Lecture 29(a)

Intro to Thread-Level Speculation

Automatic Parallelization

Proving independence of threads is hard:

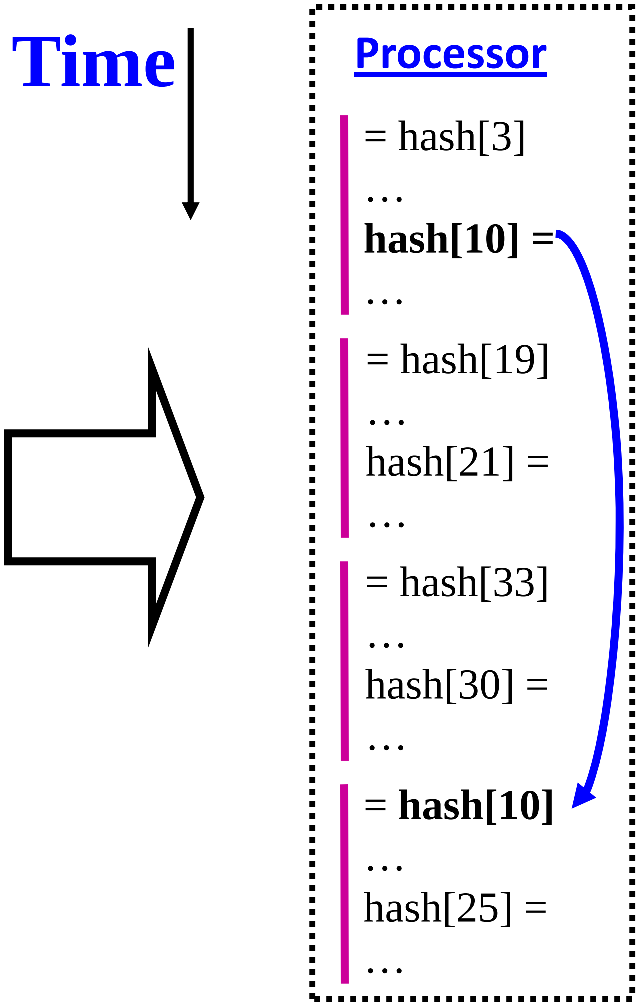
- complex control flow
- complex data structures
- pointers, pointers, pointers
- run-time inputs

How can we make the compiler's job feasible?

☞ **Thread-Level Speculation (TLS)**

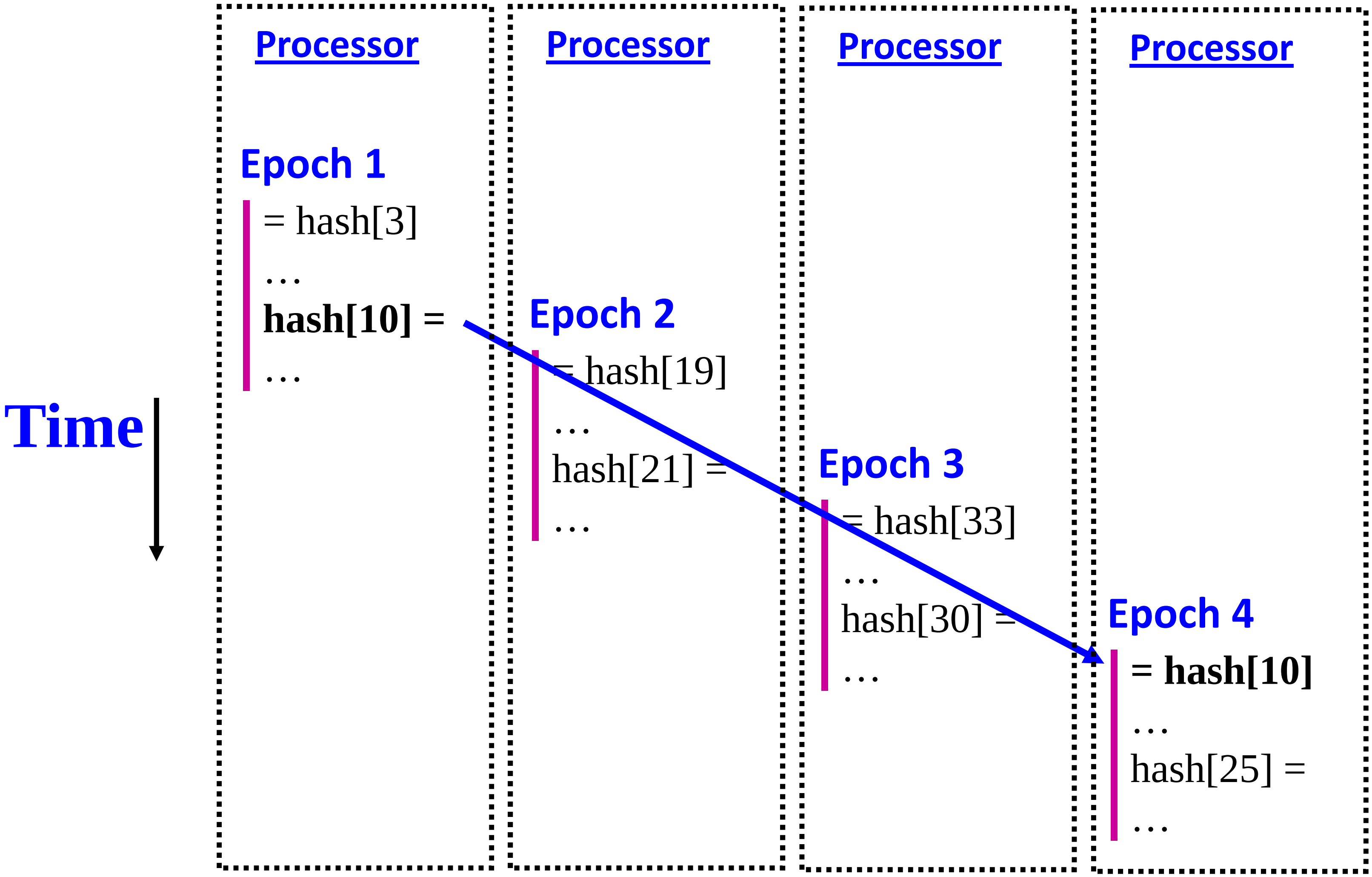
Example

```
while (...){

    x = hash[index1];
    …
    hash[index2] = y;
    ...

}
```



```
= hash[3]
…
hash[10] =
…
= hash[19]
…
hash[21] =
…
= hash[33]
…
hash[30] =
…
= hash[10]
…
hash[25] =
…
```

Example of Thread-Level Speculation



Time

Processor

Epoch 1

= hash[3]

…

hash[10] =

…

Processor

Epoch 2

= hash[19]

…

hash[21] =

…

Processor

Epoch 3

= hash[33]

…

hash[30] =

…

Processor

Epoch 4

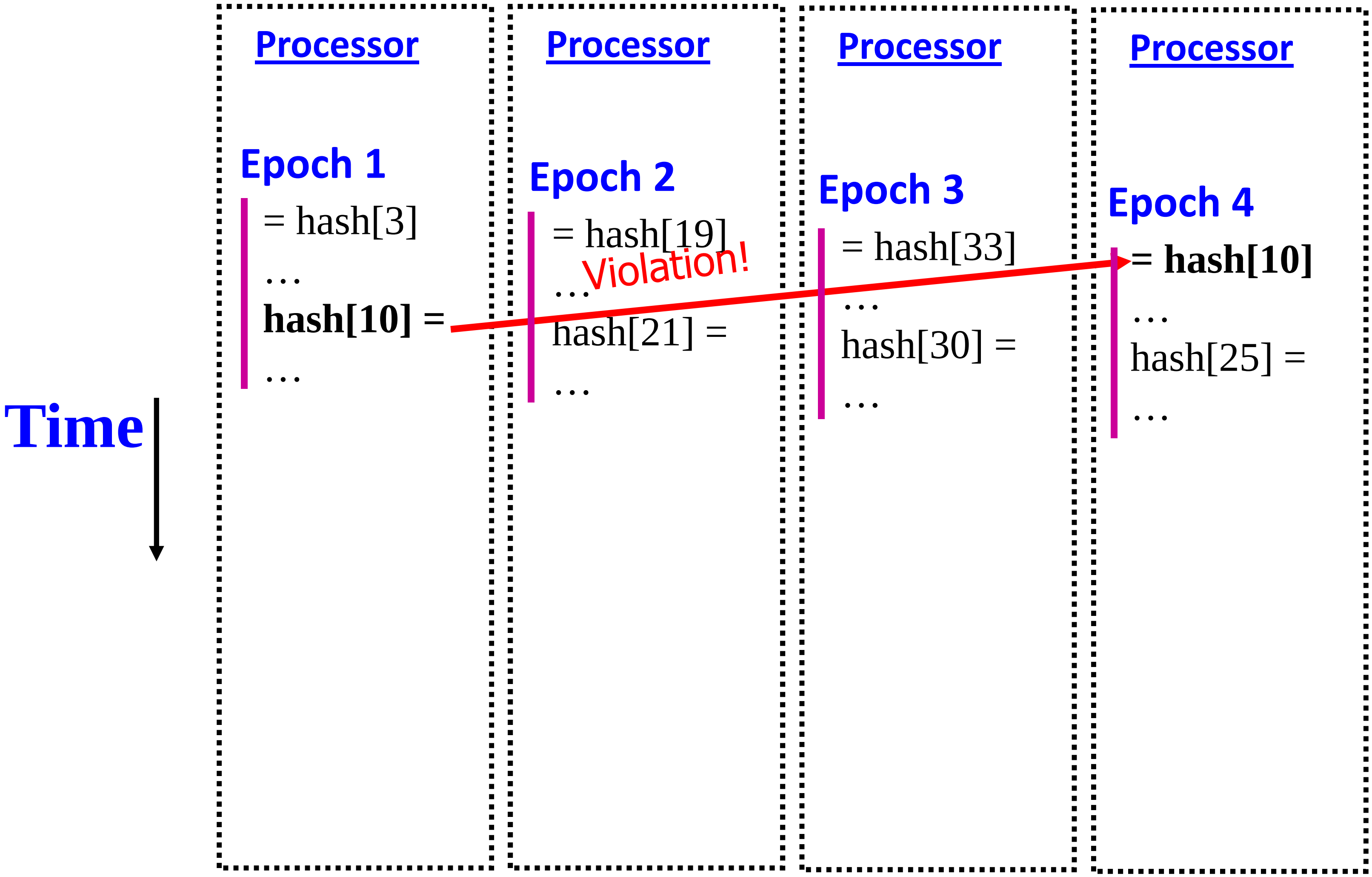
= hash[10]

…

hash[25] =

…

Example of Thread-Level Speculation



Time

Processor

Epoch 1

= hash[3]

…

hash[10] =

…

Processor

Epoch 2

= hash[19]

…

hash[21] =

…

Violation!

Processor

Epoch 3

= hash[33]

…

hash[30] =

…

Processor

Epoch 4

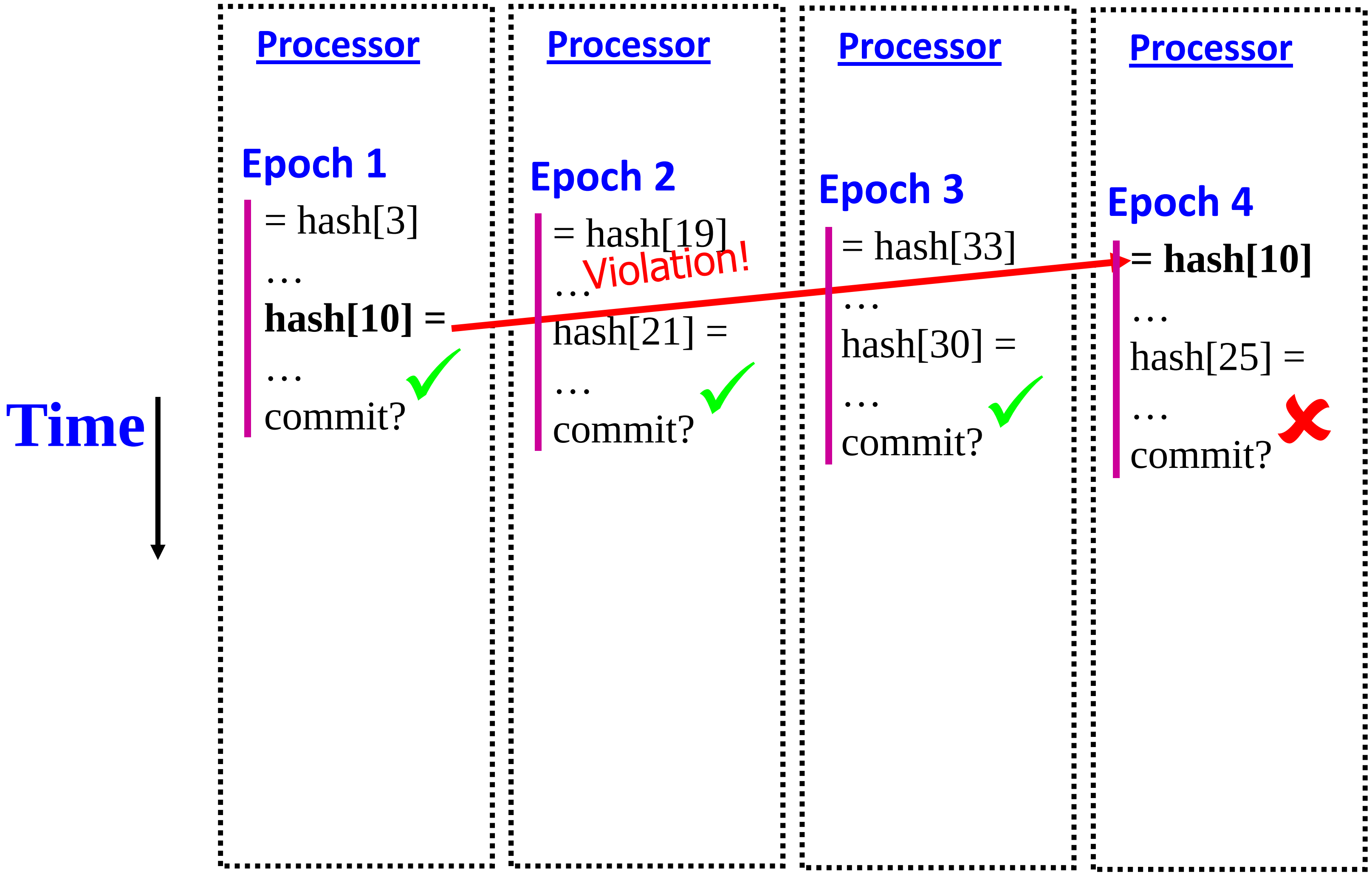
= hash[10]

…

hash[25] =

…

Example of Thread-Level Speculation



Time

Processor

Epoch 1

= hash[3]
…
hash[10] =
…
commit? ✓

Processor

Epoch 2

= hash[19]
…
hash[21] =
…
commit? ✓

Violation!

Processor

Epoch 3

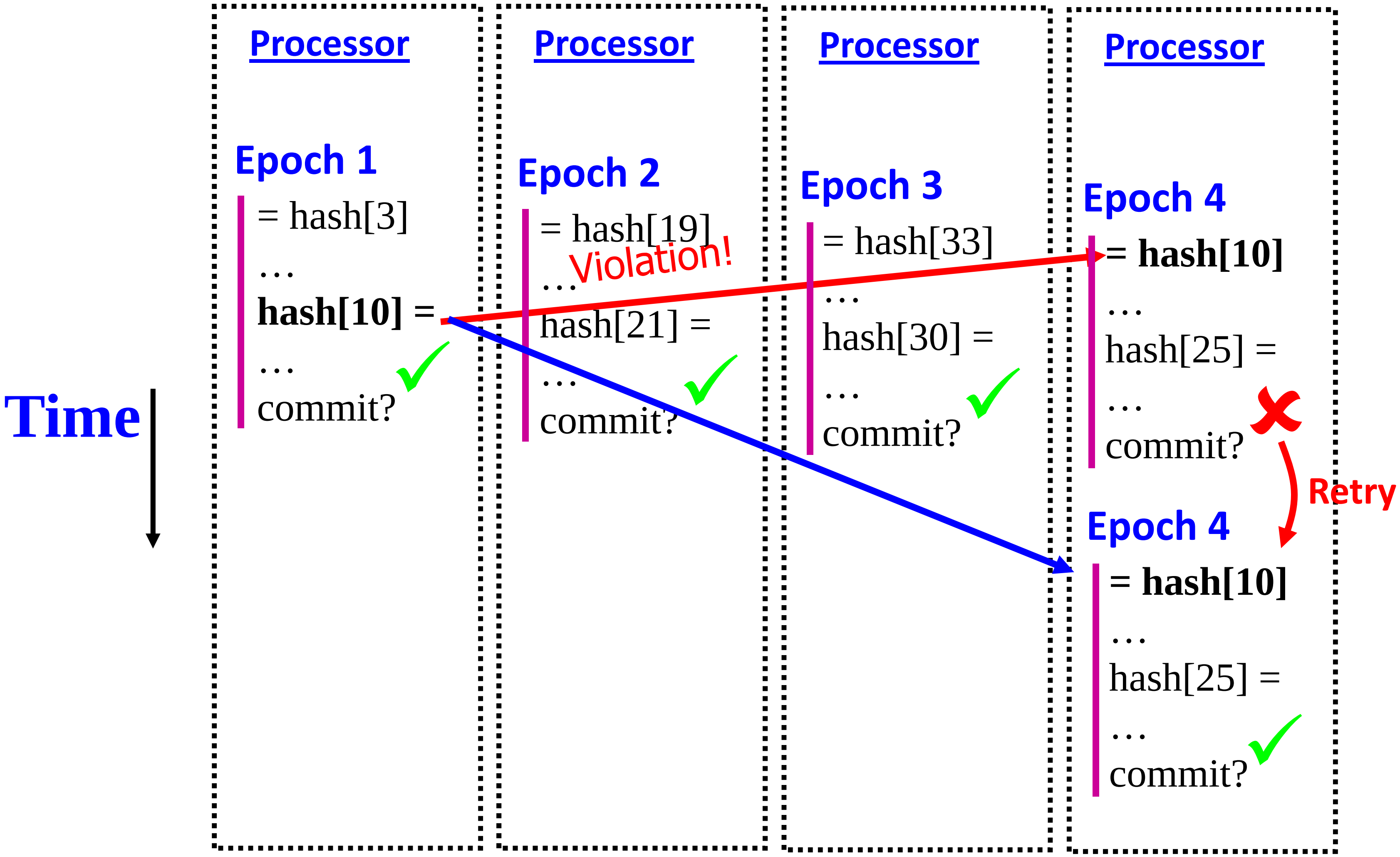
= hash[33]
…
hash[30] =
…
commit? ✓

Processor

Epoch 4

= hash[10]
…
hash[25] =
…
commit? ✗

Example of Thread-Level Speculation



Time

Processor

Epoch 1

= hash[3]

…

hash[10] =

…

commit? ✓

Processor

Epoch 2

= hash[19]

…

hash[21] =

…

commit? ✓

Violation!

Processor

Epoch 3

= hash[33]

…

hash[30] =

…

commit? ✓

Processor

Epoch 4

= hash[10]

…

hash[25] =

…

commit? ✗

Retry

Epoch 4

= hash[10]

…

hash[25] =

…

commit? ✓

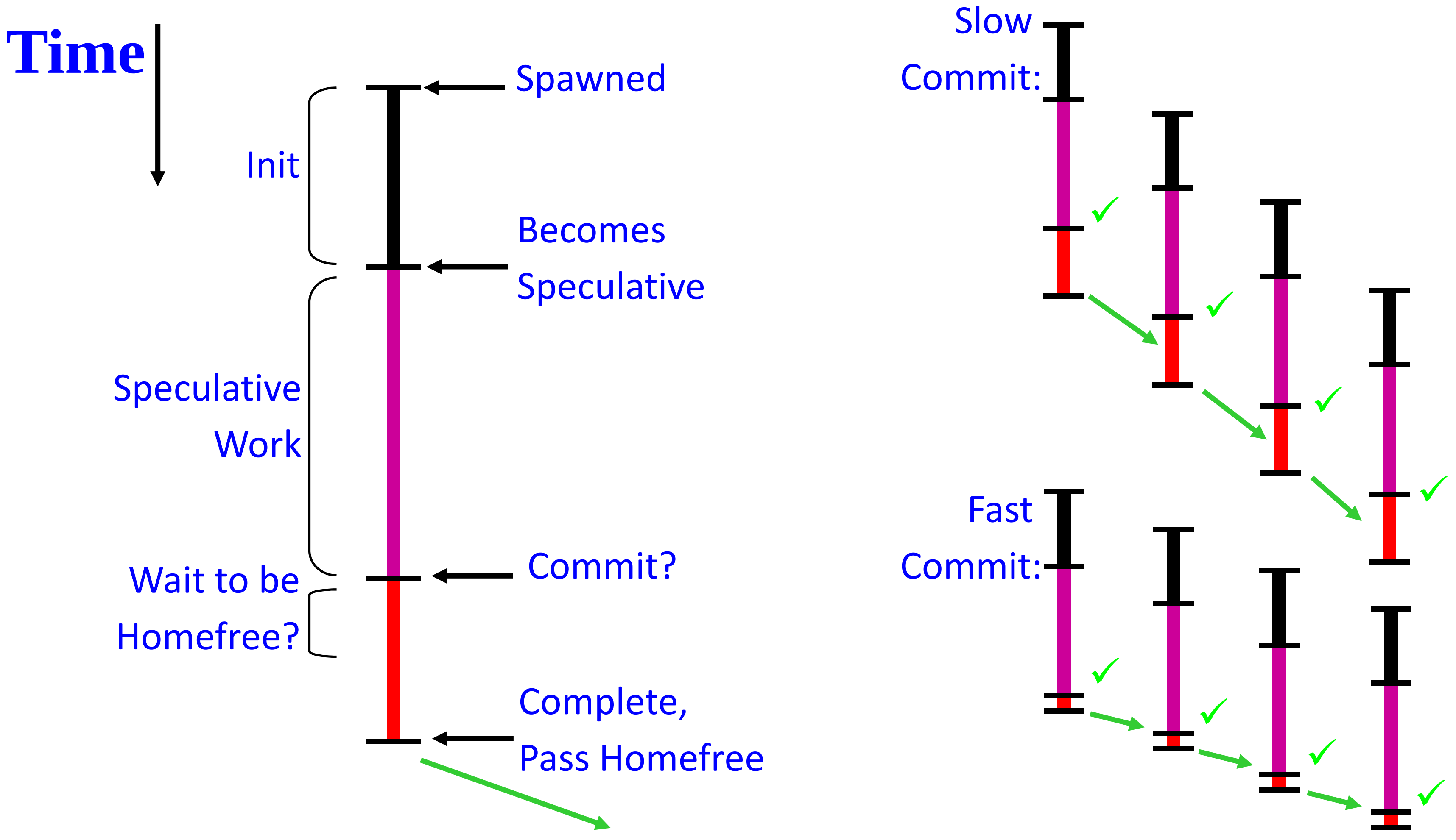
Overview of Our Approach

System requirements:

1) Detect data dependence violations
    - extend invalidation-based cache coherence

2) Buffer speculative modifications
    - use the caches as speculative buffers

Life Cycle of an Epoch



Time

Init

Spawned

Becomes Speculative

Speculative Work

Commit?

Wait to be Homefree?

Complete, Pass Homefree

Slow Commit:

Fast Commit:

Simulation Infrastructure

Compiler system and tools based on SUIF

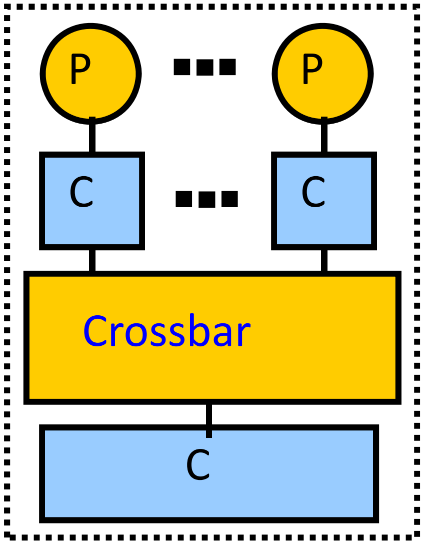
- help analyze dependences, insert synchronization
- produce **MIPS** binaries containing TLS primitives

Benchmarks (all run to completion)

- buk, compress95, ijpeg, equake

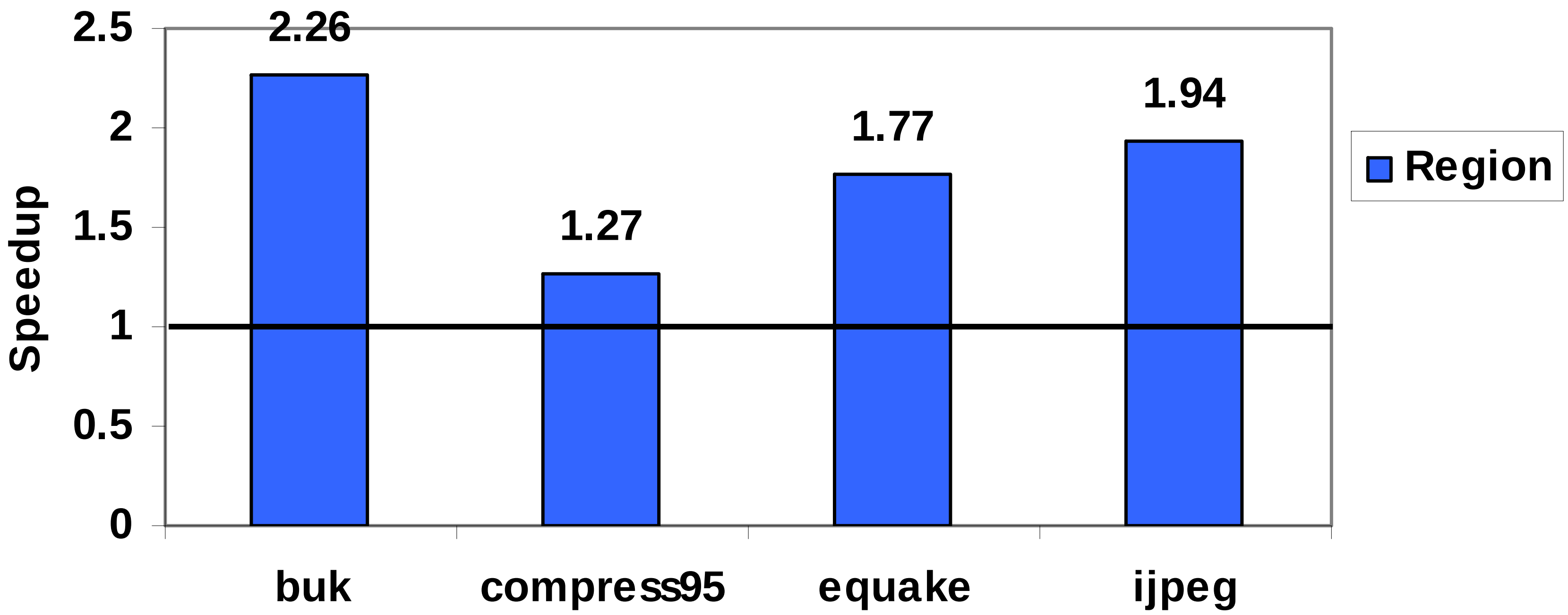
Simulator

- superscalar, similar to **MIPS R10K**
- models all bandwidth and contention



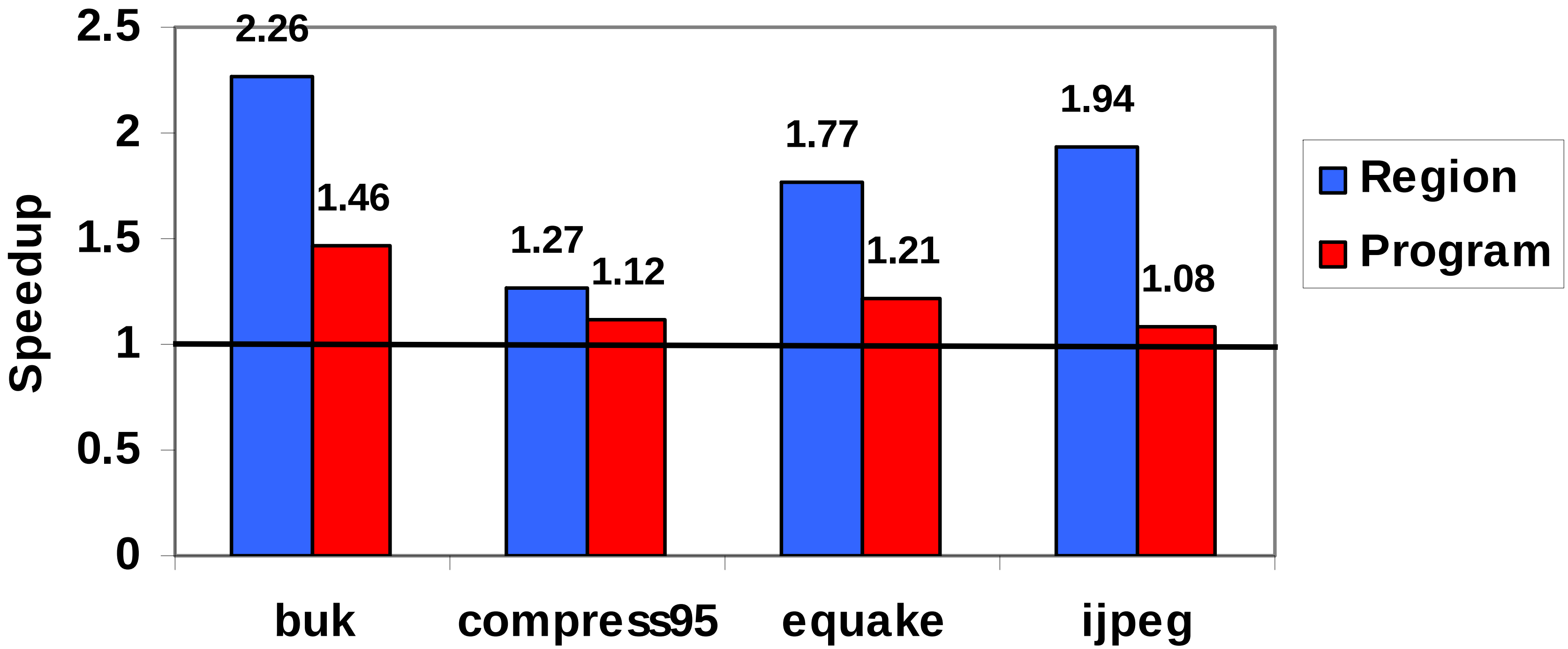
☞**detailed simulation!**

Performance on a 4-Processor CMP



Parallel Coverage: 56.6% 47.3% 39.3% 22.1%

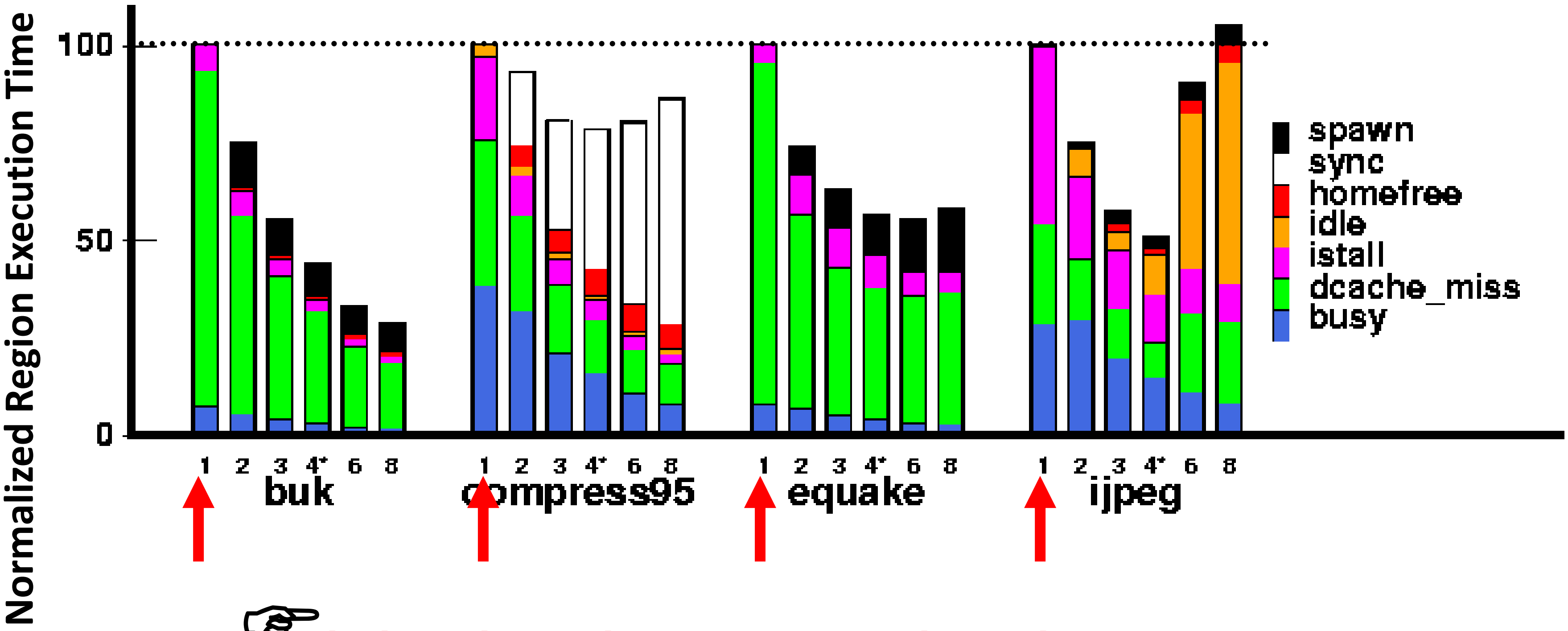
Performance on a 4-Processor CMP



Parallel Coverage: 56.6% 47.3% 39.3% 22.1%

☞ **program speedups are limited by coverage**

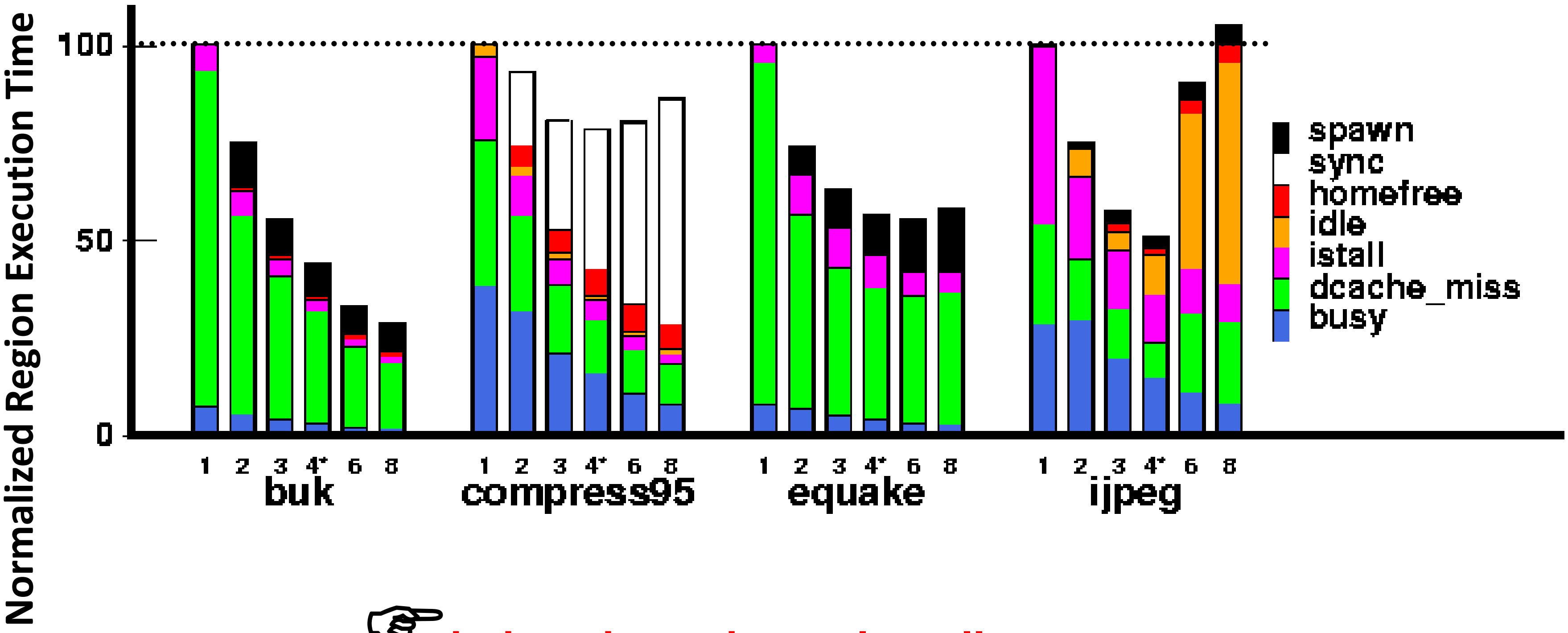
Varying the Number of Processors



☞ buk and equake are memory-bound

☞ compress95 and ijpeg are computation-intensive

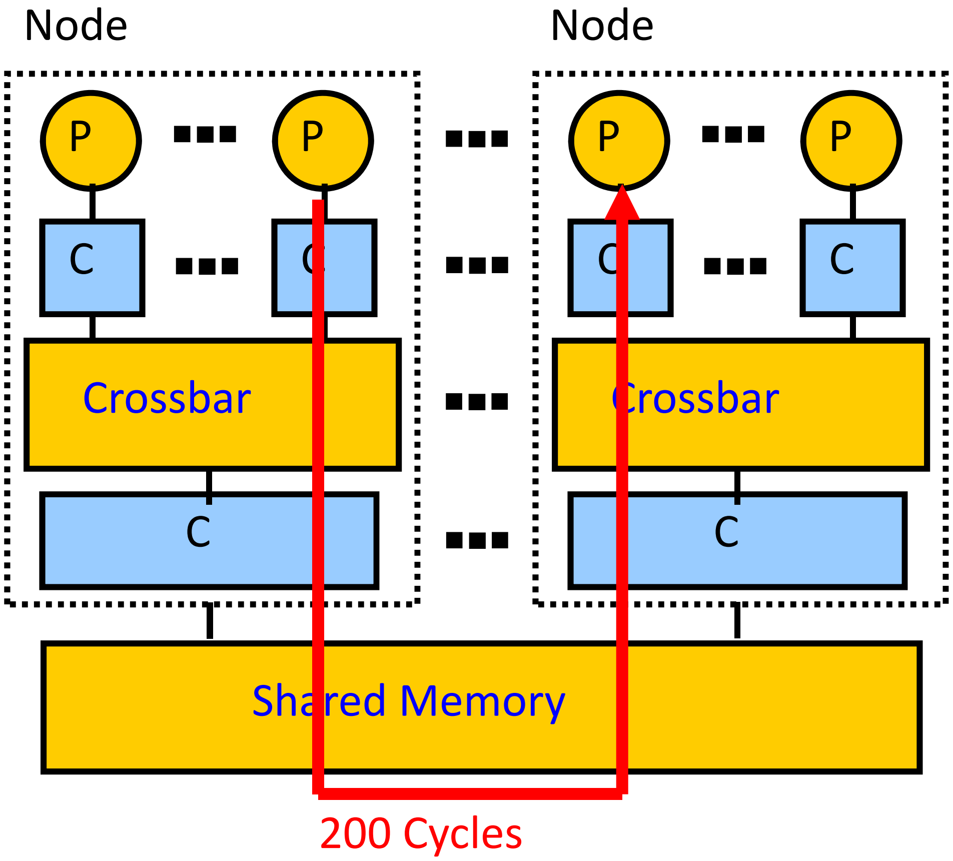
Varying the Number of Processors



☞ **buk and equake scale well**

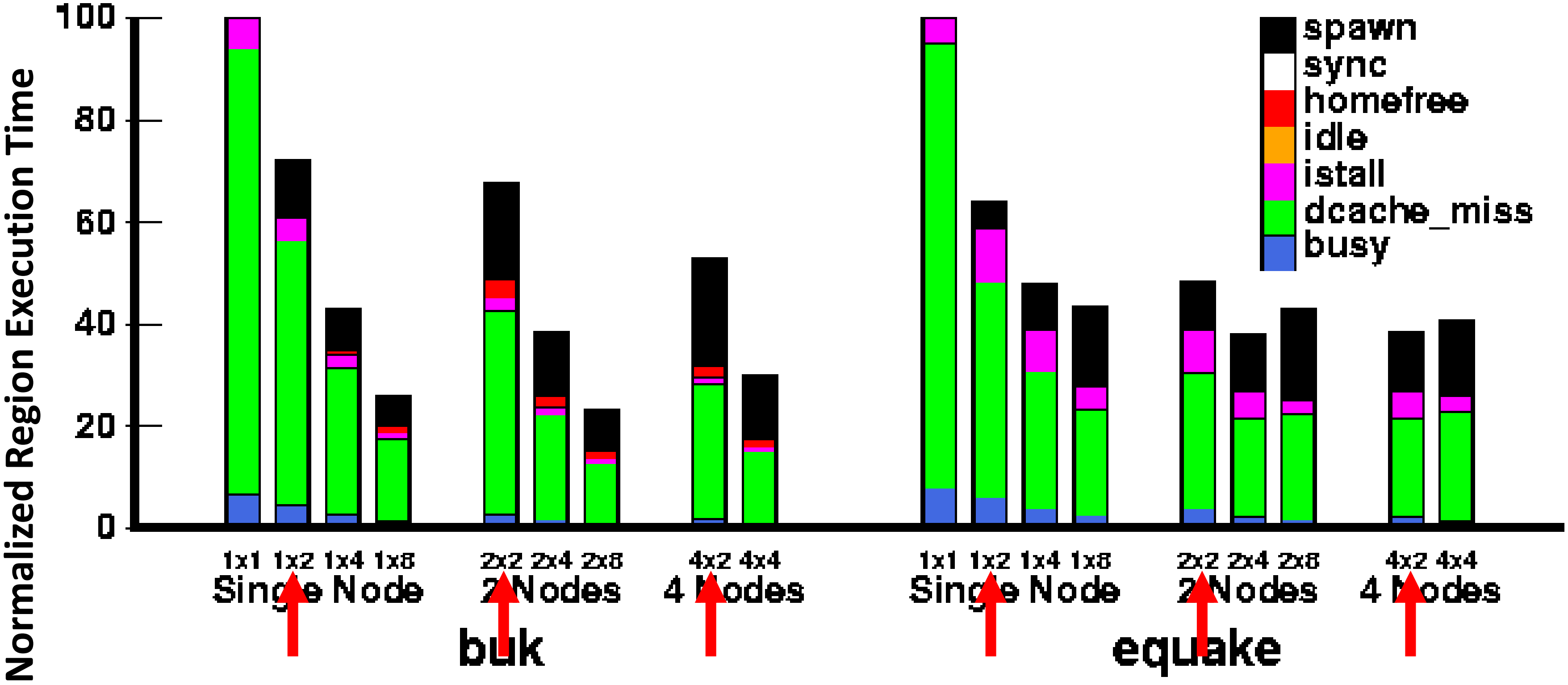
☞ **passing the homefree token is not a bottleneck**

Scaling Beyond Chip Boundaries



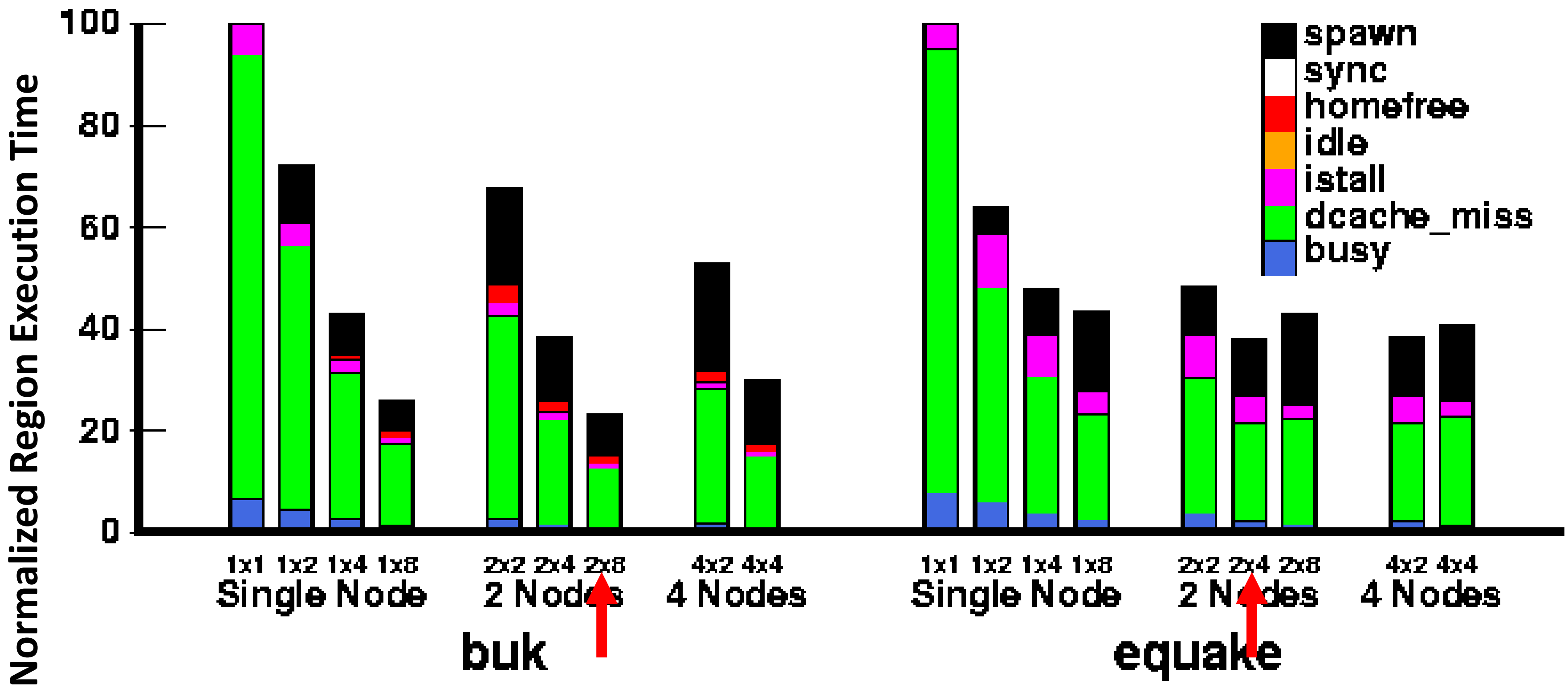
☞ **simulate architectures with 1, 2 and 4 nodes**

Scaling Beyond Chip Boundaries



☞ **multi-chip systems benefit from TLS**

Scaling Beyond Chip Boundaries



☞ **our scheme scales well**

Conclusions

The overheads of our scheme are low:

- mechanisms to squash or commit are not a bottleneck
- per-word speculative state is not always necessary

It offers compelling performance improvements:

- program speedups from 8% to 46% on a 4-processor CMP
- program speedups up to 75% on multi-chip architectures

It is scalable:

- coherence provides elegant data dependence tracking

☞ **seamless TLS on a wide range of architectures**