Verification of weak memory models

Elli Anastasiadi

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1. Weak memory
   - Why - how - examples

2. Verification
   - Basic problems
   - Basic principles

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Starting point: distributed programs & architectures.

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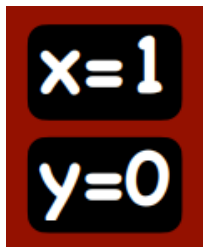

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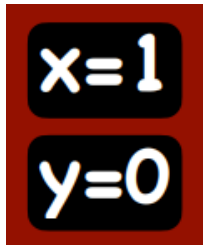

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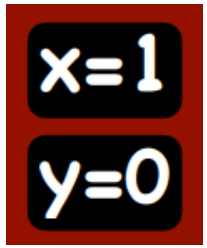

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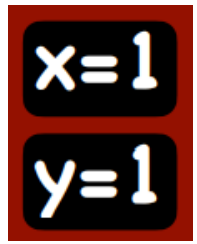

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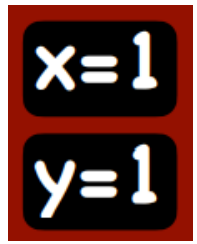

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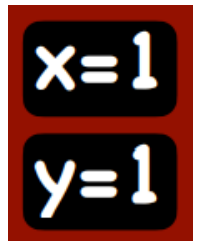

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Interleaving: implementation

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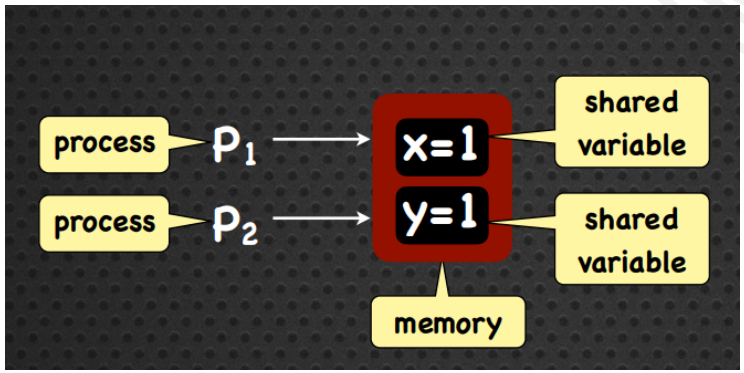
- atomic writes,
- read-from-memory



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Interleaving: formally

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Interleaving: formally

Sequential consistency - SC

On a global trace, the evens of a process will occur in the order stated locally for the process.

Or: only the events of different processes can be shuffled.

So what is weak memory?

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Rule of thumb: Anything “below” interleaving.

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...extra reorderings

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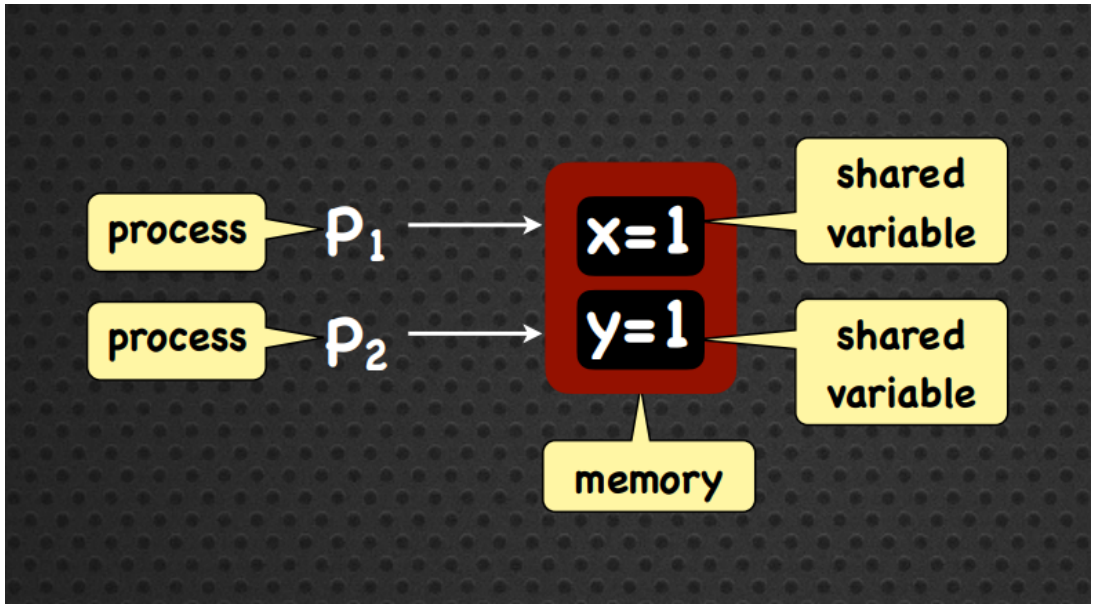

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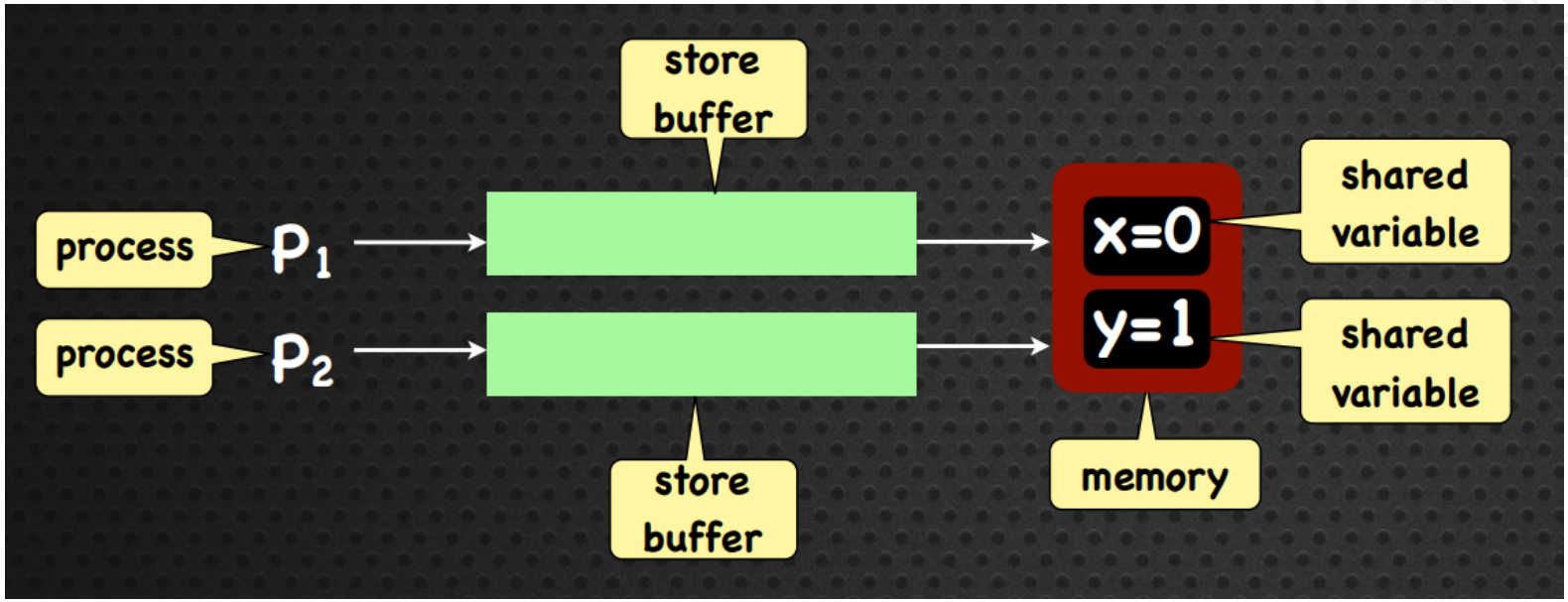
How?


process
P1
process
P2
x=0
y=1
memory
shared variable
shared variable

How?



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An example: total store order (TSO)

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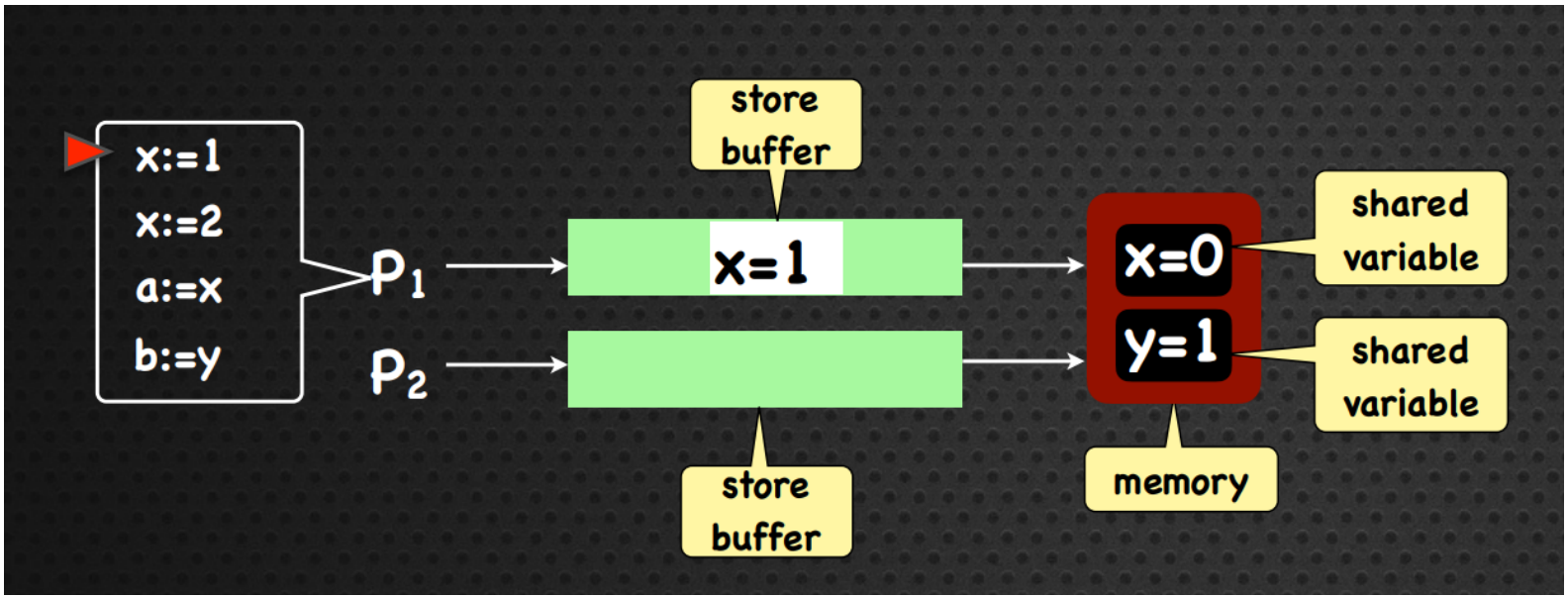

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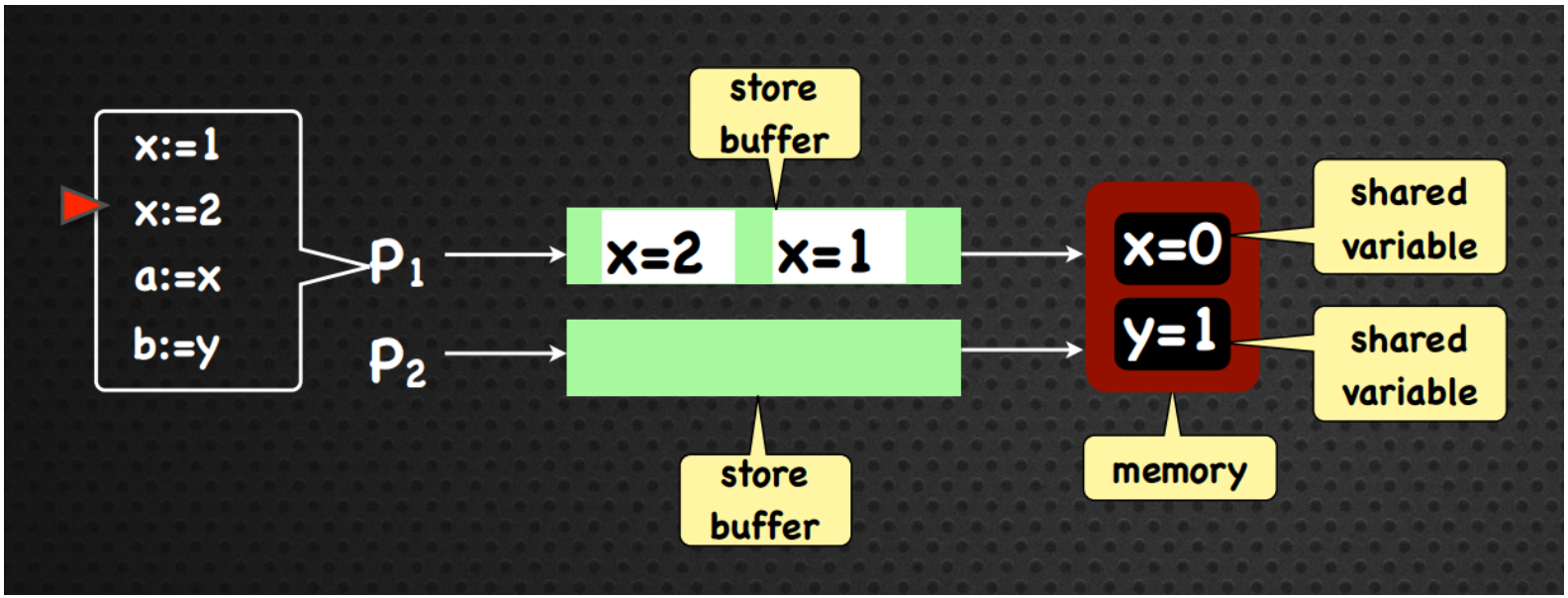

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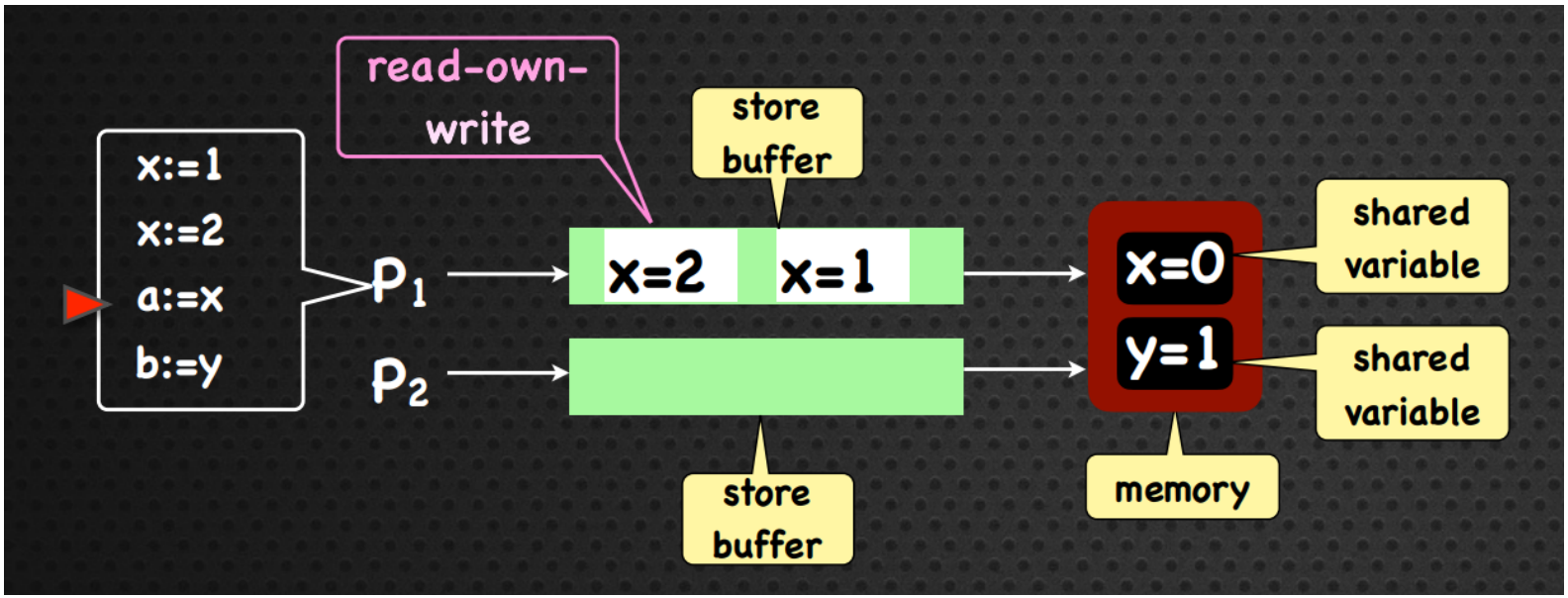

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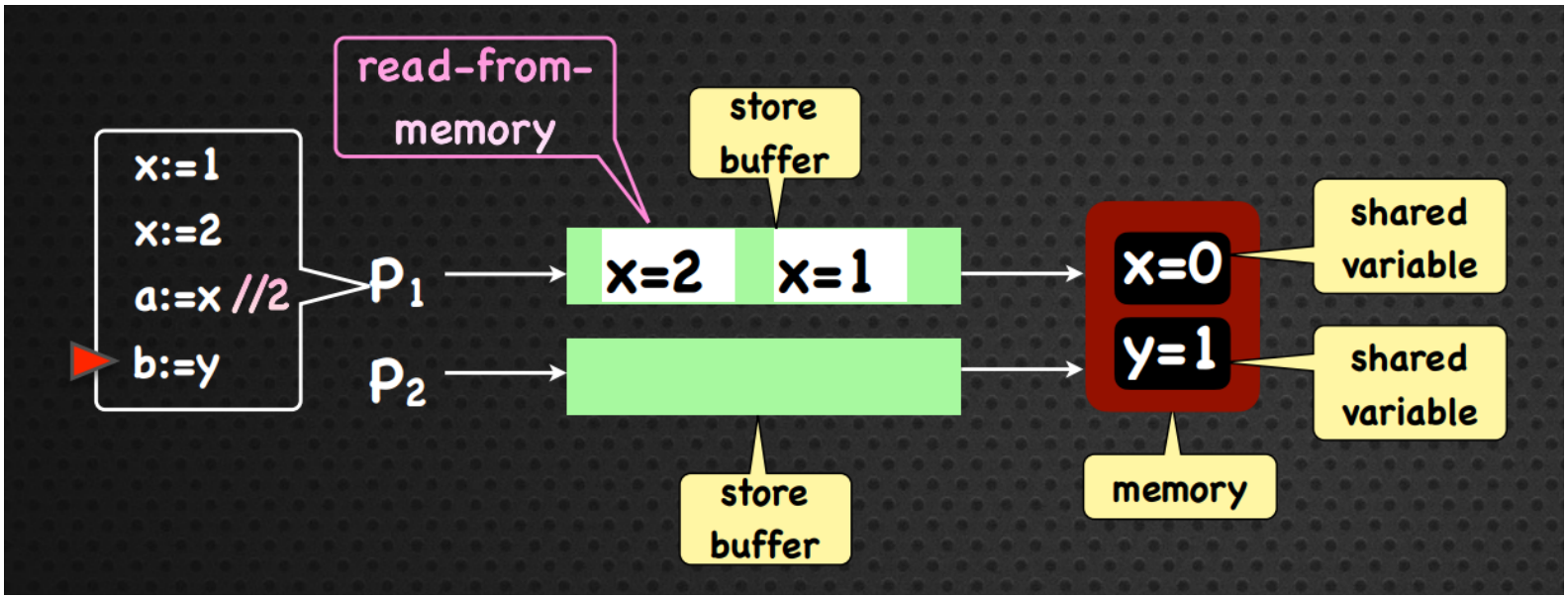
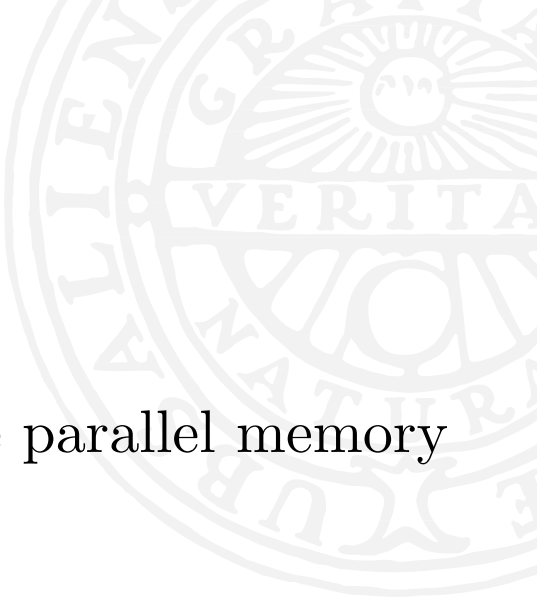


A *specification* of how an implementation will tackle parallel memory access is called a *memory model*.



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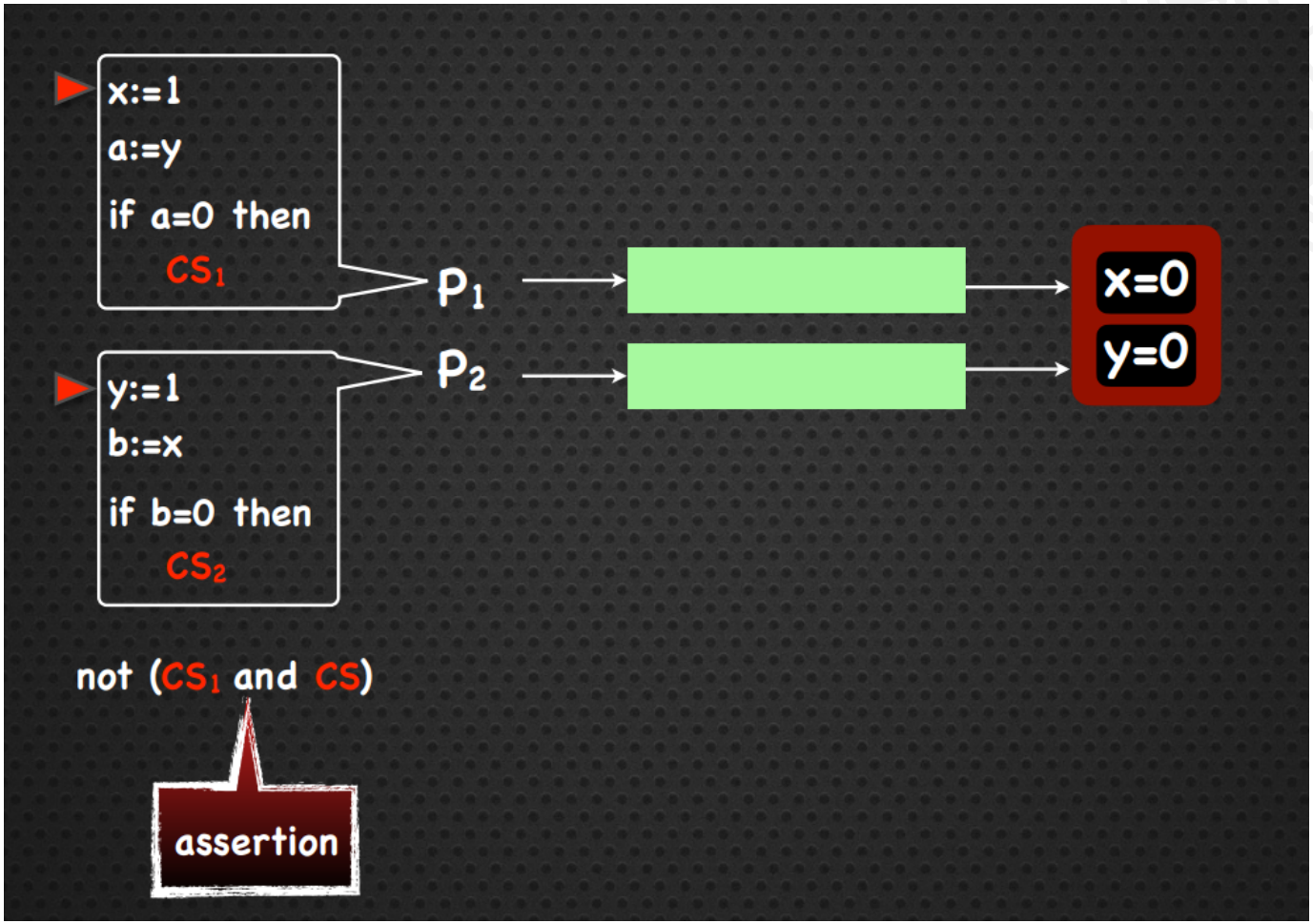
potentially bad behaviors

Dekker under TSO



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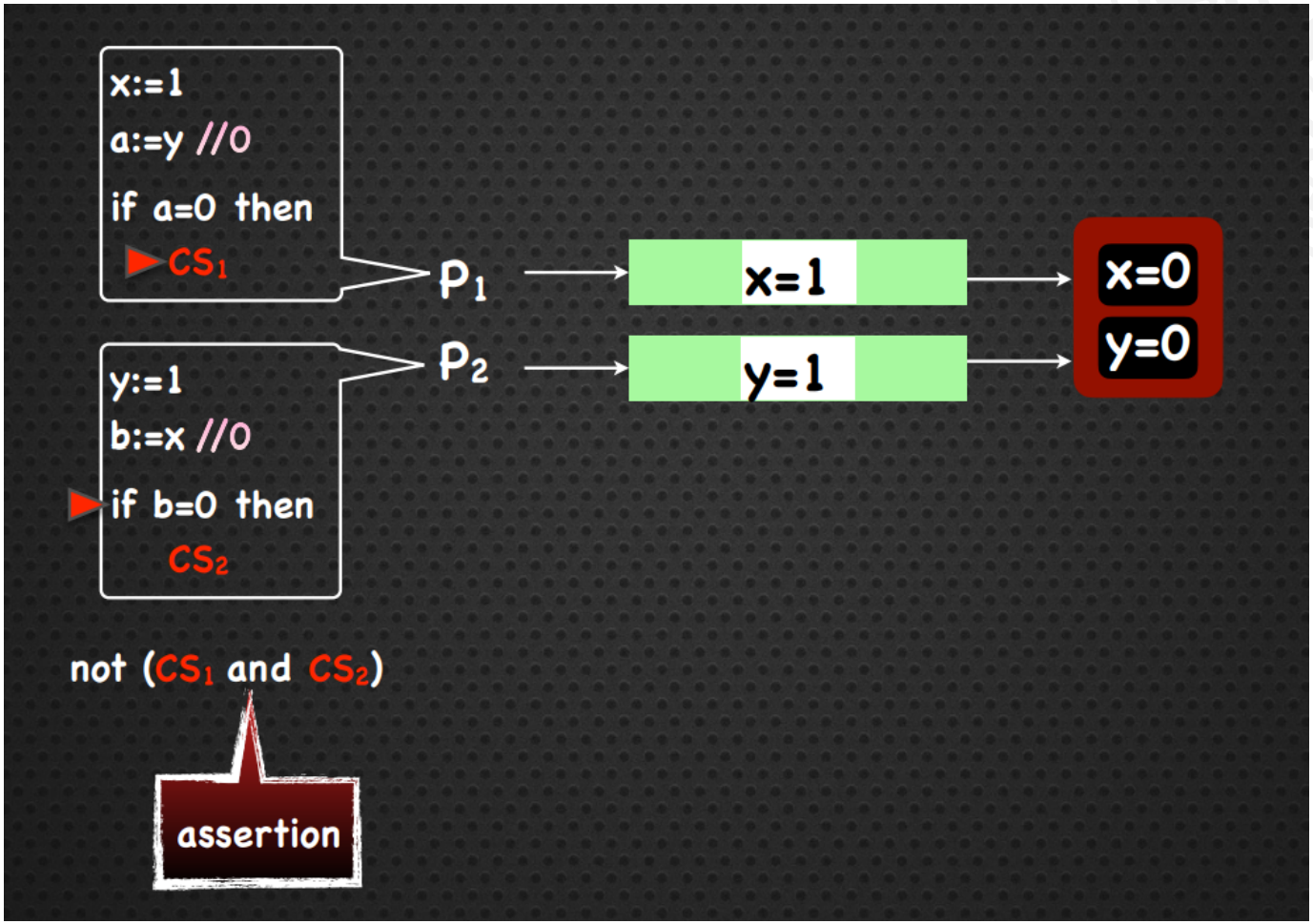

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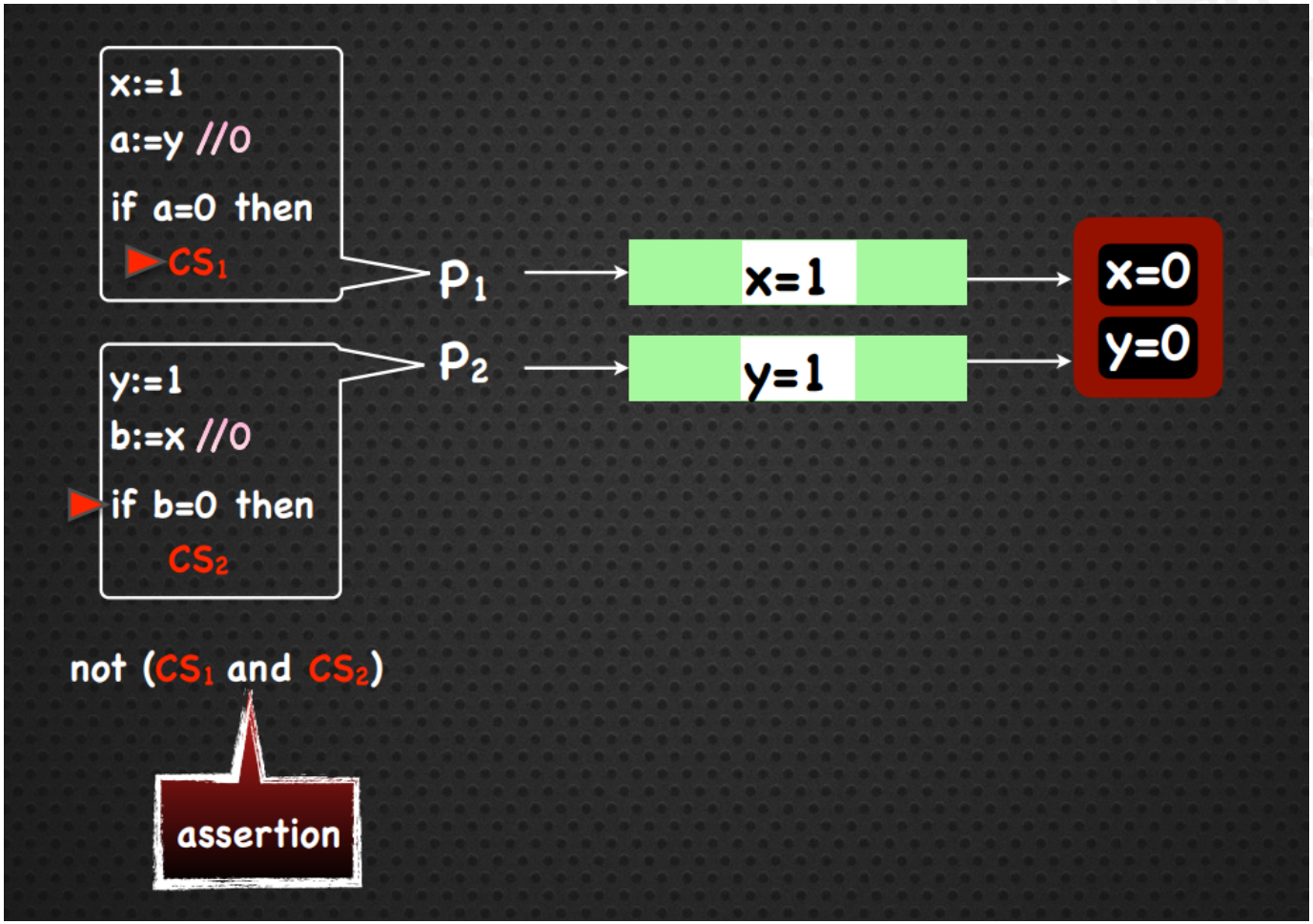

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The dichotomy

Sequential consistency

- intuitive, well-researched ☺
- slow, unrealistic ☹

Weak memory

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Road-map: Semantics → Complexity → Techniques

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Common scenarios

- New software: only works when the architecture below satisfies **at least** a specific weak memory model.

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  We need: algorithm for detecting "illegal" memory accesses.

- New architecture: claims it satisfies some weak memory model.

  We need: guarantee all runs of the new architecture are safe.

Scenario 1

Potentially we don't know the architecture.

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Some verification primitives: Shasha-Snir traces

P_1 : read(x,1), write(y,1)
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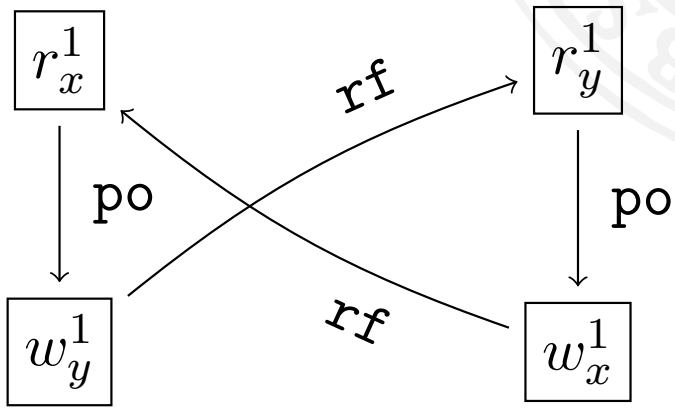

Example use: for SC the execution graph must be acyclic.

Sad result: Given the traces, to solve this is NP-complete

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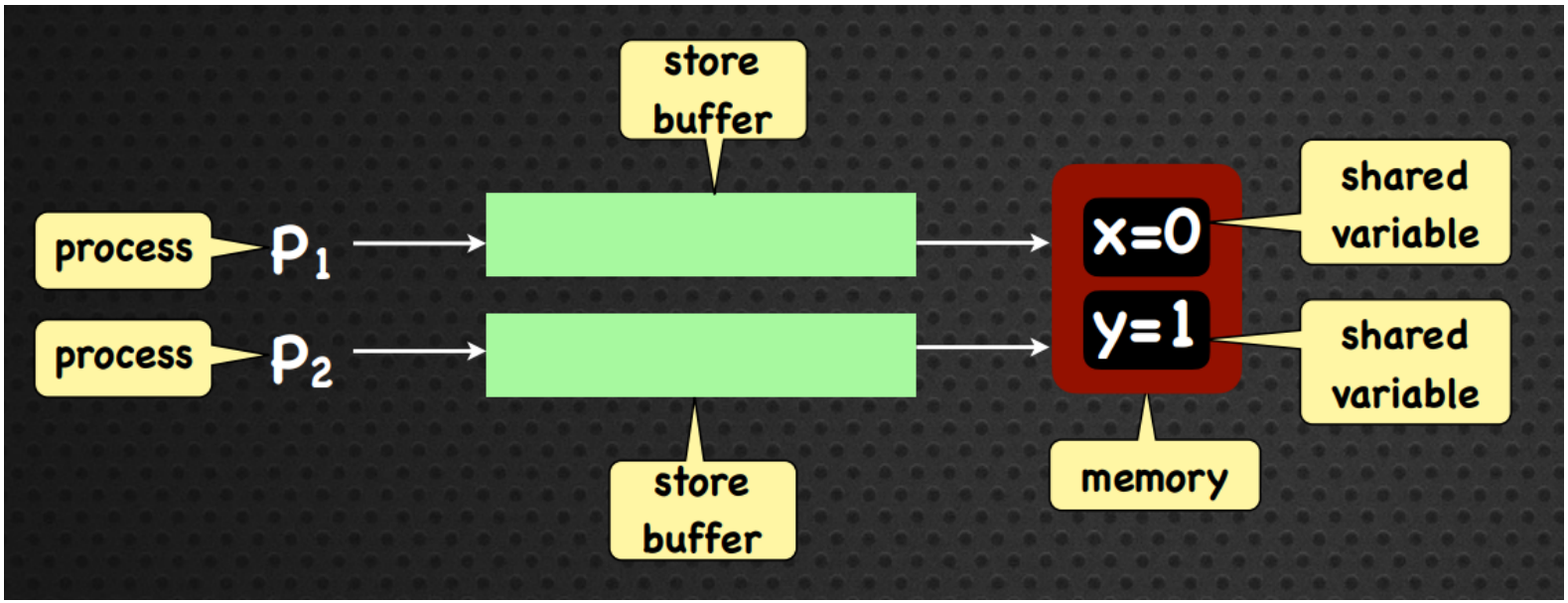

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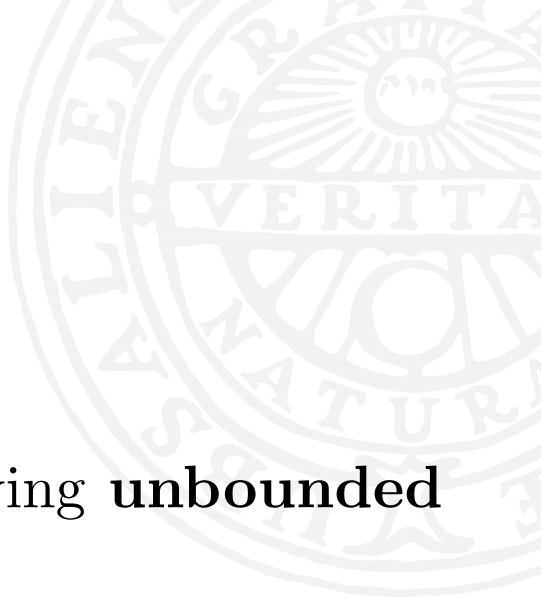
Weak memory (almost always) has semantics involving **unbounded data structures**.



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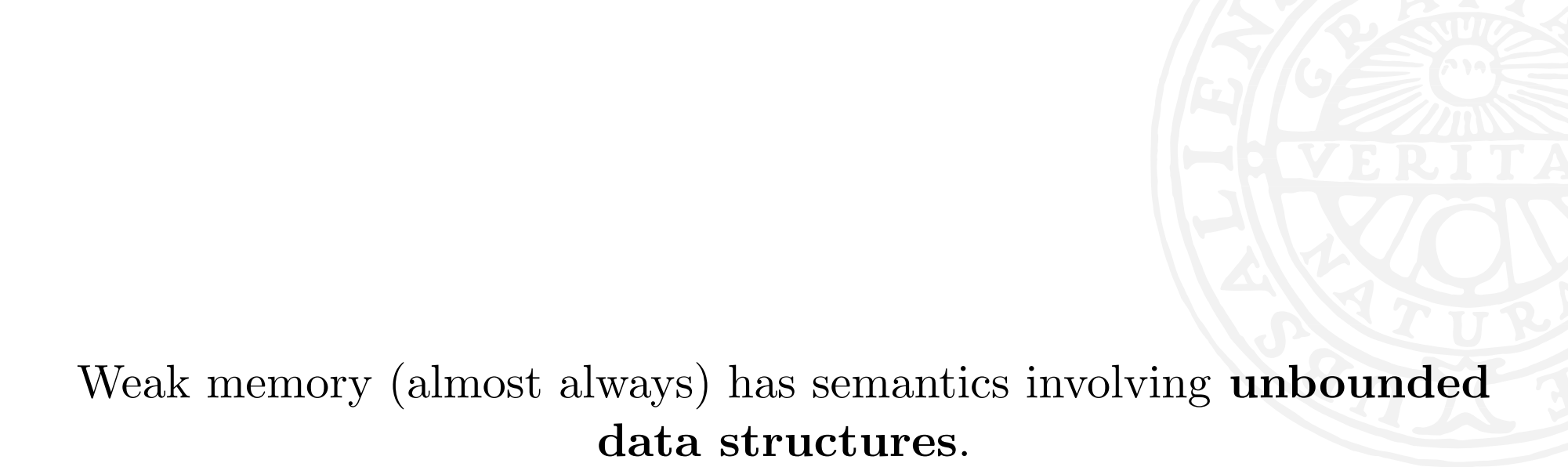

Some cool things

- Bad patterns
- Well quasi-orderings & monotonicity
- Well-structured systems

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Bad patterns

Event sequences that are known to be violating a weak memory model.

When we are lucky: a finite set of bad patterns characterizes a given weak memory model.

Use: Only test these and we get answers for **any** sequence of events.

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Some cool things

Well quasi orderings

Orderings between states of the (unavoidable) unbounded data structure associated to the semantics of the model.

When we are lucky: ordering between configurations means monotonicity in satisfaction of memory model.

Use: help us prune the infinitely large tree of configurations that we explore for reachability.

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Some cool things

Well-structured systems

Semantic models for weak memory that have:

- Unbounded but FIFO components.
- Monotonicity

When we are lucky: we manage to transform the semantics of a weak memory model to a form that is well-structured.

Use: (Theorem) Reachability is always decidable.

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Summary:

- basic idea of how weak memory shows up
- why is it problematic
- what we (usually) do about it.

Future:

- develop good algorithms for specific memory models
- develop hardness results
- (maybe) unification results.

Thank you for your attention!

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Questions?