Verification of Concurrent Algorithms: an Abstraction Refinement Approach

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MCC Uppsala 2009

Outline

Introduction

Concurrent Algorithms

Symbolic Representation and Abstraction for Verification

Counter Example Guided Abstraction Refinement

Conclusion

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Introduction: parallelization

Exponential increase in processors speed has reached its technological limits

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Exponential increase in processors speed has reached its technological limits

- Increase the parallelization
- Divide the workload on parallel threads
- Sustain the performance growth
- Concurrent algorithms are already a reality, e.g. the java.util.concurrent

Introduction:price

Parallelization comes at a price:

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Goal: Develop automatic tools that analyze source code and check correctness for all possible interleavings and all possible numbers of threads

Verification Approach

Tools are to implement verification techniques:

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$$\text{Model} \quad \models \quad \text{Spec}$$

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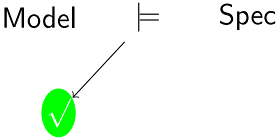

Model $\models$ Spec

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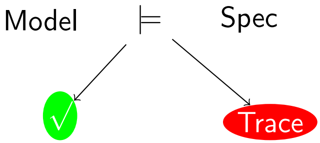

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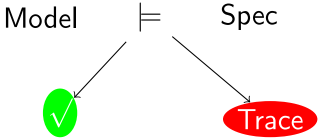

Goal: Extend Model Checking to analyze concurrent algorithms

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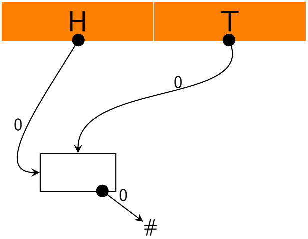

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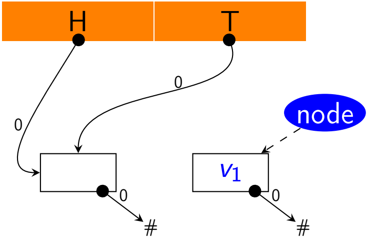

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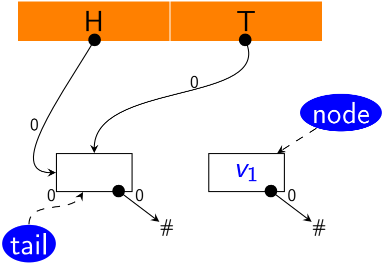

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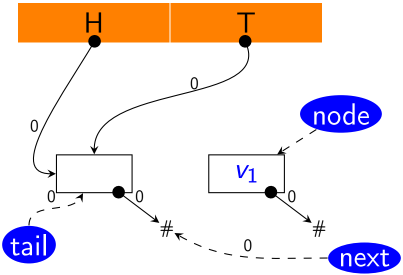

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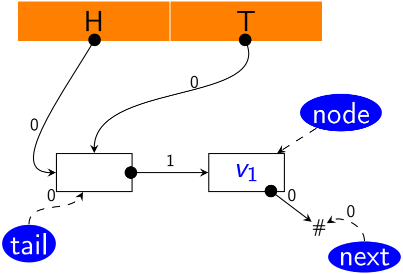

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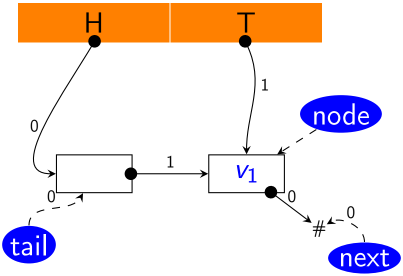

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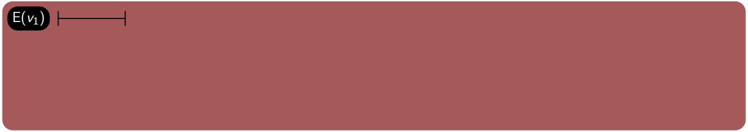

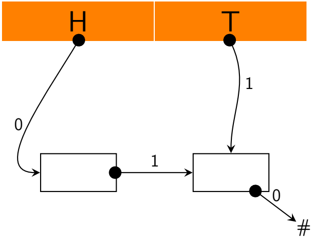

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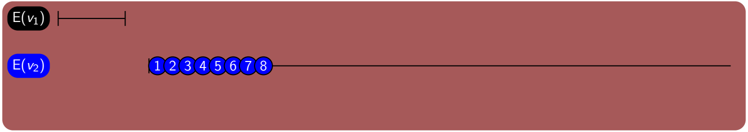

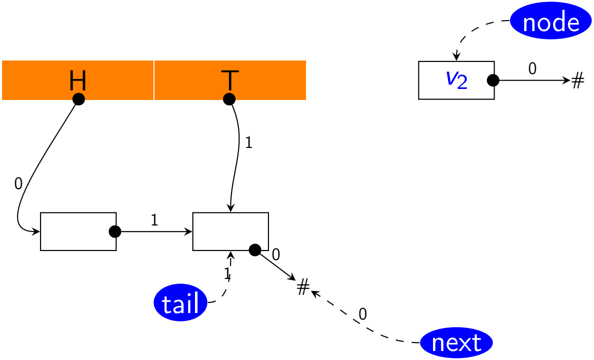

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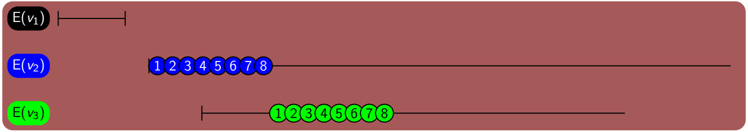

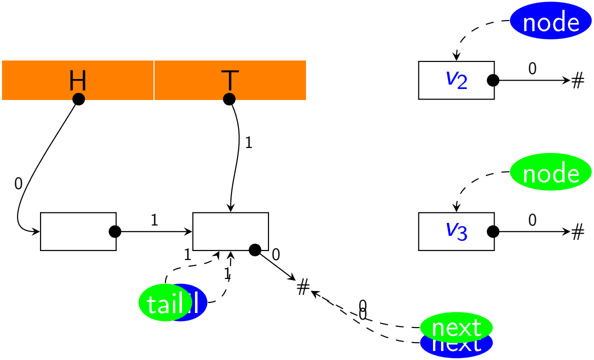

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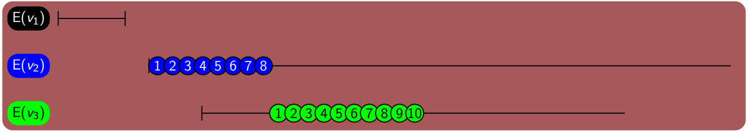

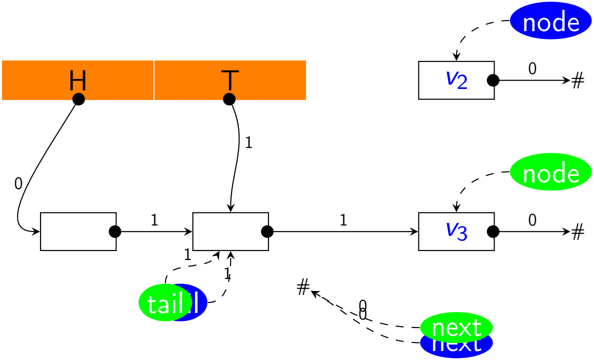

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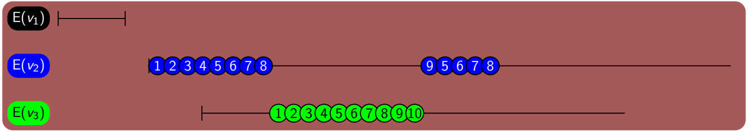

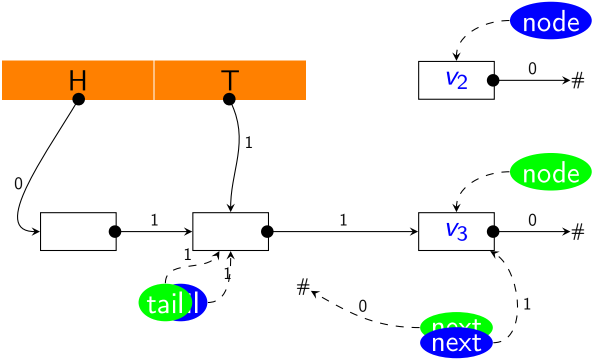

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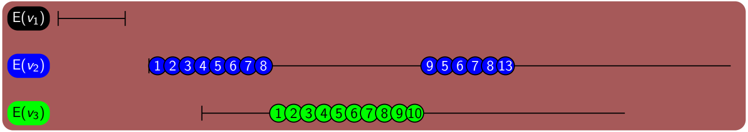

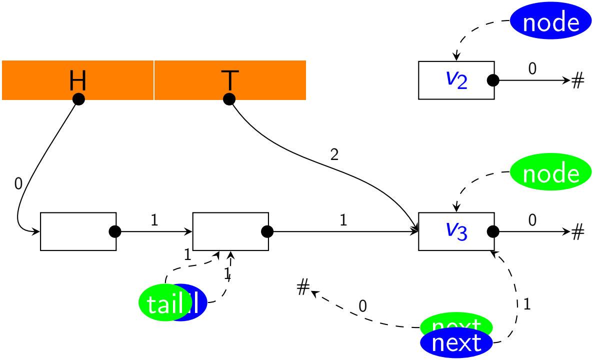

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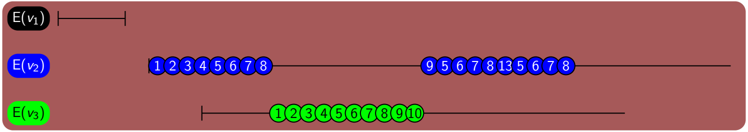

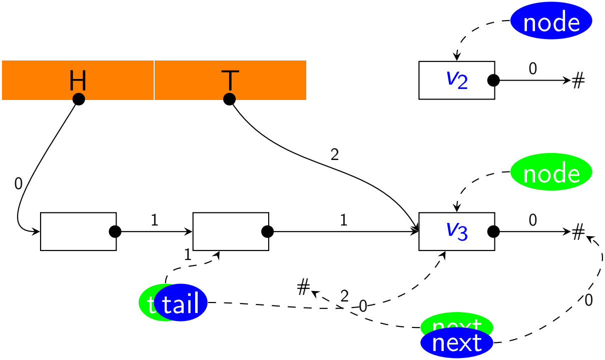

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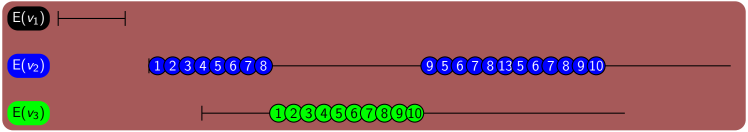

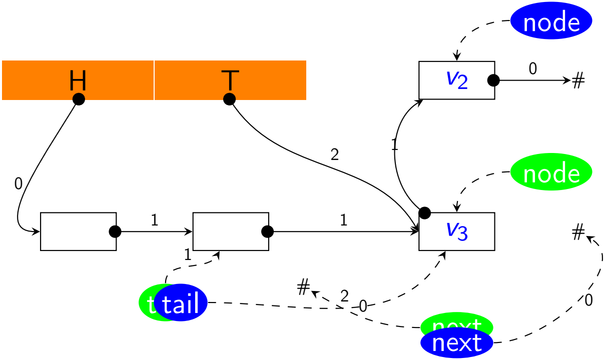

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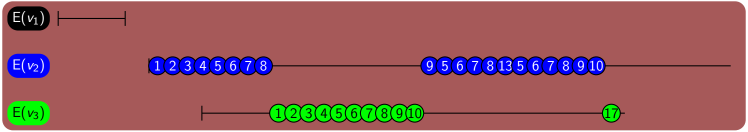

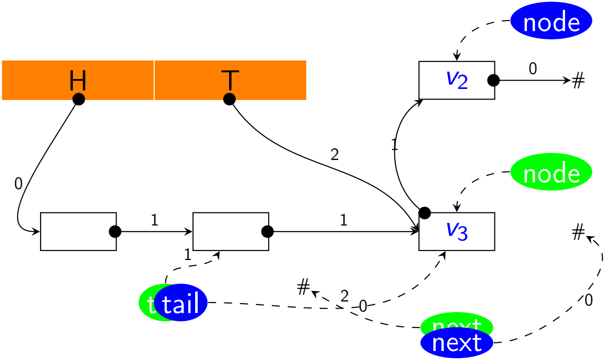

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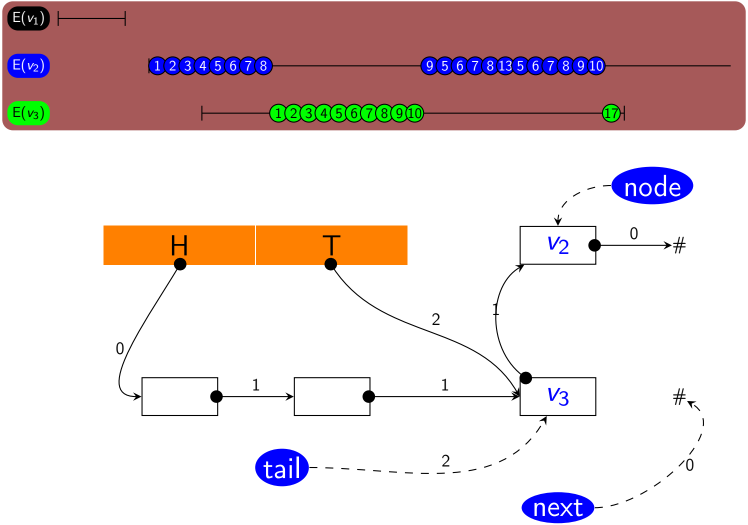

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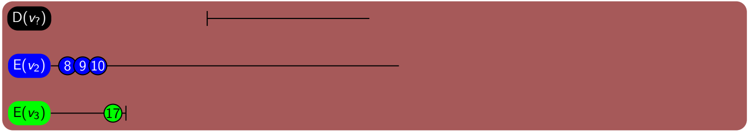

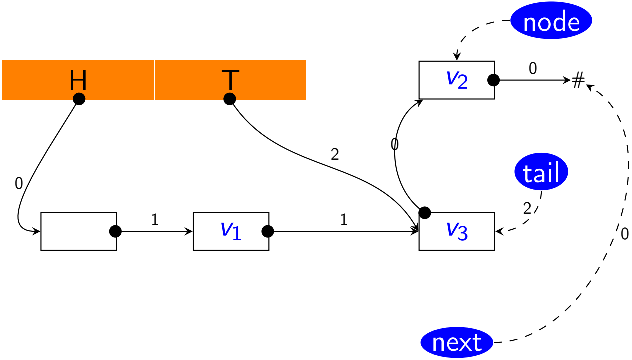

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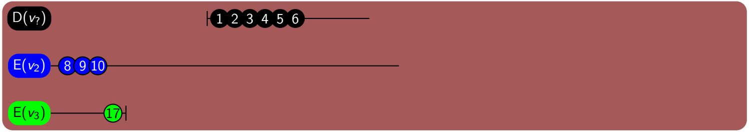

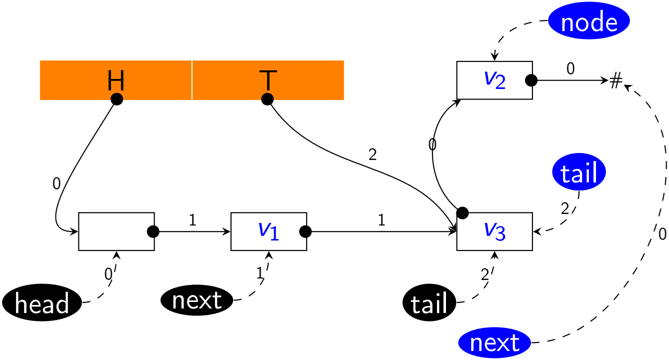

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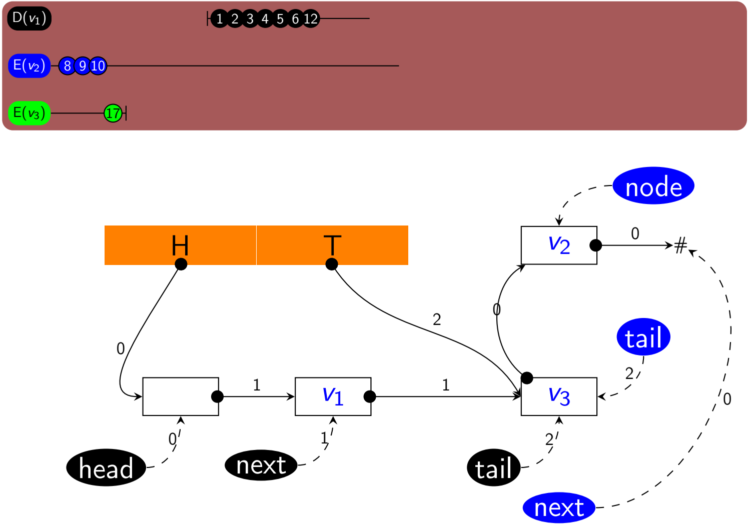

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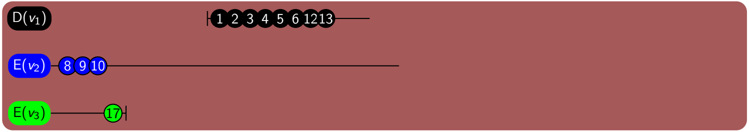

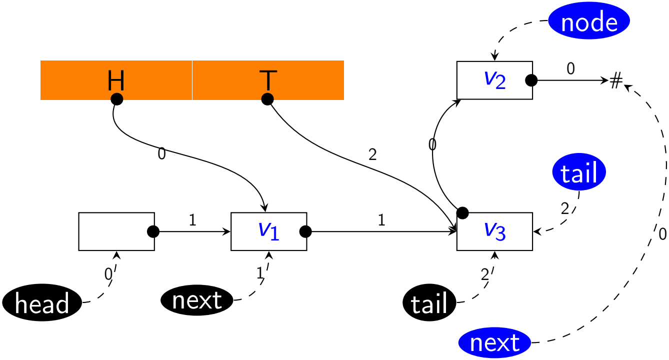

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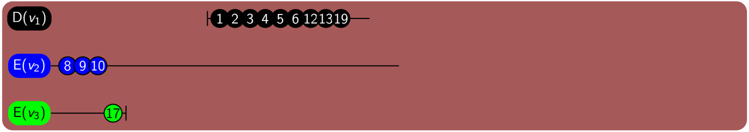

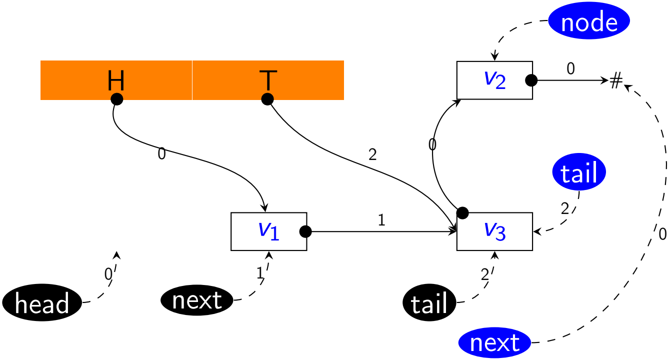

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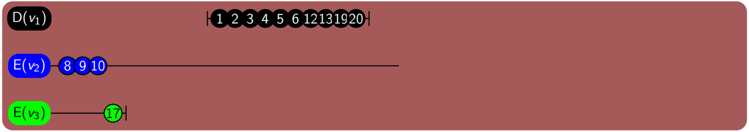

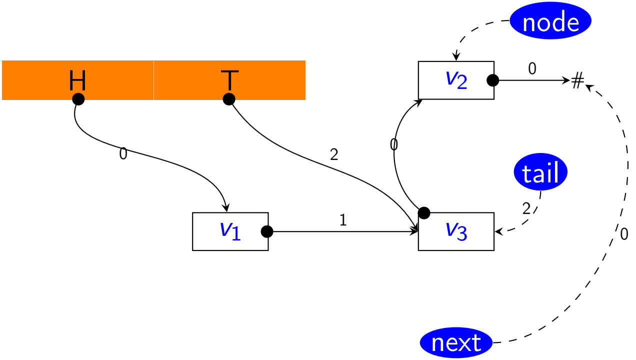

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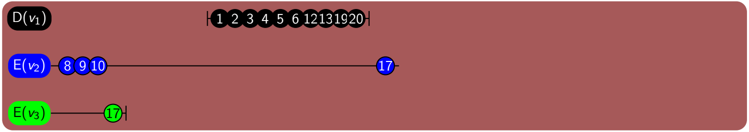

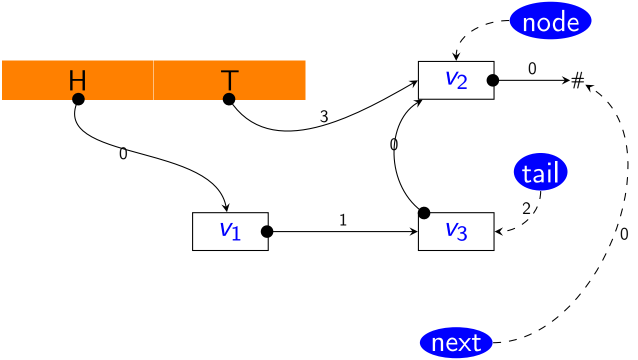

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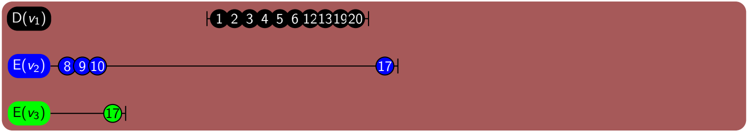

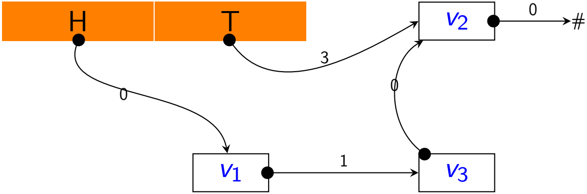

Concurrent Algorithms

Analysis needs to take into account several sources of difficulty:

- Arbitrary numbers of threads
- Infinite data domains
- Dynamic memory
- Memory model guaranteed by the machine
- ...

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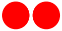

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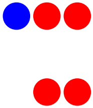

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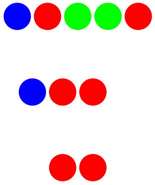

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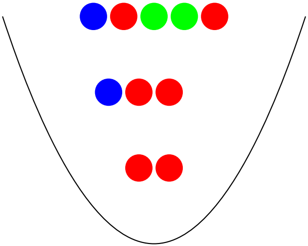
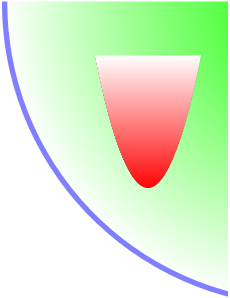


Use upward closed sets as symbolic representations for states violating safety properties

Symbolic Representation and Backward Analysis



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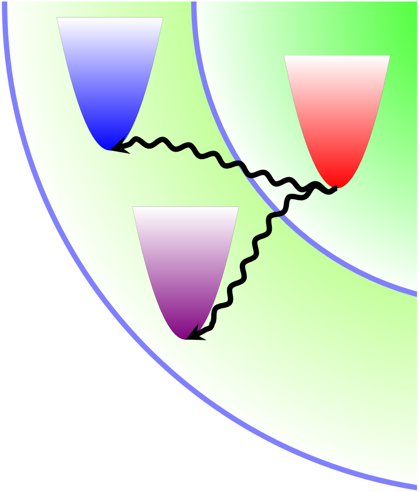

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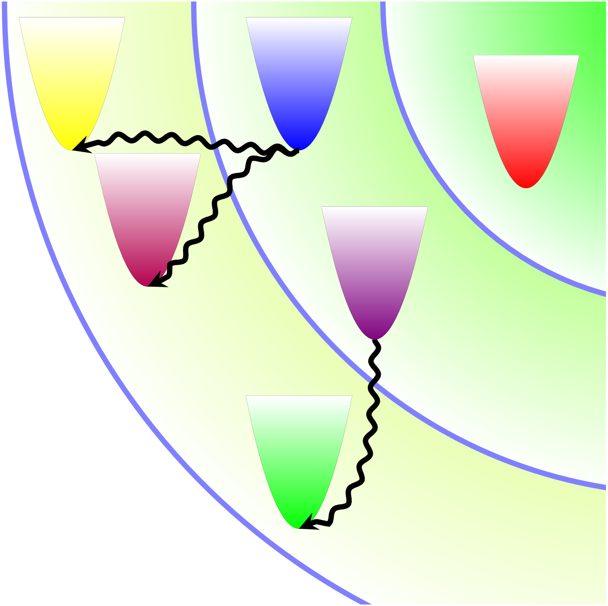

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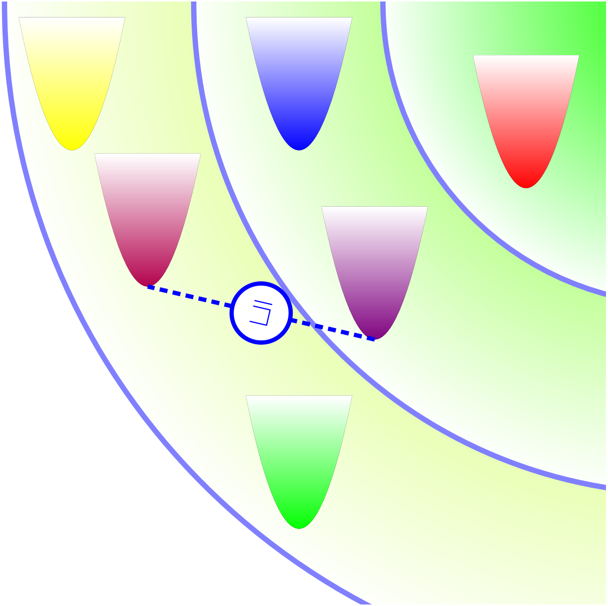

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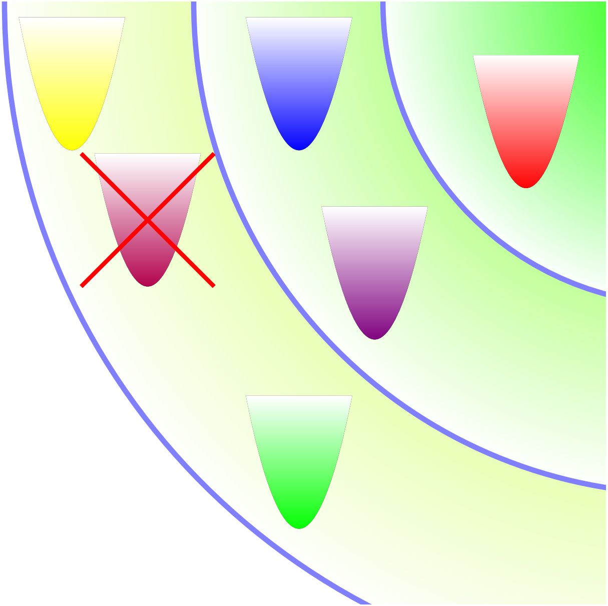

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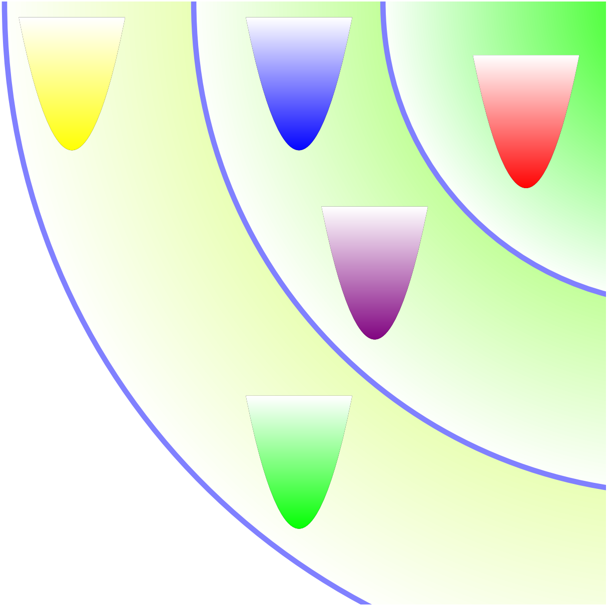

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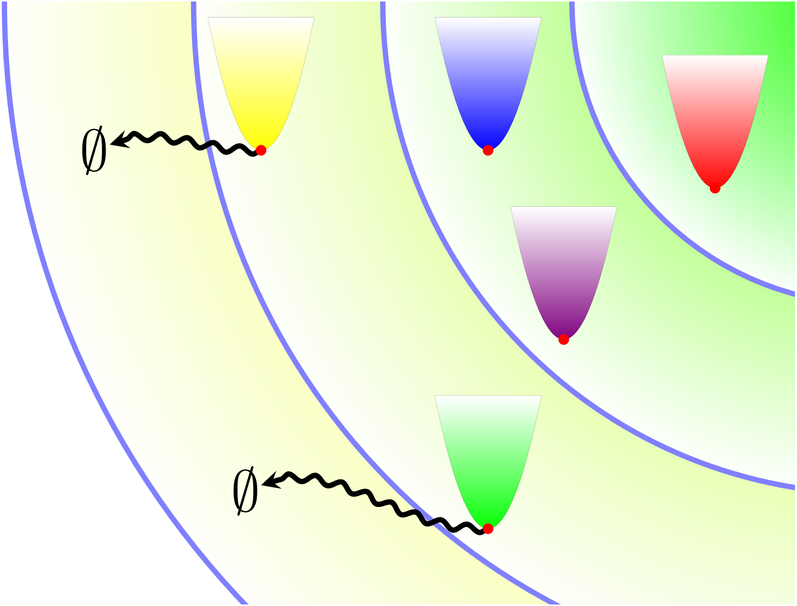

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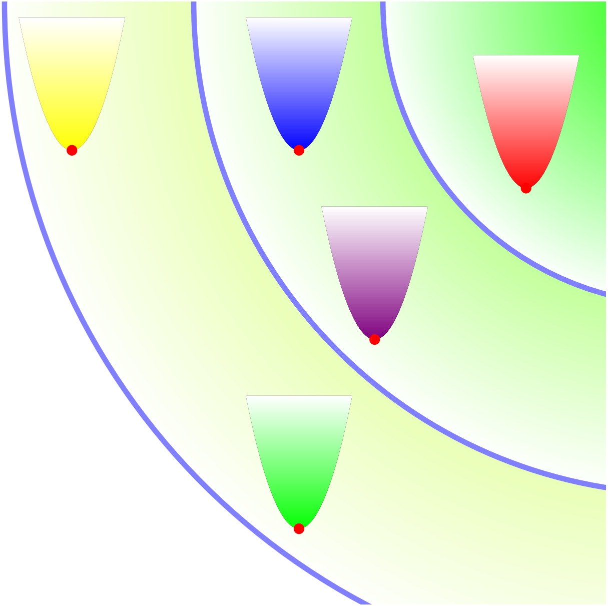

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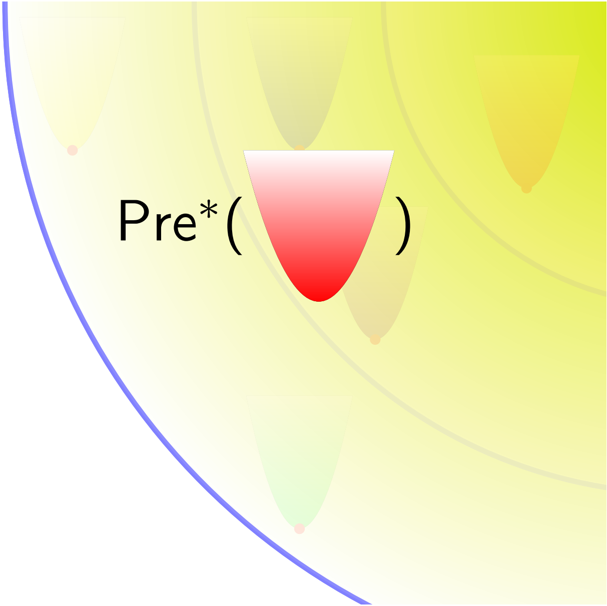

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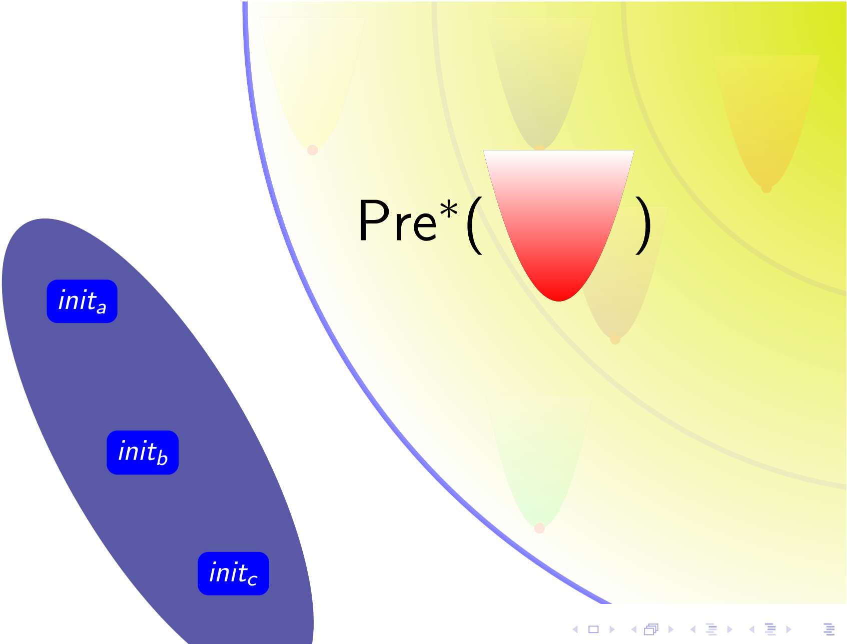

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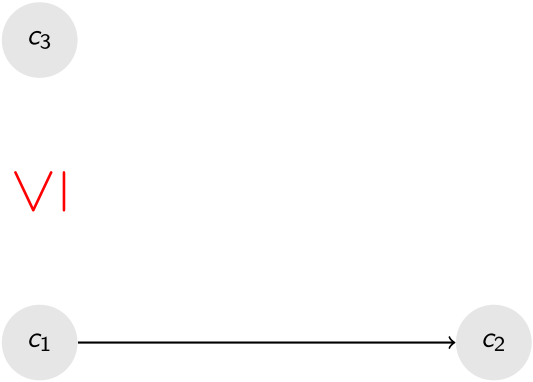

Abstraction to Permit Symbolic Analysis

$$\begin{tikzcd}
c_3 \arrow[r] & c_4 \\
c_1 \arrow[r] \arrow[u, phantom, sloped, "\leq"] & c_2 \arrow[u, phantom, sloped, "\leq"]
\end{tikzcd}$$

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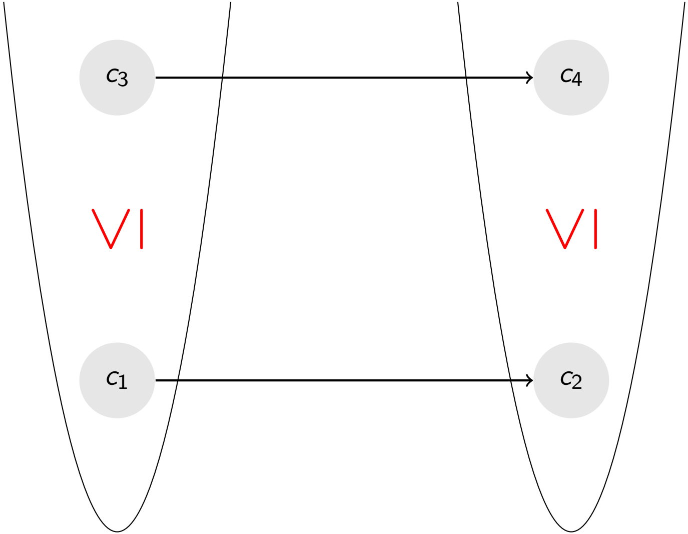

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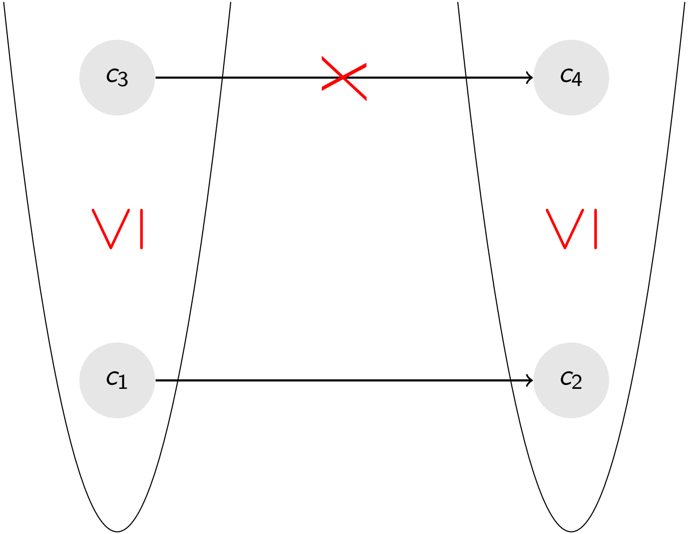
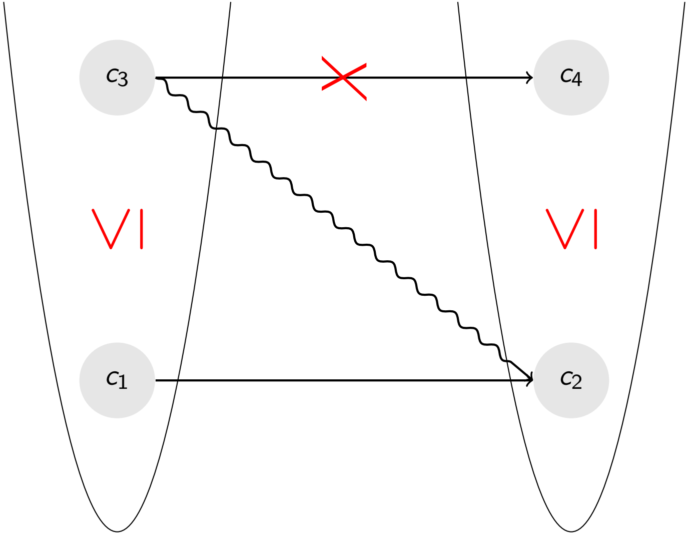
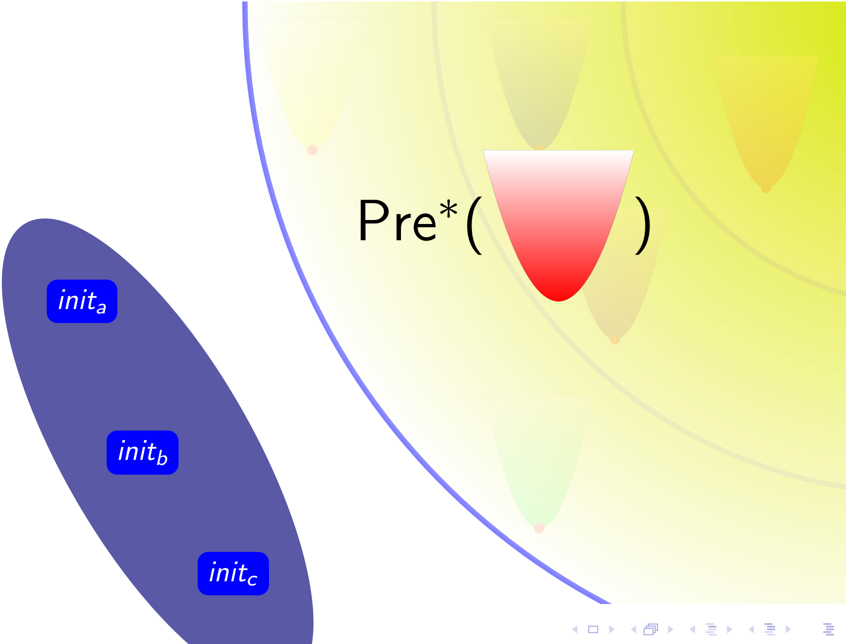


Abstraction to Permit Symbolic Analysis



Abstraction and Backward Analysis



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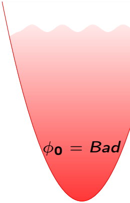

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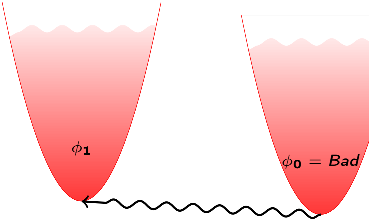
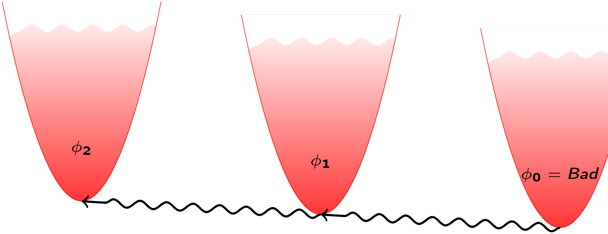


Counter Example Guided Abstraction Refinement



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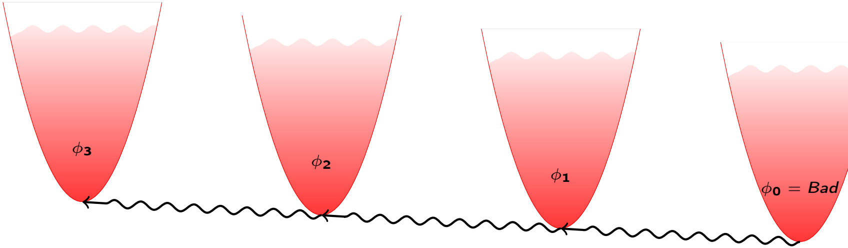

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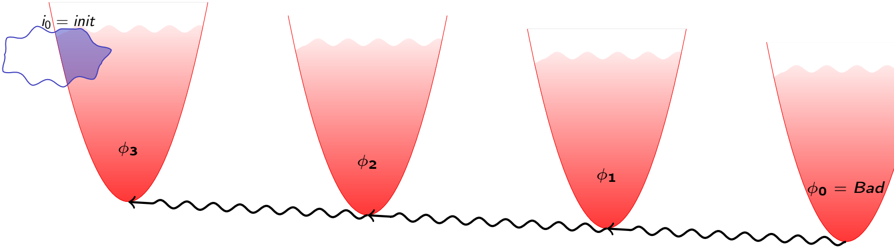

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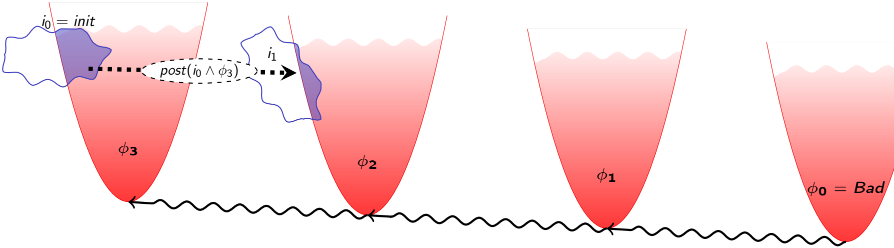

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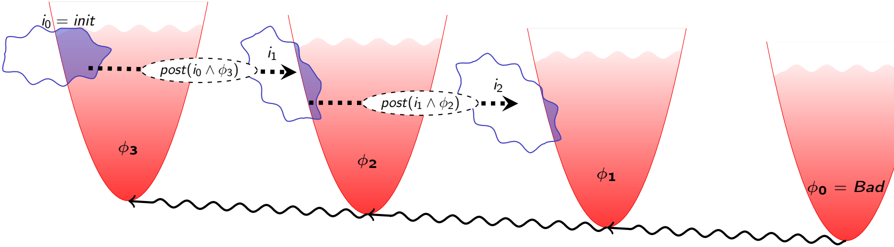

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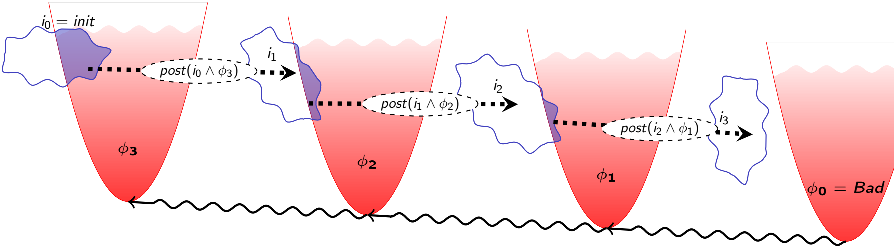
$i_0 = init$
$post(i_0 \wedge \phi_3)$
i_1
ϕ_3
$post(i_1 \wedge \phi_2)$
i_2
ϕ_2
$post(i_2 \wedge \phi_1)$
i_3
ϕ_1
$\phi_0 = Bad$

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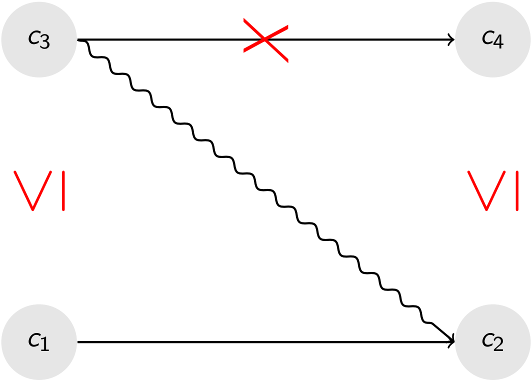

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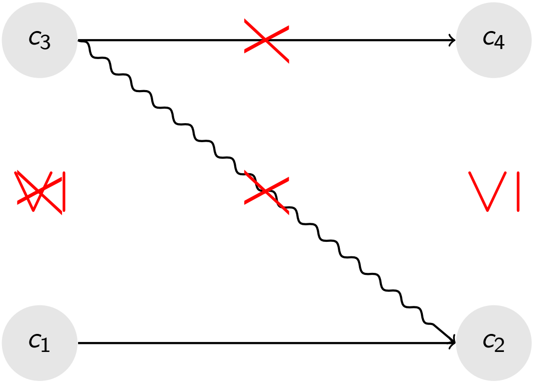

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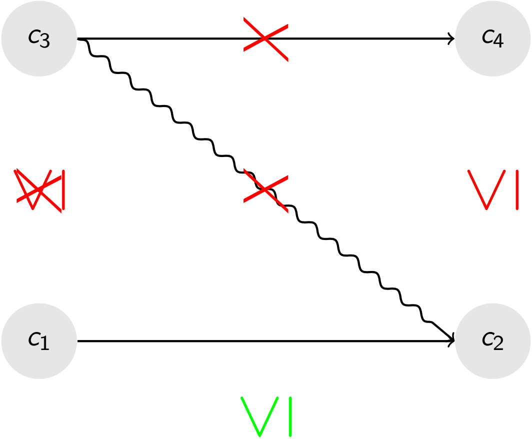

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- We build automatic symbolic techniques to increase confidence in concurrent algorithms
- Our techniques explore all interleavings for arbitrary numbers of threads
- We obtained successful results and are working on the verification of code found in widespread software, like the java.util.concurrent package