Automatic Repair and Deadlock Detection for Parameterized Systems

Swen Jacobs [1] **Mouhammad Sakr** [2] Marcus Völp [2]

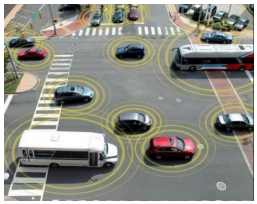
[1]CISPA Helmholtz Center for Information Security, Saarbrücken, Germany

[2]SnT, University of Luxembourg, Luxembourg

October 19, 2022

Parameterized Concurrent Systems are everywhere

source: sheffield.ac.uk



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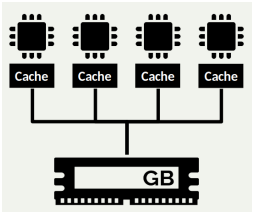

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Concurrent and Parameterized Systems

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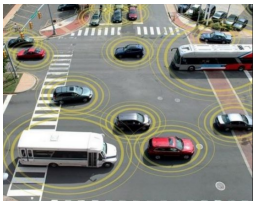

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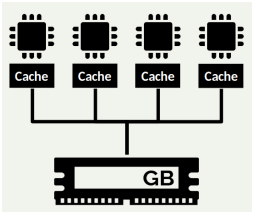

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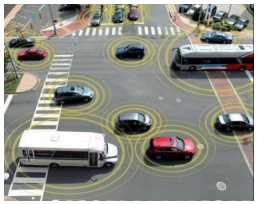

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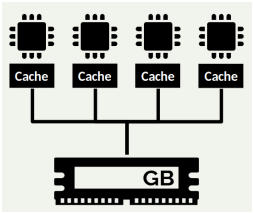

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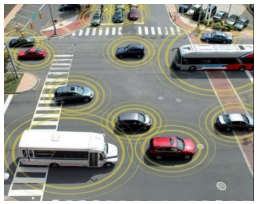

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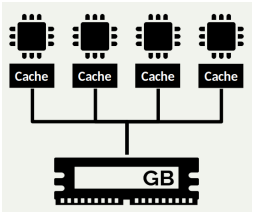

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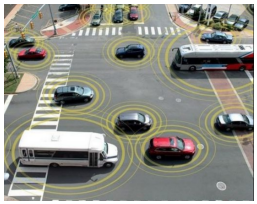

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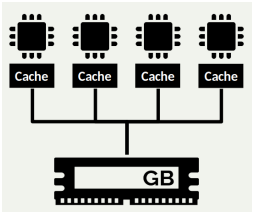

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Concurrent and Parameterized Systems

decidable classes

undecidable

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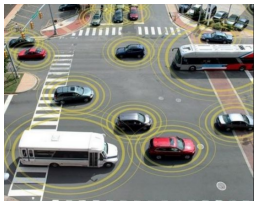

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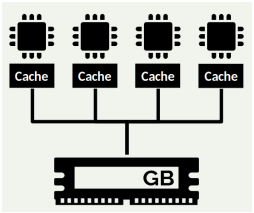

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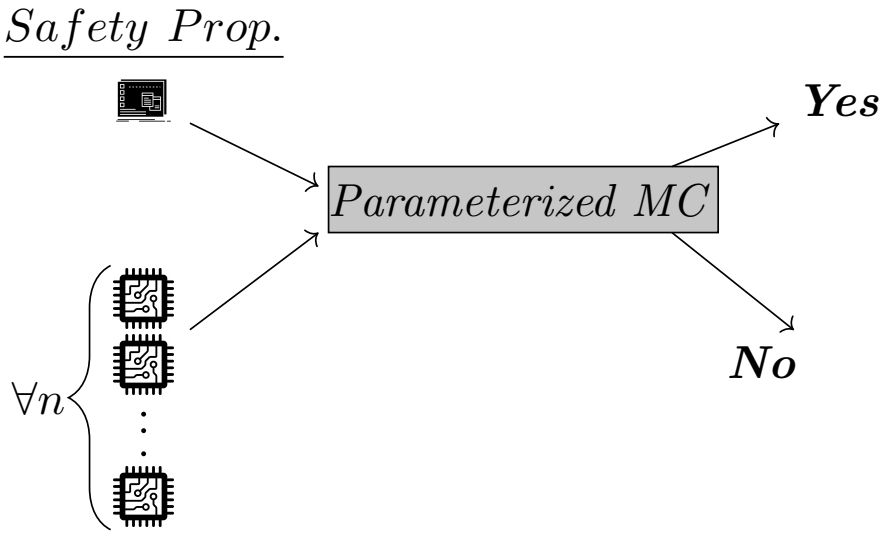

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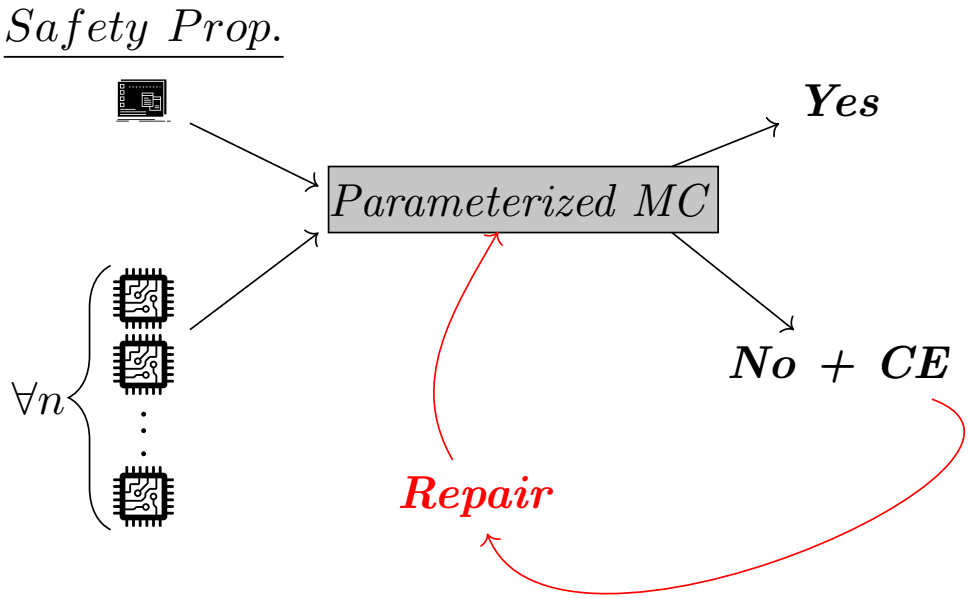

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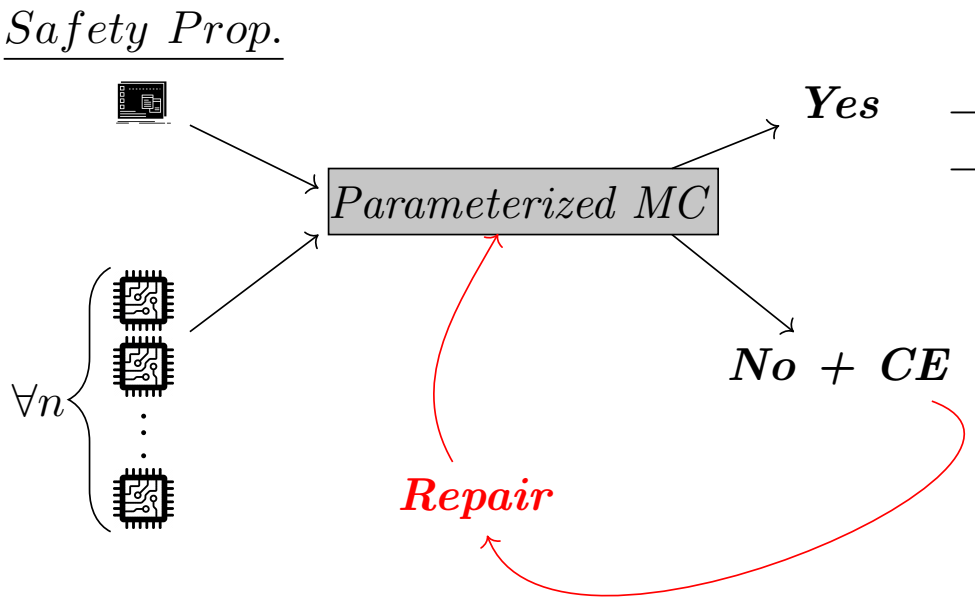

→ Repair Internal Behavior
→ Repair Communication

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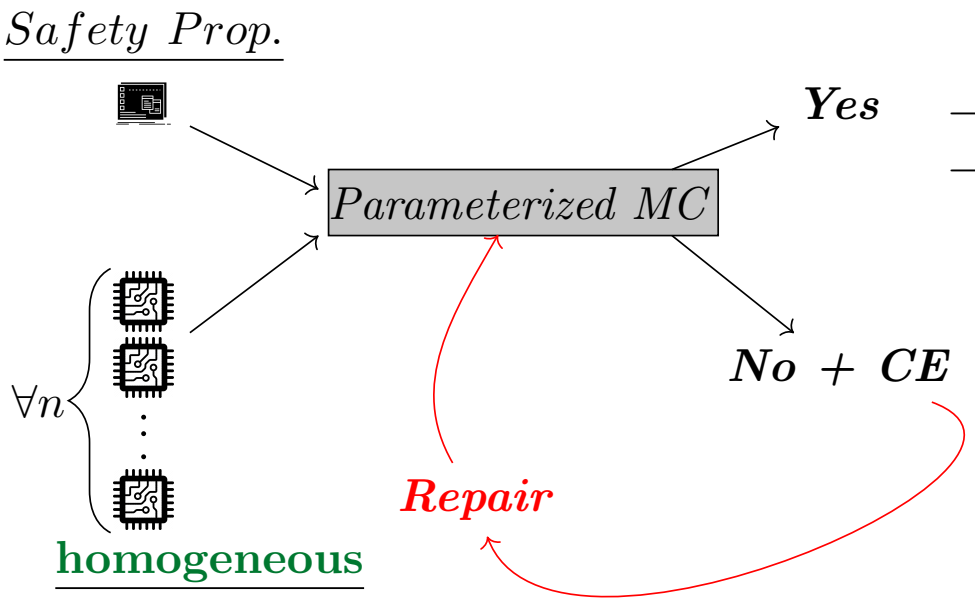

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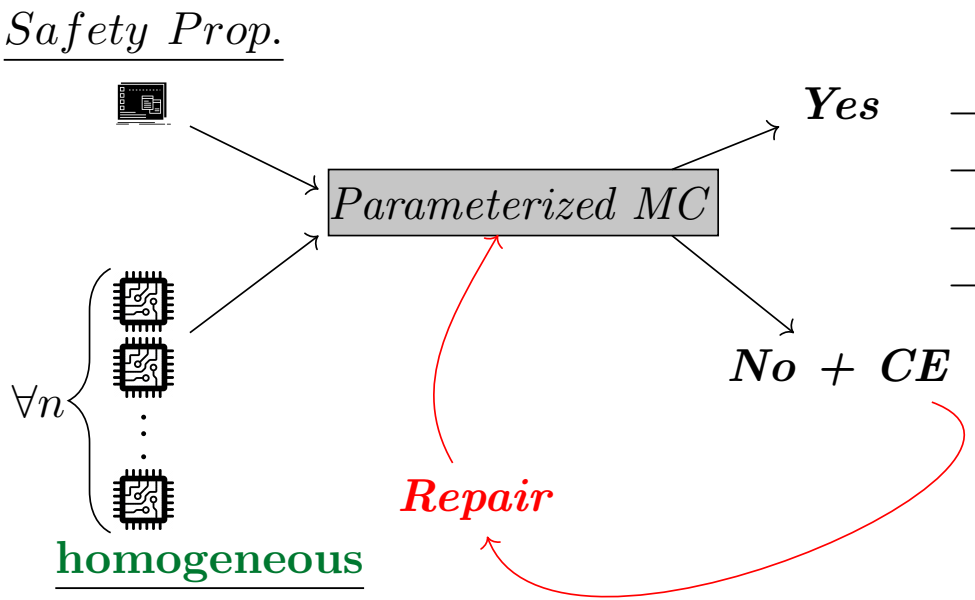

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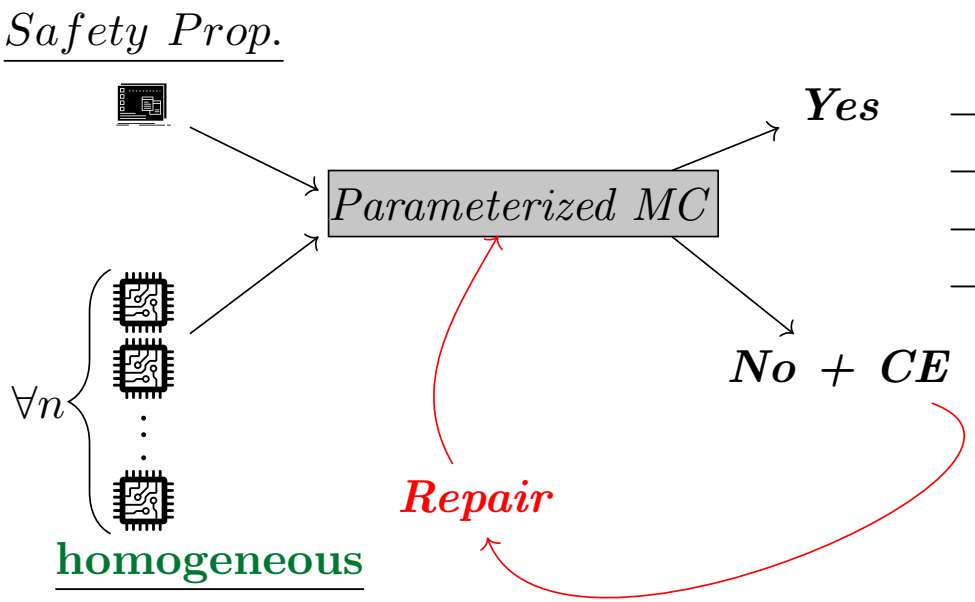

→ Repair Internal Behavior
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→ **Avoid trivial solutions**
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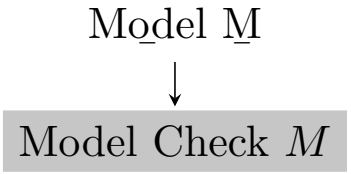
The repair problem is, for a given process implementation, to find a **refinement** such that a given safety property is satisfied.

Parameterized Repair Basic Idea

Model M

Parameterized Repair Basic Idea



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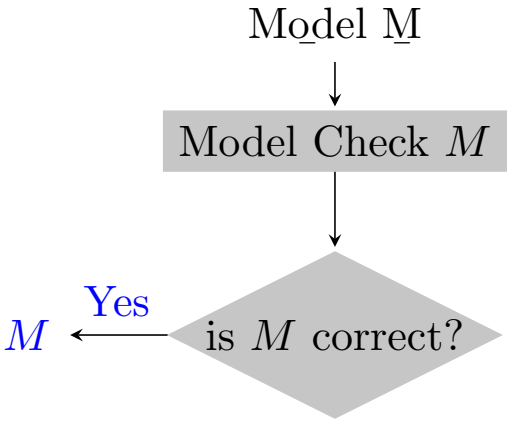

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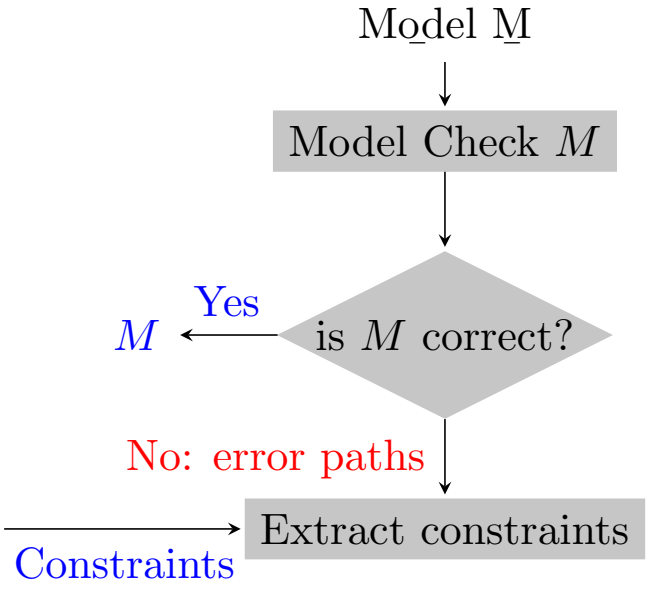

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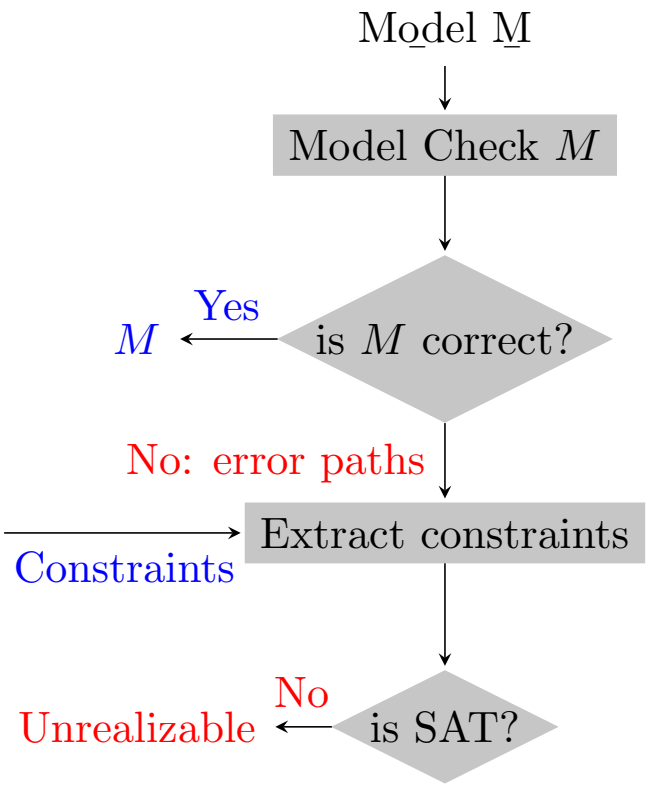

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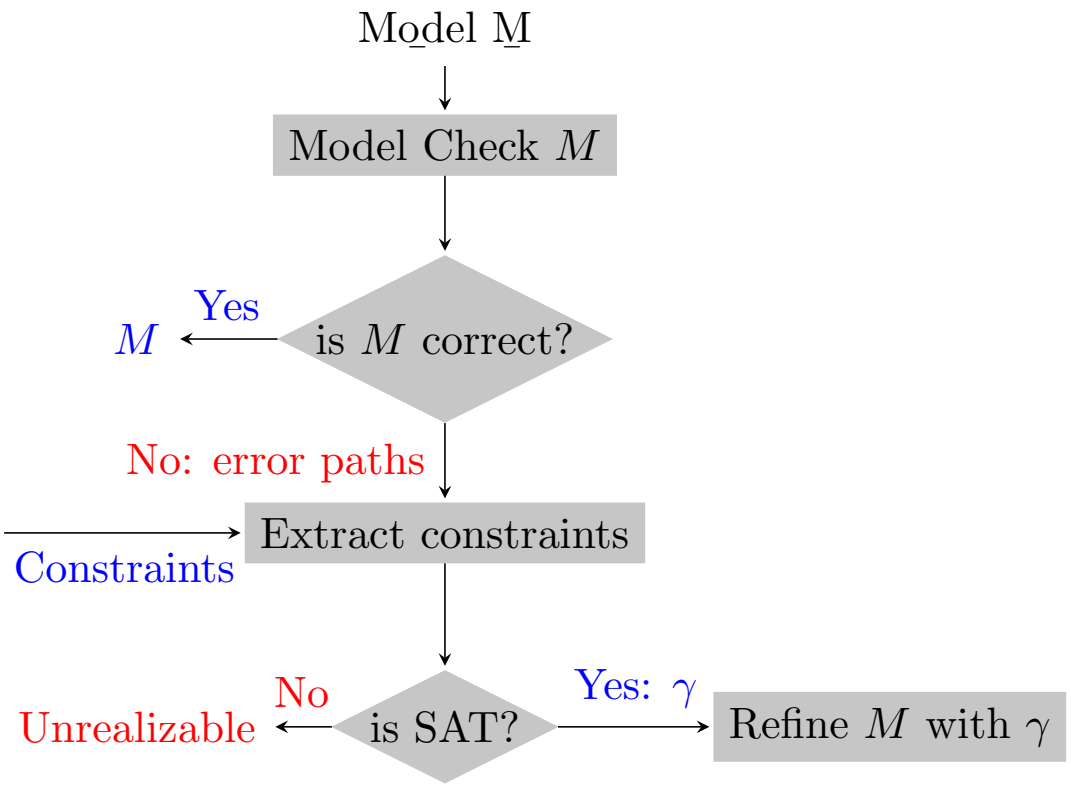

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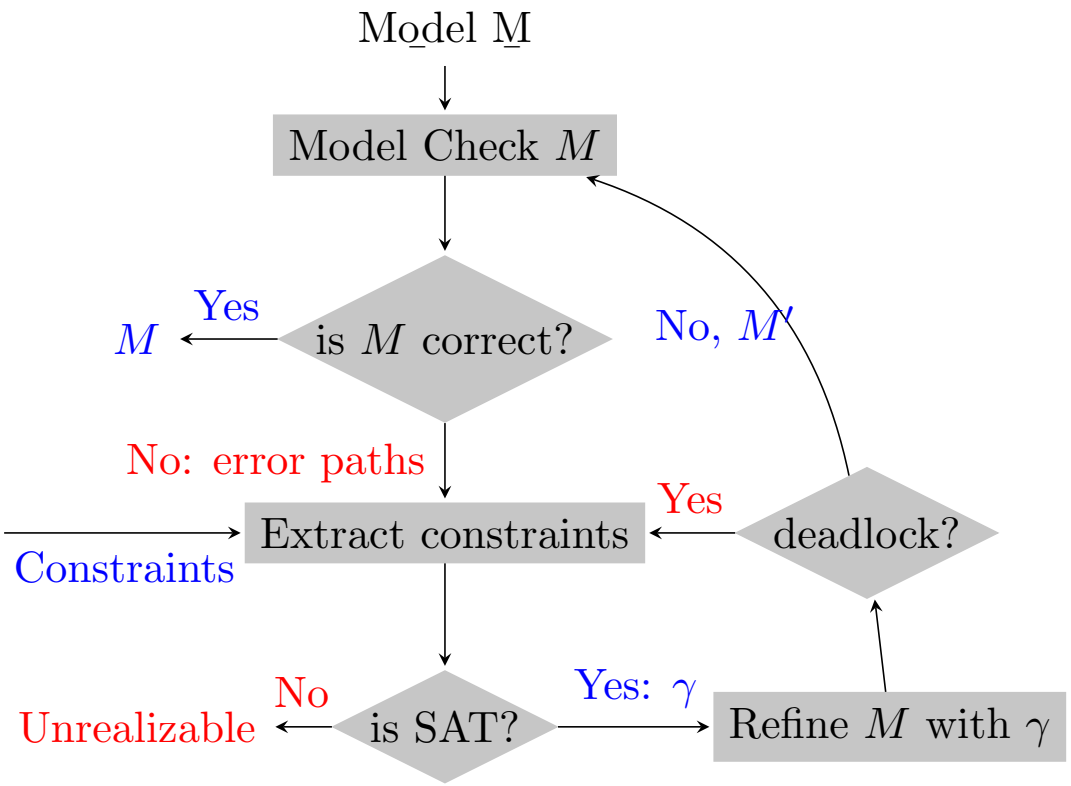

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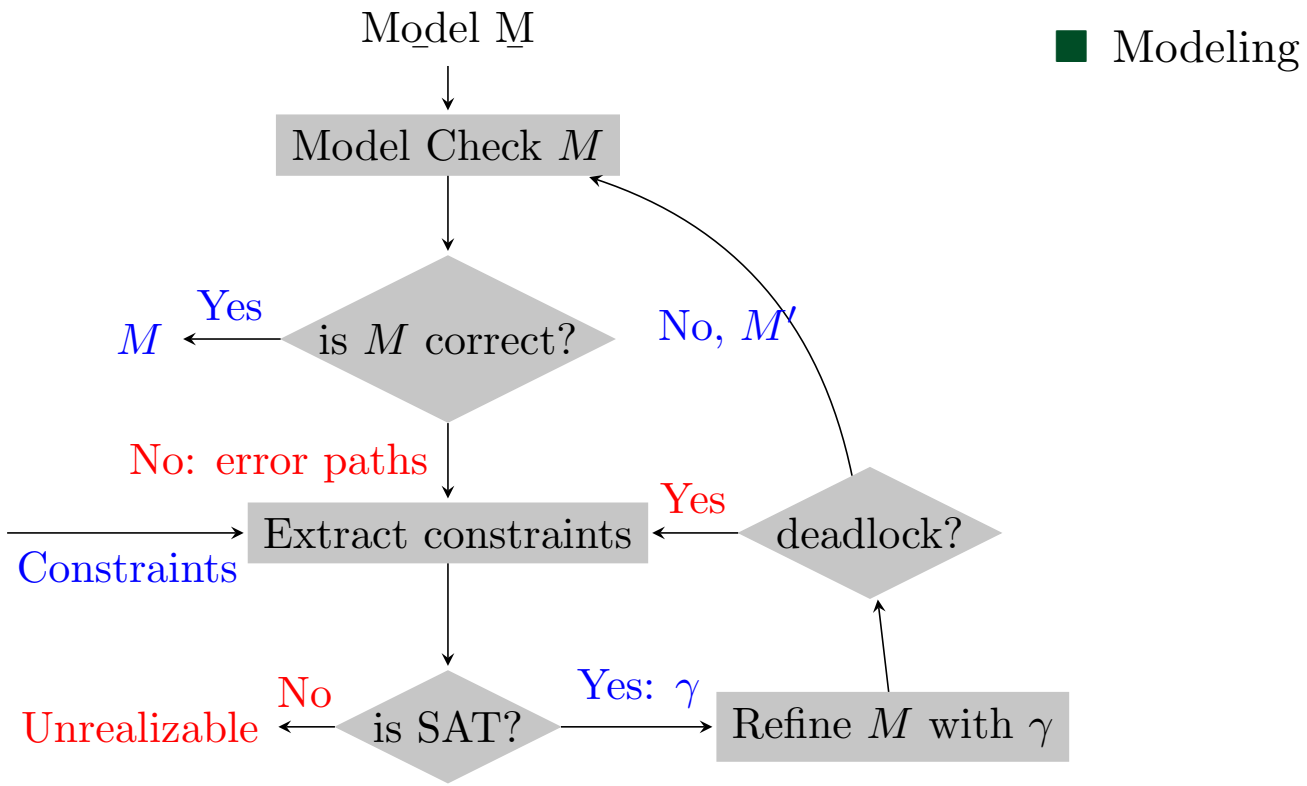
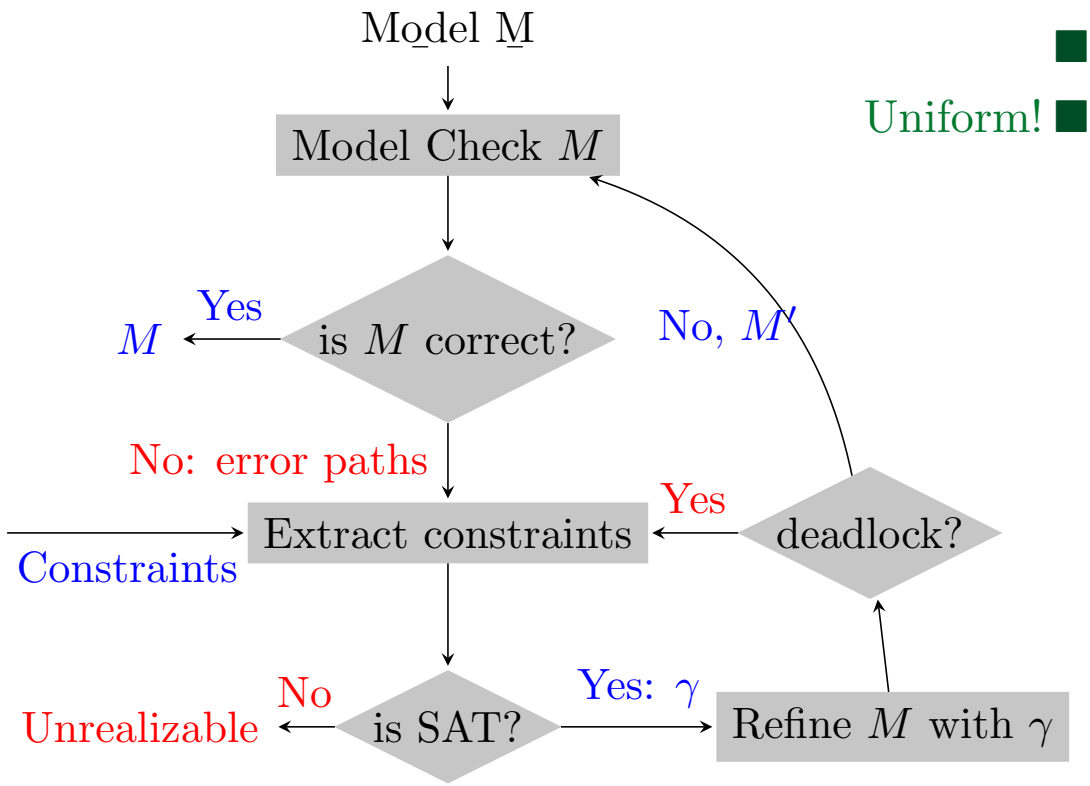


Modeling

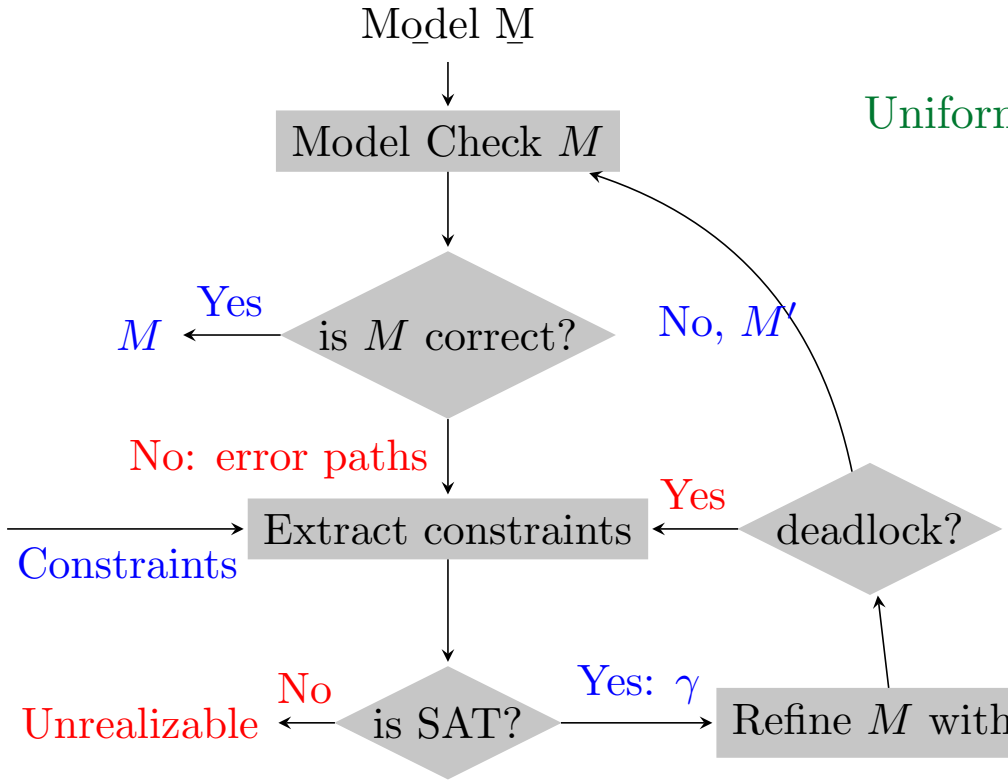
Parameterized Repair Basic Idea



Modeling

Uniform! PMC Undecidable!

Parameterized Repair Basic Idea



- Modeling
- PMC Uniform! Undecidable!
- Repair $\forall \mathbf{n}$

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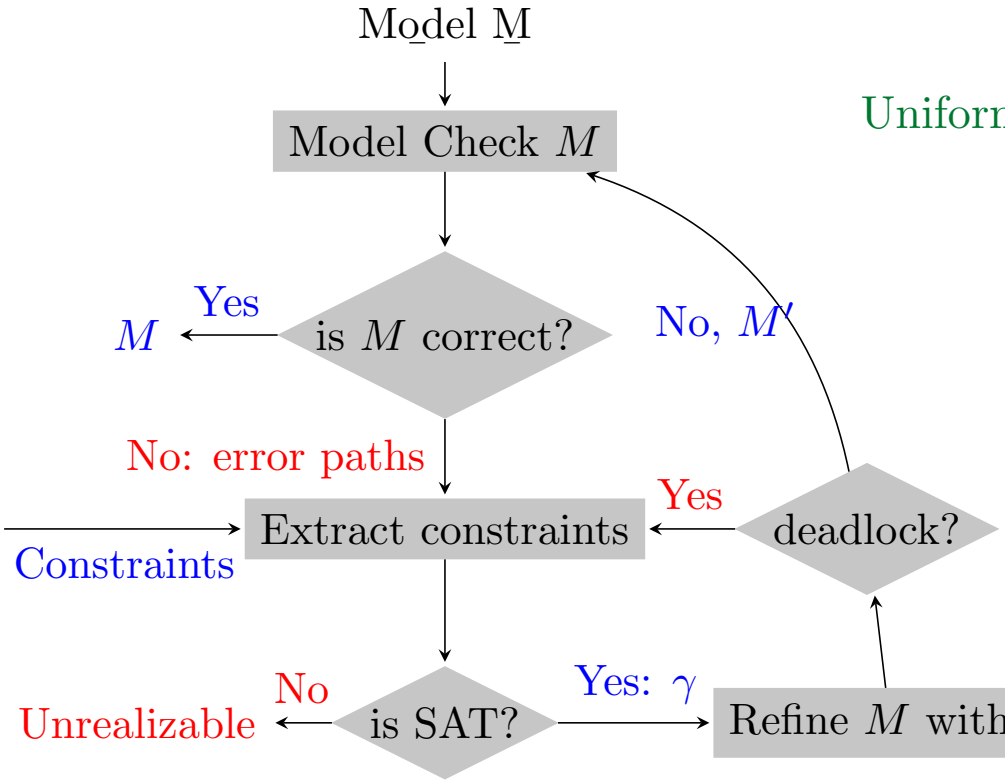

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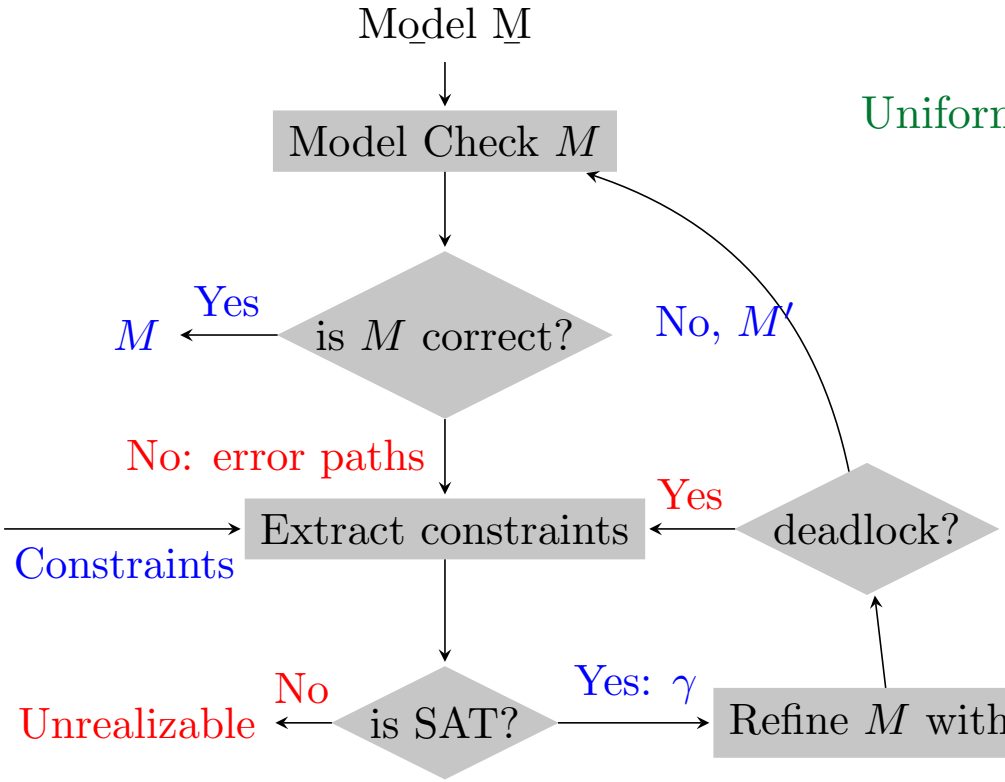

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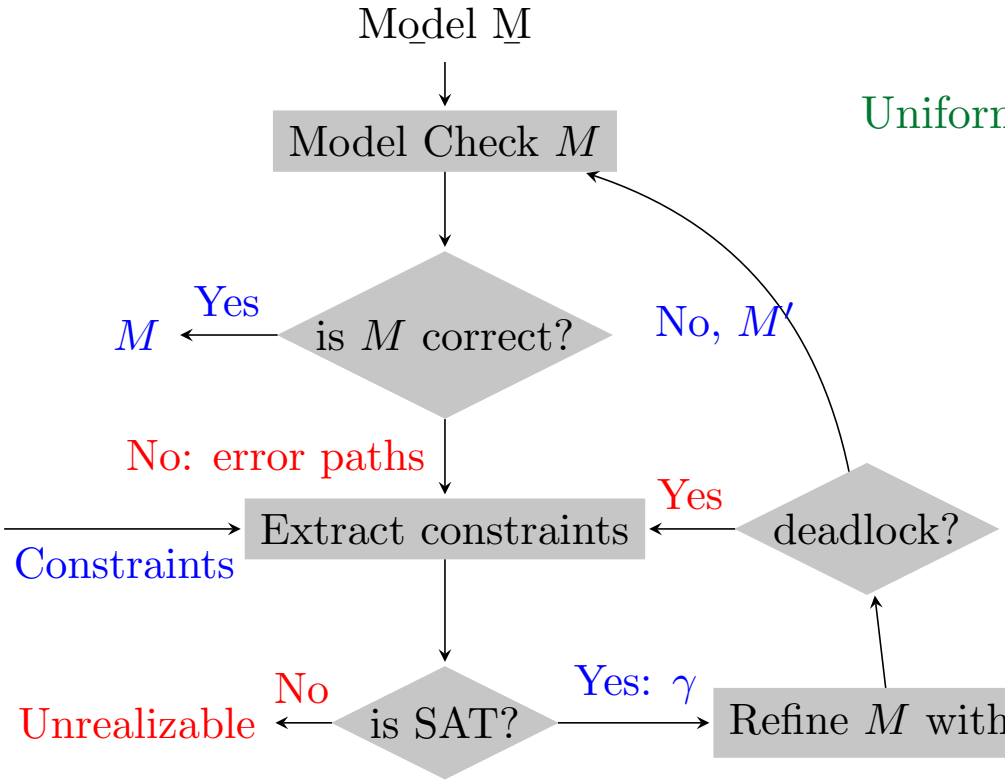

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- Tackle Challenges
- Extensions
- Experiments

Modeling: Counter Representation

Counter System

Idea: keep track of **how many processes** are in each local state.

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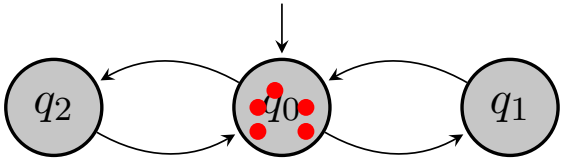
$(q_0, q_0, q_0, q_0, q_0) \rightarrow (5, 0, 0)$



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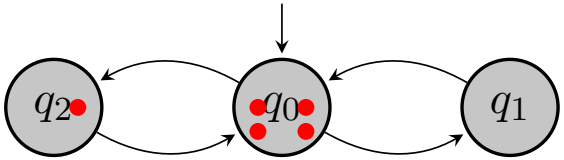
$(q_0, q_0, q_0, q_0, q_2) \to (4, 0, 1)$



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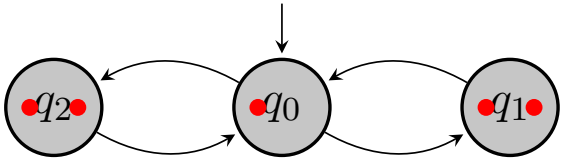
$(q_1, q_0, q_2, q_2, q_1) \to (1, 2, 2)$



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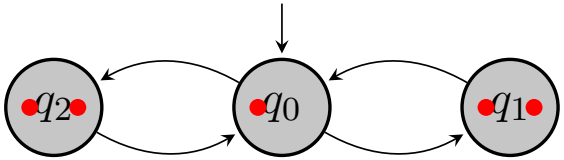

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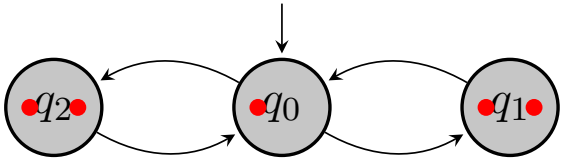

Infinite State

PMC: WSTS

Well Structured Transition System

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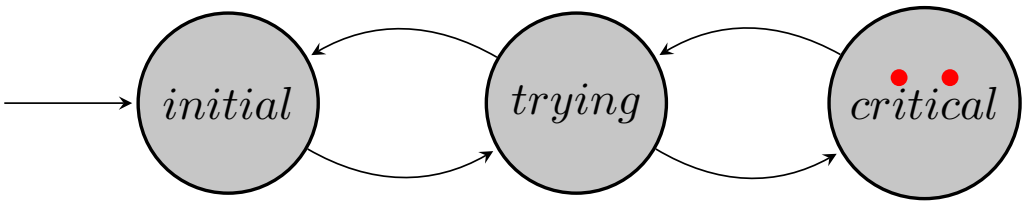

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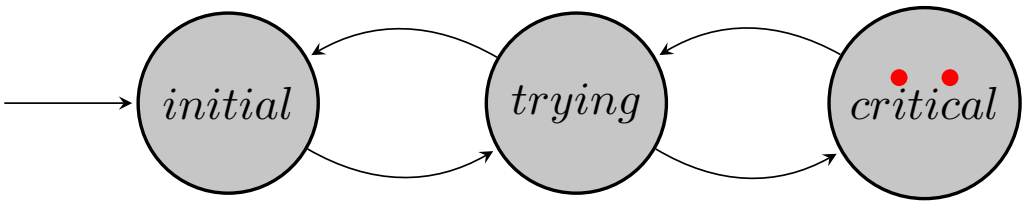

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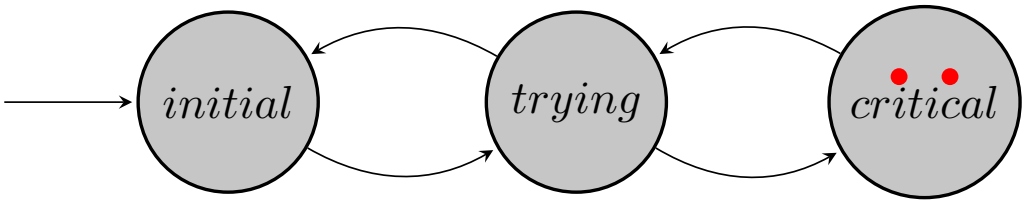

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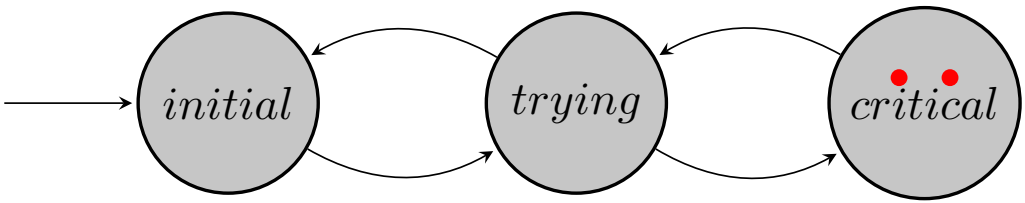

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Well Structured Transition System

Given the basis B' of an infinite set E^∞, we can compute the basis B' of $predecessor(E^\infty)$

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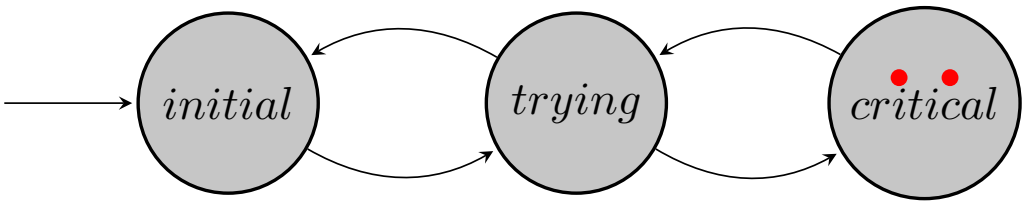

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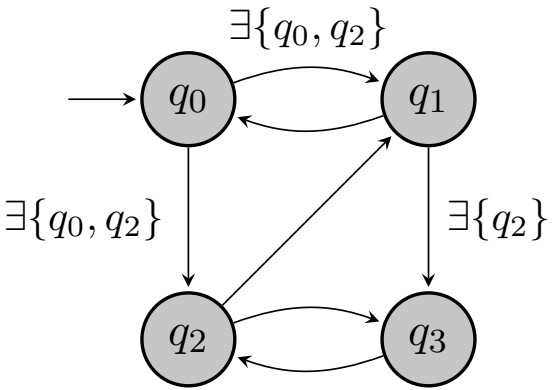
PMC and Deadlock Detection: Disjunctive Systems



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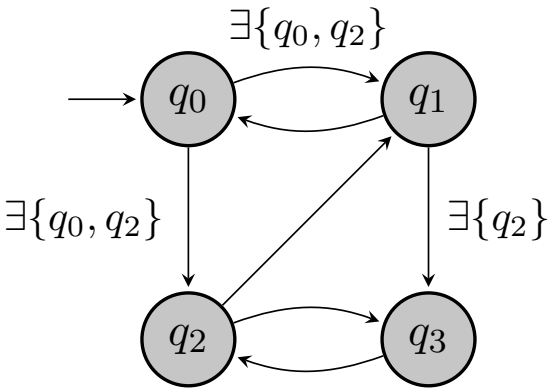
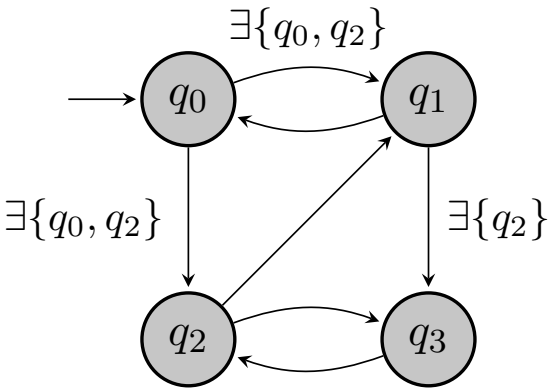


Theorem

The counter representation of disjunctive systems is a ***WSTS with effective predecessor*** *basis.*

PMC and Deadlock Detection: Disjunctive Systems



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*The counter representation M of disjunctive systems has a deadlocked run iff The 01-counter system of M has a deadlocked run (****Now****: $\underline{EXPTIME}$, ****Previously****: cutoff $= 2|Q|$).*

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  - Constraints that ensure certain **states remain reachable**.

The repair Algorithm

Algorithm Parameterized Repair Algorithm

1: **ParamRepair**(M, ERR, $InitConstr$)
2: $accCnstr \leftarrow InitConstr$, $isCorrect \leftarrow False$
3: **while** $isCorrect = False$ **do**
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Theorem

Deadlock detection in broadcast protocols is undecidable.

Lemma

There is a ***polynomial-time reduction*** *from the reachability problem of* ***affine VASS*** *with broadcast matrices to the deadlock detection problem in broadcast protocols.*

Experiments

SEP: Single Error Path **EPT:** Error Paths Transitions

Benchmark	Size		Errors	[SEP=F & EPT=F]			[SEP=T & EPT=F]			[SEP=F & EPT=T]			[SEP=T & EPT=T]		
	States	Edges		#Iter	Time	#D.T.	#Iter	Time	#D.T.	#Iter	Time	#D.T.	#Iter	Time	#D.T.
RW1 (PW)	5	12	C	3	2.5	4	3	2.9	4	**2**	**1.7**	**2**	**2**	**1.7**	**2**
RW2 (PW)	15	42	C	3	3.8	14	3	4.8	14	**2**	**3.2**	**7**	7	8.4	**7**
RW3 (PW)	35	102	C	3	820.7	34	3	**7.6**	34	**2**	552.3	**17**	17	40.3	**17**
RW4 (PW)	45	132	C	TO	TO	TO	**3**	**11.8**	44	TO	TO	TO	22	99.2	**22**
DLS	10	95	P1	**1**	**0.8**	13	**1**	**0.8**	13	3	2.4	**5**	5	5.6	**5**
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RF	10	147	P1	**1**	2.5	32	**1**	**1.2**	32	TO	TO	TO	8	12.4	**13**
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SD	6	39	C	**1**	**1**	**4**	**1**	**1**	**4**	3	2.4	**4**	3	3	**4**
2OT	12	128	P1	12	18.8	26	**6**	**8.3**	26	16	73.8	**17**	16	34	**17**
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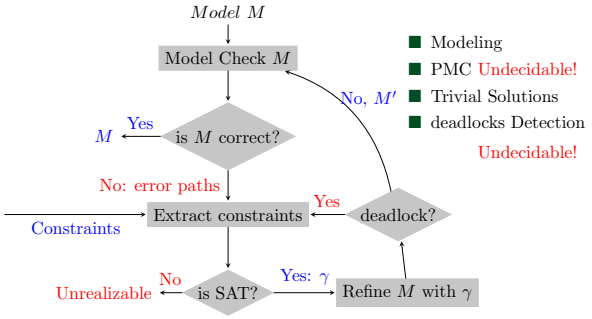

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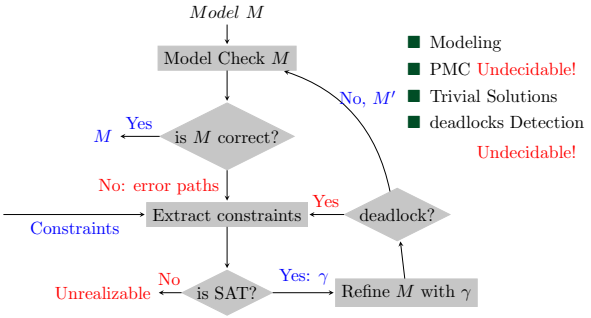
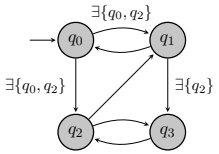


Disjunctive Systems Results



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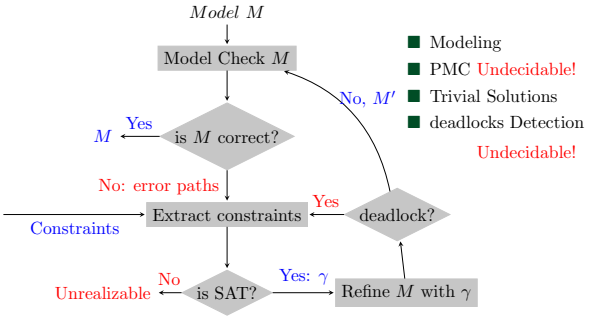

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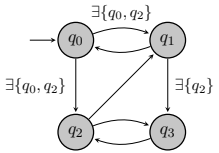

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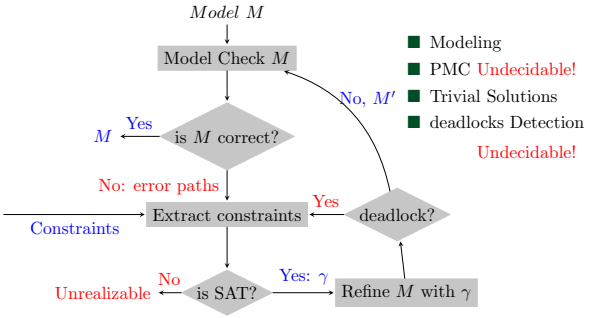
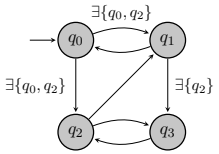


Disjunctive Systems Results



Theorem

The counter representation of disjunctive systems is a WSTS with effective predecessor basis.

Theorem

*The counter representation M of disjunctive systems has a deadlocked run iff The 01-counter system of M has a deadlocked run (**Now**: $EXPTIME$, **Previously**: $Q^{2^{|Q|}}$).*

Safety Property, Pairwise and Broadcast Systems

- Our Algorithm can be used for general **safety properties**, based on the **automata-theoretic** approach.
- We extended our algorithm to repair **pairwise and broadcast systems**. Both types of systems are known to be WSTS, however
  - Deadlock detection in pairwise systems **Tower-hard**

Theorem

Deadlock detection in broadcast protocols is undecidable.

Experiments

SEP: Single Error Path **EPT: Error Paths Transitions**

Benchmark	Size		Errors	[SEP=F & EPT=F]			[SEP=T & EPT=F]			[SEP=F & EPT=T]			[SEP=T & EPT=T]		
	States	Edges		#Iter	Time	#D.T.	#Iter	Time	#D.T.	#Iter	Time	#D.T.	#Iter	Time	#D.T.
RW1 (PW)	5	12	C	3	2.5	4	3	2.9	4	**2**	**1.7**	**2**	**2**	**1.7**	**2**
RW2 (PW)	15	42	C	3	3.8	14	3	4.8	14	**2**	**3.2**	**7**	7	8.4	**7**
RW3 (PW)	35	102	C	3	820.7	34	3	**7.6**	34	**2**	552.3	**17**	17	40.3	**17**
RW4 (PW)	45	132	C	TO	TO	TO	**3**	**11.8**	44	TO	TO	TO	22	99.2	**22**
DLS	10	95	P1	**1**	**0.8**	13	**1**	**0.8**	13	3	2.4	**5**	5	5.6	**5**
DLS	10	95	P2	**1**	**0.8**	13	2	1.7	13	3	2.6	**9**	7	5.5	**9**
DLS	10	95	C	**2**	4.2	13	**2**	**1.5**	13	3	3	**9**	9	8.1	**9**
RF	10	147	P1	**1**	2.5	32	**1**	**1.2**	32	TO	TO	TO	8	12.4	**13**
RF	10	147	P2	**1**	**1.2**	32	**1**	1.3	32	TO	TO	TO	8	11.3	**14**
RF	10	147	C	**1**	7.8	32	**1**	**1.4**	32	TO	TO	TO	8	12.5	**12**
SD	6	39	C	**1**	**1**	**4**	**1**	**1**	**4**	3	2.4	**4**	3	3	**4**
2OT	12	128	P1	12	18.8	26	**6**	**8.3**	26	16	73.8	**17**	16	34	**17**
2OT	12	128	P2	**1**	**1.8**	26	**1**	**1.8**	26	4	2958	**11**	8	16.5	12
2OT	12	128	C	11	17.2	Unreal.	**6**	**11.7**	Unreal.	TO	TO	TO	11	48.6	Unreal.
MESI1	4	26	C	**1**	2.4	6	**1**	**0.9**	6	2	1.8	**5**	4	3.5	**5**
MESI2	9	71	C	**1**	**1.1**	26	**1**	**1.1**	26	3	56.4	20	6	6.8	**15**
MESI3	14	116	C	**1**	109.4	46	**1**	**108.1**	46	TO	TO	TO	6	289.9	**15**

Constraints Example

Disjunctive Systems: $A||B^n$

$$TRConstr_{Disj} = \bigwedge_{q_A \in Q_A} \bigvee_{t_A \in \delta_A(q_A)} t_A \wedge \bigwedge_{q_B \in Q_B} \bigvee_{t_B \in \delta_B(q_B)} t_B$$

Broadcast Systems: A^n

$$\bigwedge_{a \in \Sigma_{sync}} [(t_{a!!} \wedge (\bigvee_{t_{a??} \in \delta_B} t_{a??})) \vee (\neg t_{a!!} \wedge (\bigwedge_{t_{a??} \in \delta_B} \neg t_{a??}))]$$

Pairwise Systems: A^n

$$\bigwedge_{a \in \Sigma_{sync}} [(t_{a!} \wedge (\bigvee_{t_{a?} \in \delta} t_{a?})) \vee (\neg t_{a!} \wedge (\bigwedge_{t_{a?} \in \delta} \neg t_{a?}))]$$

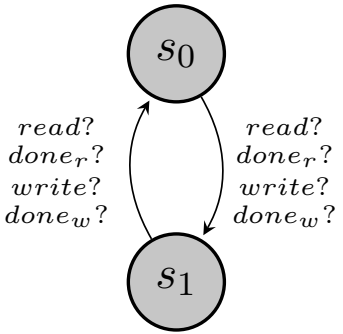
Faulty Pairwise Rendezvous System

Pairwise Synchronization: $q_0 \xrightarrow{a!} q_1,\ s_0 \xrightarrow{a?} s_1$

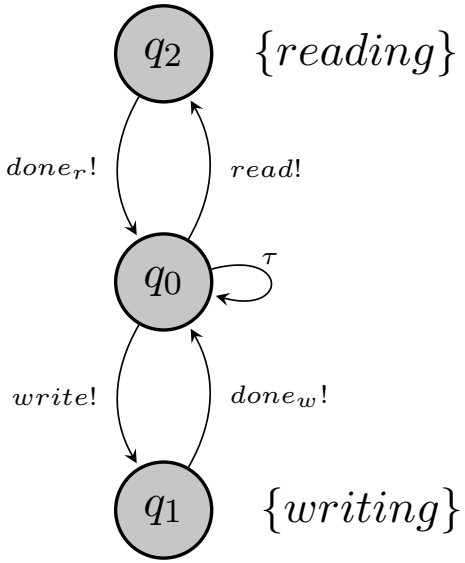
Faulty Pairwise Rendezvous System

Pairwise Synchronization: $q_0 \xrightarrow{a!} q_1$, $s_0 \xrightarrow{a?} s_1$

Scheduler



Reader-Writer



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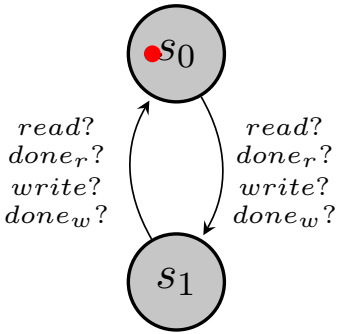
Scheduler



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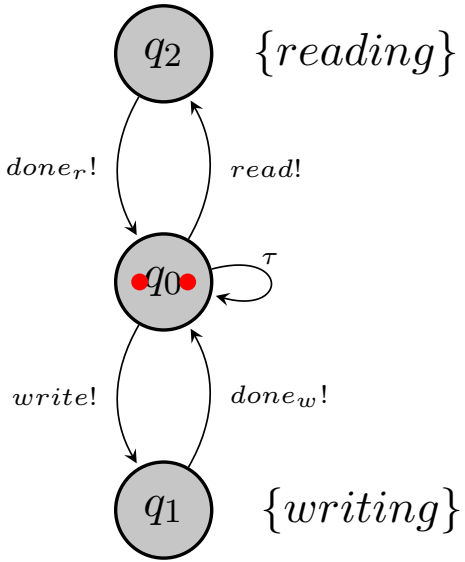

s_0, q_0, q_0

Faulty Pairwise Rendezvous System

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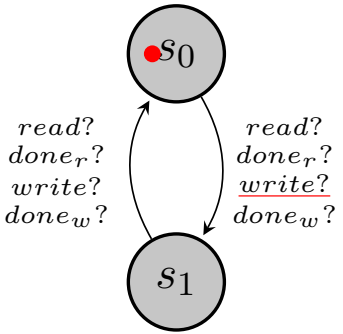
Scheduler



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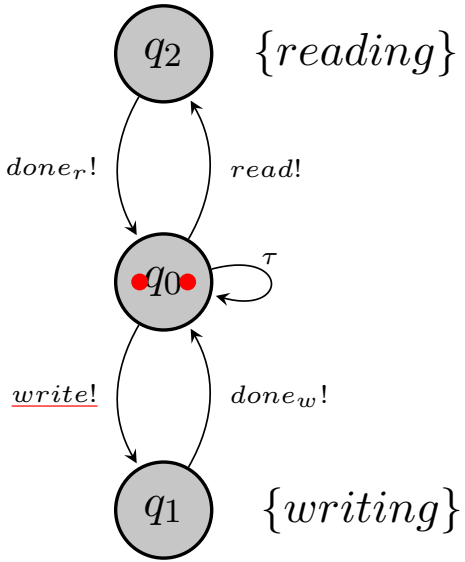
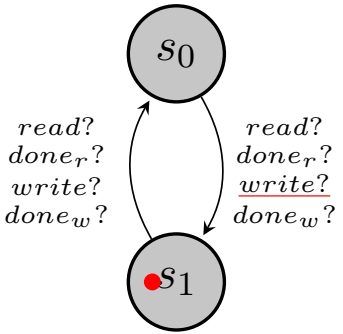


$s_0, q_0, q_0 \xrightarrow{(write!, write?)}$

Faulty Pairwise Rendezvous System

Pairwise Synchronization: $q_0 \xrightarrow{a!} q_1,\ s_0 \xrightarrow{a?} s_1$

Scheduler



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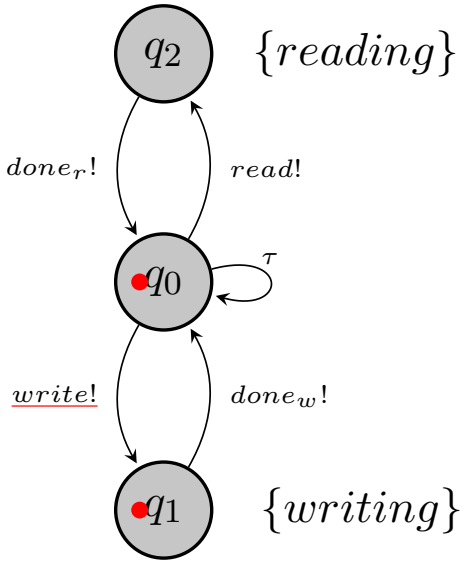
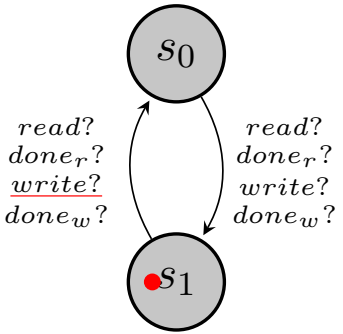


$$s_0, q_0, q_0 \xrightarrow{(write!, write?)} s_1, q_1, q_0$$

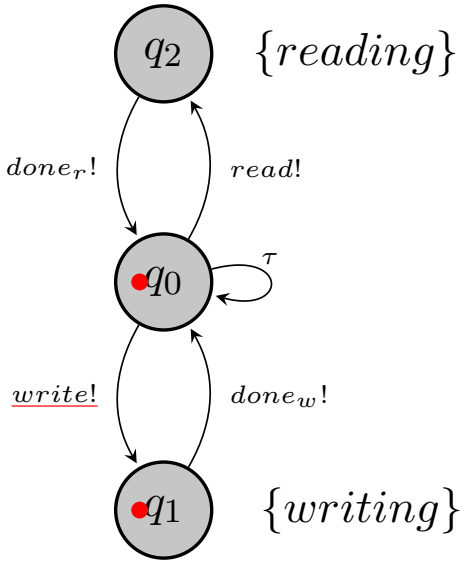
Faulty Pairwise Rendezvous System

Pairwise Synchronization: $q_0 \xrightarrow{a!} q_1,\ s_0 \xrightarrow{a?} s_1$

Scheduler



Reader-Writer



$s_0, q_0, q_0 \xrightarrow{(write!,write?)} s_1, q_1, q_0 \xrightarrow{(write!,write?)}$

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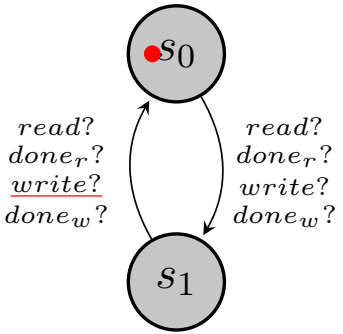
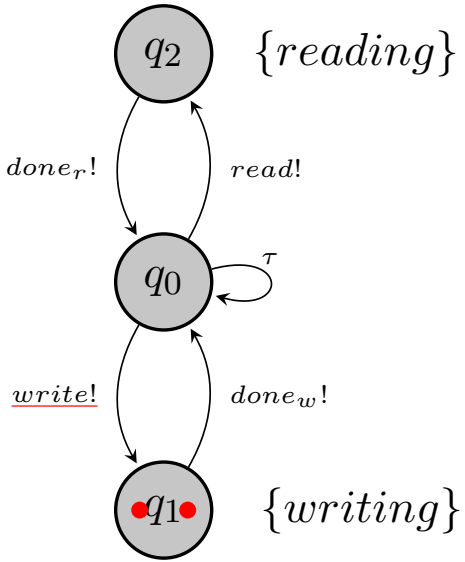


Reader-Writer



$s_0, q_0, q_0 \xrightarrow{(write!,write?)} s_1, q_1, q_0 \xrightarrow{(write!,write?)} s_0, q_1, q_1$

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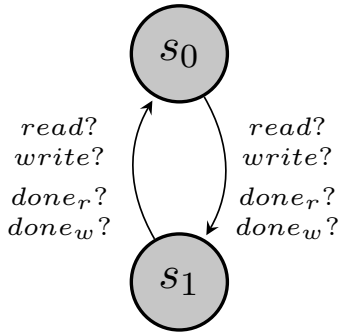
Scheduler



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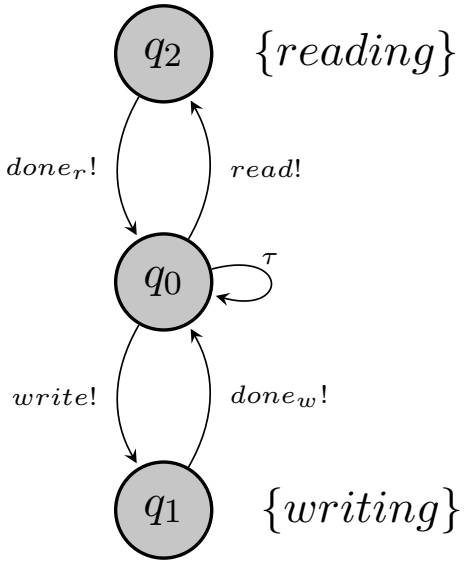

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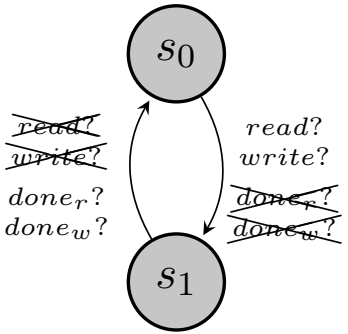

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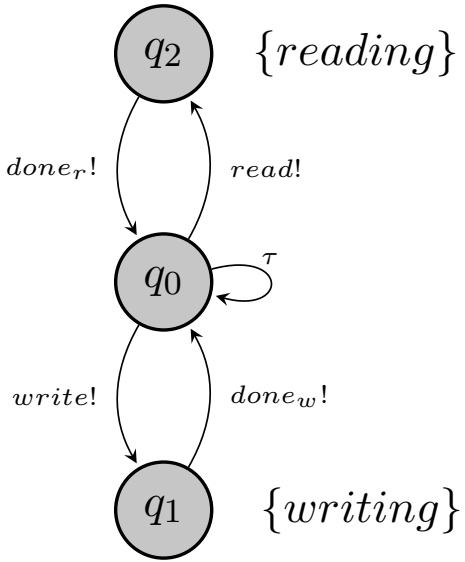

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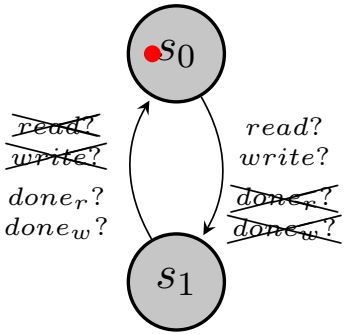

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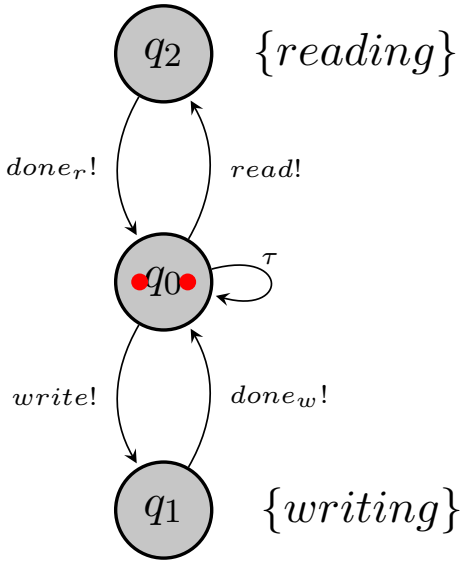

s_0, q_0, q_0

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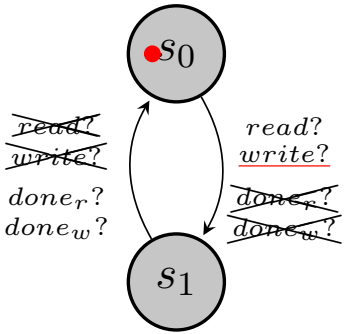

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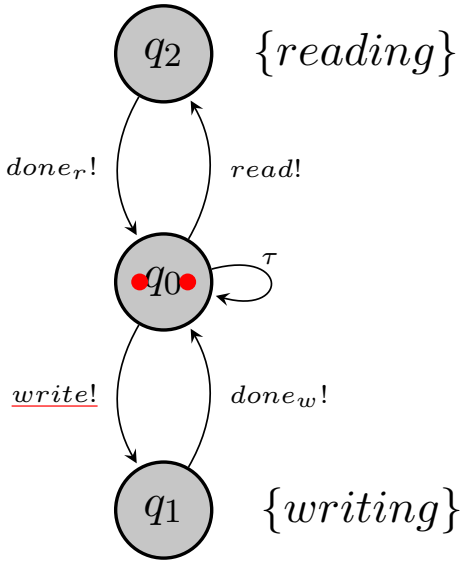

$s_0, q_0, q_0 \xrightarrow{(write!, write?)}$

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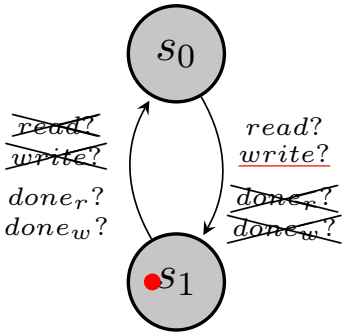

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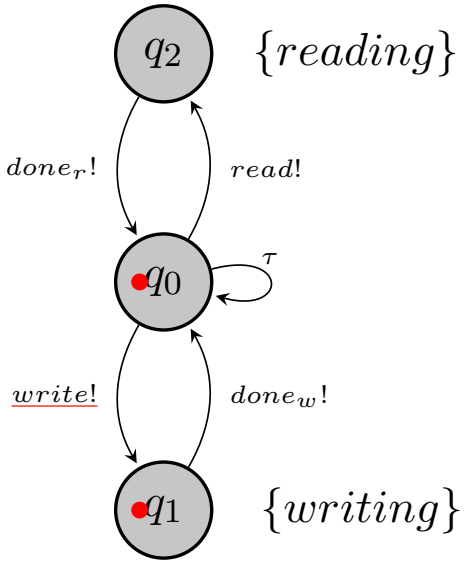

$$s_0, q_0, q_0 \xrightarrow{(write!, write?)} s_1, q_1, q_0$$

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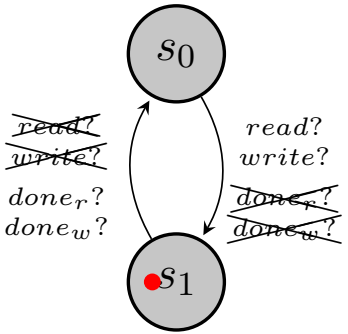

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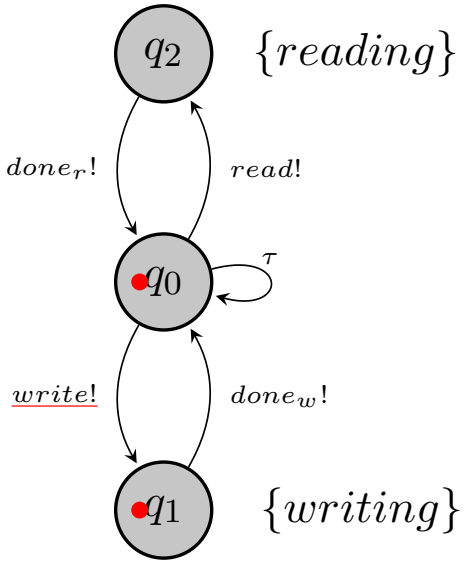

$$s_0, q_0, q_0 \xrightarrow{(write!, write?)} s_1, q_1, q_0 \xrightarrow{(write!, write?)}$$