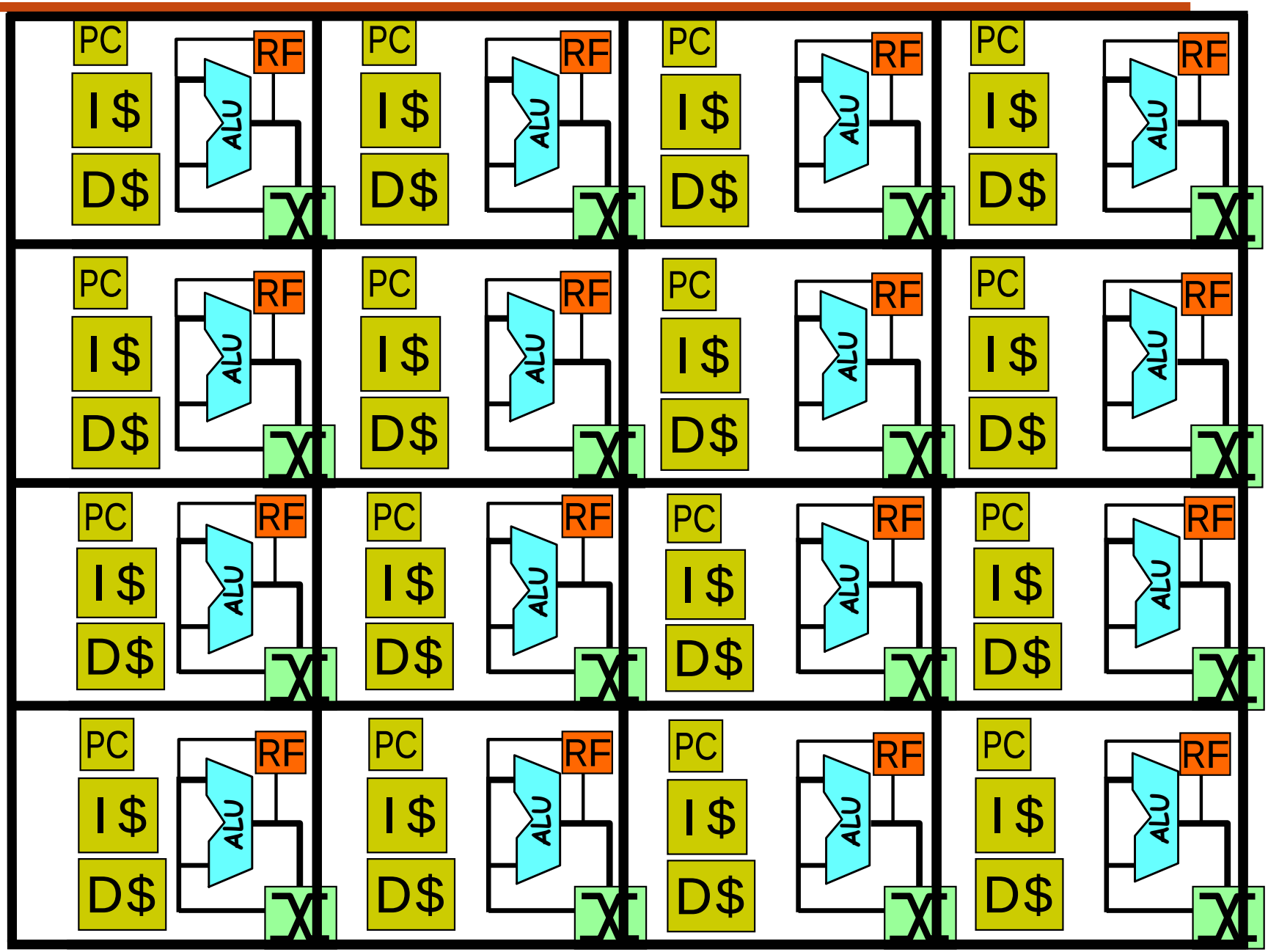
Wide Fetch (16 inst)

Control

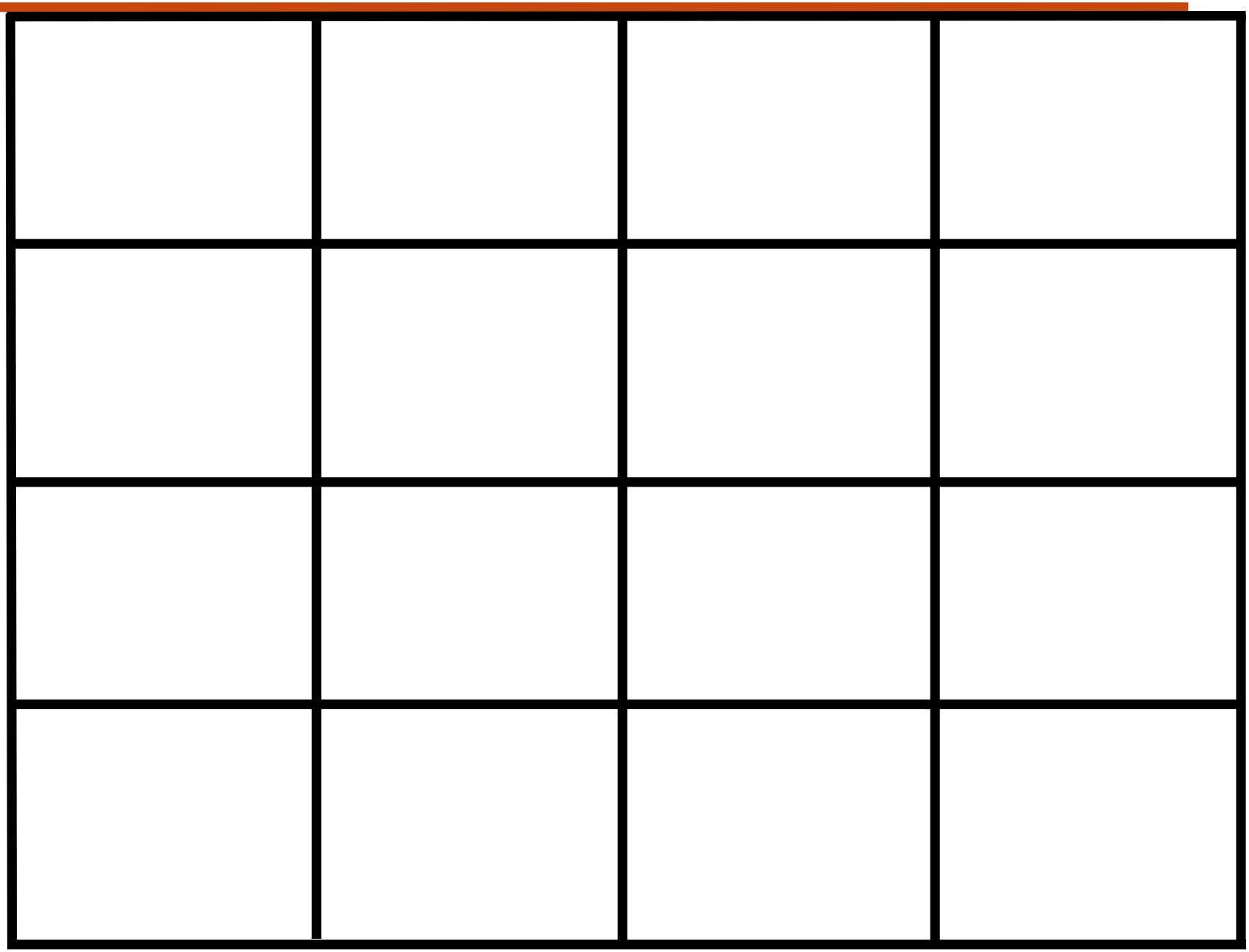
Unified Load/Store Queue



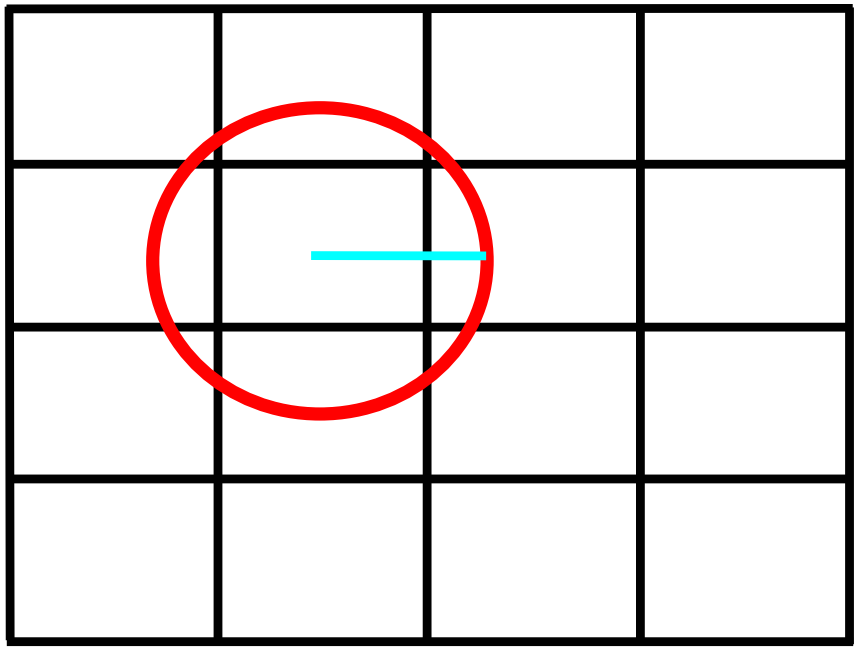
Tiled Processor



Tiled Processor

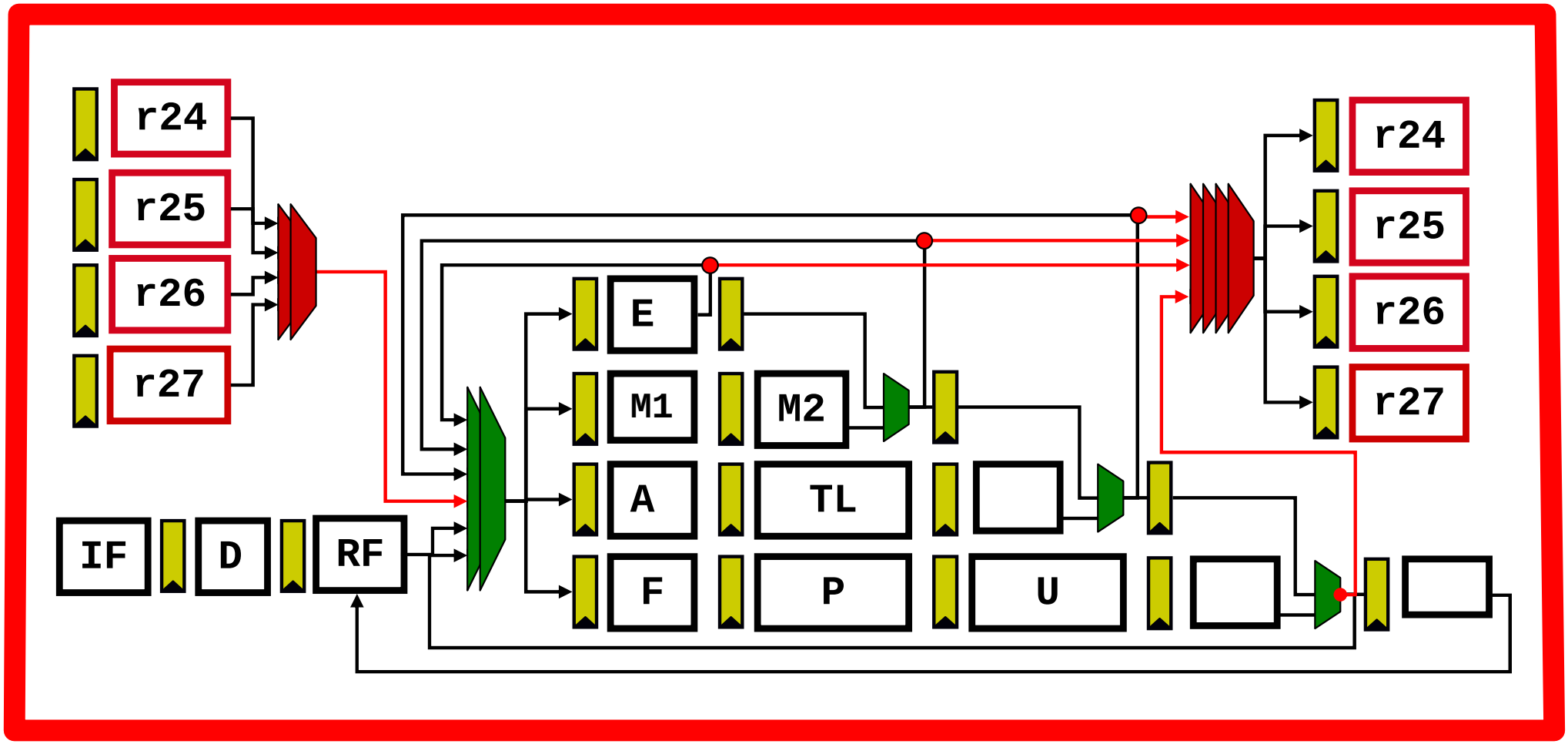


Tiled Processor (Taylor PhD 2007)

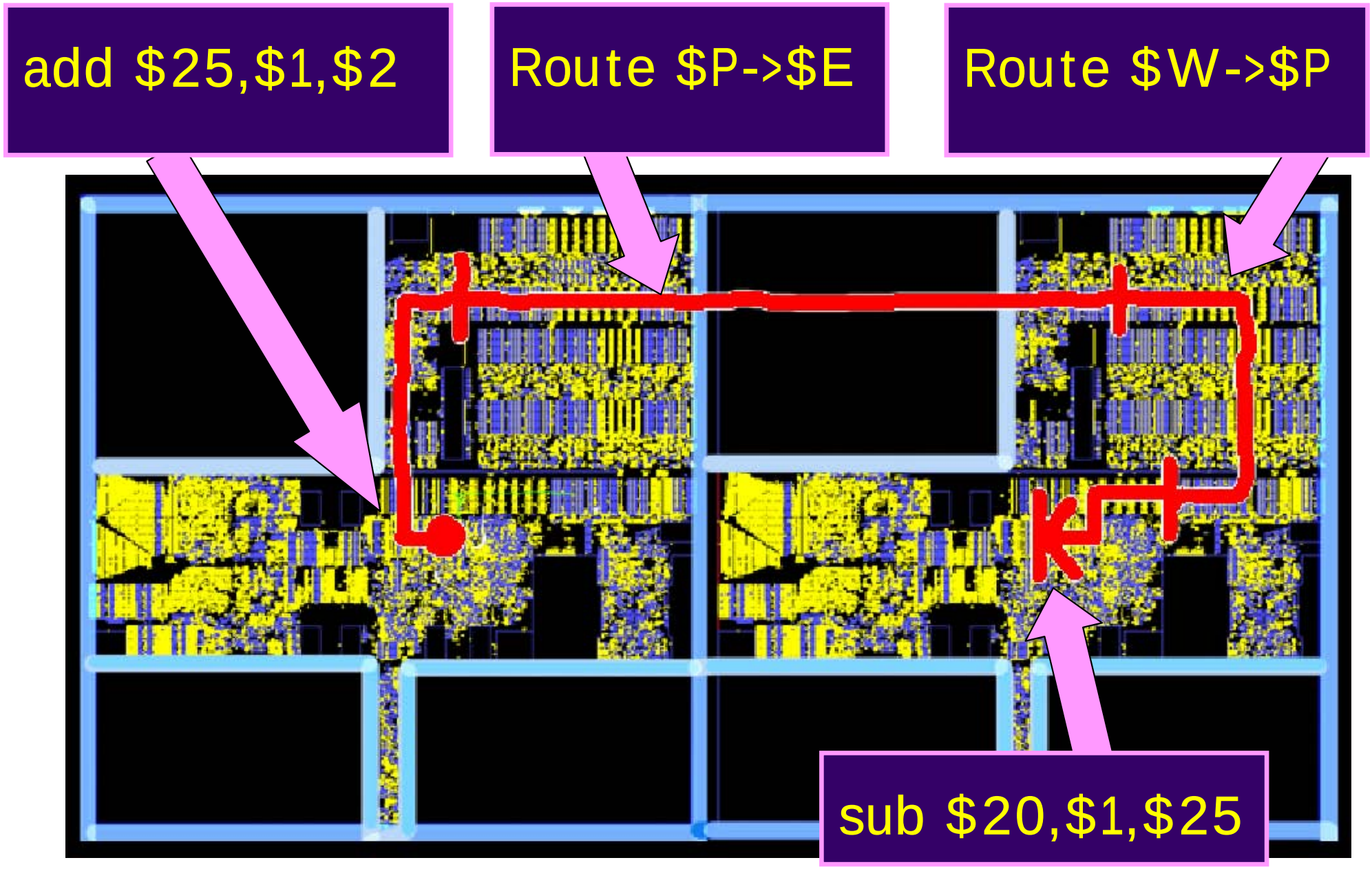


- Fast inter-tile communication through point-to-point pipelined scalar operand network (SON)
- Easy to scale for the same reasons as multicores

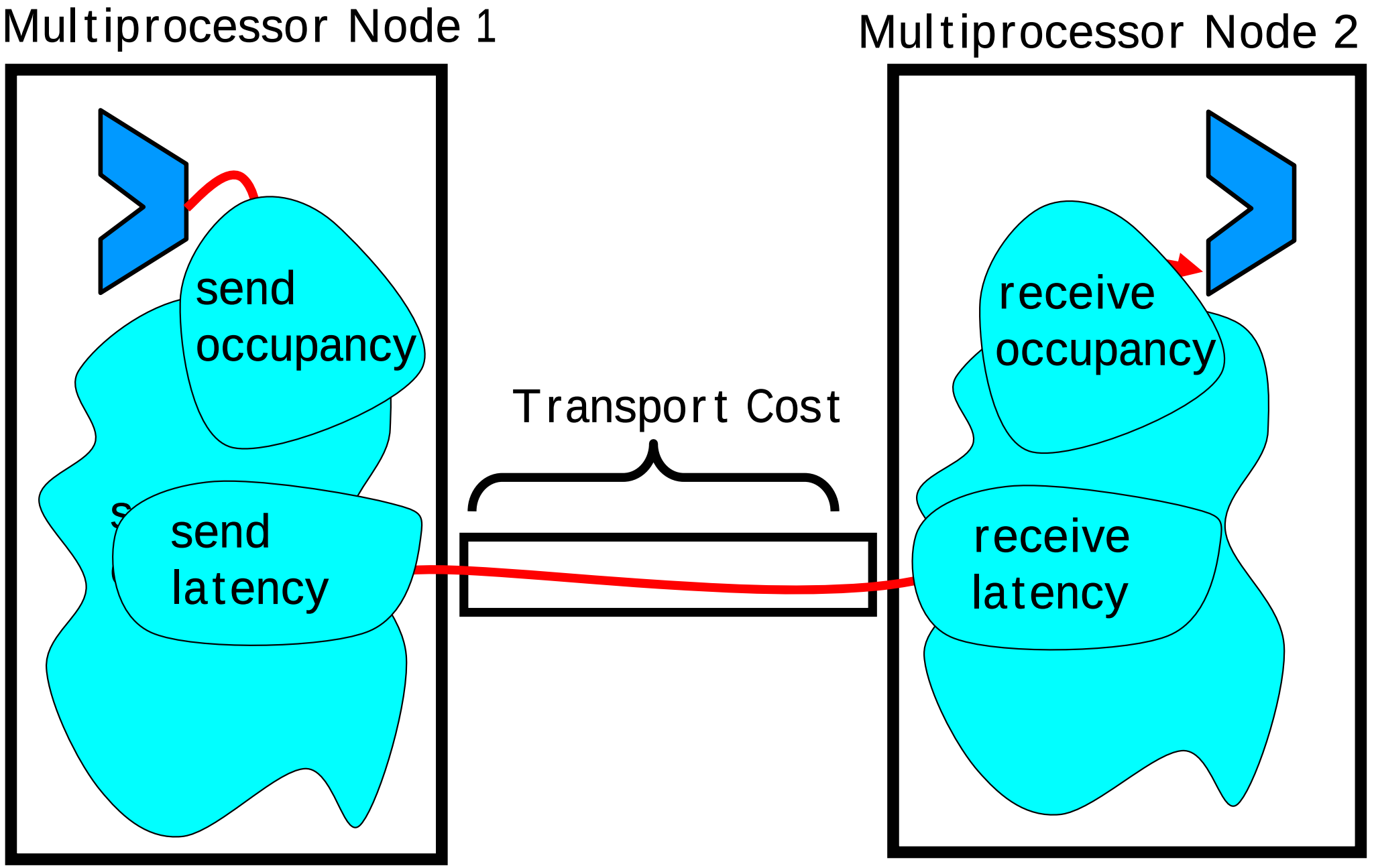
Raw Compute Processor Internals



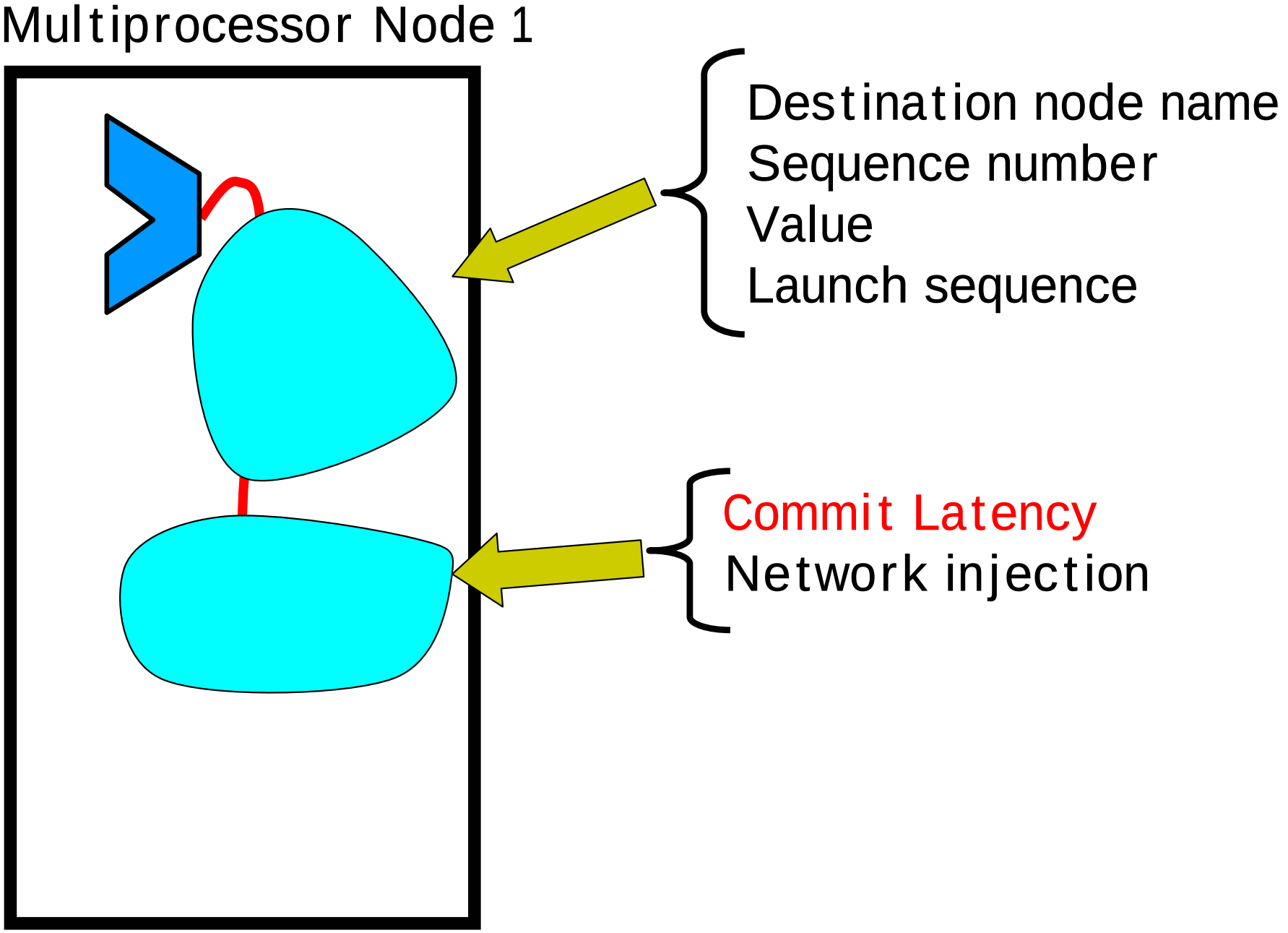
Tile-Tile Communication



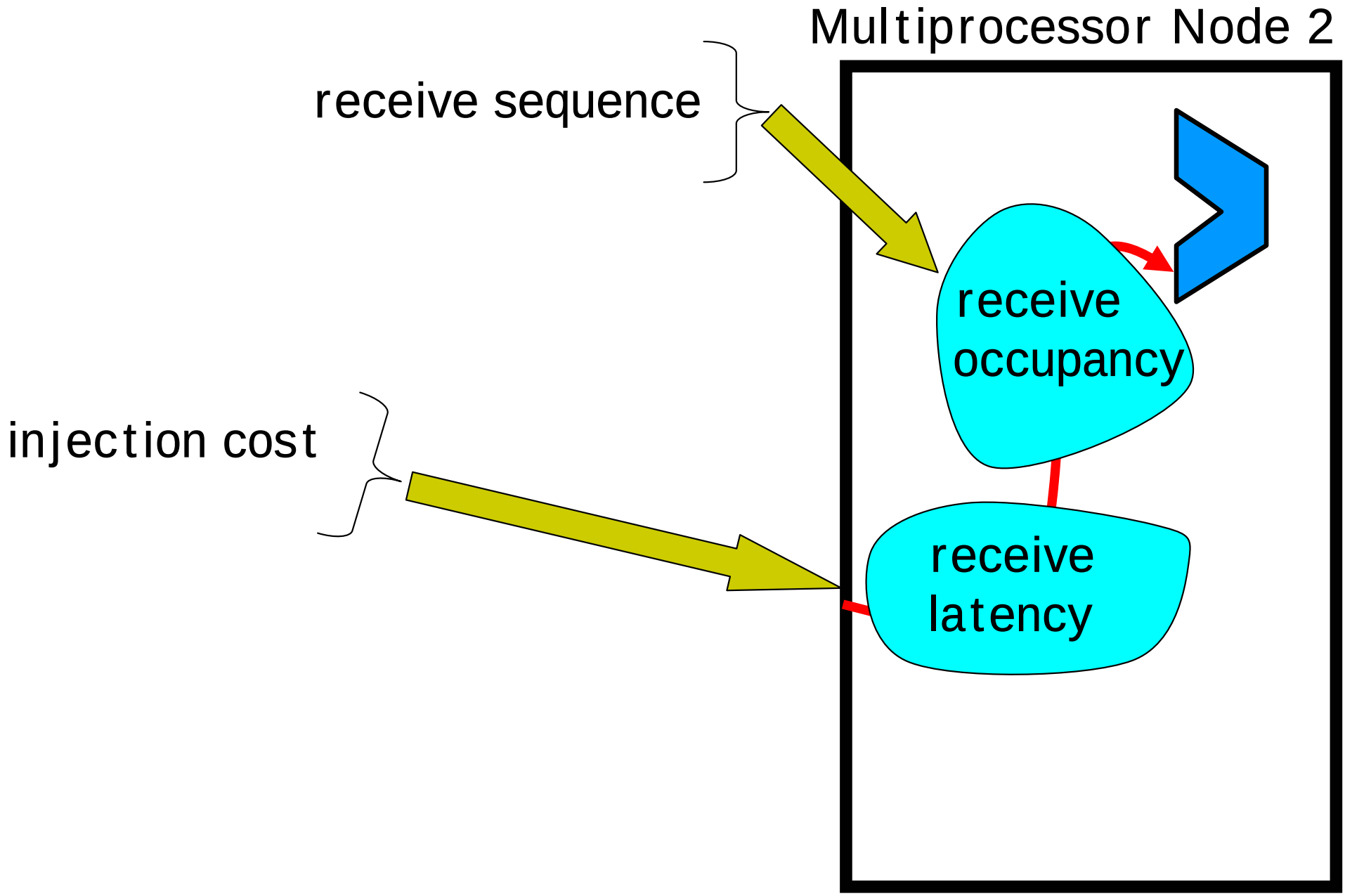
Why Communication Is Expensive on Multicores



Why Communication Is Expensive on Multicores



Why Communication Is Expensive on Multicores



A Figure of Merit for SONs

- 5-tuple **<SO, SL, NHL, RL, RO>**
  - Send occupancy
  - Send latency
  - Network hop latency
  - Receive latency
  - Receive occupancy

- Tip: Ordering follows timing of message from sender to receiver

The Interesting Region

Scalable Multiprocessor (on-chip)

- Where is Cell in this space?

<2, 14, 3, 14,4>

Raw SON (scalable)

< 0, 0, 1, 2, 0>

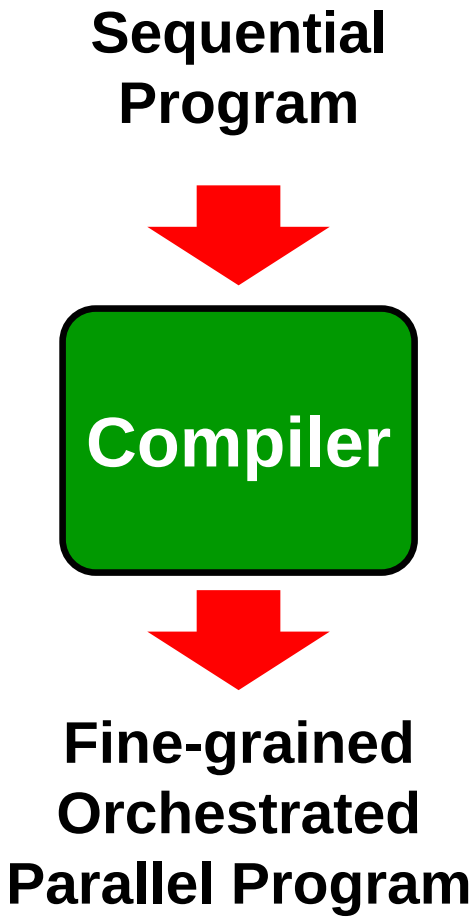
Superscalar (not scalable)

< 0, 0, 0, 0, 0>

The Raw Experience

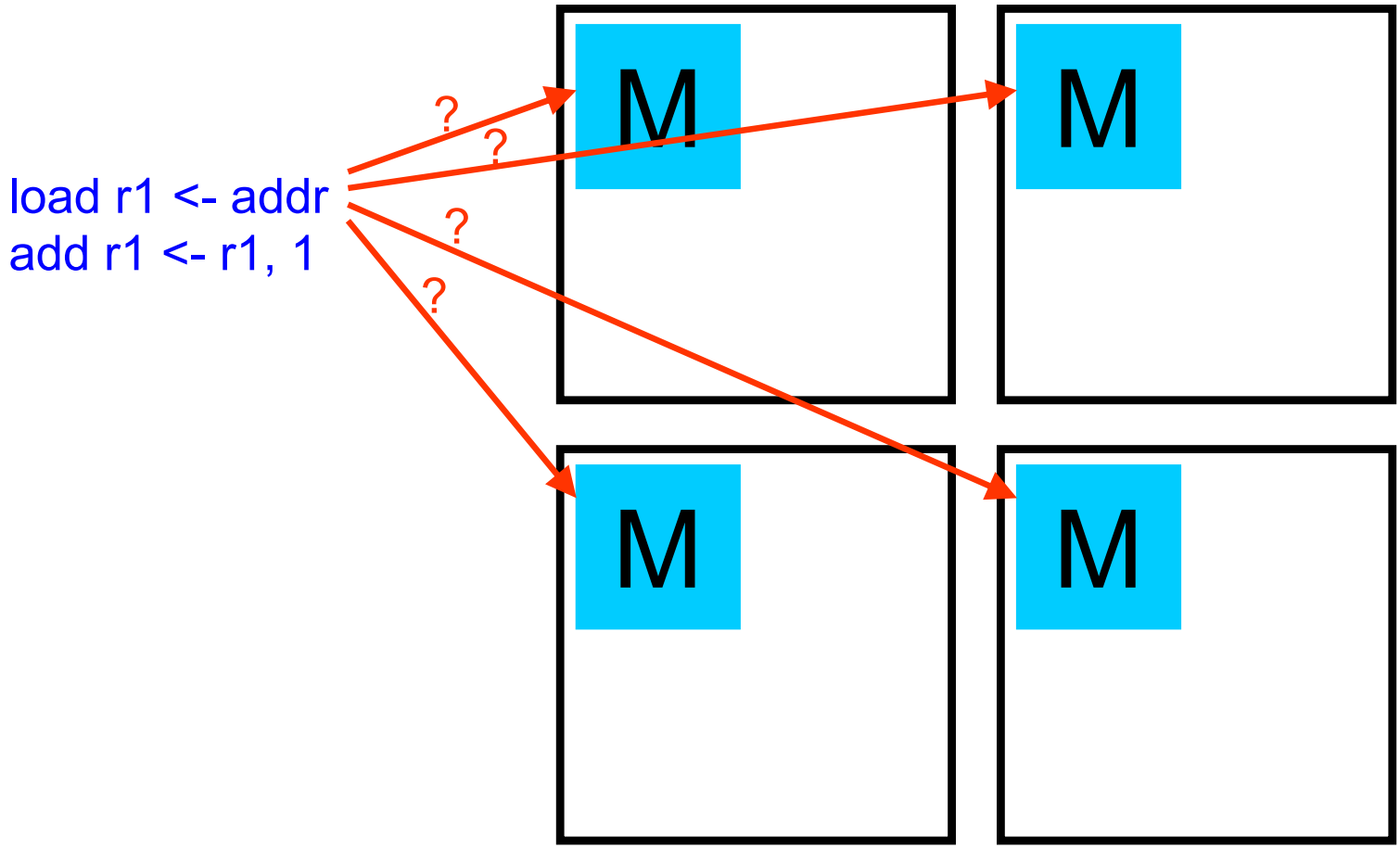
- Insights into the design Raw architecture
- Raw parallelizing compiler

Raw Parallelizing Compiler (Lee PhD 2005)

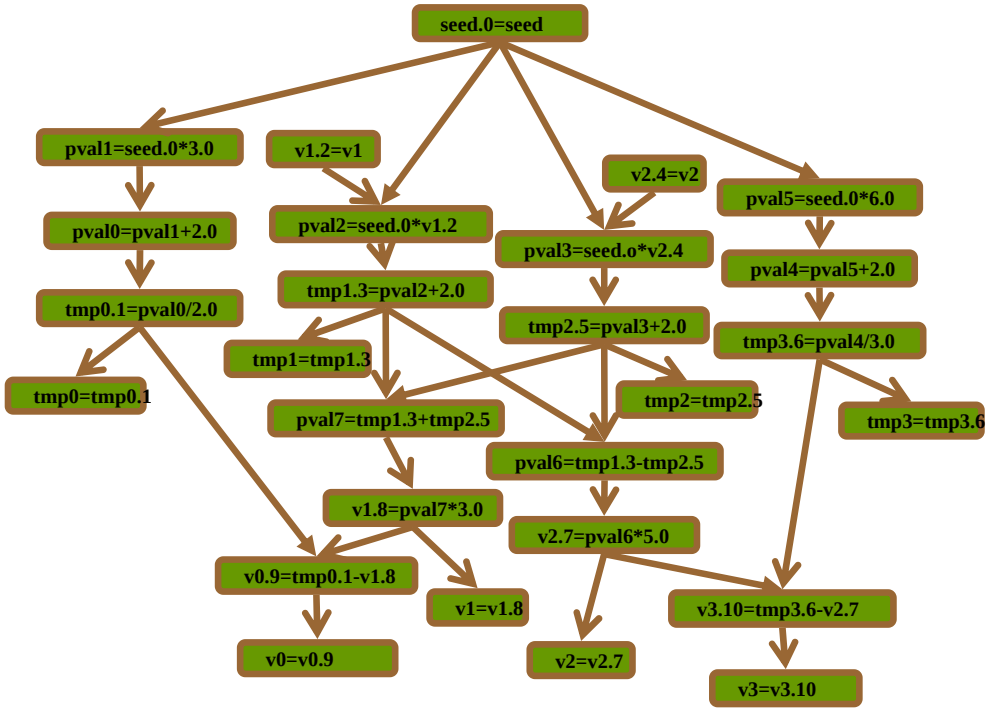


- Data distribution
- Instruction distribution
- Coordination
  - Communication
  - Control flow

Data Distribution

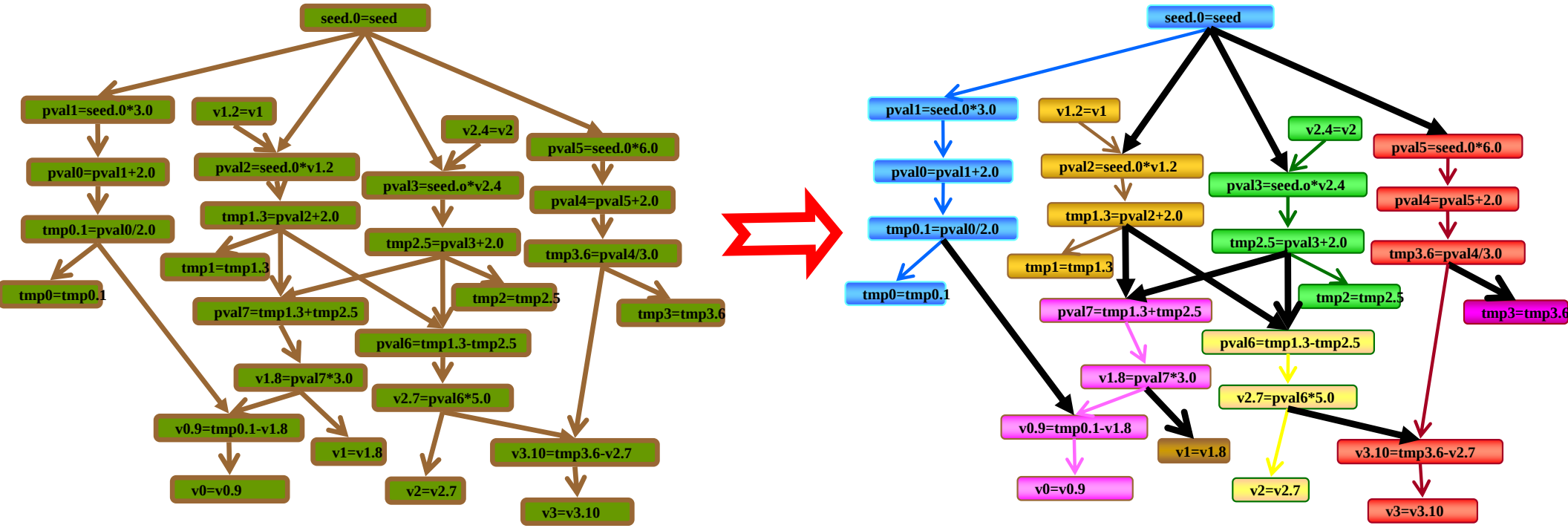


Instruction Distribution

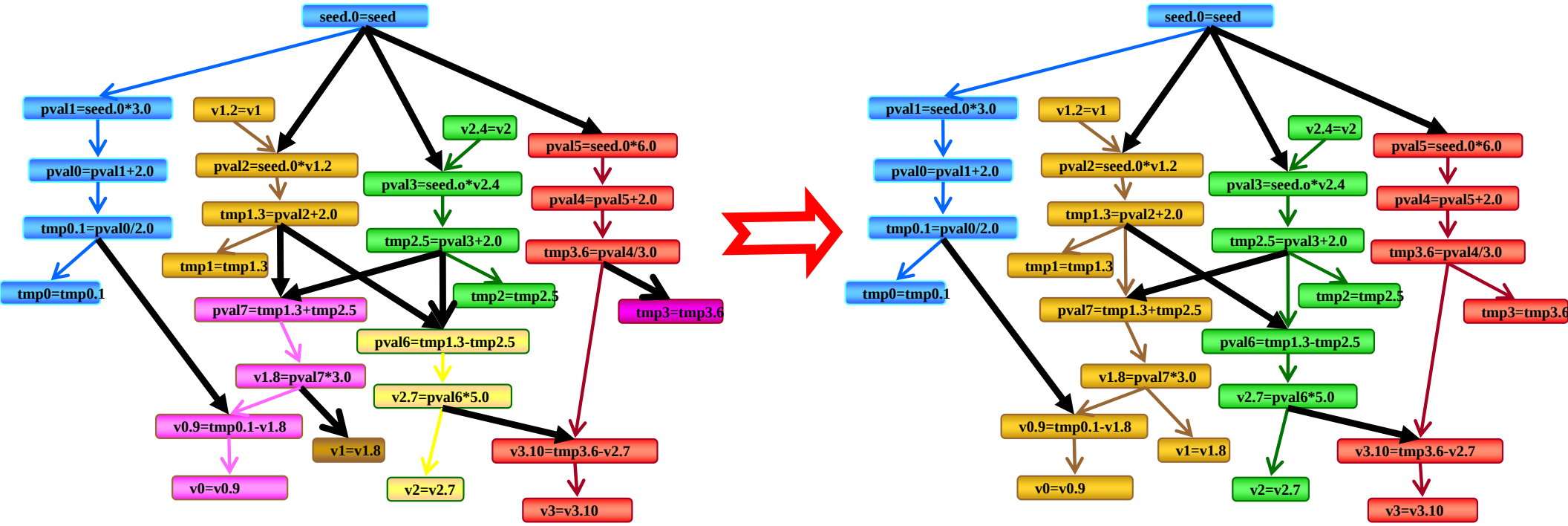


basic block

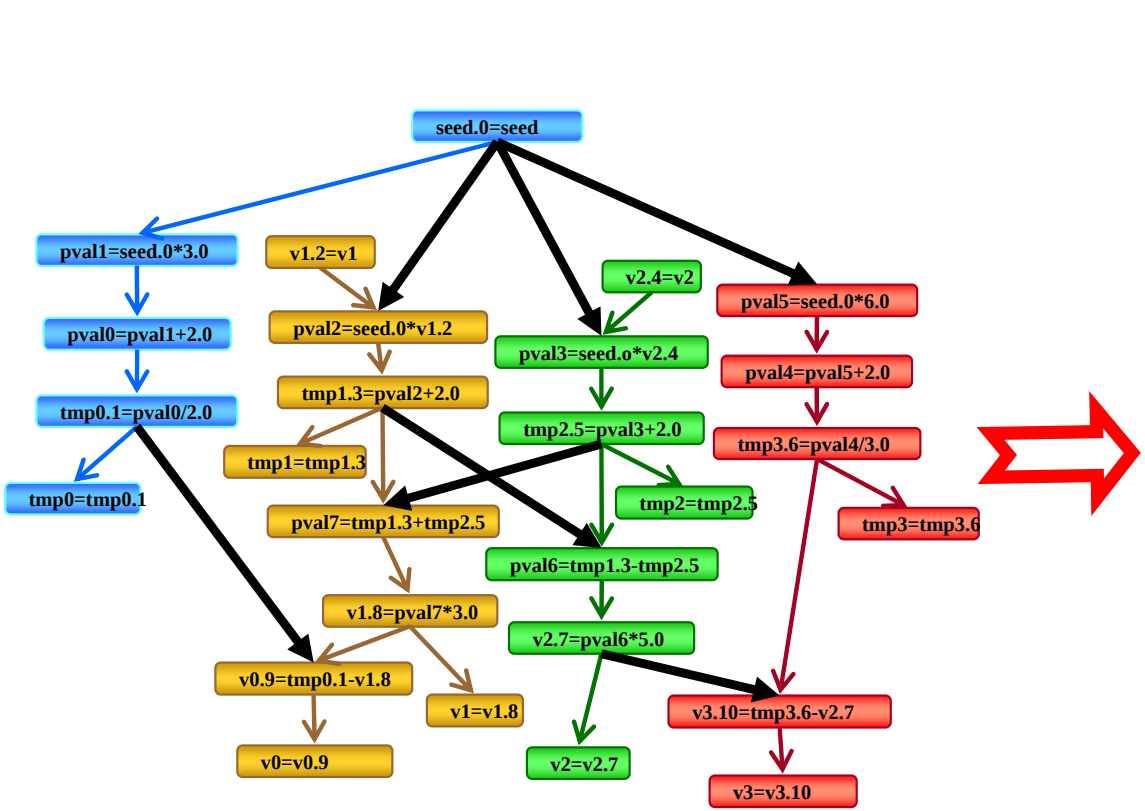
Clustering: Parallelism vs. Communication

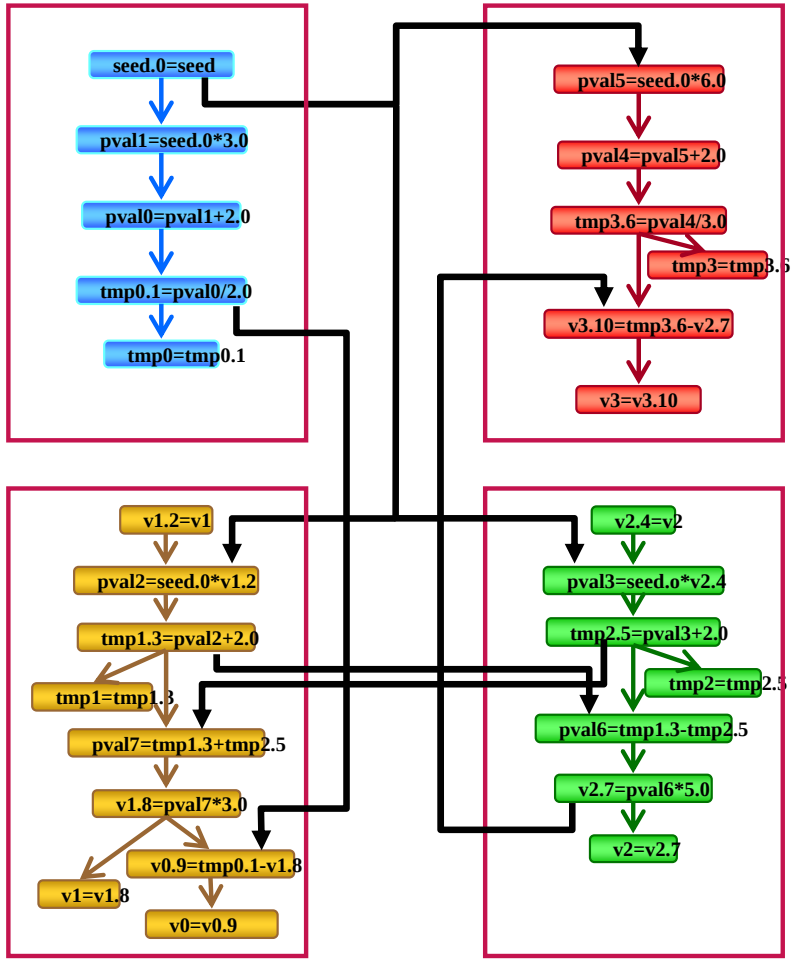


Adjusting Granularity: Load Balancing

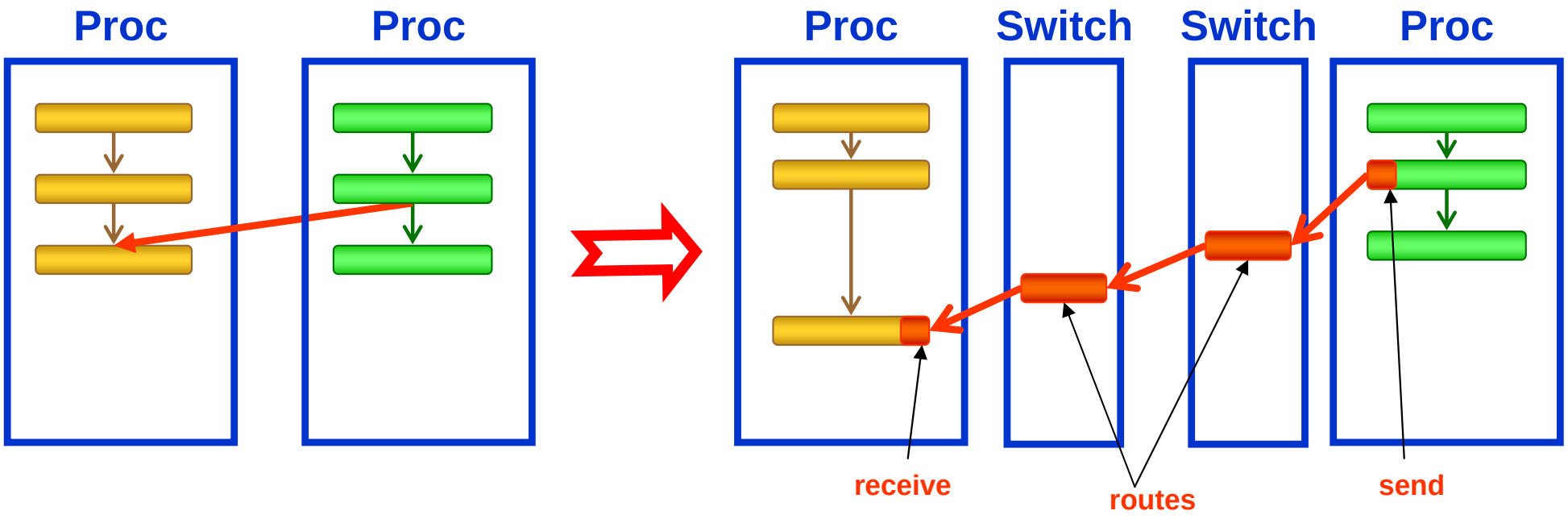


Placement

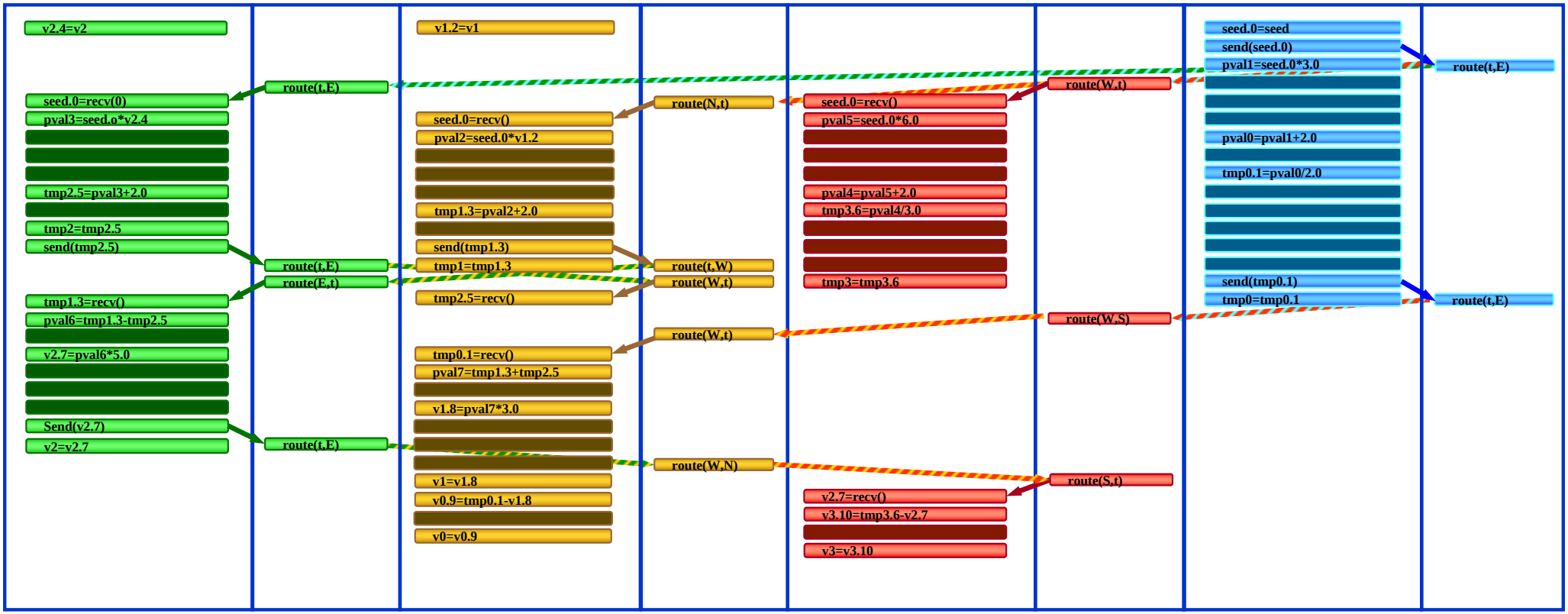

seed.0=seed
pval1=seed.0*3.0
v1.2=v1
v2.4=v2
pval5=seed.0*6.0
pval0=pval1+2.0
pval2=seed.0*v1.2
pval3=seed.o*v2.4
pval4=pval5+2.0
tmp0.1=pval0/2.0
tmp1.3=pval2+2.0
tmp2.5=pval3+2.0
tmp3.6=pval4/3.0
tmp0=tmp0.1
tmp1=tmp1.3
tmp2=tmp2.5
tmp3=tmp3.6
pval7=tmp1.3+tmp2.5
pval6=tmp1.3-tmp2.5
v1.8=pval7*3.0
v2.7=pval6*5.0
v0.9=tmp0.1-v1.8
v1=v1.8
v3.10=tmp3.6-v2.7
v0=v0.9
v2=v2.7
v3=v3.10


seed.0=seed
pval1=seed.0*3.0
pval0=pval1+2.0
tmp0.1=pval0/2.0
tmp0=tmp0.1
pval5=seed.0*6.0
pval4=pval5+2.0
tmp3.6=pval4/3.0
v3.10=tmp3.6-v2.7
v3=v3.10
v1.2=v1
pval2=seed.0*v1.2
tmp1.3=pval2+2.0
pval7=tmp1.3+tmp2.5
v1.8=pval7*3.0
v0.9=tmp0.1-v1.8
v1=v1.8
v0=v0.9
v2.4=v2
pval3=seed.o*v2.4
tmp2.5=pval3+2.0
pval6=tmp1.3-tmp2.5
v2.7=pval6*5.0
v2=v2.7

Communication Coordination

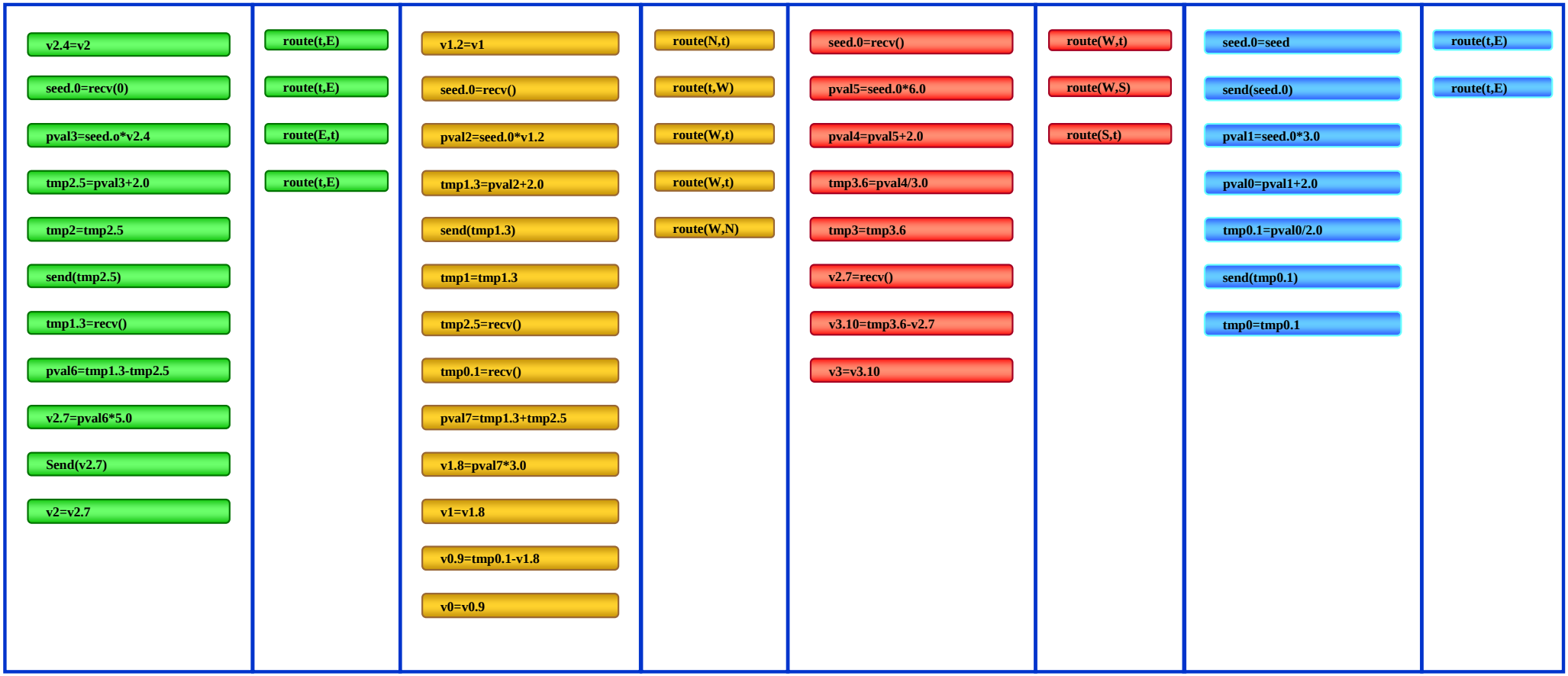


Instruction Scheduling

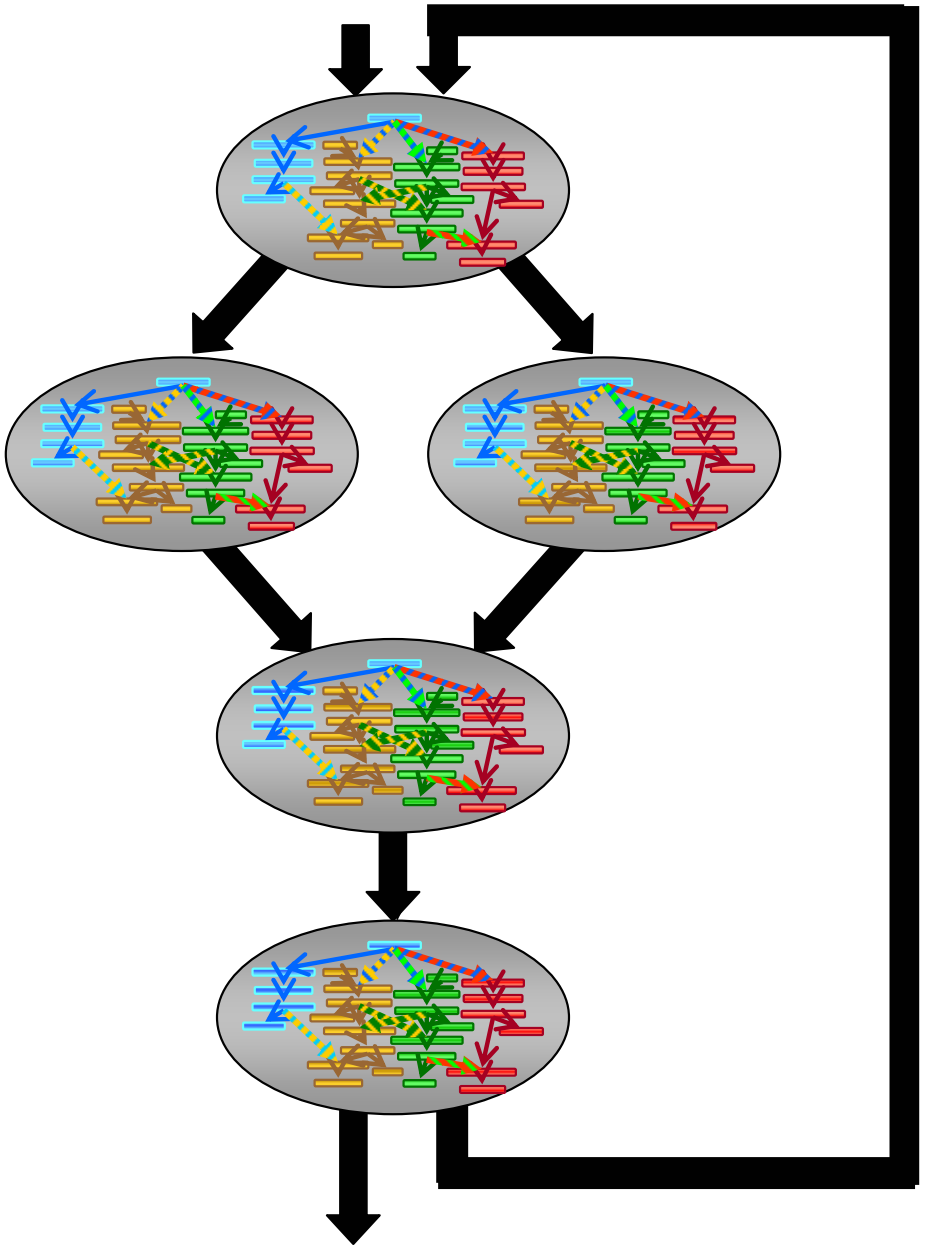


- Inter-tile cycle scheduling schedules communication and can guarantee deadlock freedom

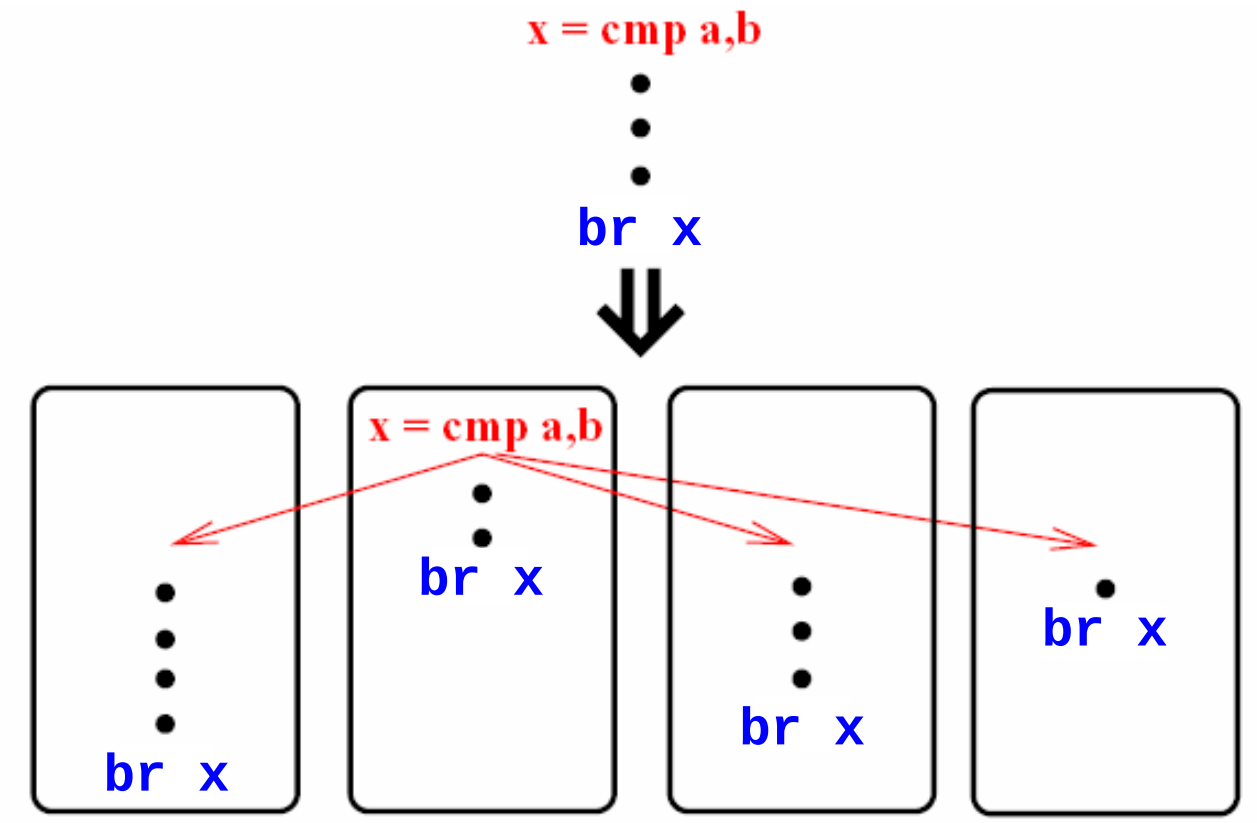
Final Code Representation



Control Coordination



Asynchronous Global Branching



Summary

- Tiled microprocessors incorporate the best elements of superscalars and multiprocessors

	Superscalar	Multicore	Tiled Processor with SON
PE-PE communication	Free	Expensive	Cheap
exploitation of parallelism	Implicit	Explicit	Both
Clean semantics	Yes	No	Yes
scalable	No	Yes	Yes
power efficient	No	Yes	Yes

Raw Project Contributors

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Ben Greenwald
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Paul Johnson
Jason Kim
Theo Konstantakopoulos
Walter Lee
Jason Miller
James Psota
Arvind Saraf
Vivek Sarkar
Nathan Shnidman
Volker Strumpen
Michael Taylor
Elliot Waingold
David Wentzlaff