EE382N (20): Computer Architecture - Parallelism and Locality

Lecture 5 – Parallelism in Hardware

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Outline

- Principles of parallel execution
- Pipelining
- Parallel HW (multiple ALUs)

Parallel Execution

- Concurrency
  - what are the multiple resources?
- Communication
  - and storage
- Synchronization
  - Implicit?
  - Explicit?
- what is being ***shared*** ?
- What is being ***partitioned*** ?

Parallelism – Circuits

- Circuits operate concurrently (always)
- Communicate through wires and registers
- Synchronize by:
  - clock
  - signals (including async)
  - design (wave-pipelined)
  - more?

Parallelism – Components

- Collections of circuits
  - memories
  - branch predictors
  - cache
  - scheduler …
  - includes ALUs, memory channels, cores but will discuss later.
- Operate concurrently
- Communicate by wires, registers, and memory
- synchronize with clock and signals
- Often pipelined

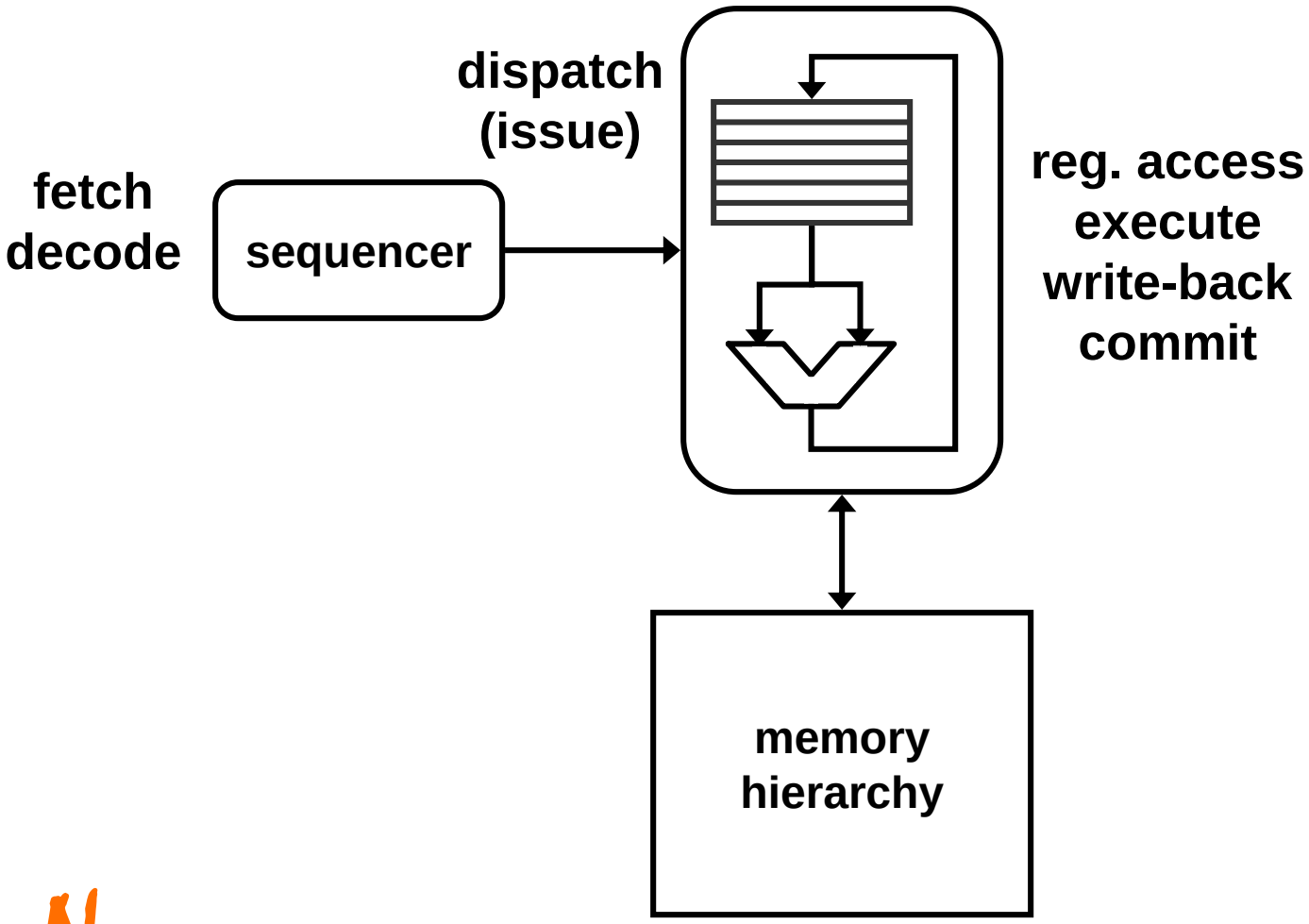
Reminders

- This is not a microarchitecture class
  - We will be discussing microarch. of various stream processors though
    - Details deferred to later in the semester
- This class is not a replacement for Parallel Computer Architecture class
  - We only superficially cover many details of parallel architectures
  - Focus on parallelism and locality at the same time

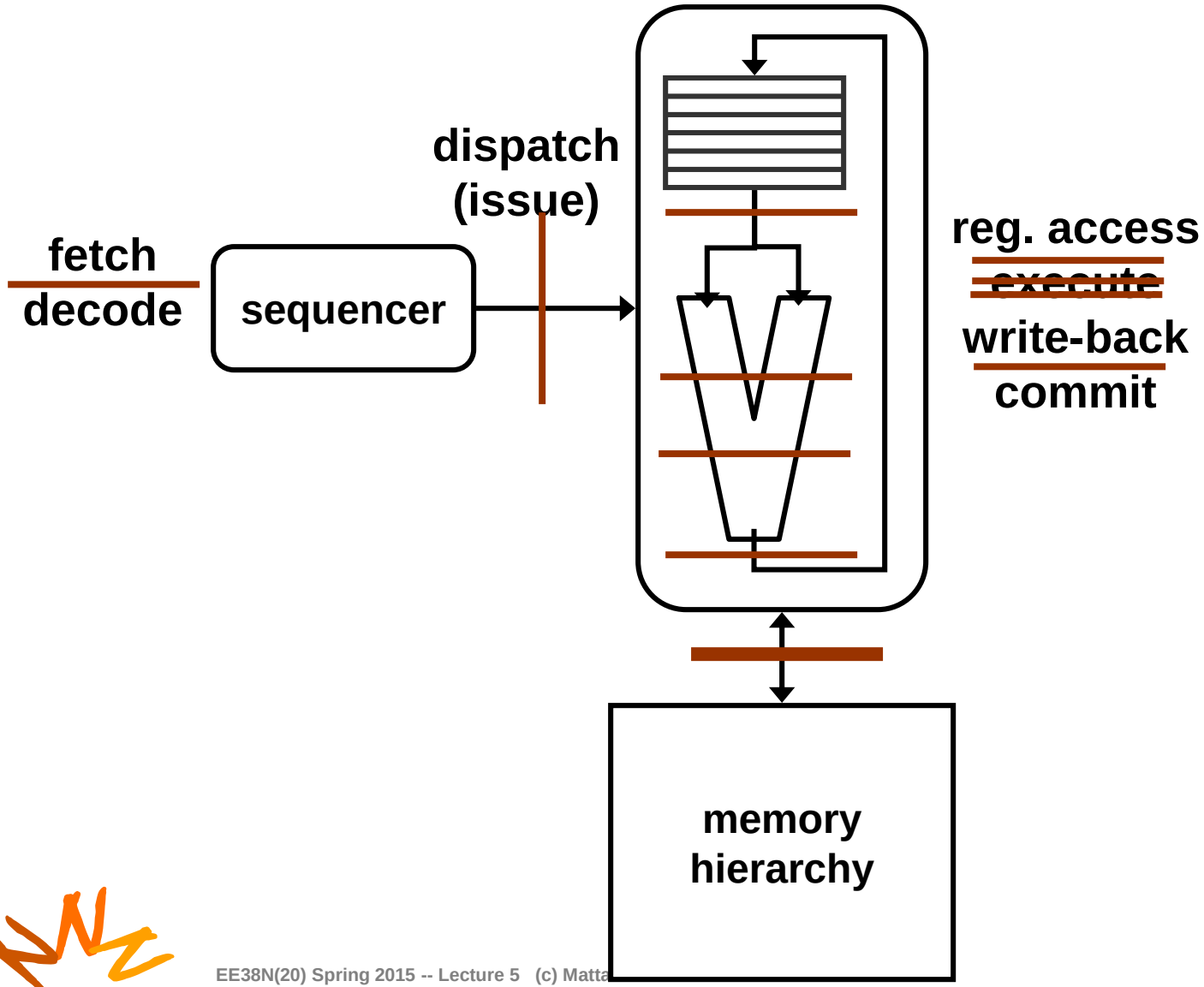
Outline

- Cache oblivious algorithms "sub-talk"
- Principles of parallel execution
- Pipelining
- Parallel HW (multiple ALUs)
  - Analyze by shared resources
  - Analyze by synch/comm mechanisms
  - ILP, DLP, and TLP organizations

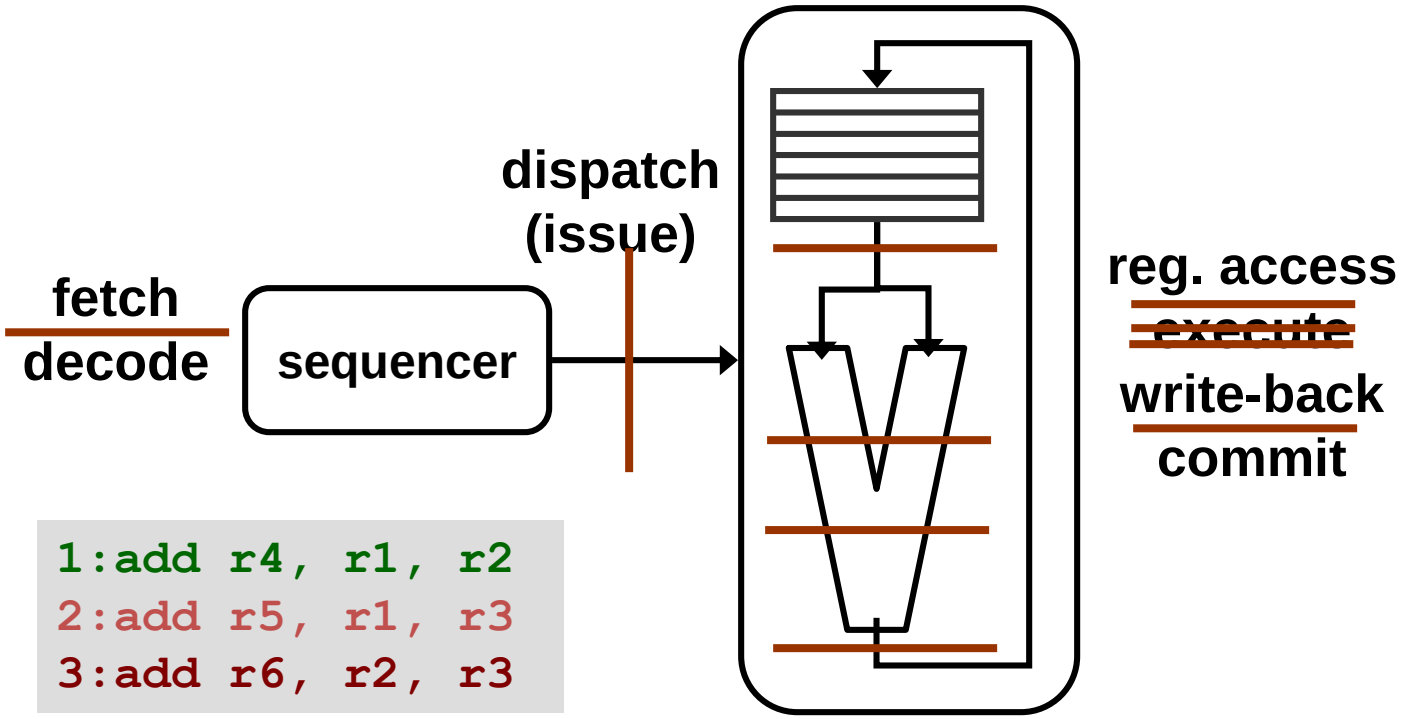
Simplified view of a processor



Simplified view of a pipelined processor



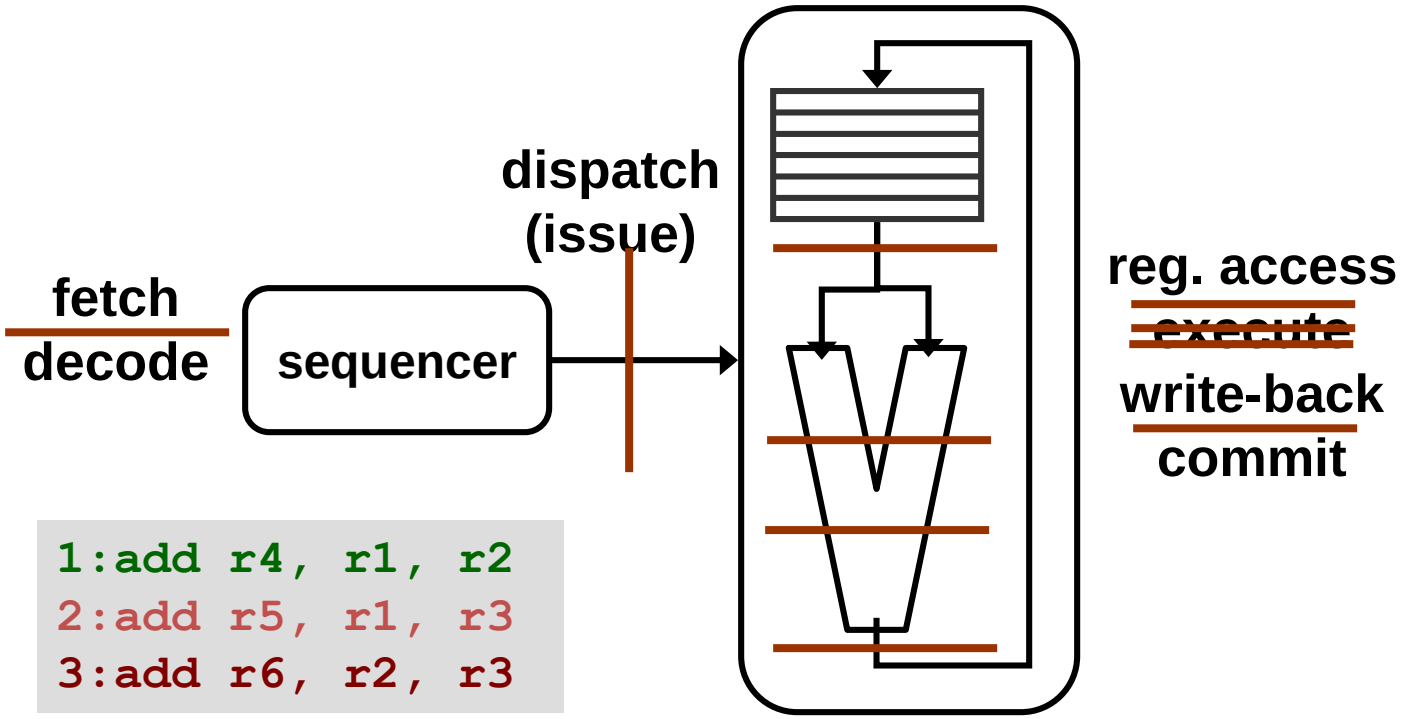
Simplified view of a pipelined processor




```
1:add r4, r1, r2
2:add r5, r1, r3
3:add r6, r2, r3
```

1	F	D	I	R	E	E	E	W	C

Simplified view of a pipelined processor

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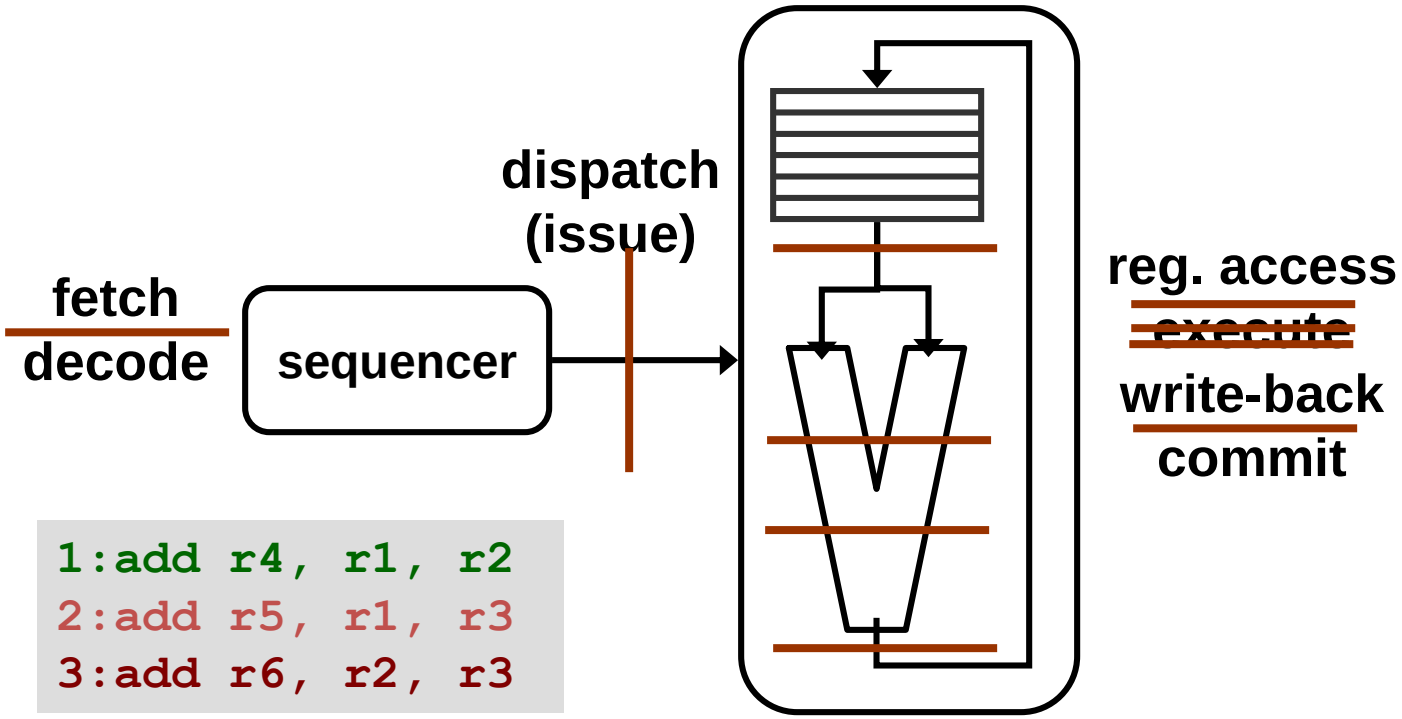


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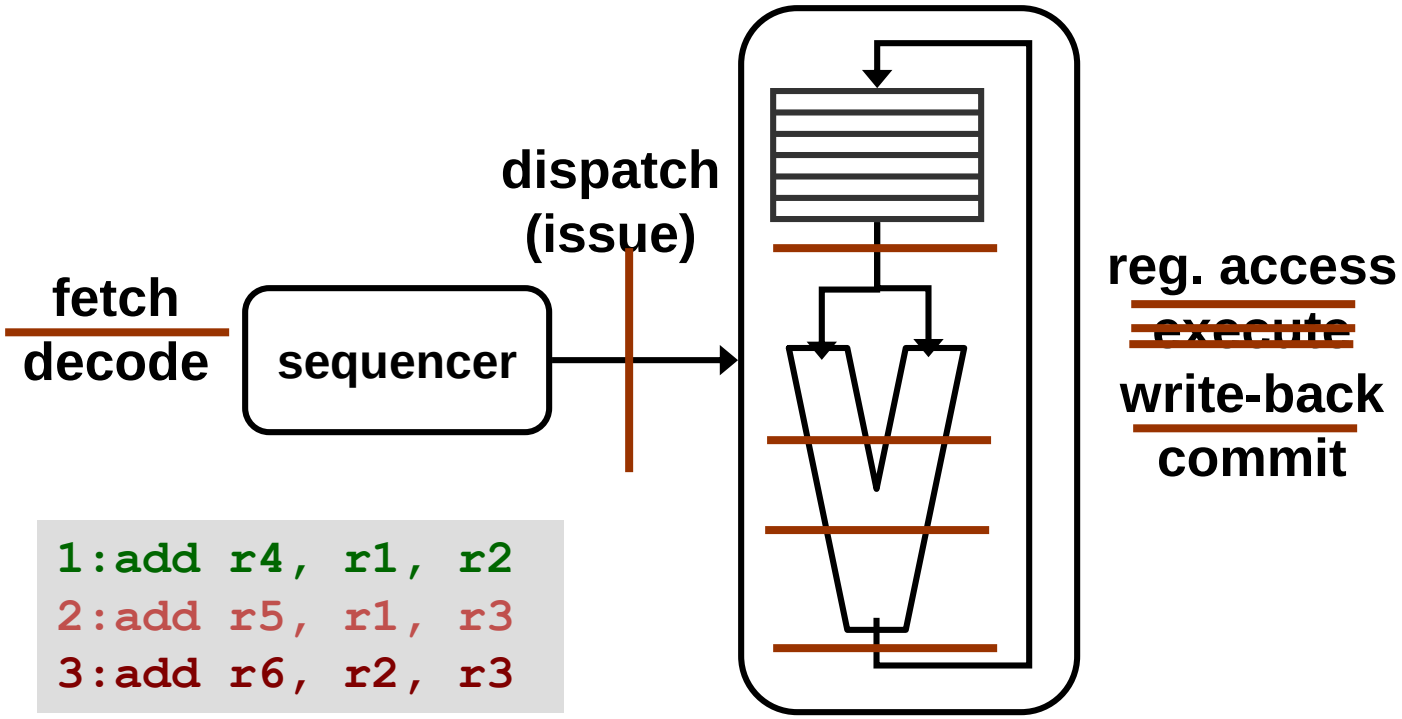


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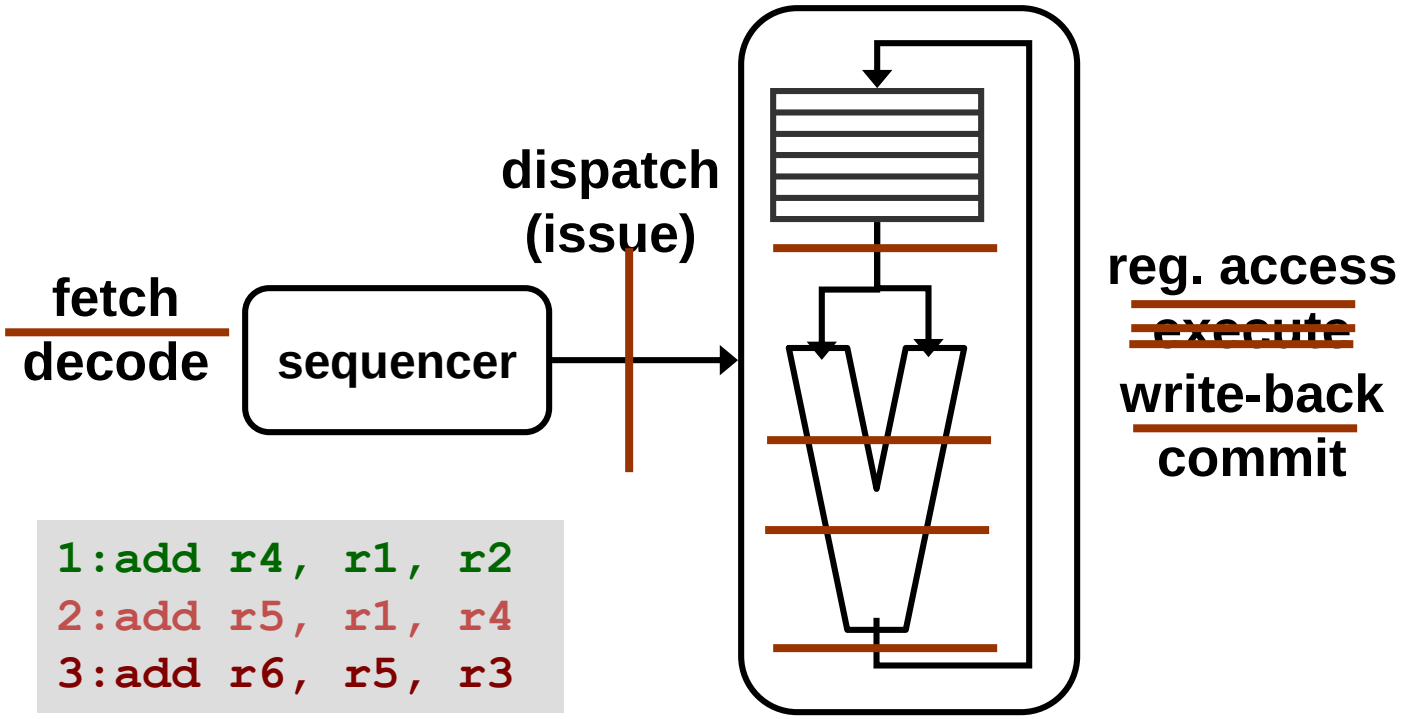
```

1	F	D	I	R	E	E	E	W	C														
2		F	D	I	R	E	E	E	W	C														
3			F	D	I	R	E	E	E	W	C													

What are the parallel resources?

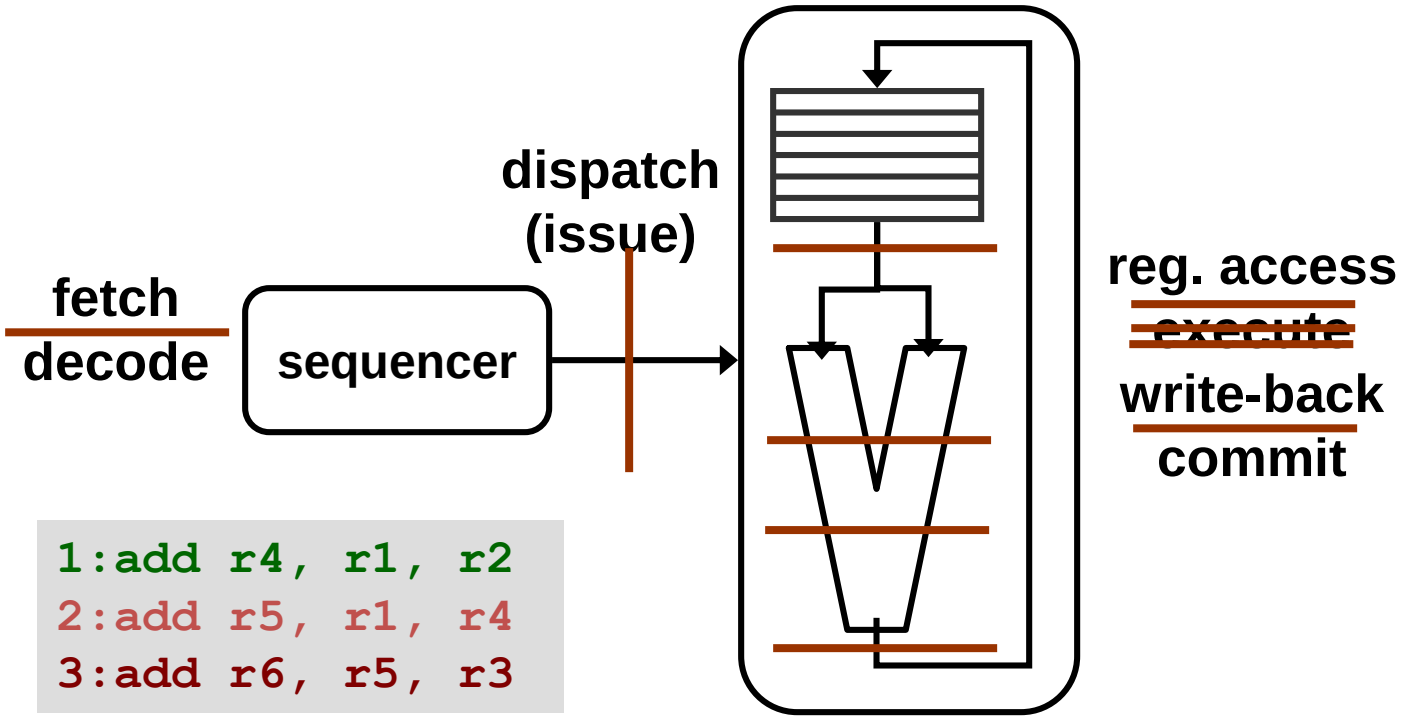
Simplified view of a pipelined processor




```
1:add r4, r1, r2
2:add r5, r1, r4
3:add r6, r5, r3
```

1	F	D	I	R	E	E	E	W	C													

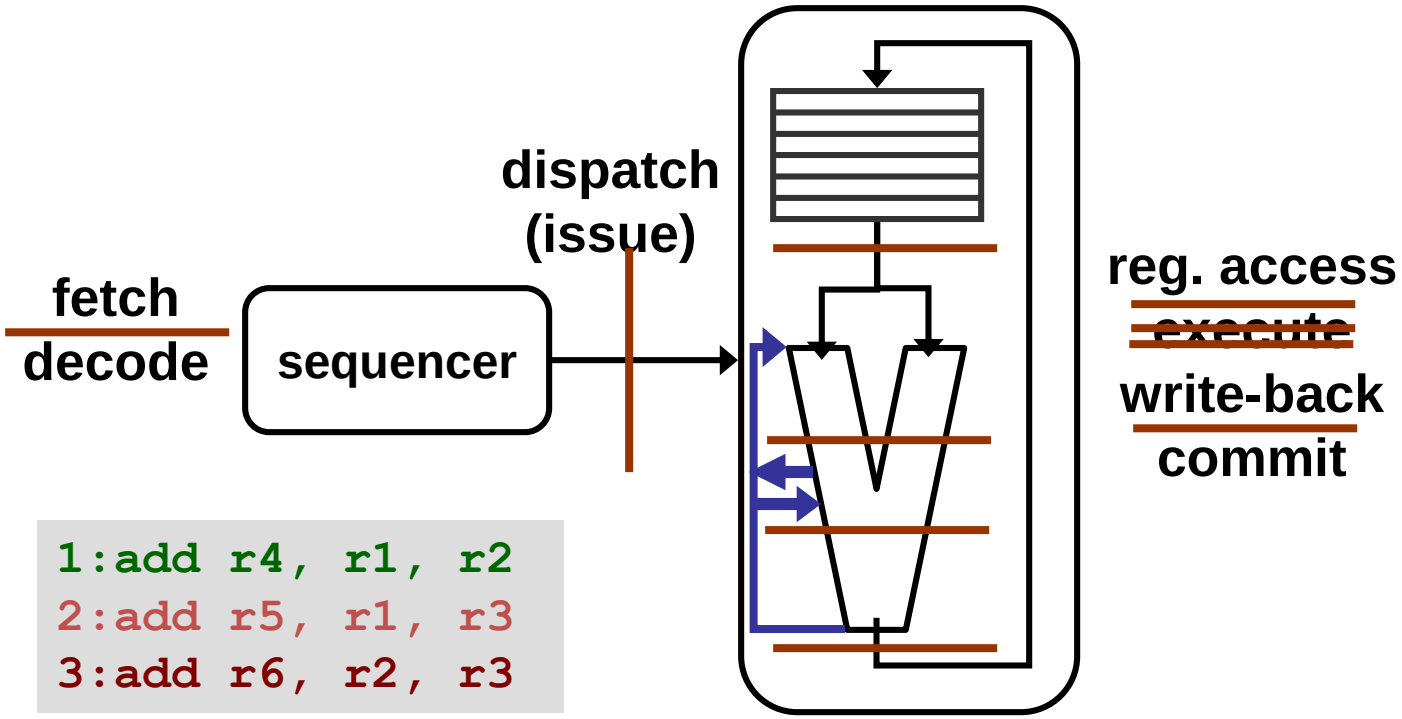
Simplified view of a pipelined processor




```
1:add r4, r1, r2
2:add r5, r1, r4
3:add r6, r5, r3
```

1	F	D	I	R	E	E	E	W	C														
2		F	D	I					R	E	E	E	W	C									
3			F	D	I									R	E	E	E	W	C				

Simplified view of a pipelined processor

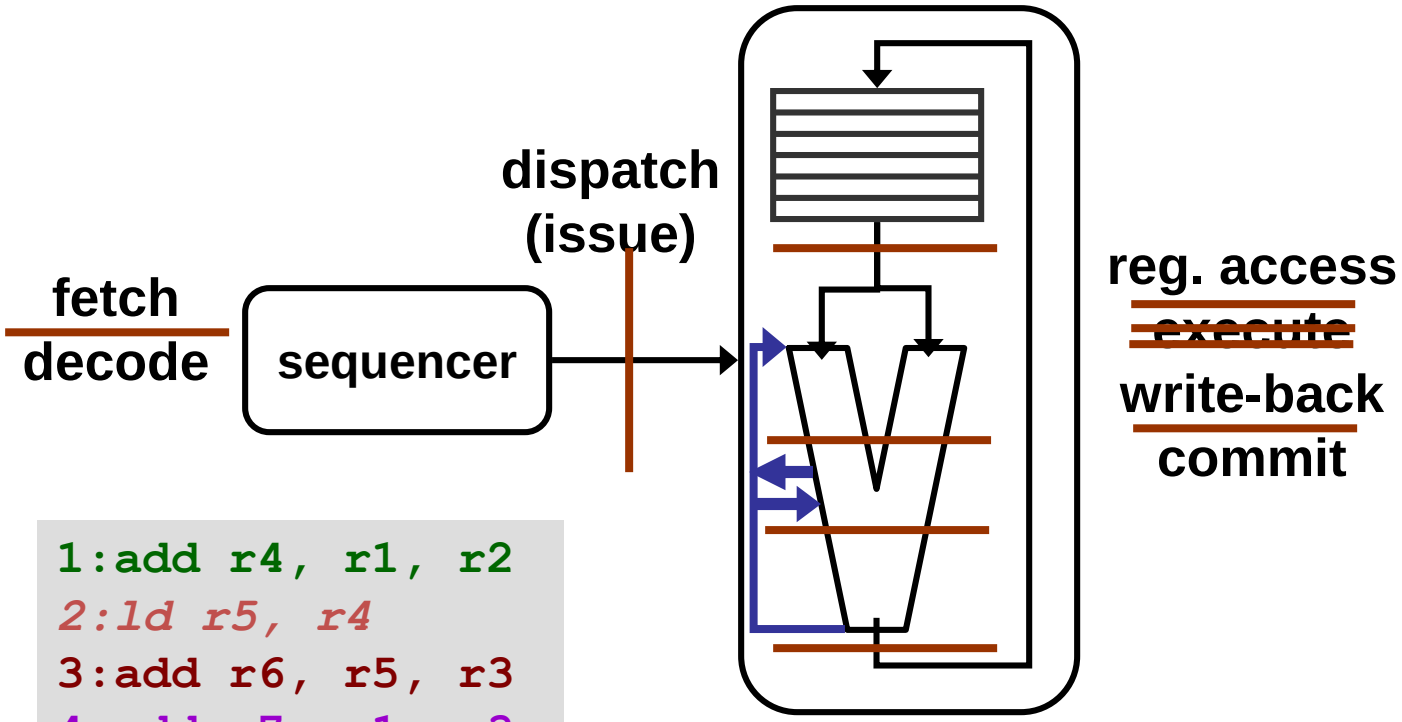



```
1:add r4, r1, r2
2:add r5, r1, r3
3:add r6, r2, r3
```

1	F	D	I	R	E	E	E	W	C														
2		F	D	I	R	E	E	E	W	C														
3			F	D	I	R	E	E	E	W	C													

Communication and synchronization mechanisms?

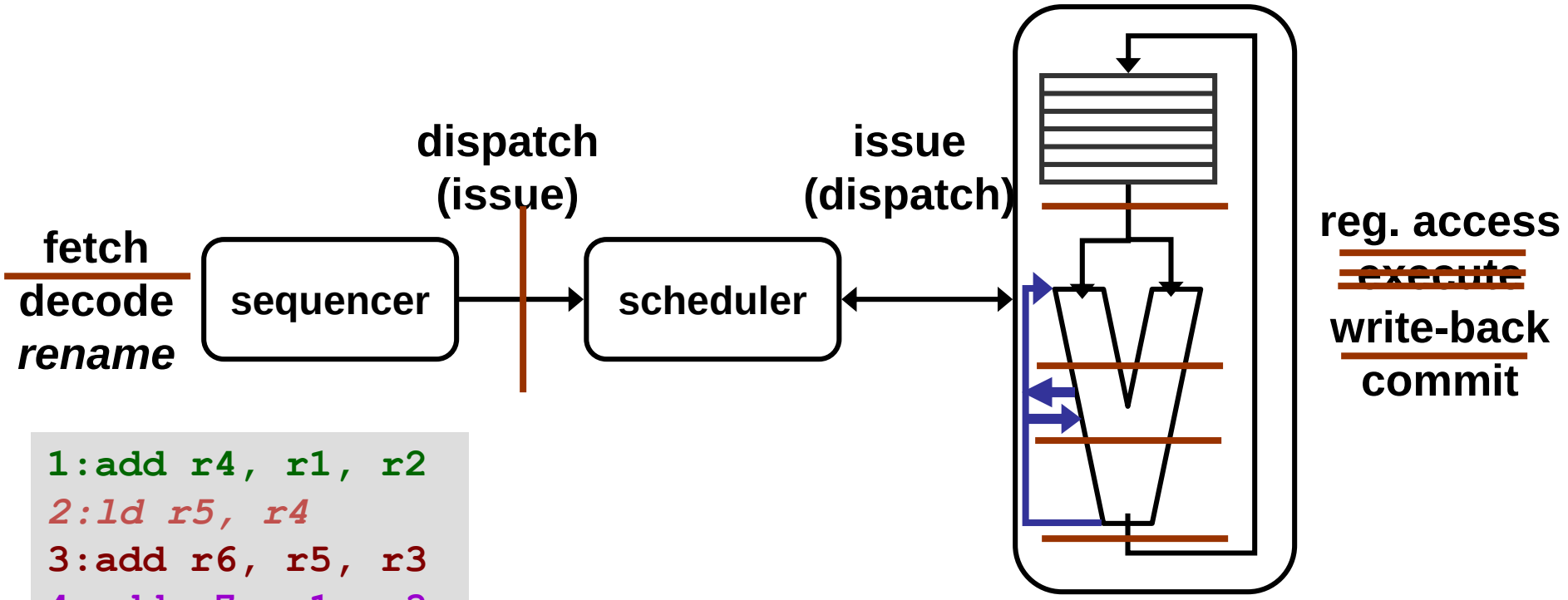
Simplified view of a pipelined processor




```
1:add r4, r1, r2
2:ld r5, r4
3:add r6, r5, r3
4:add r7, r1, r3
```

1	F	D	I	R	E	E	E	W	C														
2		F	D	I	R	L	L	L	L	L	L	L	L	L	W	C							
3			F	D	I											R	E	E	E	W	C		
4				F	D											I	R	E	E	E	W	C	

Simplified view of a OOO pipelined processor




```
1:add r4, r1, r2
2:ld r5, r4
3:add r6, r5, r3
4:add r7, r1, r3
```

1	F	D	I	d	R	E	E	E	W	C													
2		F	D	I	d	R	L	L	L	L	L	L	L	L	L	W	C							
3			F	D	I	d	R	E	E	E	W	C												

Communication and synchronization mechanisms?

Pipelining Summary

- Pipelining is using parallelism to hide latency
  - Do useful work while waiting for other work to finish
- Multiple parallel components, not multiple instances of same component
- Examples:
  - Execution pipeline
  - Memory pipelines
    - Issue multiple requests to memory without waiting for previous requests to complete
  - Software pipelines
    - Overlap different software blocks to hide latency: **computation/communication**

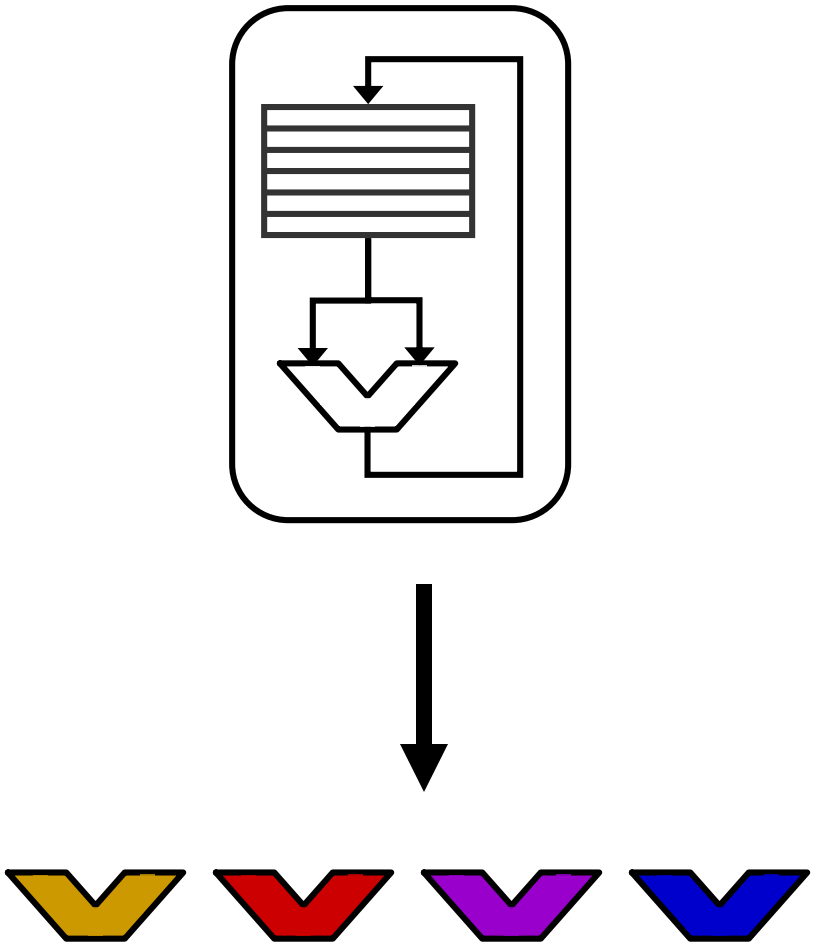
Resources in a parallel processor/system

- Execution
  - ALUs
  - Cores/processors
- Control
  - Sequencers
  - Instructions
  - OOO schedulers
- State
  - Registers
  - Memories
- Networks

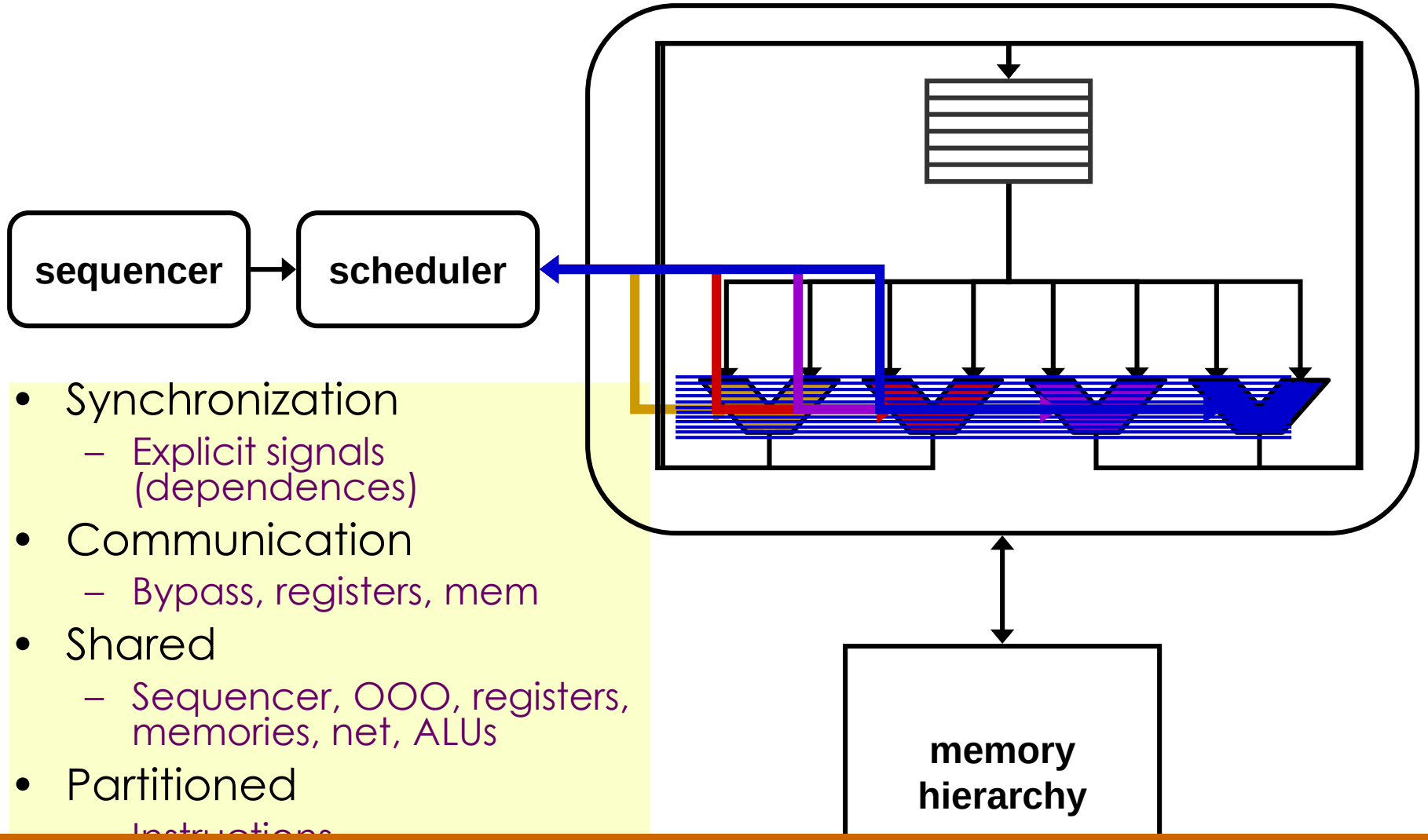
Communication and synchronization

- Synchronization
  - Clock – explicit compiler order
  - Explicit signals (e.g., dependences)
  - Implicit signals (e.g., flush/stall)
    - More for pipelining than multiple ALUs
- Communication
  - Bypass networks
  - Registers
  - Memory
  - Explicit (over some network)

Organizations for ILP (for multiple ALUs)



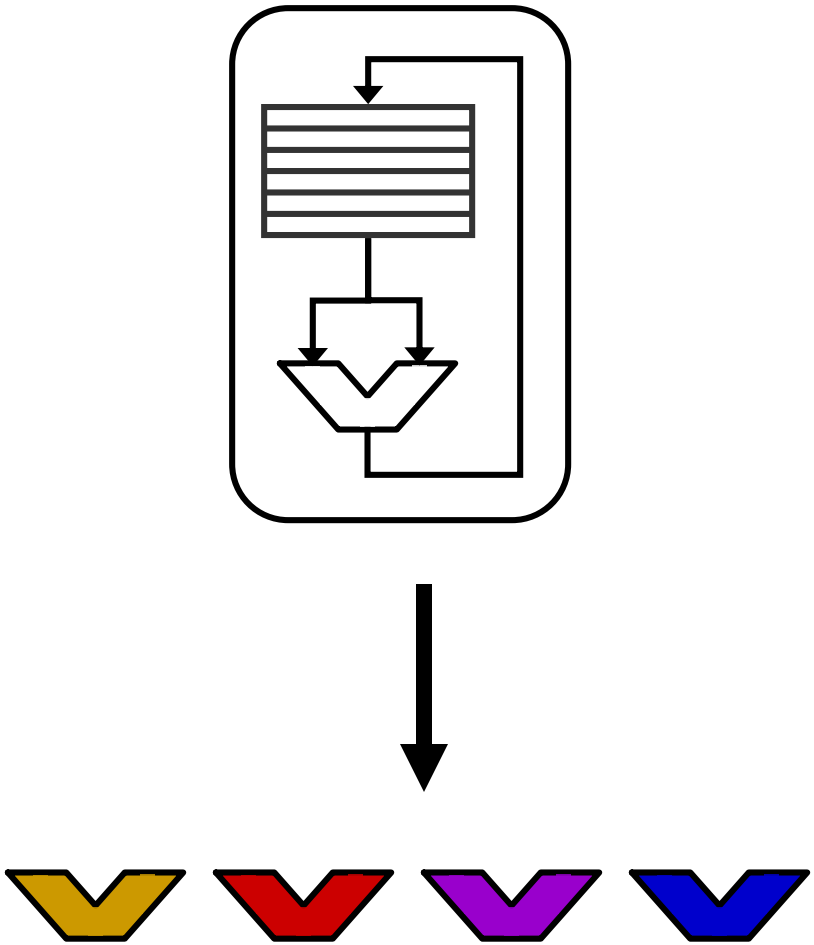
Superscalar (ILP for multiple ALUs)



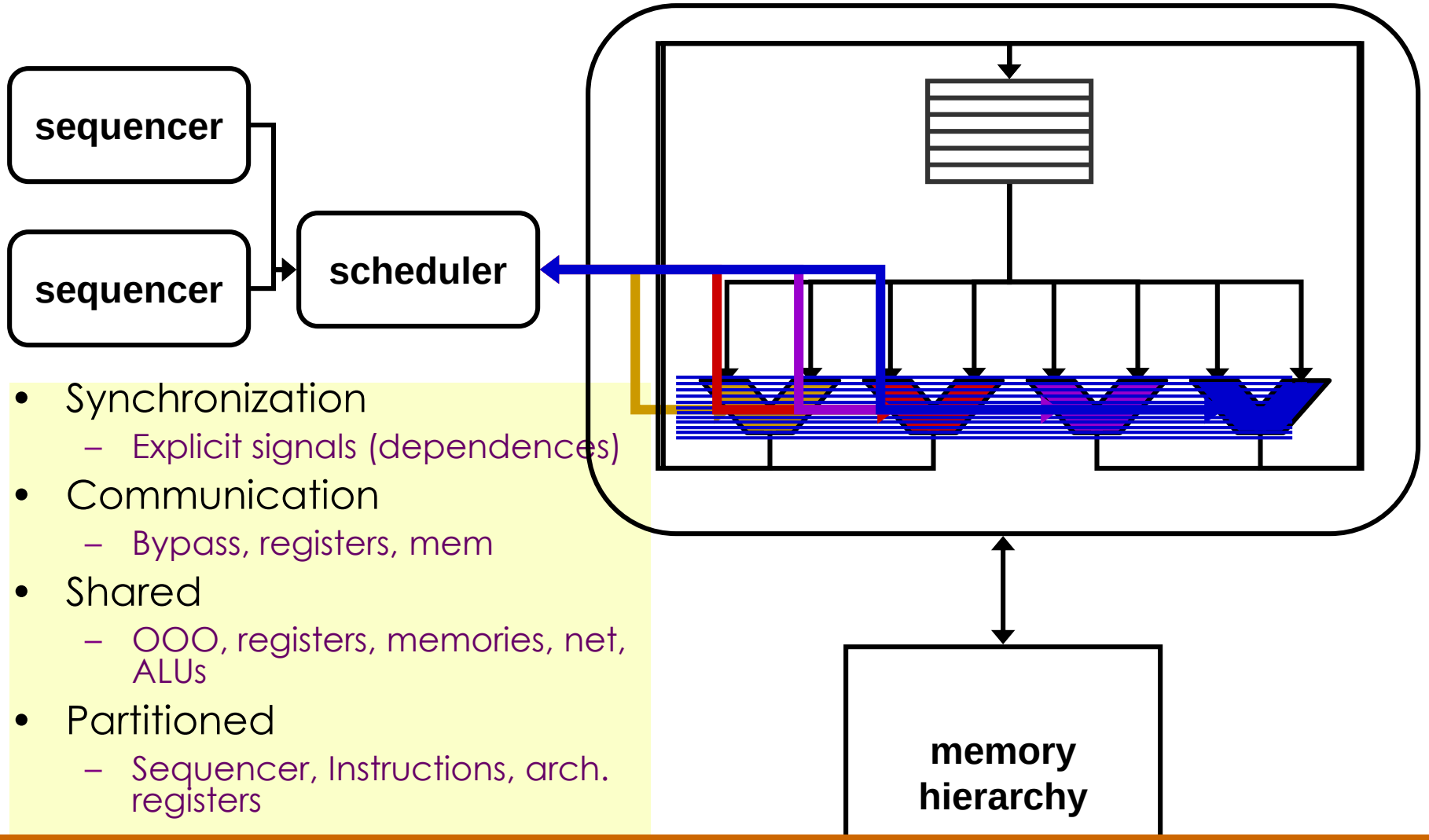
- Synchronization
  - Explicit signals (dependences)
- Communication
  - Bypass, registers, mem
- Shared
  - Sequencer, OOO, registers, memories, net, ALUs
- Partitioned
  - Instructions

How many ALUs?

SMT/TLS (ILP for multiple ALUs)



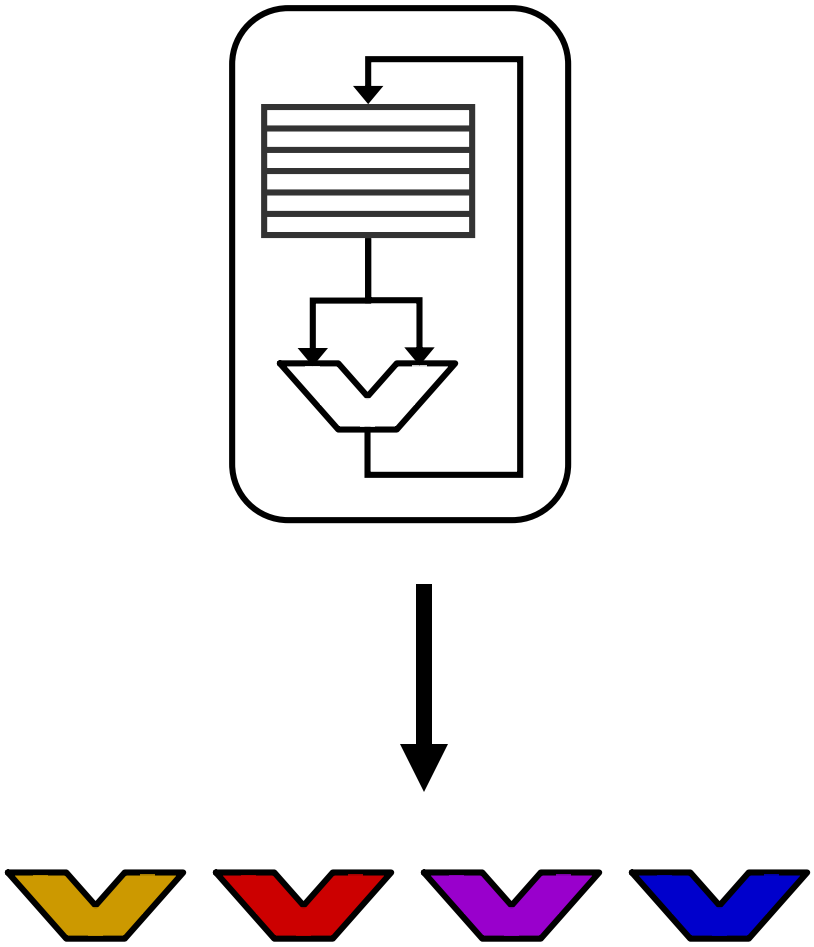
SMT/TLS (ILP for multiple ALUs)



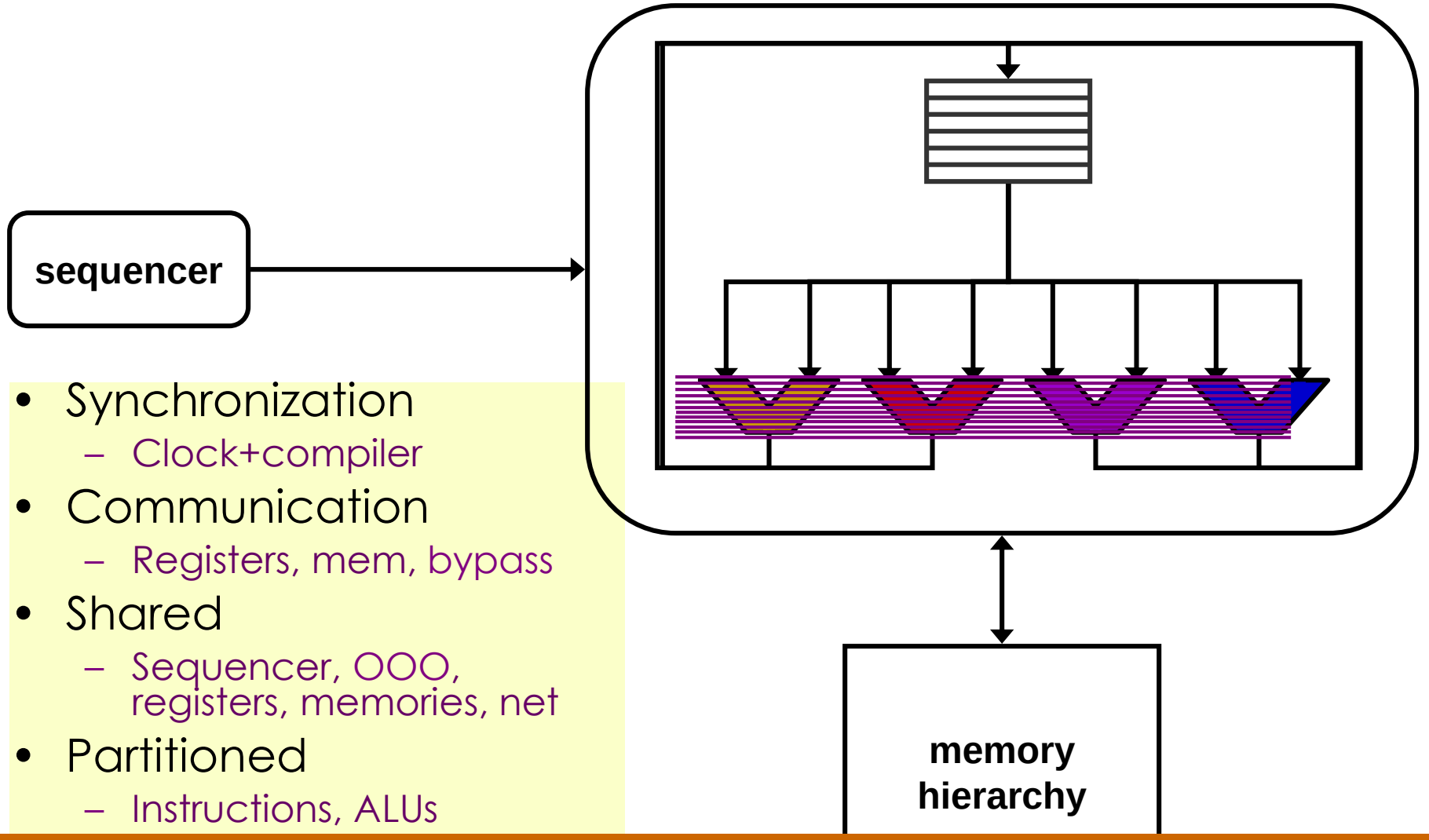
- Synchronization
  - Explicit signals (dependences)
- Communication
  - Bypass, registers, mem
- Shared
  - OOO, registers, memories, net, ALUs
- Partitioned
  - Sequencer, Instructions, arch. registers

Why is this ILP? How many threads?

VLIW (ILP for multiple ALUs)



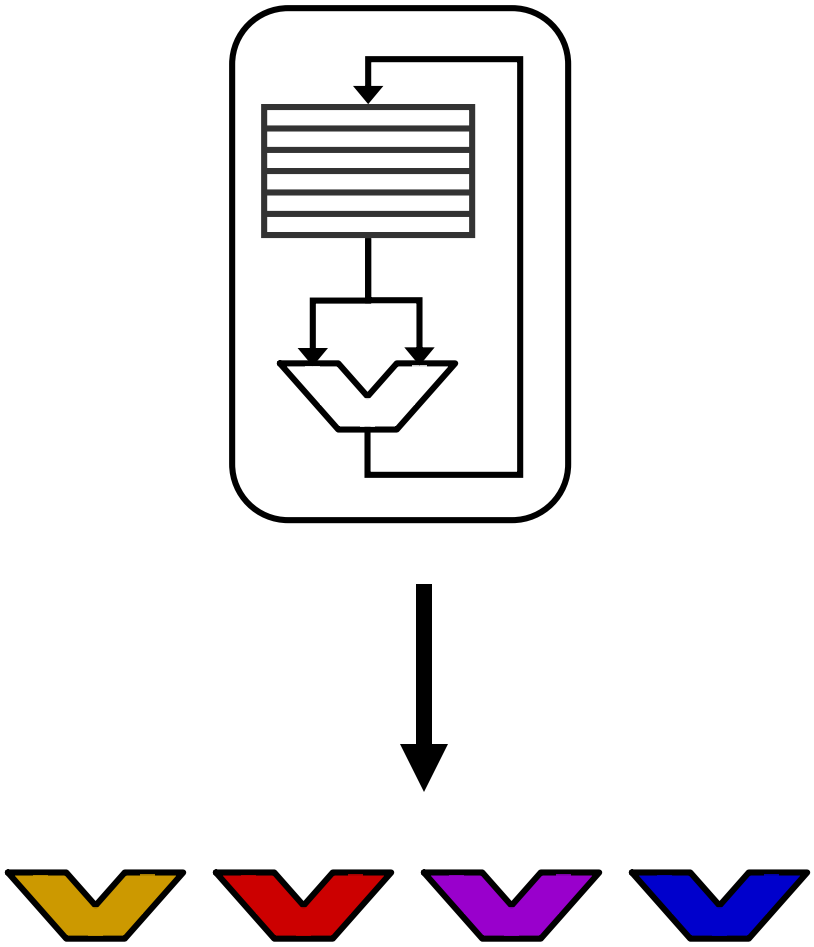
VLIW (ILP for multiple ALUs)



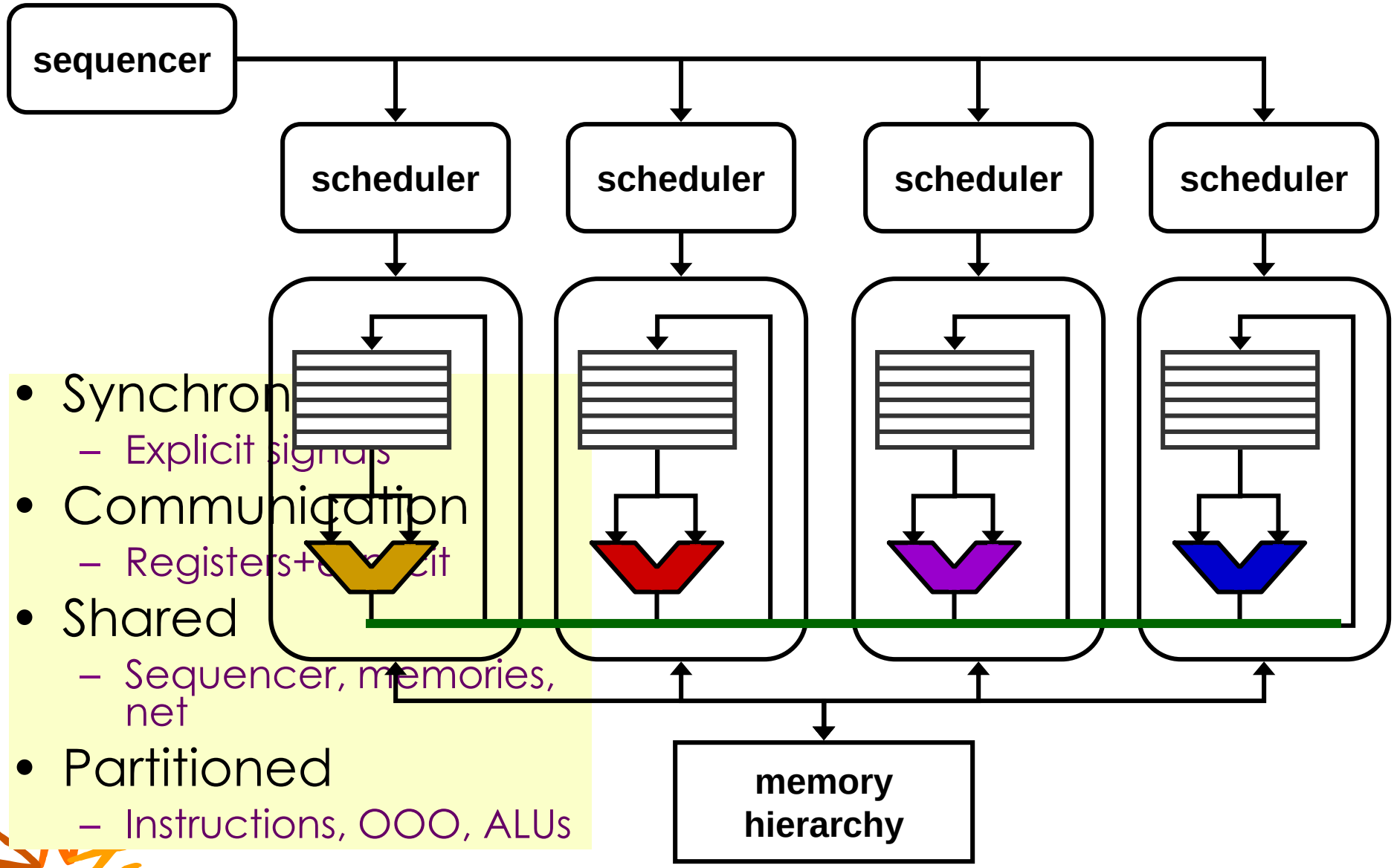
- Synchronization
  - Clock+compiler
- Communication
  - Registers, mem, bypass
- Shared
  - Sequencer, OOO, registers, memories, net
- Partitioned
  - Instructions, ALUs

How many ALUs?

Explicit Dataflow (ILP for multiple ALUs)

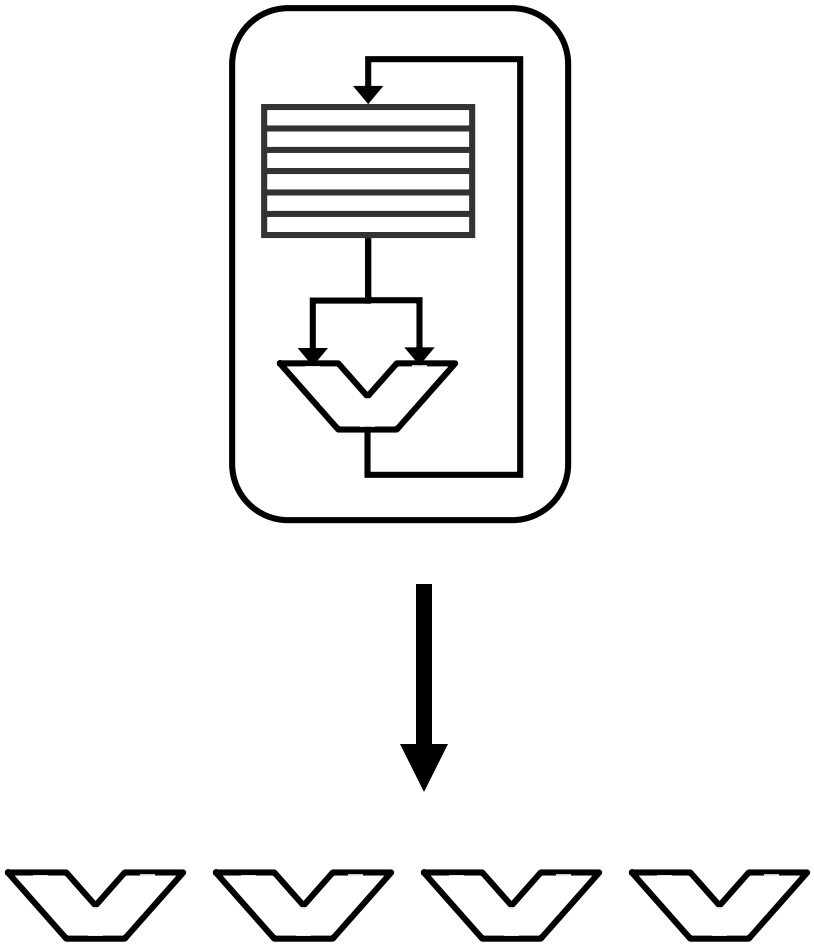


Explicit Dataflow (ILP for multiple ALUs)



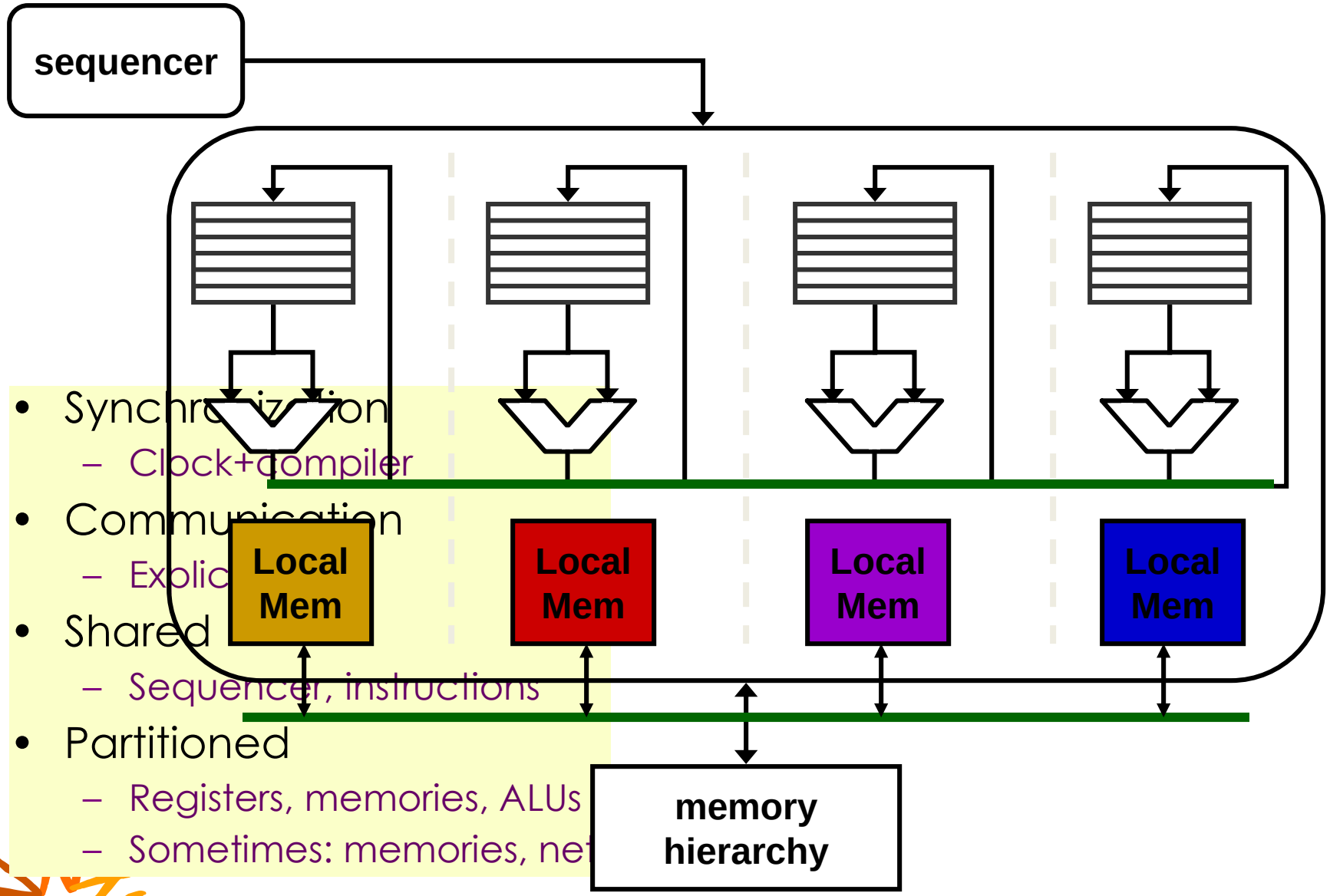
- Synchron
  - Explicit signals
- Communication
  - Registers+Explicit
- Shared
  - Sequencer, memories, net
- Partitioned
  - Instructions, OOO, ALUs

DLP for multiple ALUs



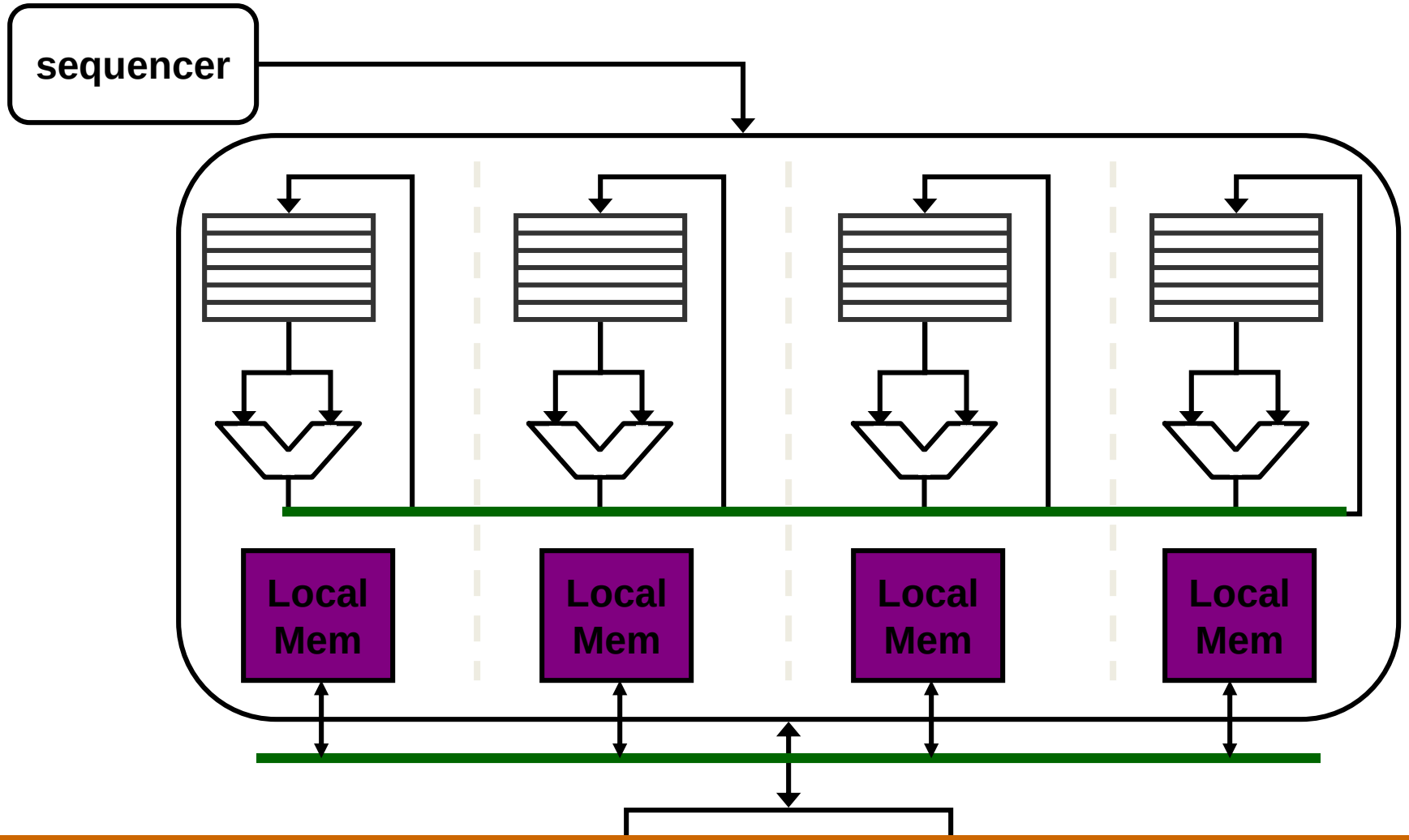
From HW – this is SIMD

SIMD (DLP for multiple ALUs)



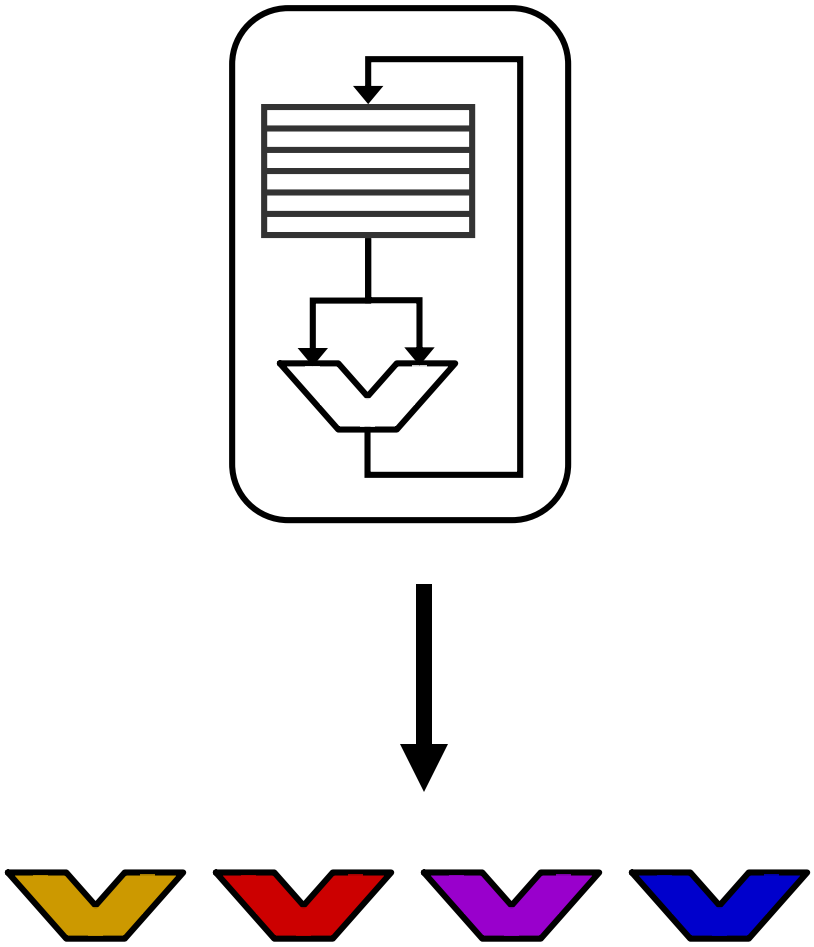
- Synchronization
  - Clock+compiler
- Communication
  - Explic
- Shared
  - Sequencer, instructions
- Partitioned
  - Registers, memories, ALUs
  - Sometimes: memories, net

Vectors (DLP for multiple ALUs)

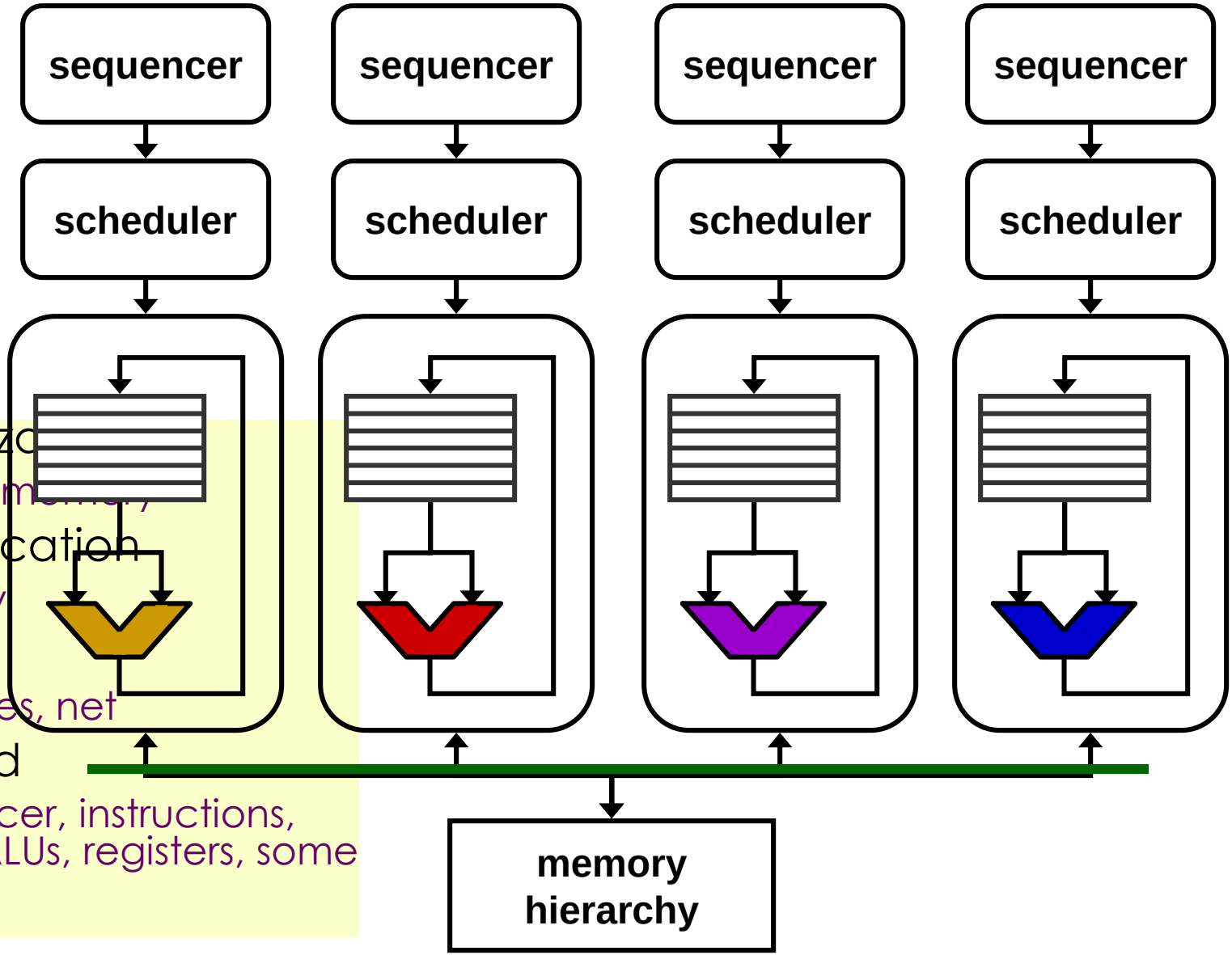


Vectors: memory addresses are part of single-instruction and not part of multiple-data

TLP for multiple ALUs



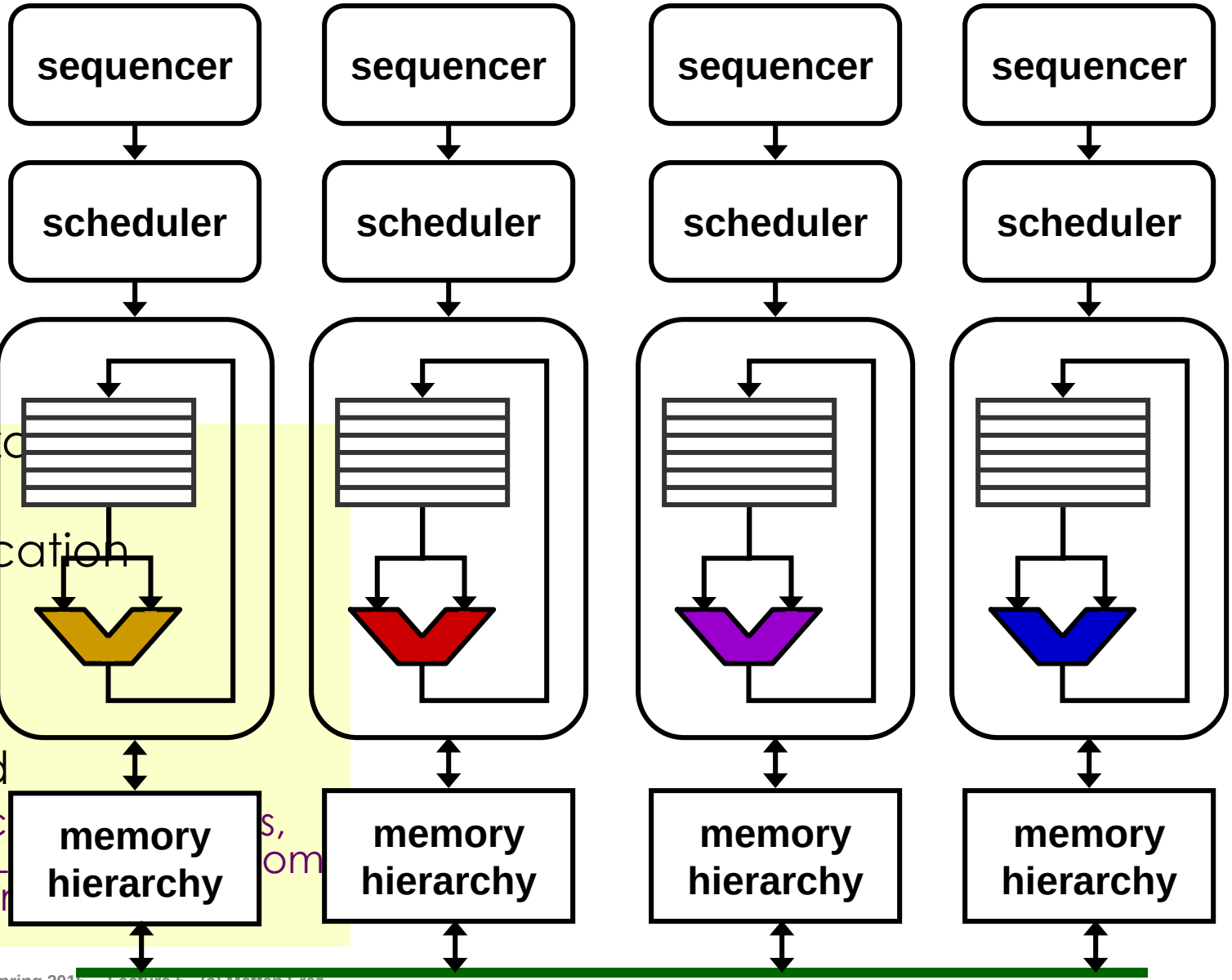
MIMD – shared memory (TLP for multiple ALUs)



- Synchroniz
  - Explicit, m
- Communication
  - Memory
- Shared
  - Memories, net
- Partitioned
  - Sequencer, instructions, OOO, ALUs, registers, some nets

MIMD – distributed memory

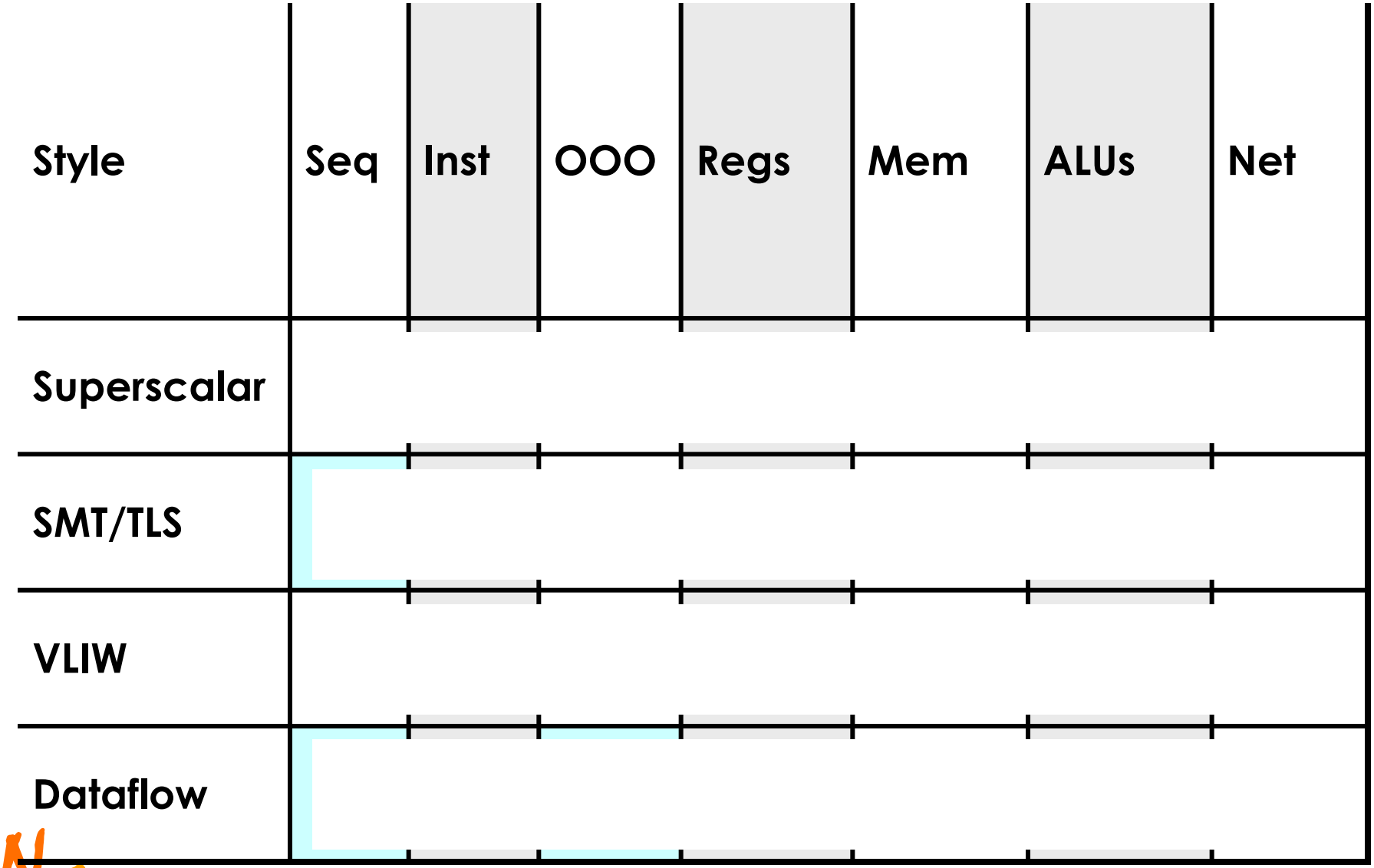
- Synchroniz
  - Explicit
- Communication
  - Explicit
- Shared
  - Net
- Partitioned
  - Sequenc s, OOO, AL om nets, mer



Summary of communication and synchronization

Style	Synchronization	Communication
Superscalar		
VLIW		
Dataflow		
SIMD		
MIMD		

Summary of sharing in ILP HW



Summary of sharing in DLP and TLP