Reachability and Safety Games under TSO Semantics

SCooL / GandALF 2024 in Reykjavik

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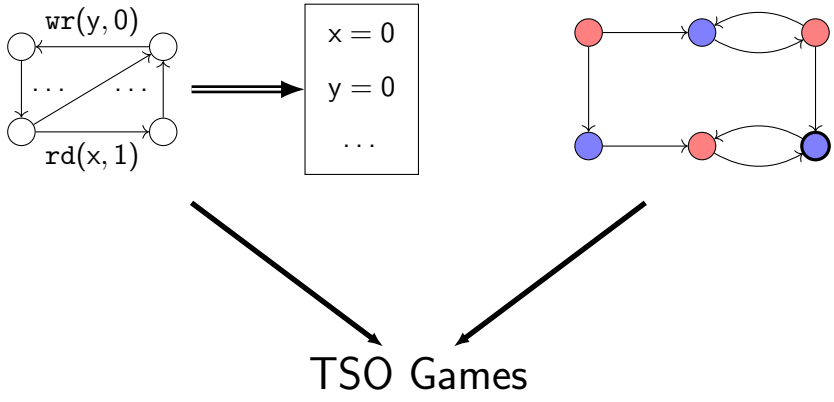
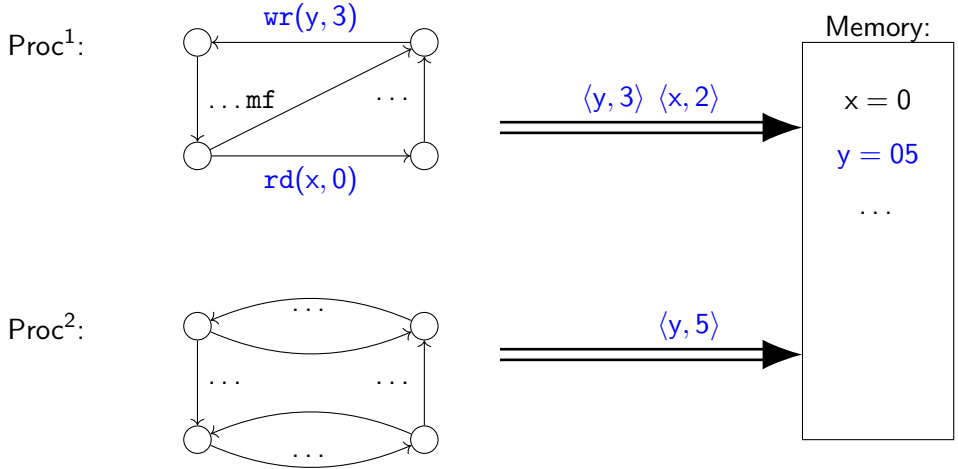
Reachability and Safety Games under TSO semantics



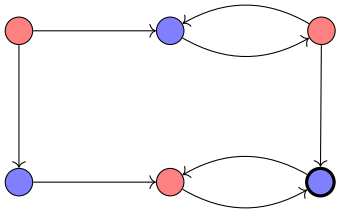
Total Store Order



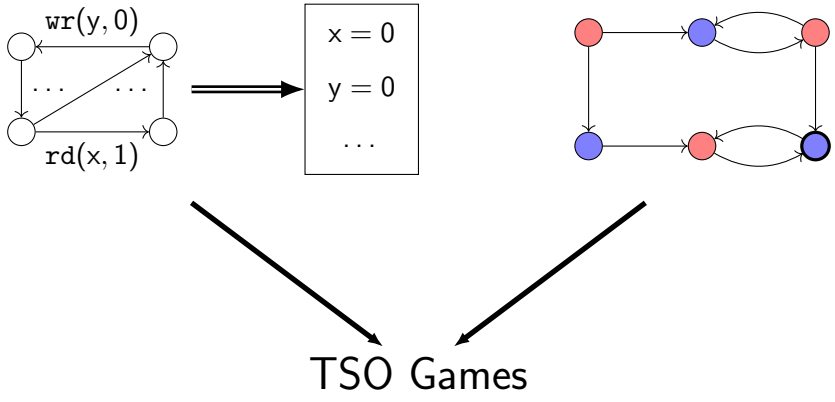
Games

- players A and B
- configurations $C = C_A \cup C_B$
- transition relation $\longrightarrow$
  - $\longrightarrow \subseteq (C_A \times C_B) \cup (C_B \times C_A)$
- final configuration $c_F \in C$

- reachability game:
  - A tries to reach C_F
  - B tries to avoid C_F
- safety game: reversed roles

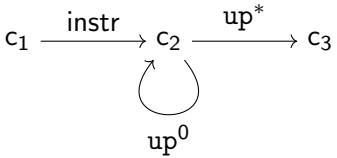


TSO Games

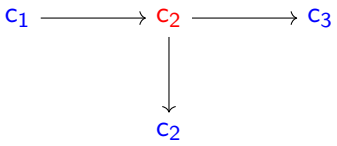


TSO Games

TSO (configuration graph):

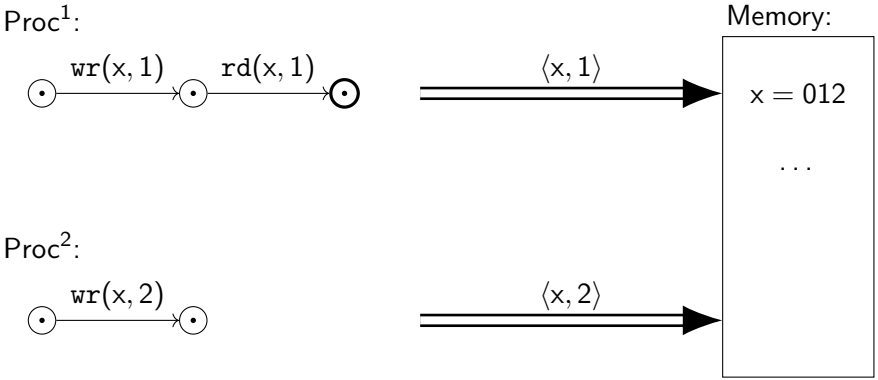


TSO Game:

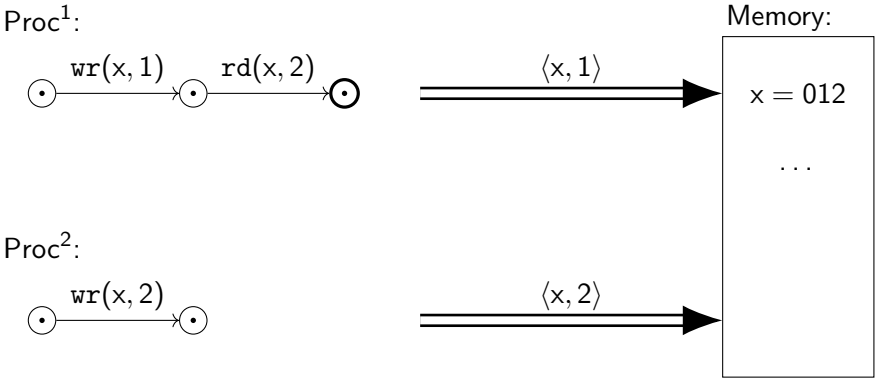


process player / *update player*

TSO Games - Reachability Problem



TSO Games - Reachability Problem



TSO Games - Reachability Problem

- Proc^ι can reach final state **without** help from other processes:
  winning strategy for process player: only play in Proc^ι
- Proc^ι can reach final state **only with** help from other processes:
  winning strategy for update player: do not update any message
- similar for *safety* games
- analysis reduces to single-process programs (finite behaviour)
- complexity: PSPACE-complete

TSO Games - Adding Fairness

- Proc^ι can reach final state **without** help from other processes:
  winning strategy for process player: only play in Proc^ι

  Process Fairness:
  Every enabled process must be executed infinitely often.

- Proc^ι can reach final state **only with** help from other processes:
  winning strategy for update player: do not update any message

  Update Fairness:
  Eventually, every buffer message must be updated to the memory.

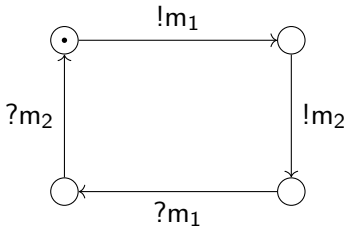
Update Fairness

Eventually, every buffer message must be updated to the memory.

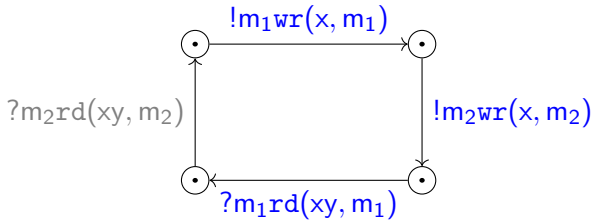
safety games? ~~safety games?~~ $\longrightarrow$ reachability games!

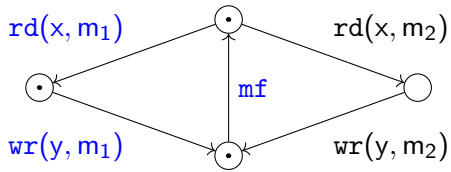
Idea: Reduction from *Perfect Channel Systems*

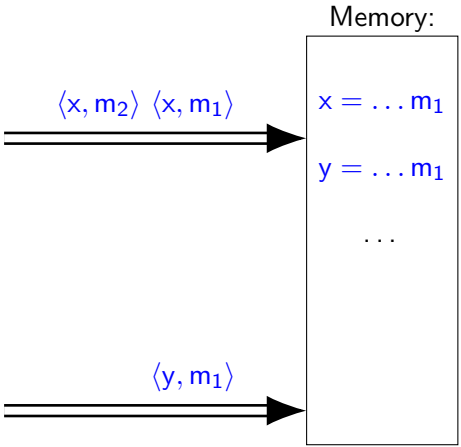
- nondeterministic finite state automata augmented by FIFO *channel*
- use TSO buffer to simulate channel
- reduce PCS reachability (undecidable) to TSO reachability game



Update Fairness - PCS Reduction



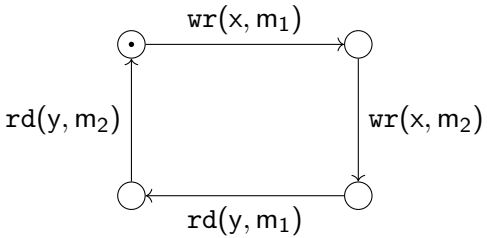




Update Fairness

Eventually, every buffer message must be updated to the memory.

- use TSO buffer to simulate PCS channel
- reduce PCS reachability (undecidable) to TSO reachability game



Theorem

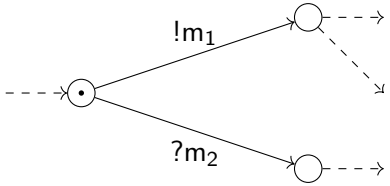
The reachability problem under TSO semantics with update fairness is undecidable.

Process Fairness

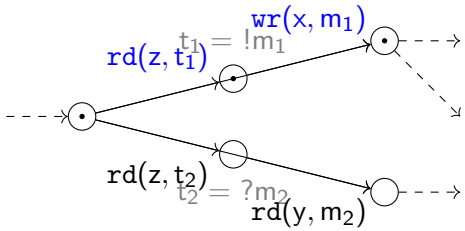
Every enabled process must be executed infinitely often.

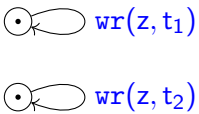
reachability games? ~~reachability games?~~ $\longrightarrow$ safety games!

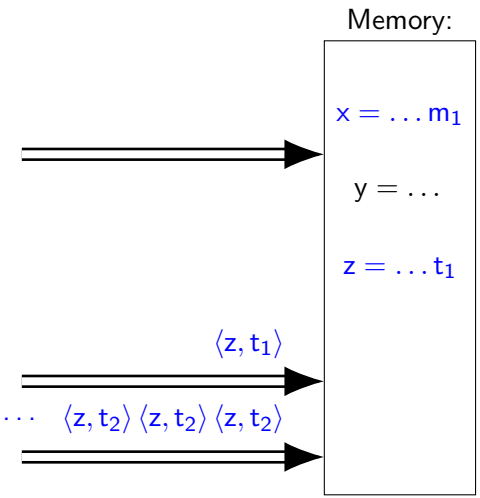
Idea: update player simulates PCS run, process player is passive



Process Fairness



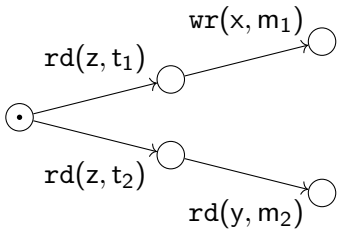




Process Fairness

Every enabled process must be executed infinitely often.

- similar to reachability games
- update player simulates PCS run, process player is passive
- reduce PCS reachability (undecidable) to TSO safety game



Theorem

The safety problem under TSO semantics with process fairness is undecidable.

Conclusion

- reachability and safety *without* fairness
  - reduce to single-process programs
  - finite behaviour / PSPACE-complete
- reachability with update fairness and safety with process fairness
  - reduction from PCS reachability
  - undecidable
- further work could consider other
  - winning conditions
  - fairness conditions
  - weak memory models

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