# Kaki: Concurrent Update Synthesis for Regular Policies via Petri Games

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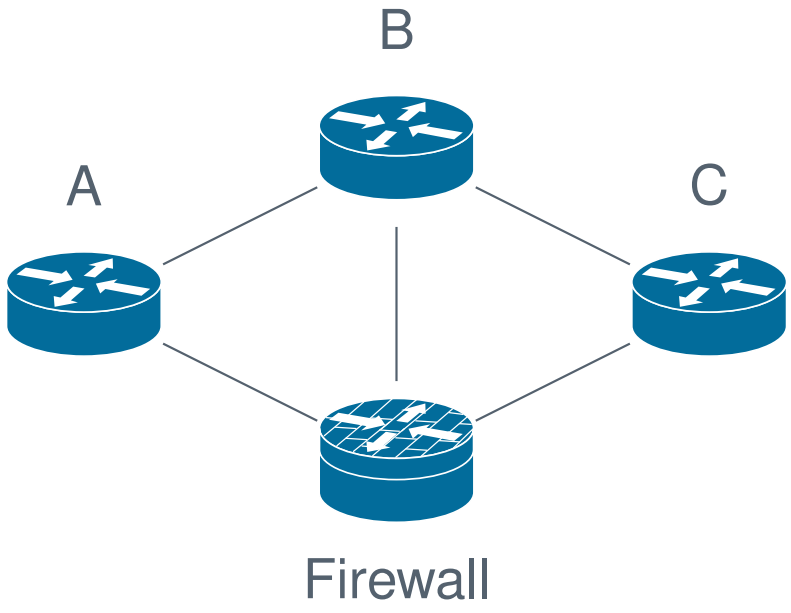
# Communication Network



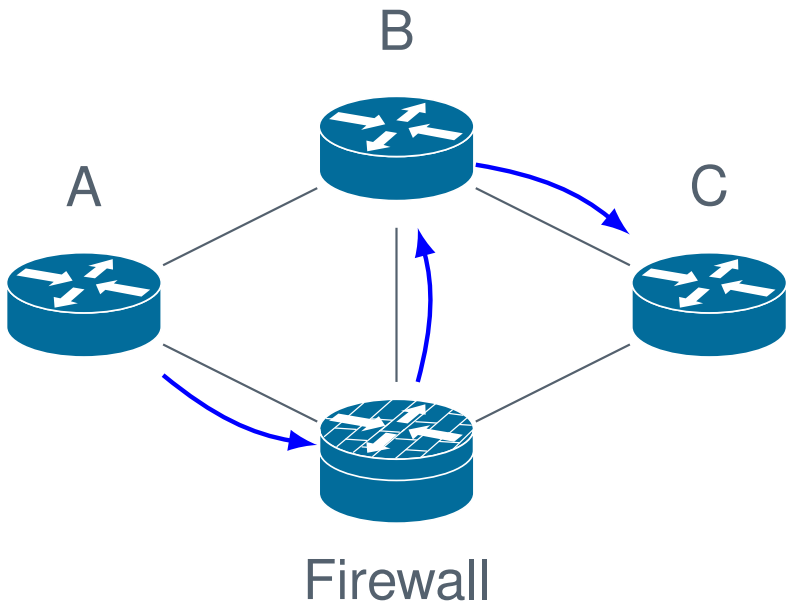



- Switches send packets across a network
- A flow is a source and destination pair for packets
- In Software Defined Networking a central controller manages traffic

# Network Update



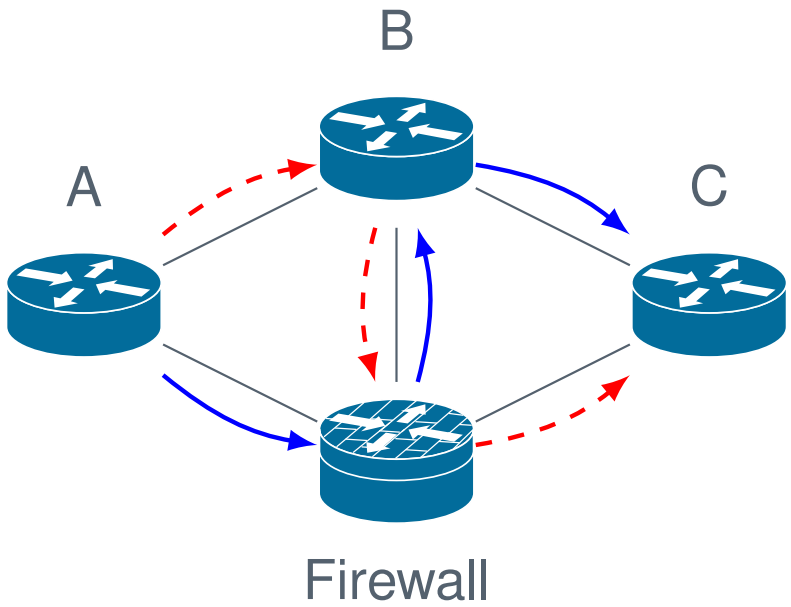
- Flow from A to C
- Initial forwarding rules



# Network Update



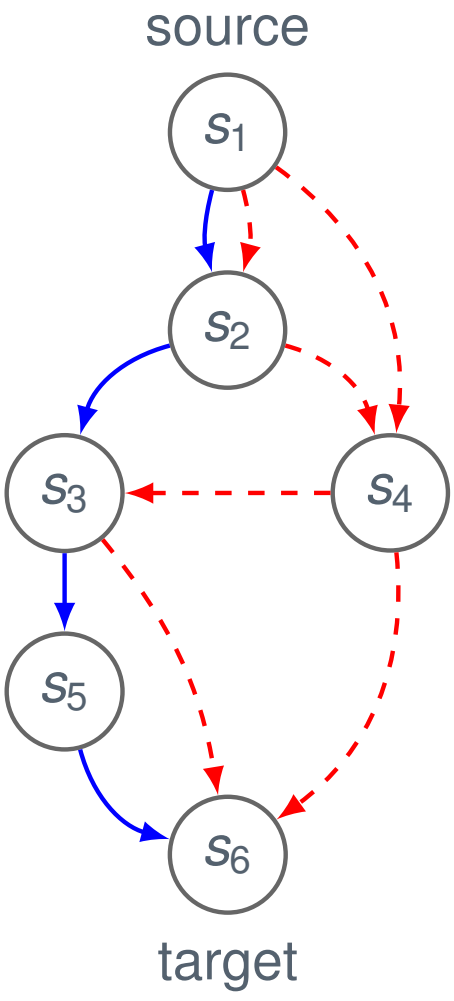
- Flow from A to C
- Initial forwarding rules
- New desired routing



# Routing



- Network
- Initial Routing
  - Trace: $s_1 s_2 s_3 s_5 s_6$
- Final Routing
  - 4 different traces
- Intermediate Routing



# Policy



- A policy $P$ is a regular expression over switches $V$, describing the language $\mathcal{L}(P) \subseteq V^*$
- A policy $P$ is satisfied for a routing $R$, if all traces for $R$ is in $\mathcal{L}(P)$

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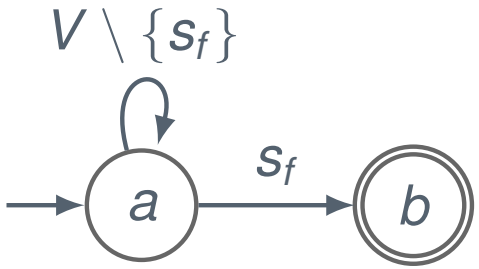
- Policy examples
  - Reachability



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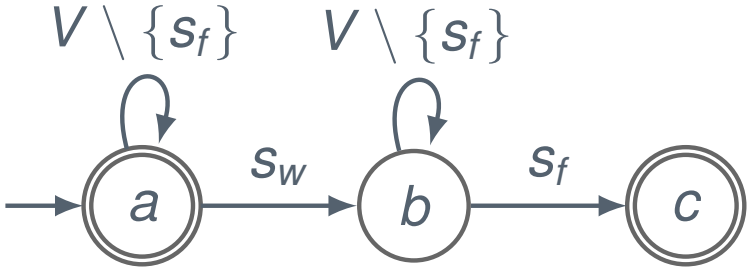
  - Waypoint



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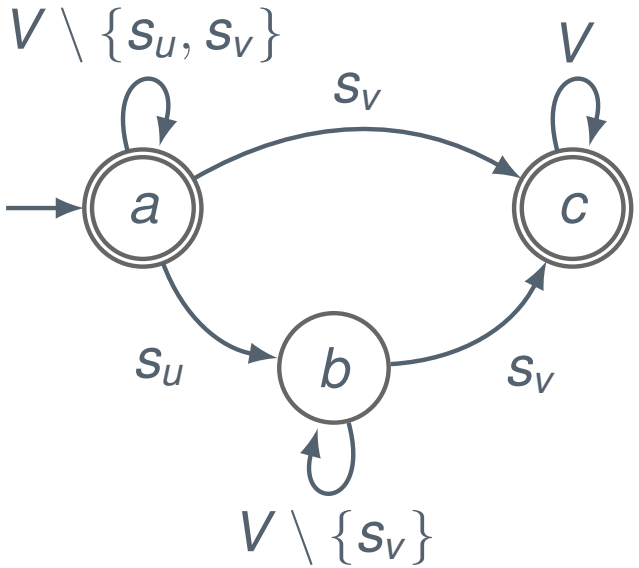
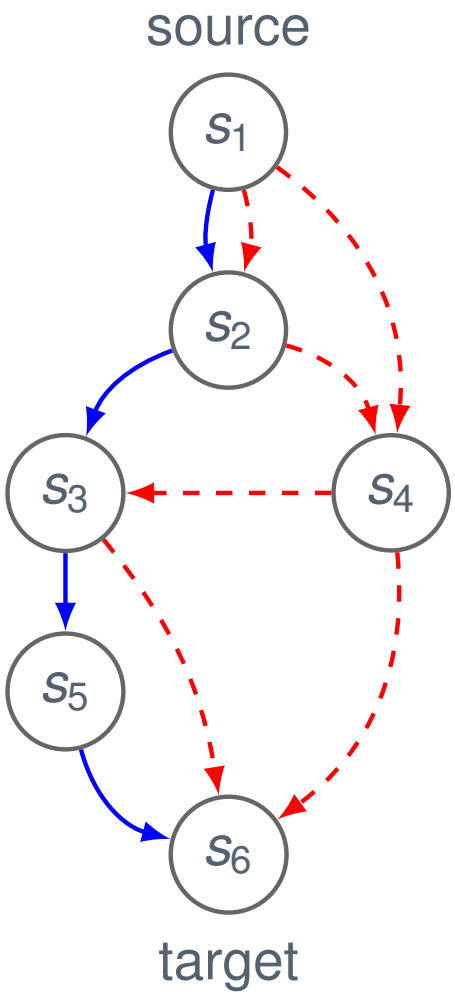
  - Reachability
  - Waypoint
  - Conditional enforcement ($s_u \Rightarrow s_v$)



# Concurrent Update Synthesis Problem



Policy: $V^*\{s_5, s_4\}V^*s_6$



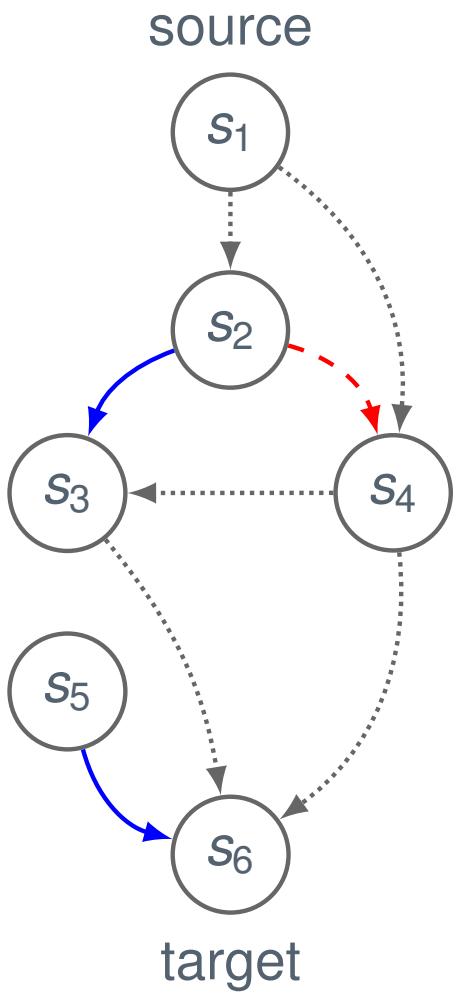
# Concurrent Update Synthesis Problem



Policy: $V^*\{s_5, s_4\}V^*s_6$

Concurrent Update Sequence:

- Batch 1: $\{s_4\}$
- Batch 2: $\{s_1, s_2, s_3\}$?
  - Six different permutations
  - $\mathbf{s_1} \rightarrow \mathbf{s_3} \rightarrow s_2$ policy violation!
  - Violating trace: $s_1 s_2 s_3 s_6 \notin \mathcal{L}(P)$



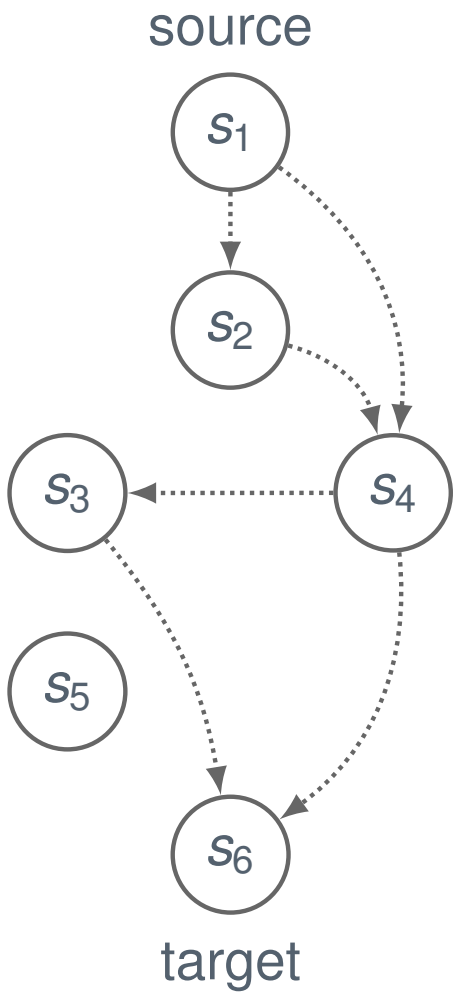
# Concurrent Update Synthesis Problem



Policy: $V^*\{s_5, s_4\}V^*s_6$

Concurrent Update Sequence:

- Batch 1: $\{s_4\}$
- Batch 2: $\{s_1, s_2\}$
- Batch 3: $\{s_3\}$
- Batch 4: $\{s_5\}$
- $\omega = \{s_4\}\{s_1, s_2\}\{s_3\}\{s_5\}$



# Translation to Petri Game

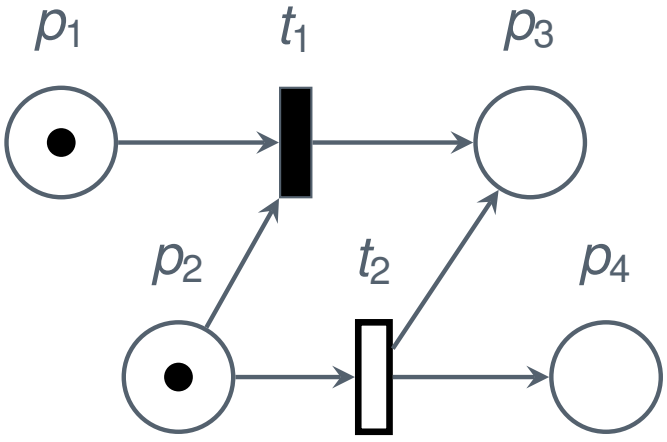


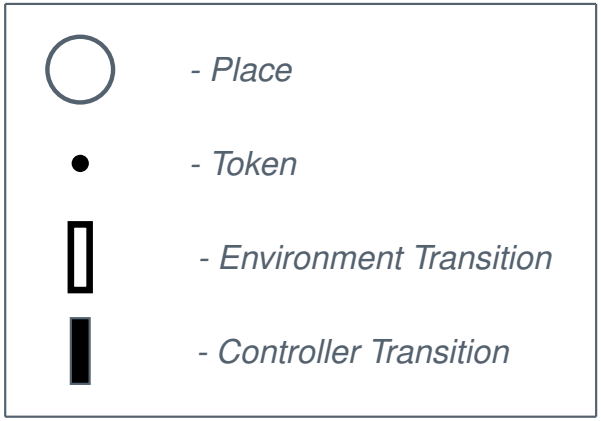
- Encode CUSP as Petri game
- Find winning strategy for controller in Petri game
- Extract *concurrent update sequence* from strategy

Strategy synthesis using TAPAAL Petri game engine

# Petri Game
## Translation



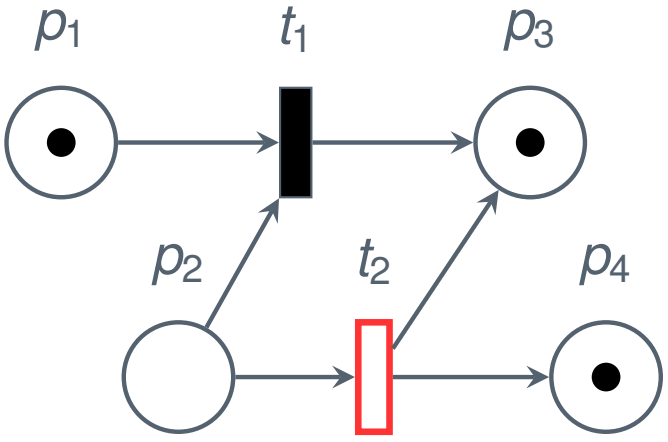


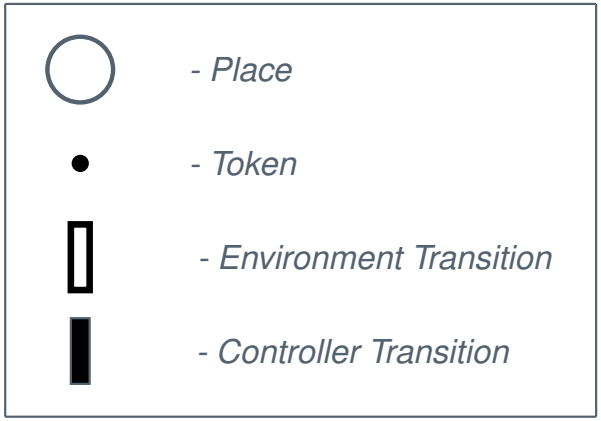




CTL query: $AF\ p3 = 1$

# Petri Game
## Translation



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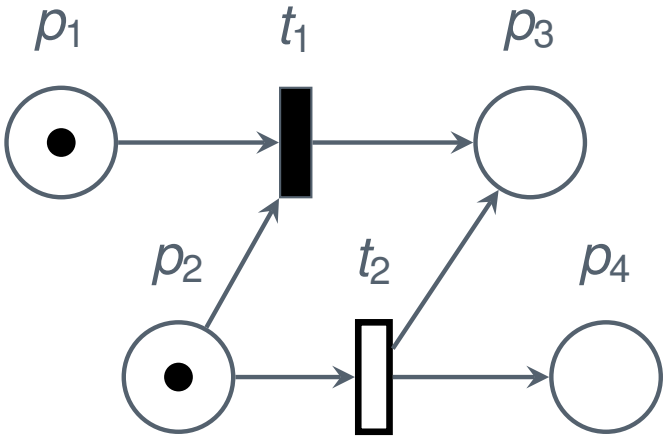


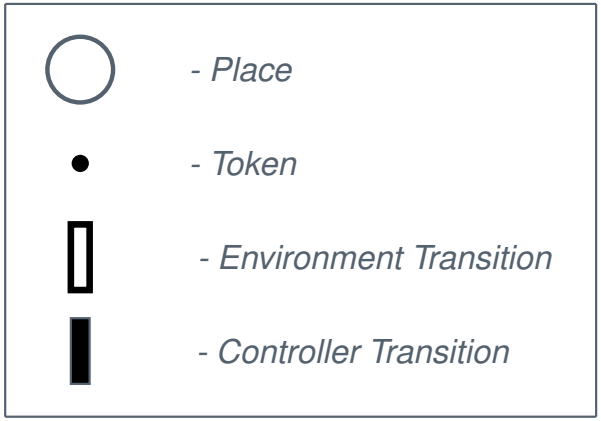


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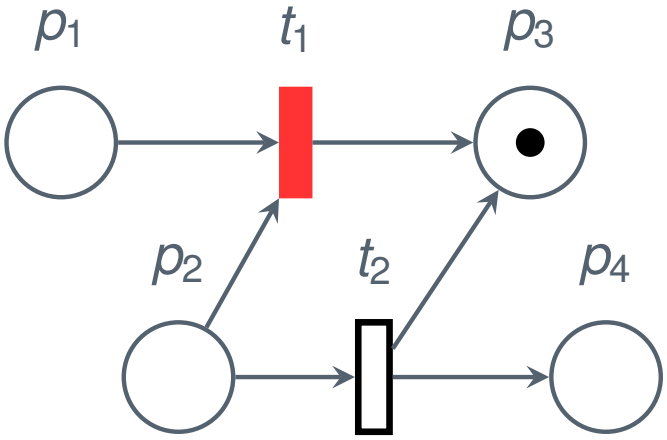


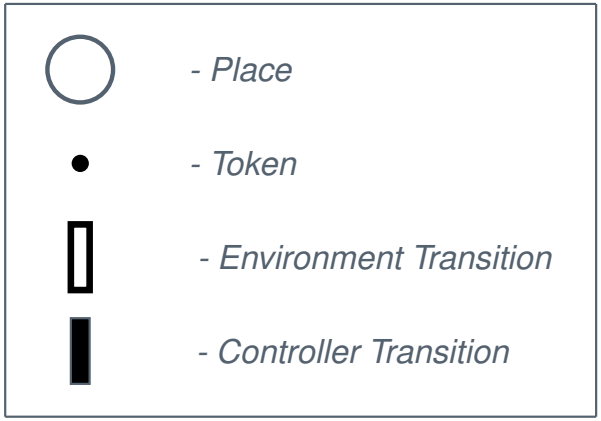


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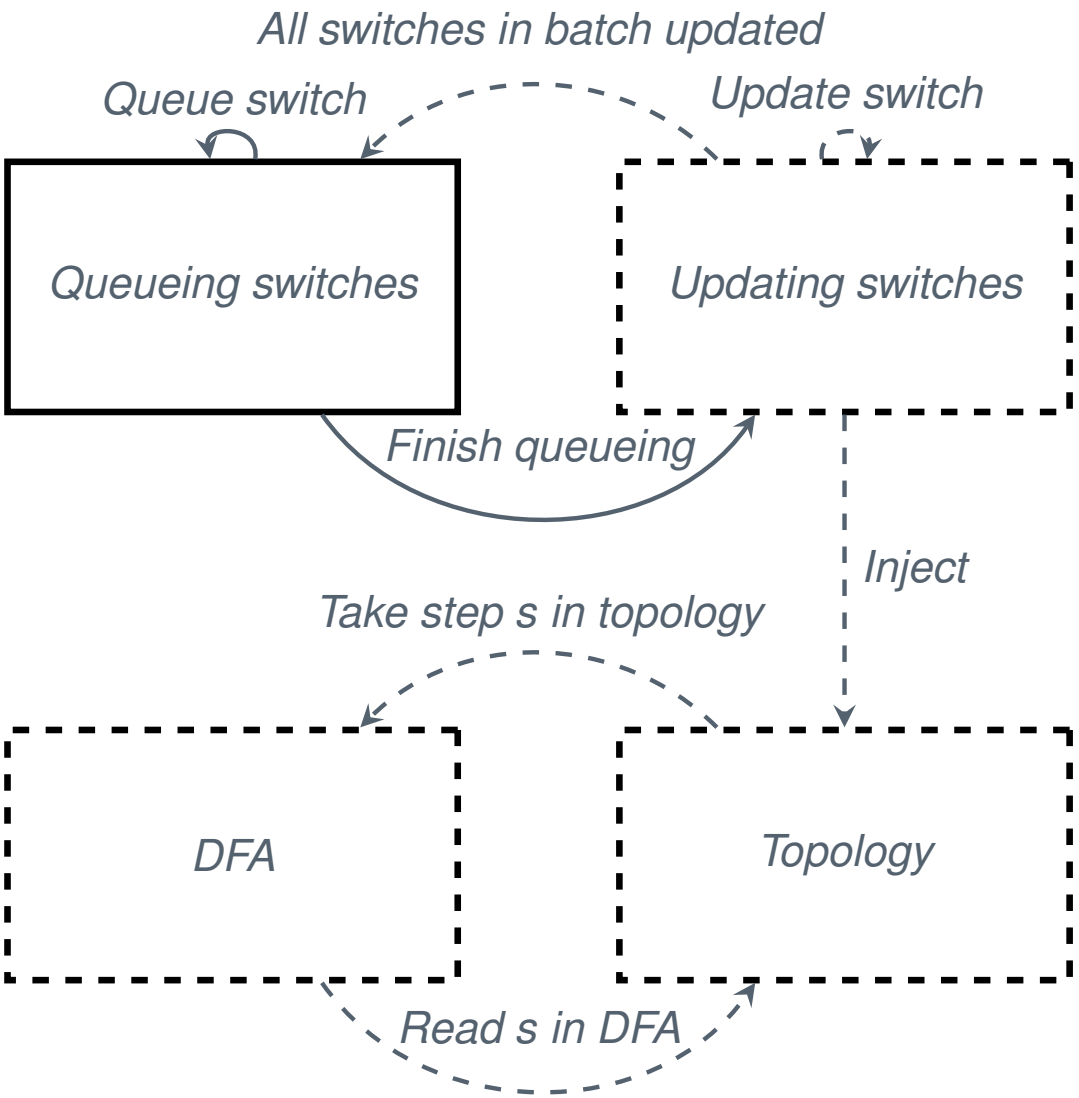
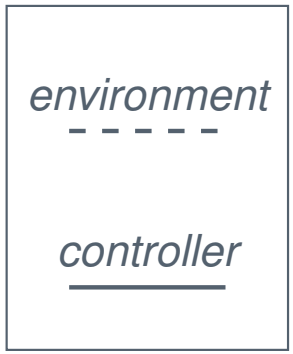
# Flowchart for Petri Game



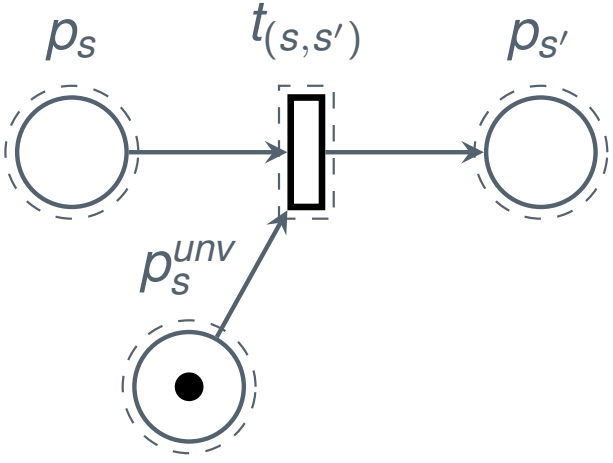


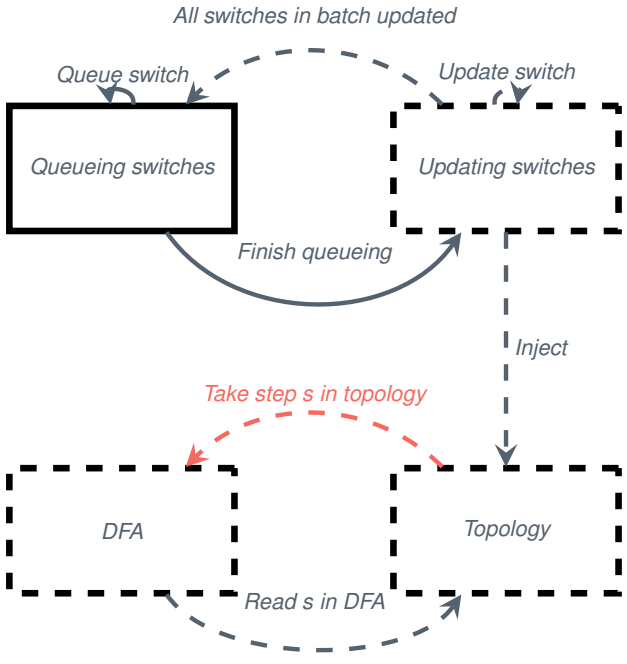



# Topology Step
## Translation



For $s, s' \in V$ where $s' \in R_i(s) \cup R_f(s)$

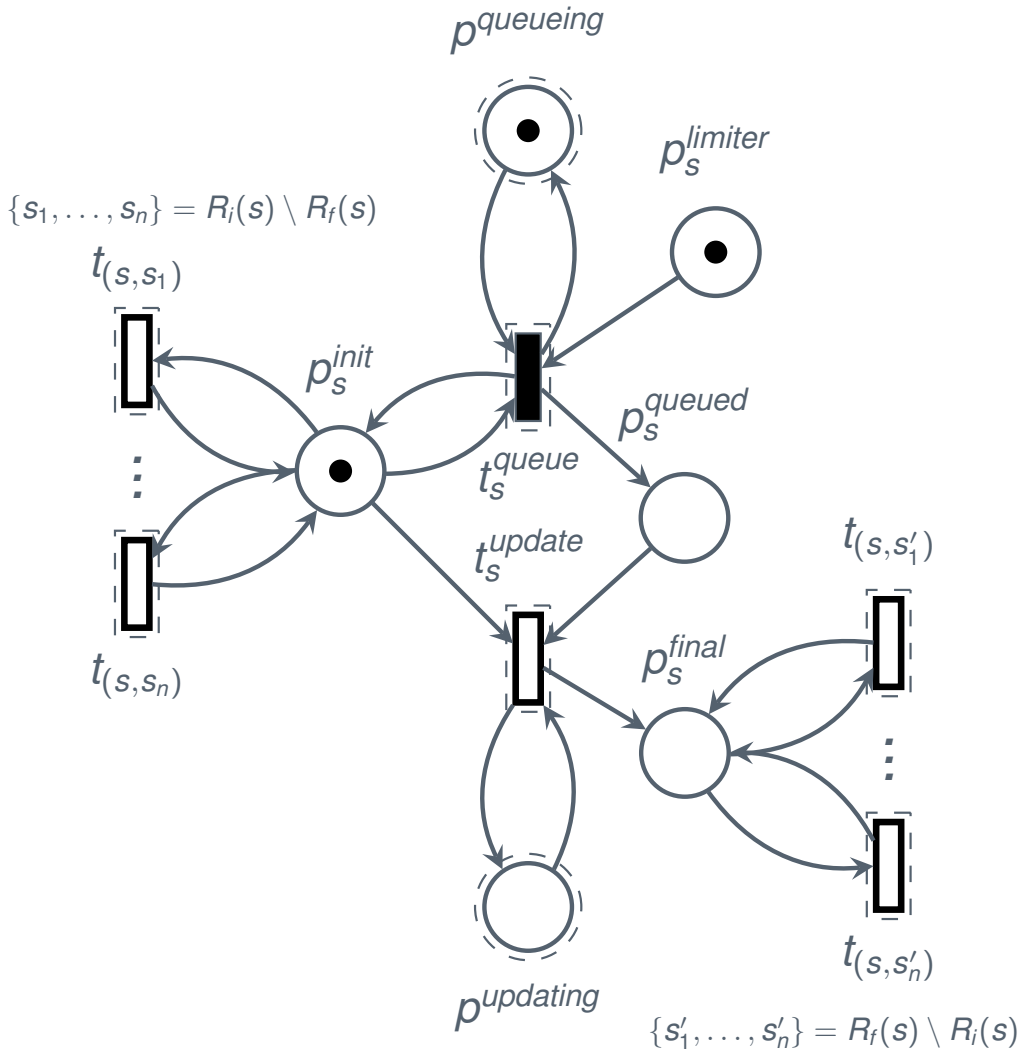


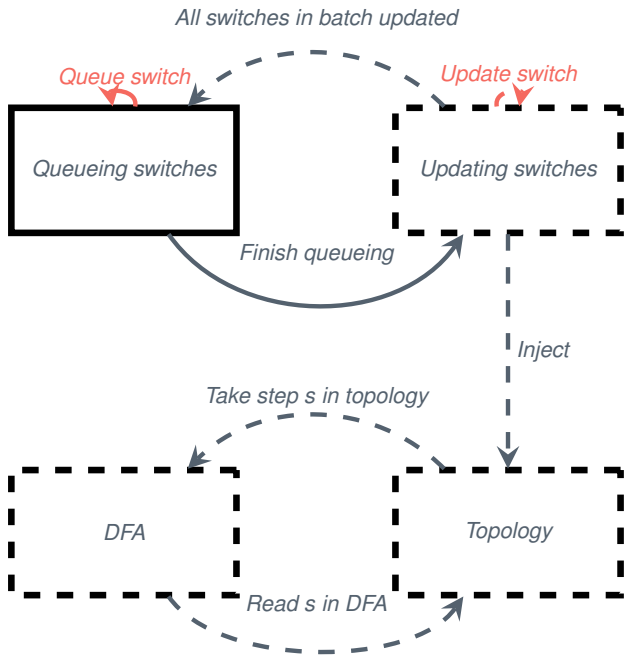




- A routing from $s$ to $s'$ is encoded by a transition $t_{(s,s')}$
- The policy is encoded as a DFA in the Petri game
- The topology and DFA components are synchronised

# Switch Component
## Translation





# Query
## Translation



- Solve CUSP by finding a winning strategy for controller

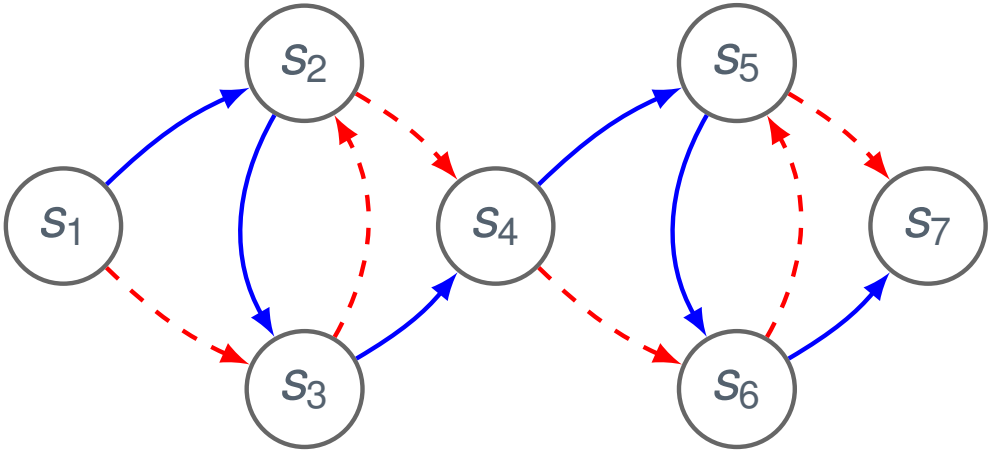
$$AF\left(p_{batches} \leq k \wedge \left(\bigvee_{q \in F} p_q = 1\right)\right)$$

- Bisection search to find lowest $k$
- Proved to find optimal solution to CUSP

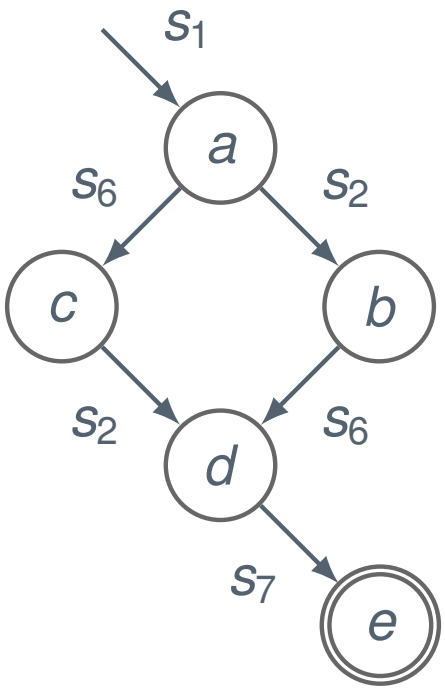
# Topological Decomposition



- Split problem into two independent subproblems
- Find potential NFA states at switches




Waypoint: $s_2, s_6$



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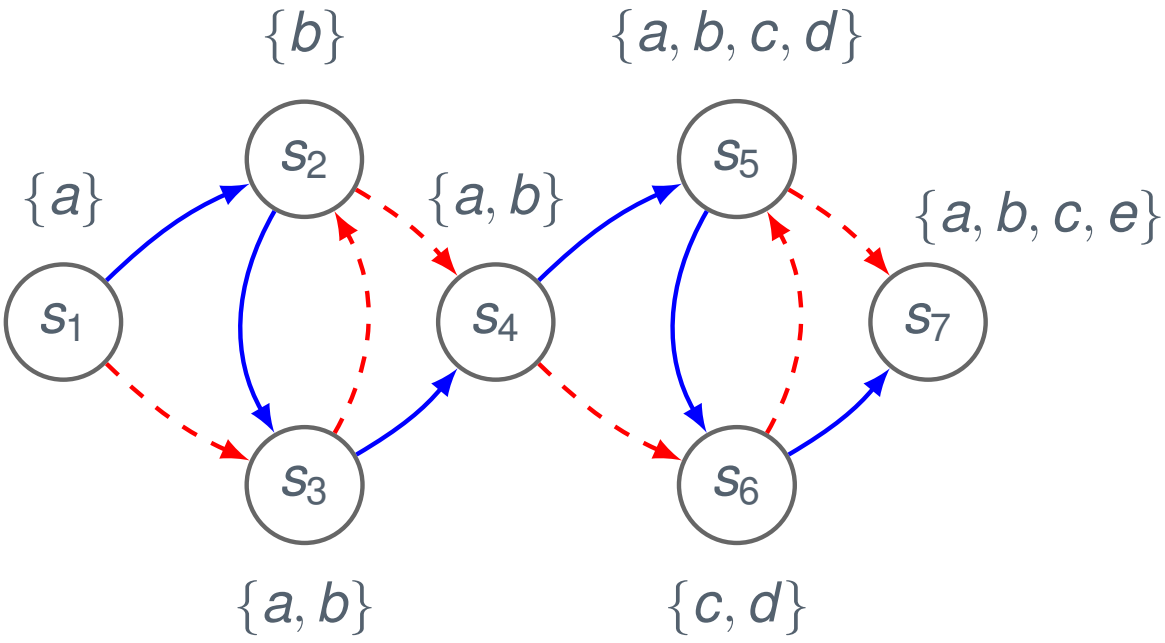
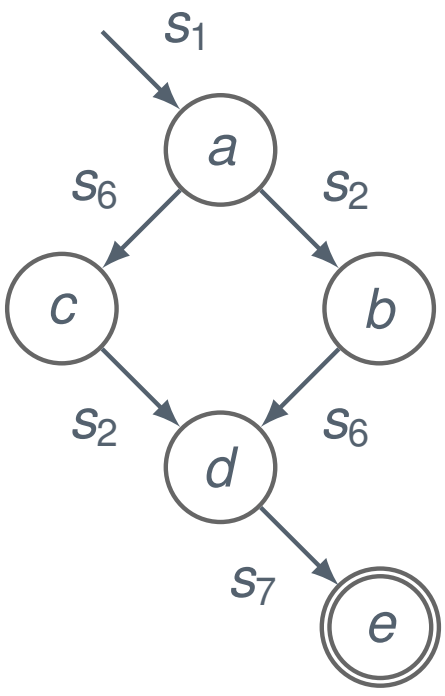



Waypoint: $s_2, s_6$



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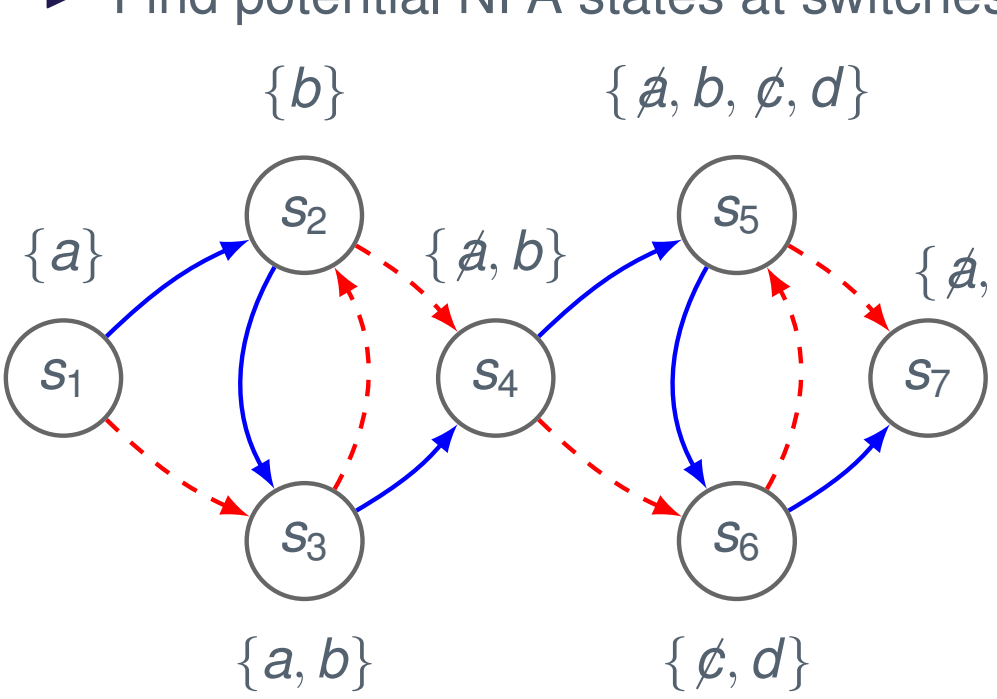


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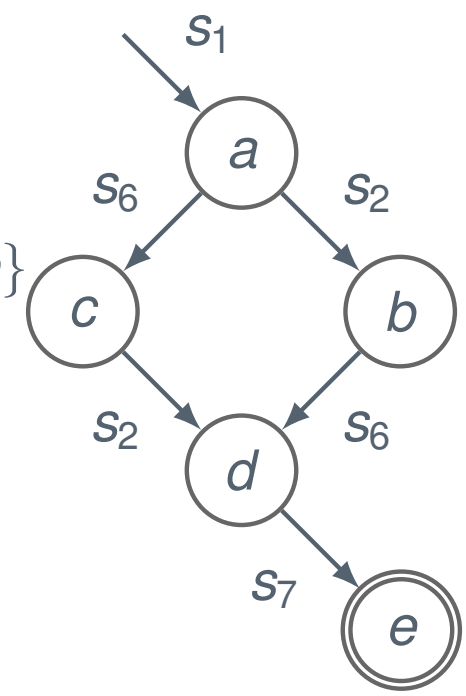
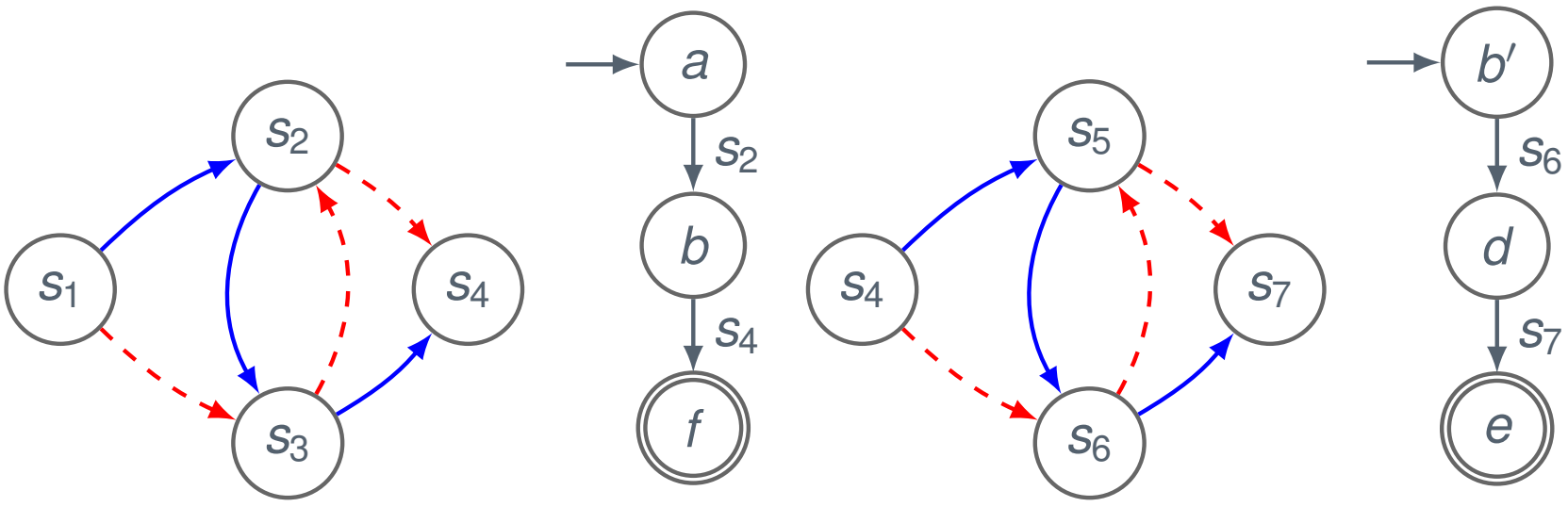



Switch $s_4$ is a topological decomposition point!

# Subproblems
## Topological Decomposition






- Original CUSP is split into 2 smaller CUSPs
- Proven: Combine optimal solution for subproblems into an optimal solution to the original problem

# Comparison with FLIP

## Results



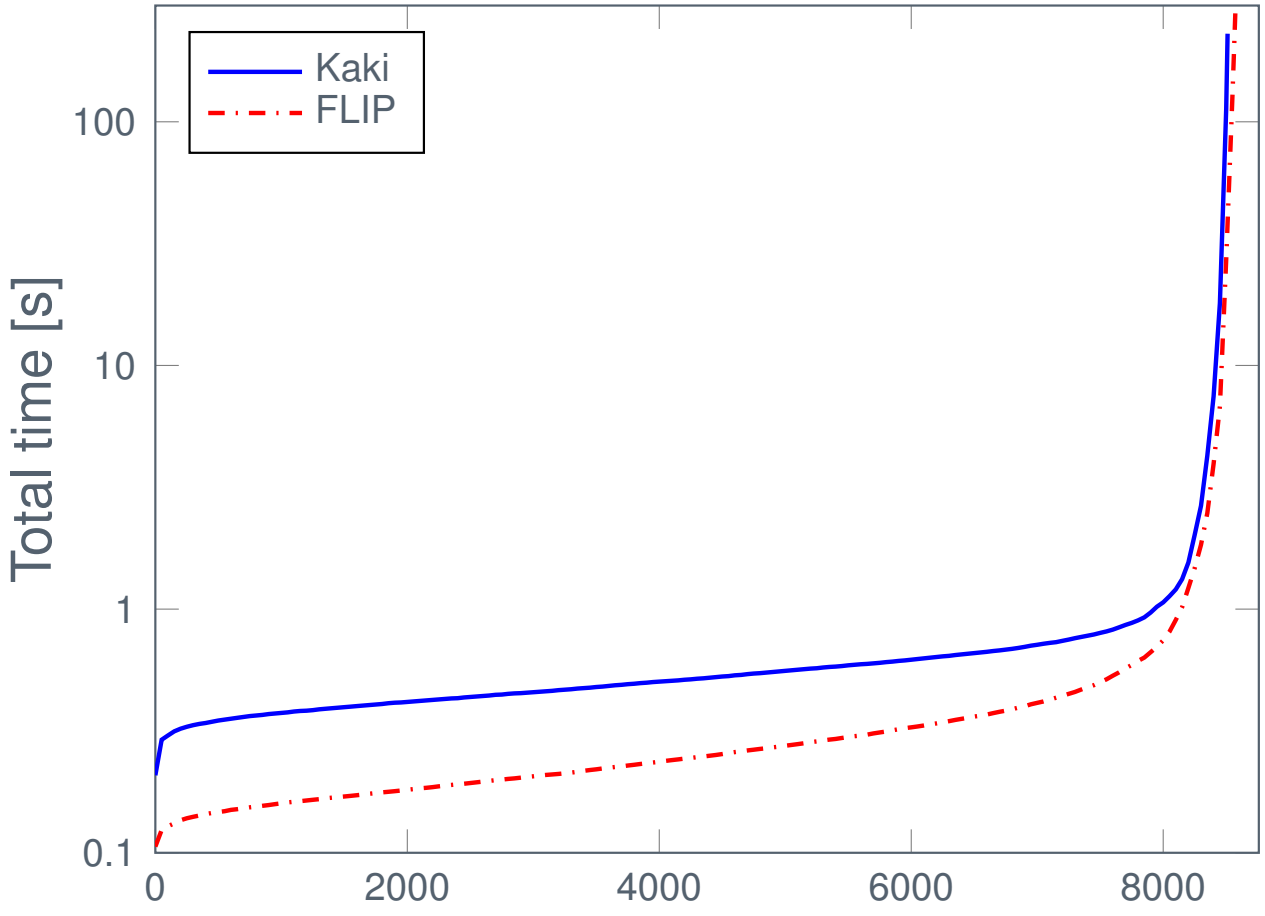



Figure: Kaki benchmarked against FLIP

| | All Problems |
|---|---|
| Total | 8759 |
| Only Kaki | 133 |
| Only FLIP | 196 |
| Suboptimal | 787 |
| Tagging | 268 |

# Comparison with NetStack

## Results



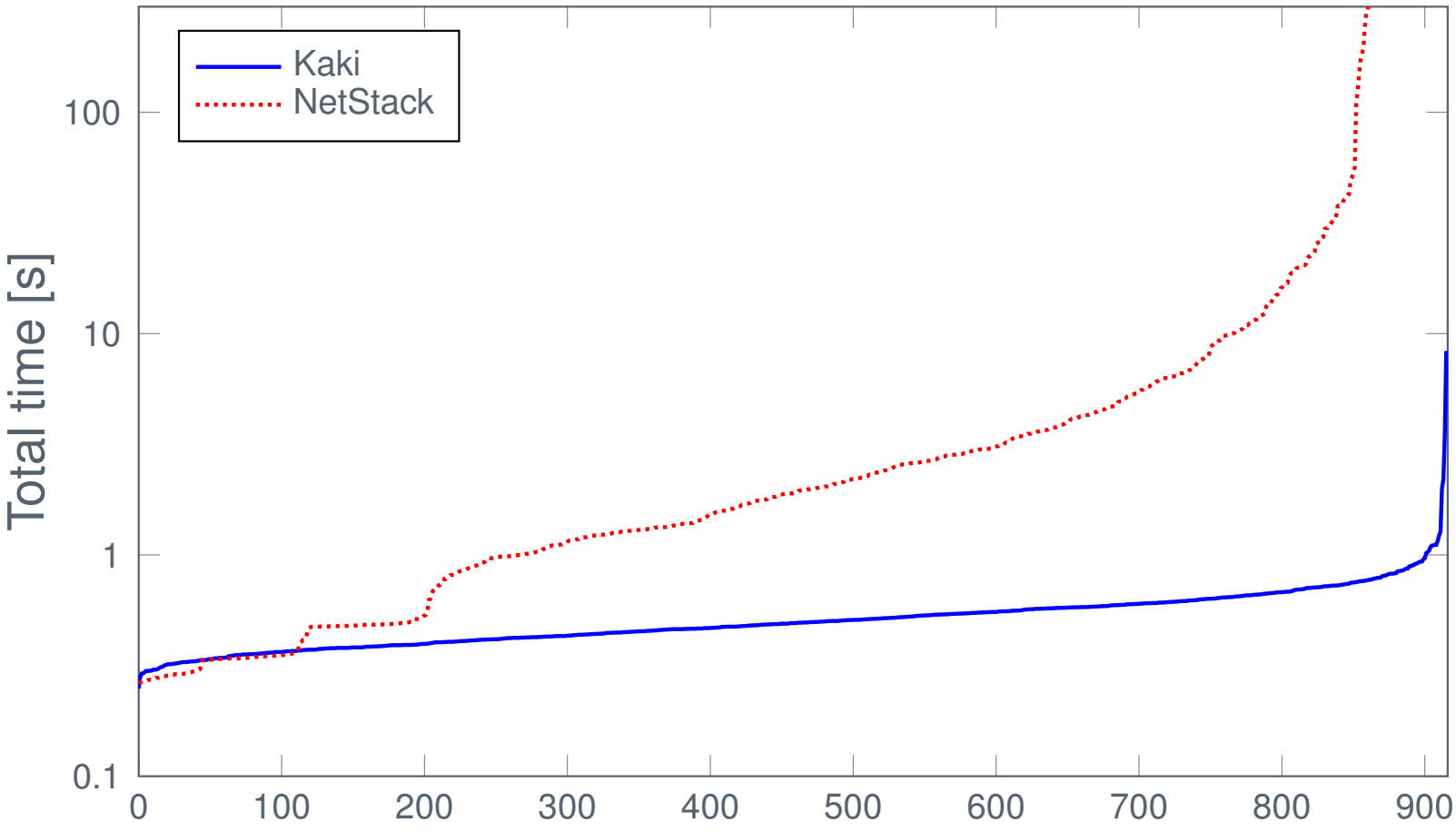



Figure: Comparion with NetStack

# Conclusion



- Kaki capabilities
  - Find optimal concurrent updates
  - Supports splittable flows
  - Supports arbitrary regular policies
- Performed on par with FLIP

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- Kaki capabilities
  - Find optimal concurrent updates
  - Supports splittable flows
  - Supports arbitrary regular policies
- Performed on par with FLIP
- Faster if subproblems are solved parallel

Presentation Concluded

# Comparison with SegPG

## Results



- Kaki limited to 1 switch per batch
- SeqPG unable to decide 2 problems

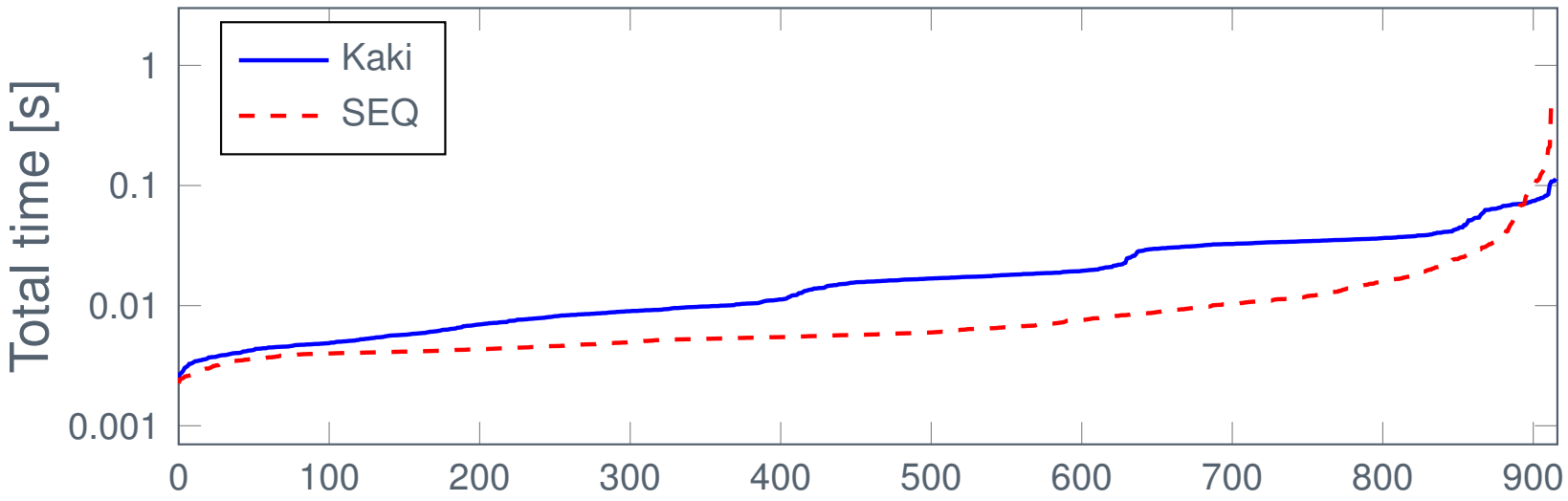



Figure: Kaki benchmarked against SeqPG

# Splitable Flows
## Results



- Comparison with ourselves
- Small overhead

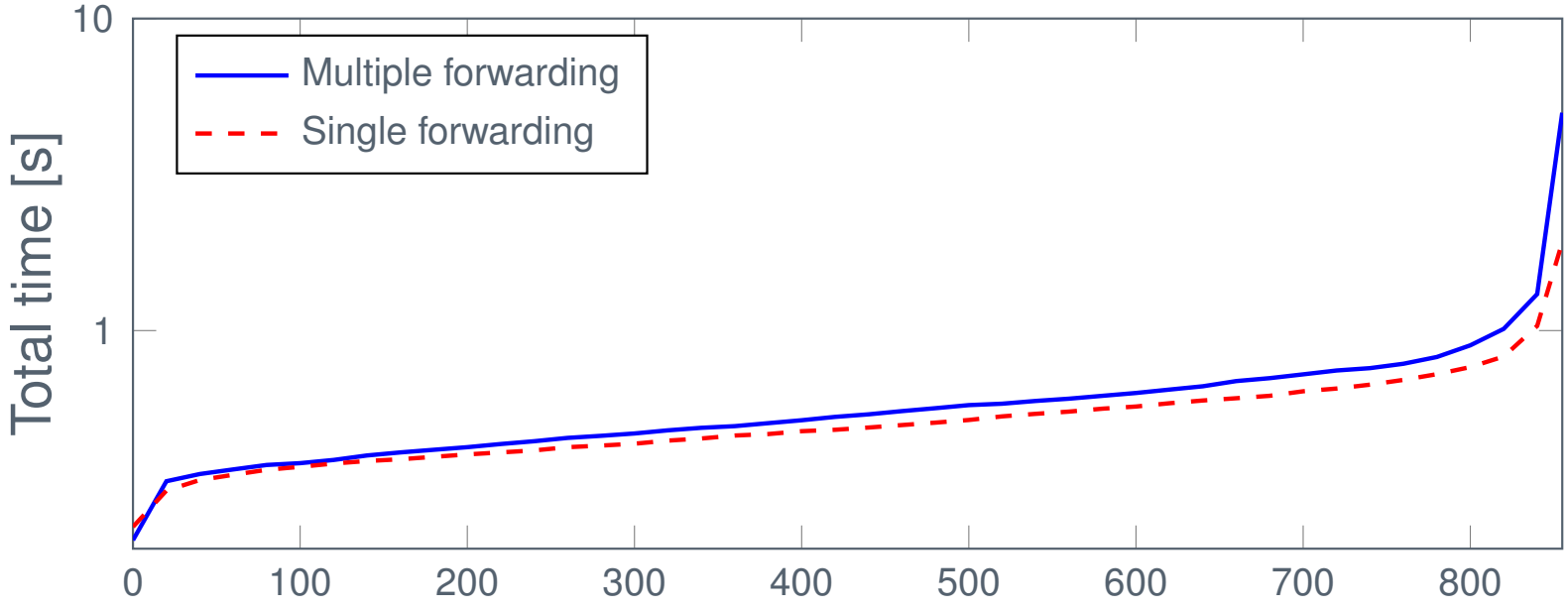



Figure: Splitable flows experiments for Kaki

# Preprocessing Techniques

## Results



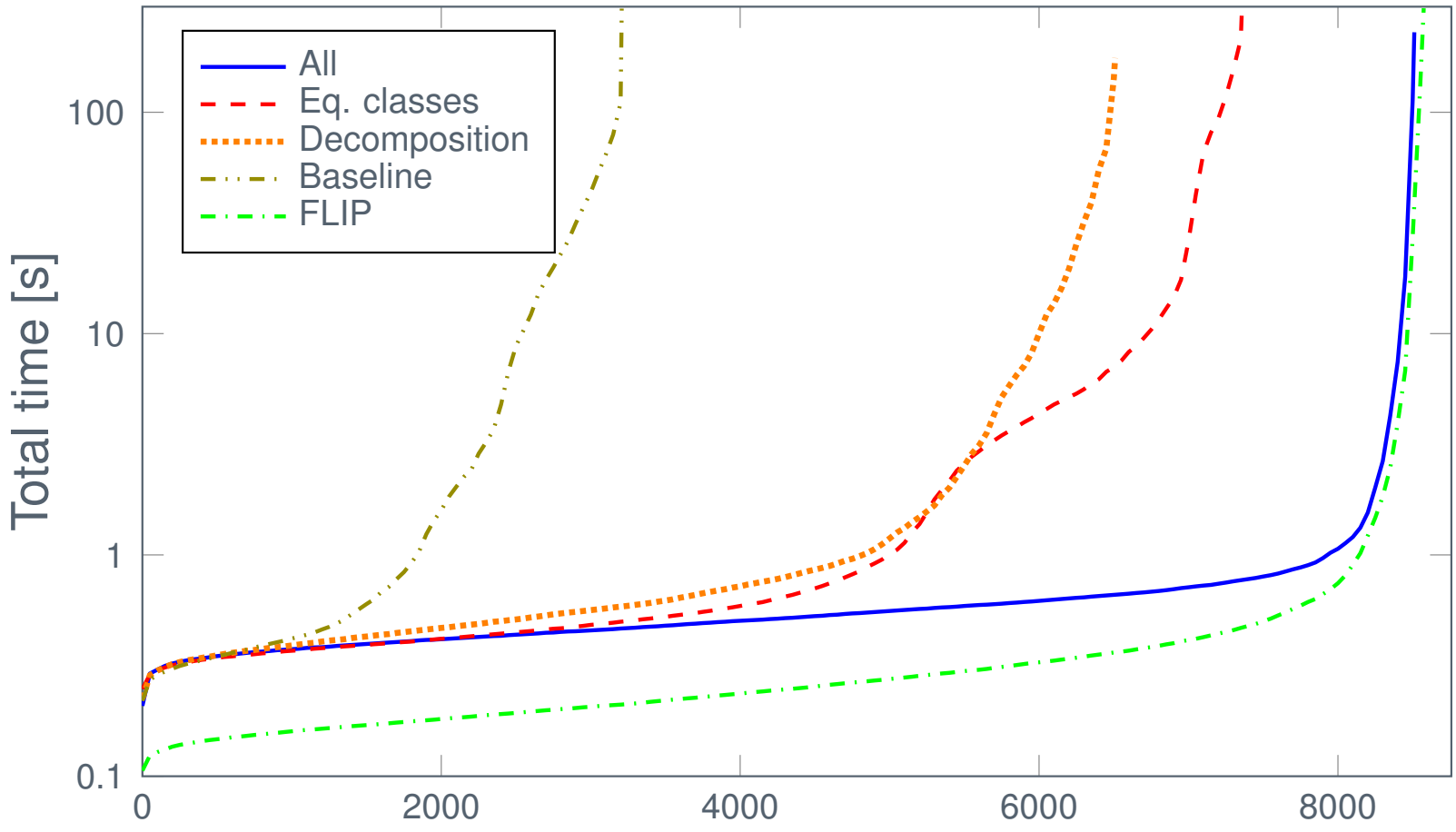
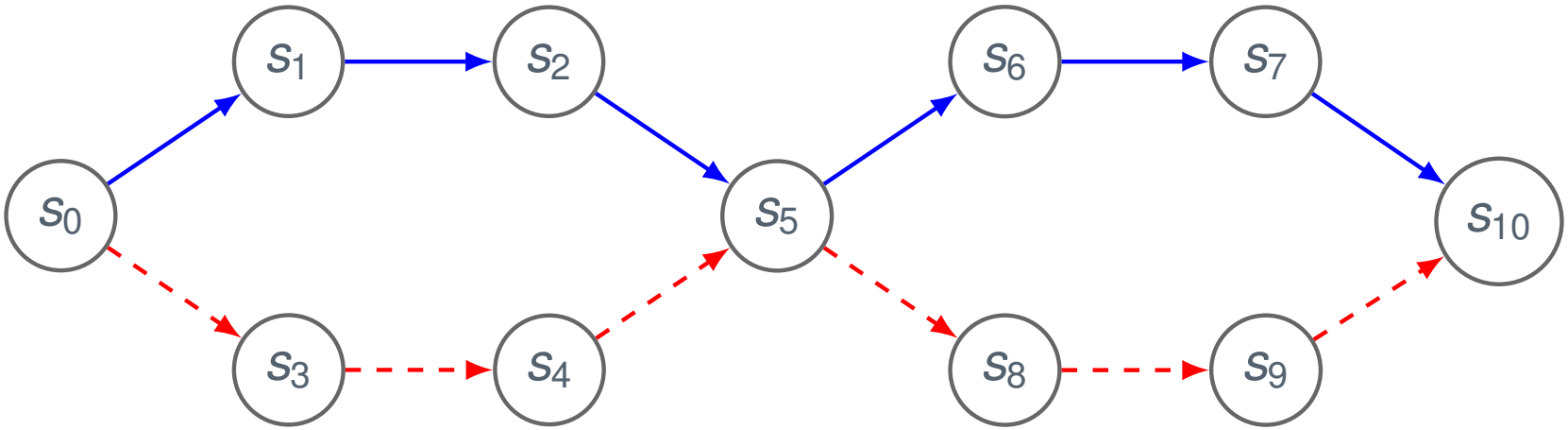



Figure: Experiments of the preprocessing techniques of Kaki

# Update Equivalence Classes



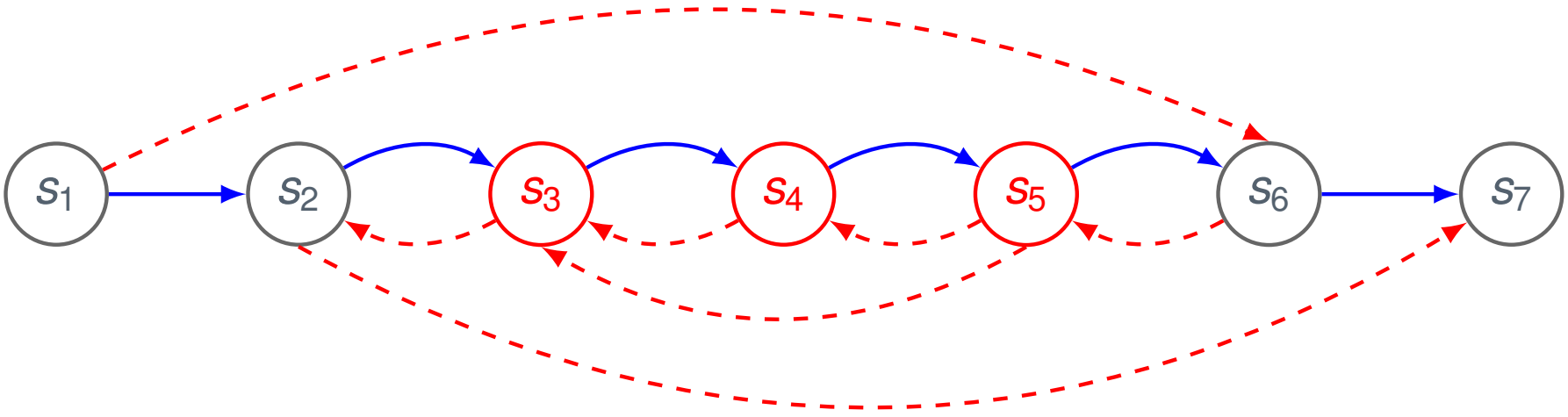



Always put $s_3, s_4, s_8, s_9$ in the first batch
Always put $s_1, s_2, s_6, s_7$ in the last batch

# Update Equivalence Classes

## Chain reduction






Switches $s_3, s_4, s_5$ can always be updated in the same batch