Model Checking under Refinement-closed Notions of Fairness and Its Application

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Motivation

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Our verification approach relates properties of the model
to properties of the system along a refinement chain.

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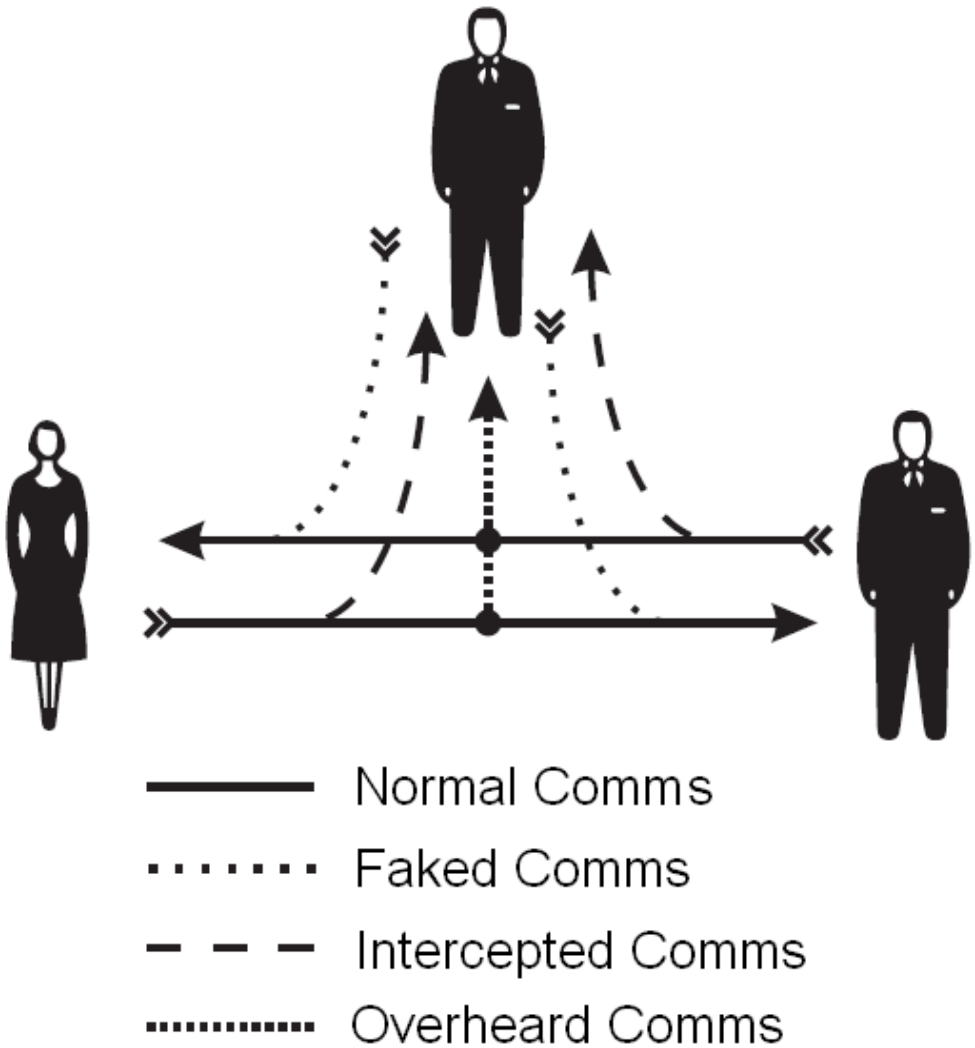
Normal Comms
Faked Comms
Intercepted Comms
Overheard Comms

Model Checking CSP

Refinement Checking

$$\frac{S \sqsubseteq_{\mathcal{M}} P \qquad P \sqsubseteq_{\mathcal{M}} Q}{S \sqsubseteq_{\mathcal{M}} Q}$$

Tool Support: FDR or PAT

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$$\frac{P \models \phi \qquad P \sqsubseteq_{\mathcal{M}} Q}{Q \models \phi}$$

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LTL for CSP

Lowe's Temporal Logic

$$\phi, \psi ::= \mathit{true} \mid \mathit{false} \mid a \mid \mathit{available}\ a \mid \mathit{deadlocked} \mid$$
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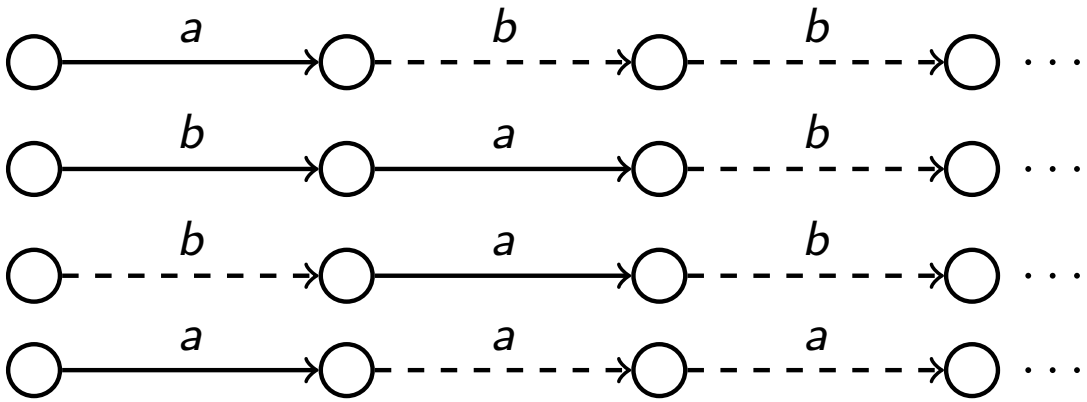

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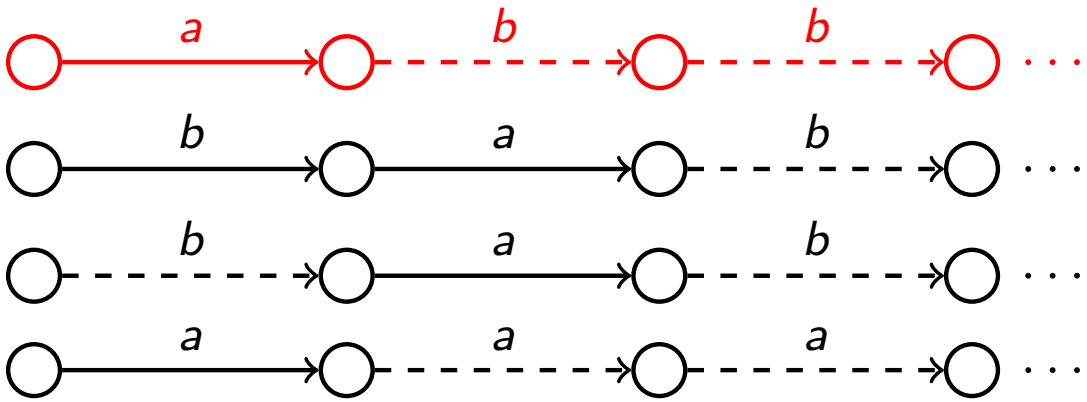

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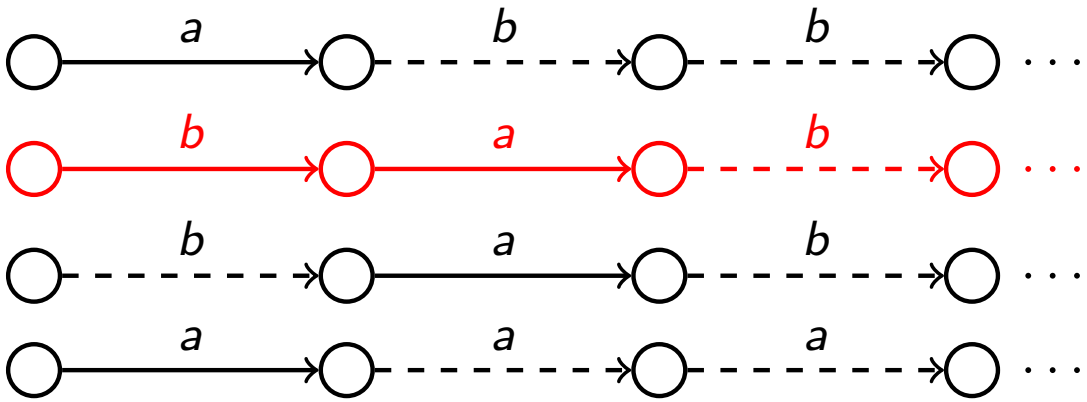

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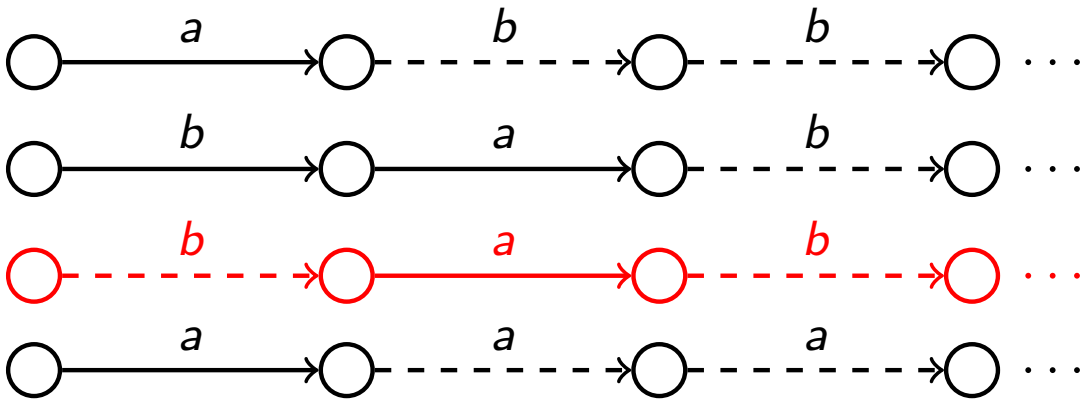

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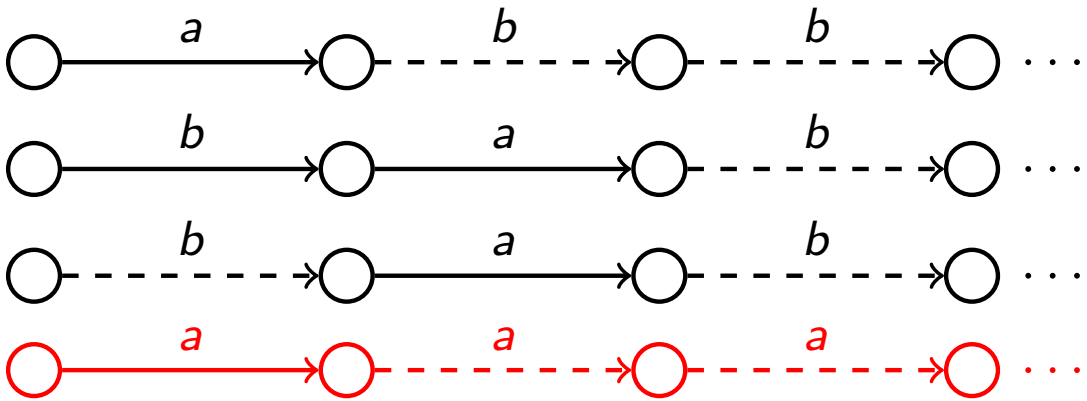
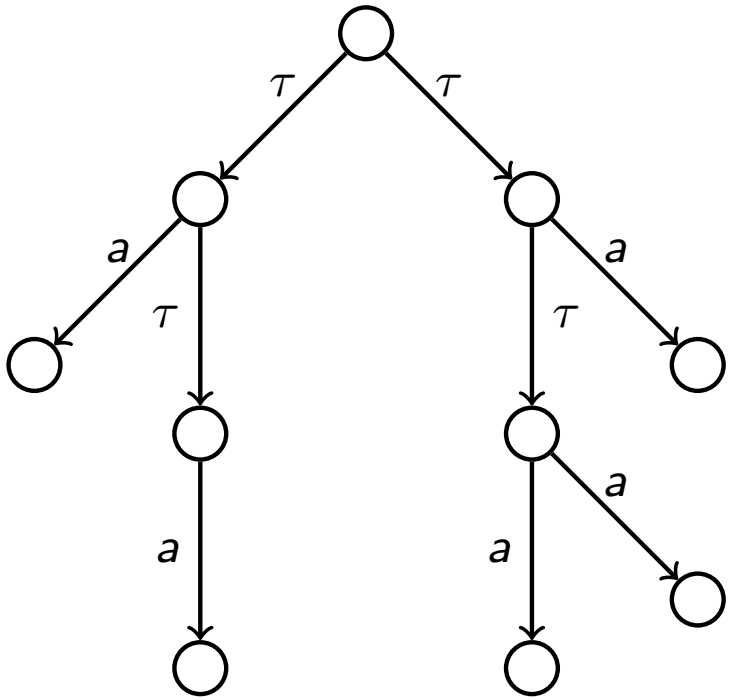


Lowe's *a* and *available a*



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The next visible event is guaranteed to be an *a*

$a \rightarrow$ [tau] U [a]

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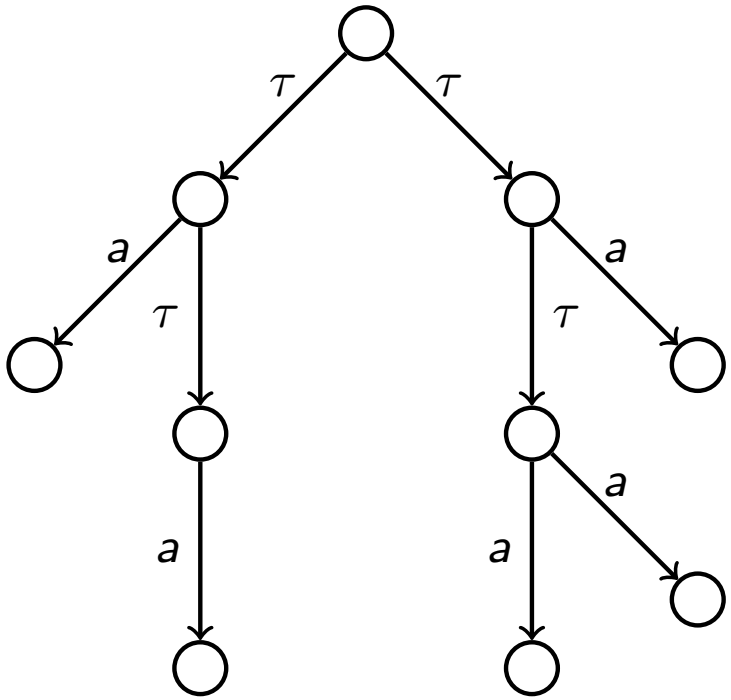

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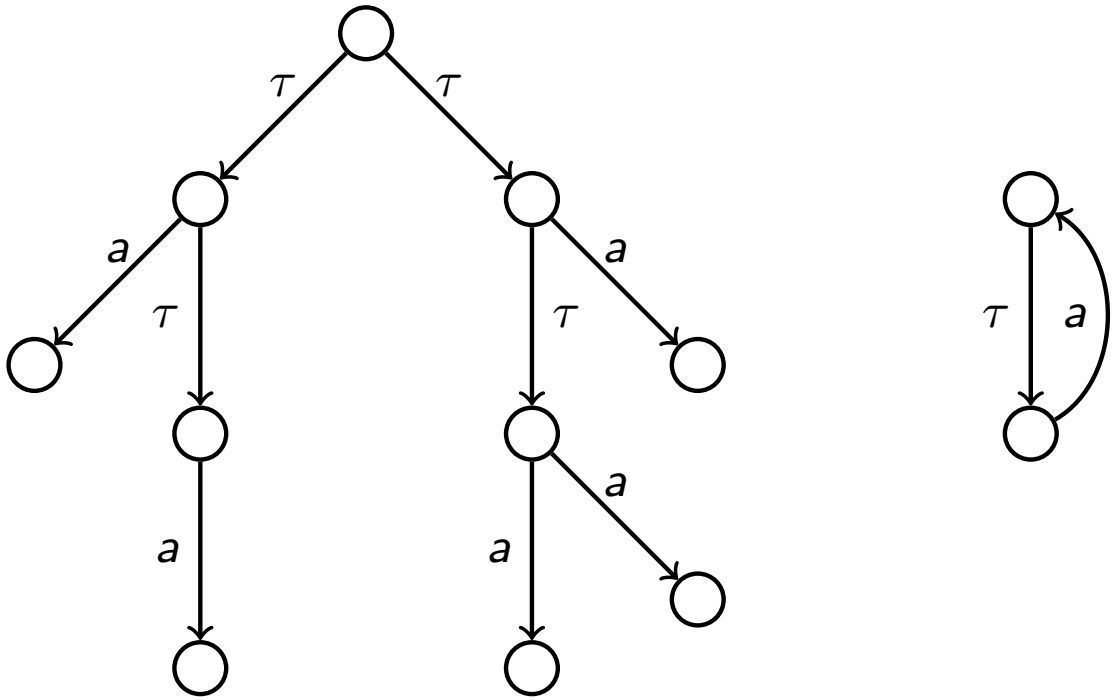

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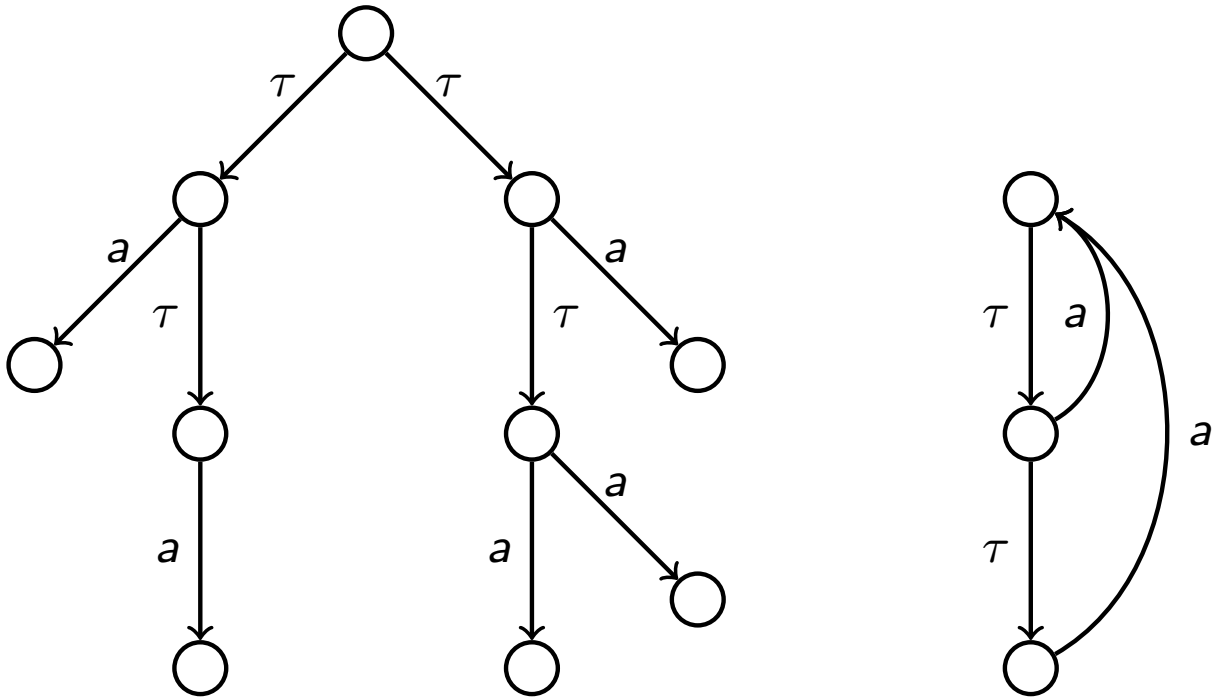

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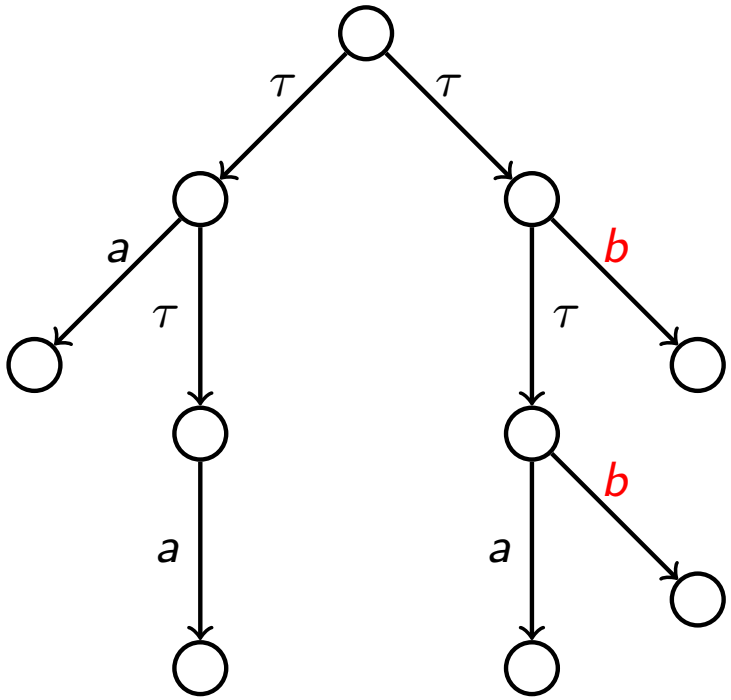

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Whenever the process stabilises before performing its first visible event, an *a* is enabled

available a → [tau] U ((e(tau) & not [tau]) or (e(a) & not e(tau)))

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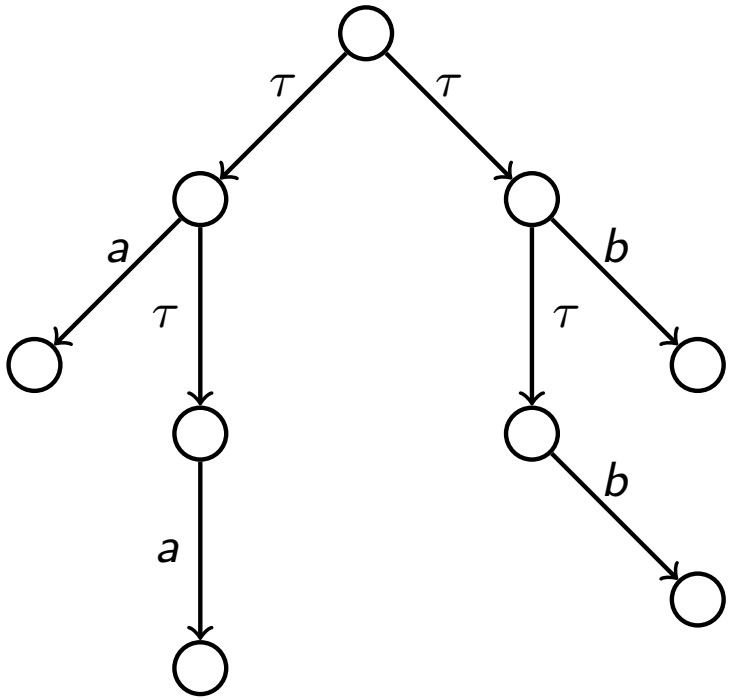

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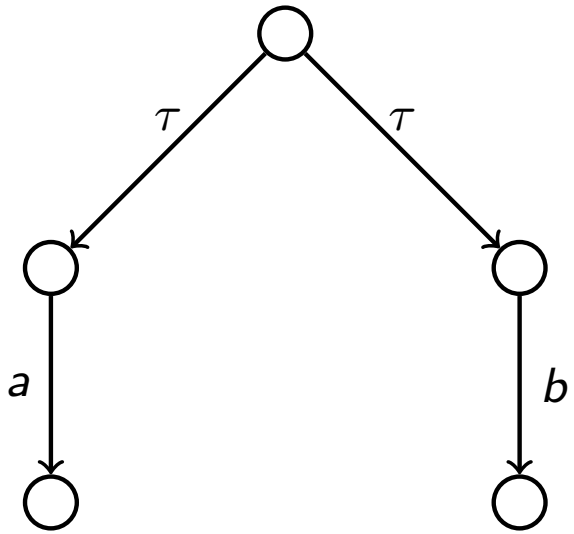
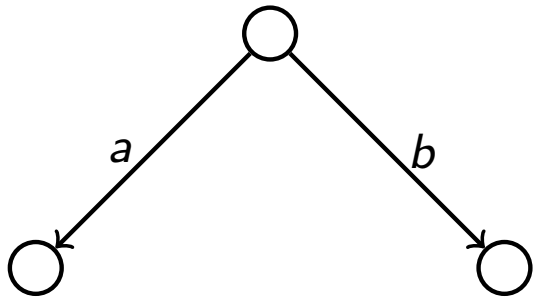
a	$\rightarrow$ [tau] U [a]
available a	$\rightarrow$ [tau] U ((e(tau) & not [tau]) or (e(a) & not e(tau)))
deadlocked	$\rightarrow$ [tau] U deadlock
$\bigcirc\phi$	$\rightarrow$ [tau] U (deadlock or (not [tau] & X ϕ))

Finite Traces vs. Stable Failures



a $\rightarrow$ *Stop* $\sqcap$ *b* $\rightarrow$ *Stop*

$=_{\mathcal{T}}$
$\neq_{\mathcal{F}}$
$\sqsubseteq_{\mathcal{F}}$



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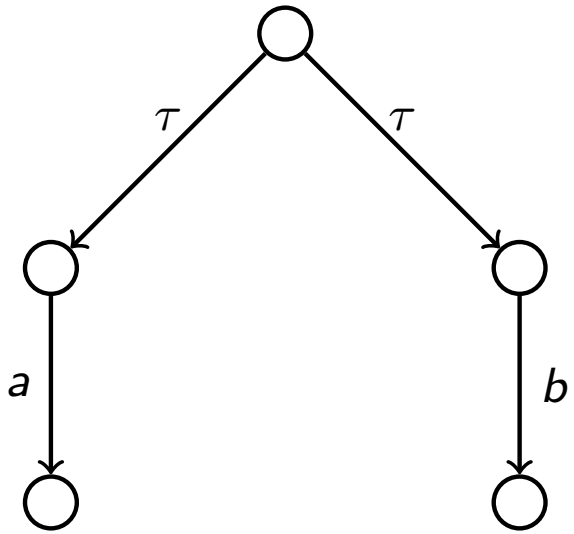

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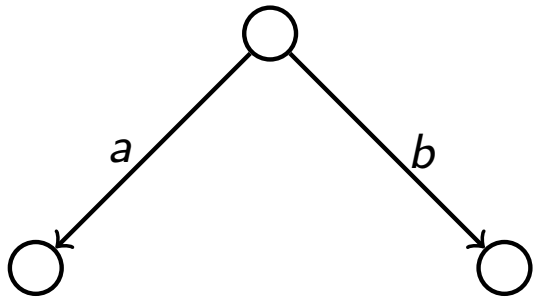

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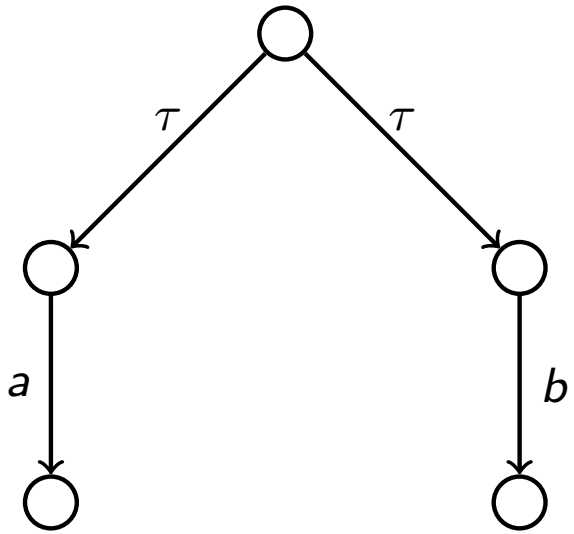

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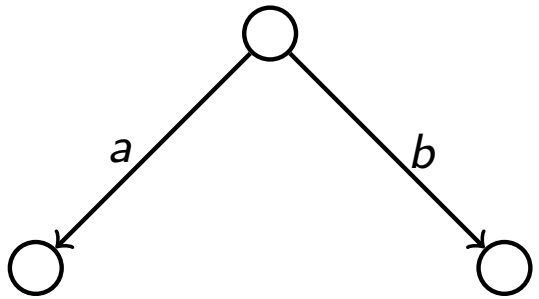

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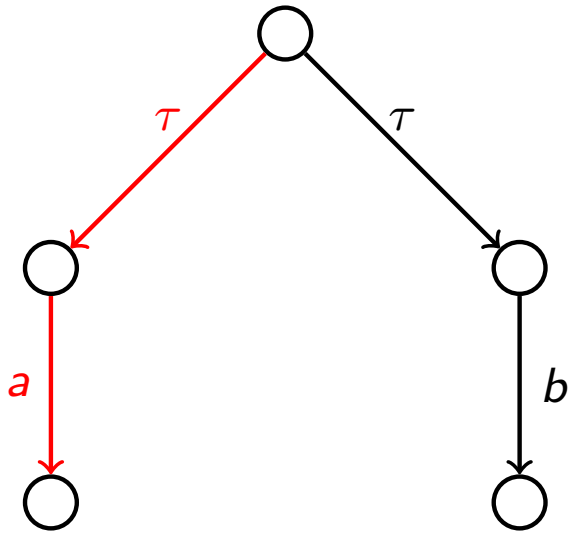

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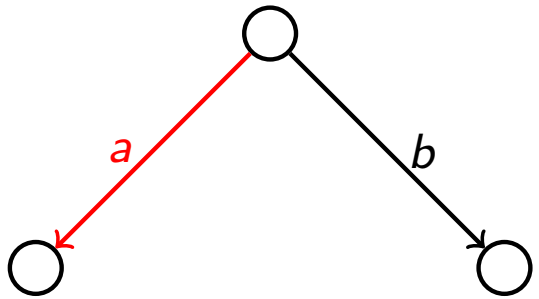

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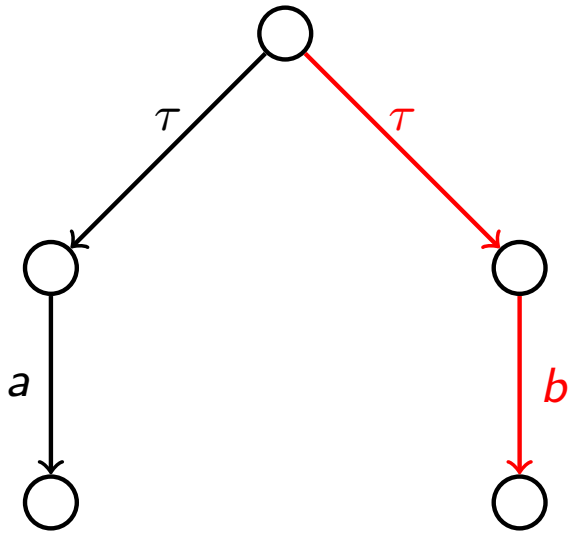

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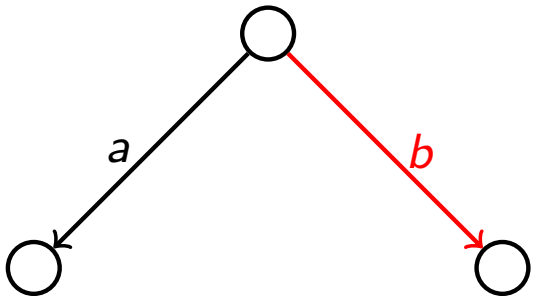

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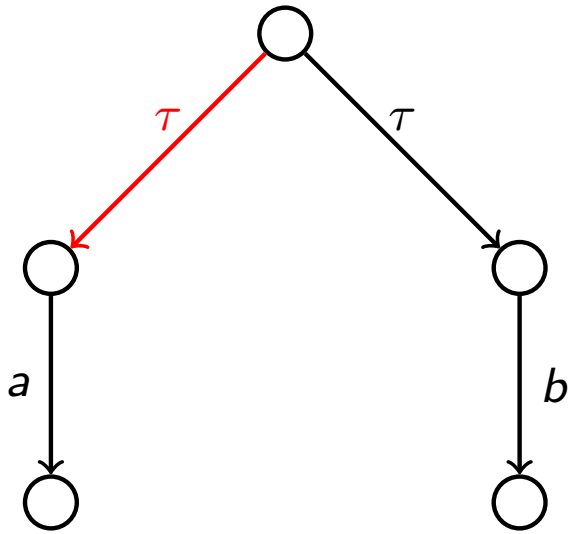

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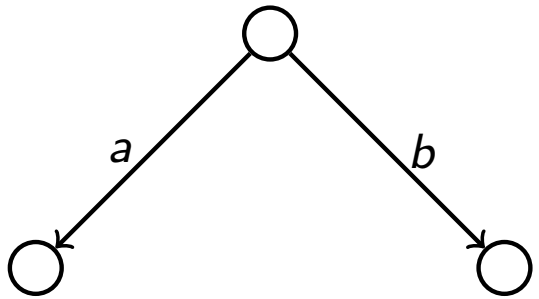

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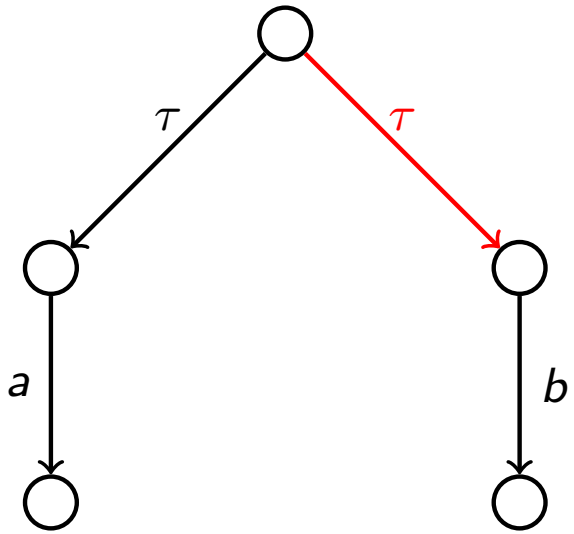

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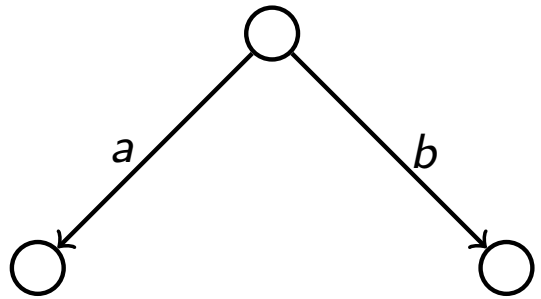

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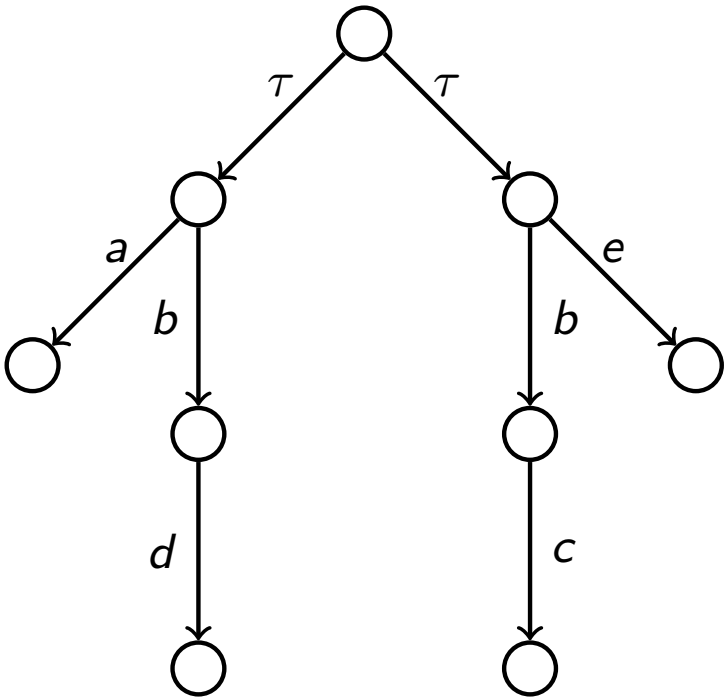
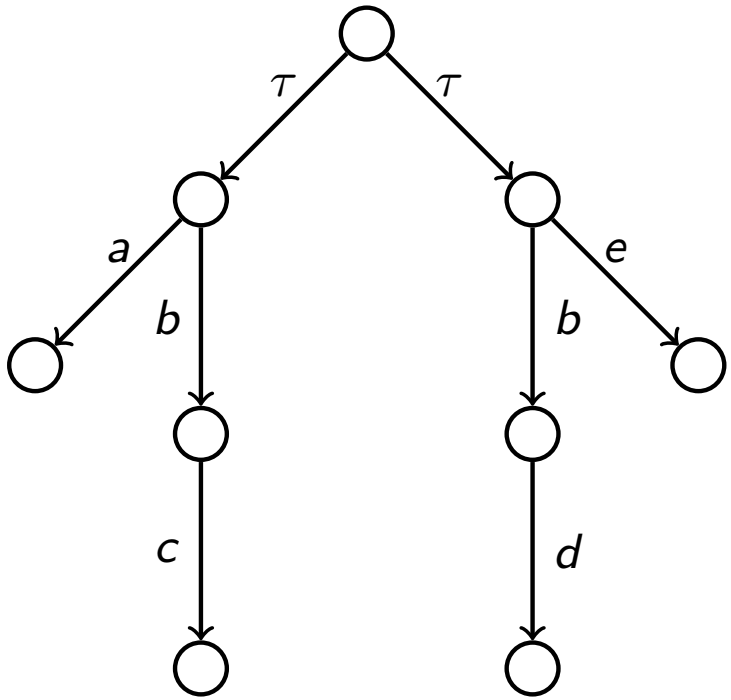
Stable Failures vs. Refusal Traces



$$=_{\mathcal{F}}$$
$$\neq_{\mathcal{RT}}$$
$$\not\sqsubseteq_{\mathcal{RT}}$$
$$\not\sqsupseteq_{\mathcal{RT}}$$



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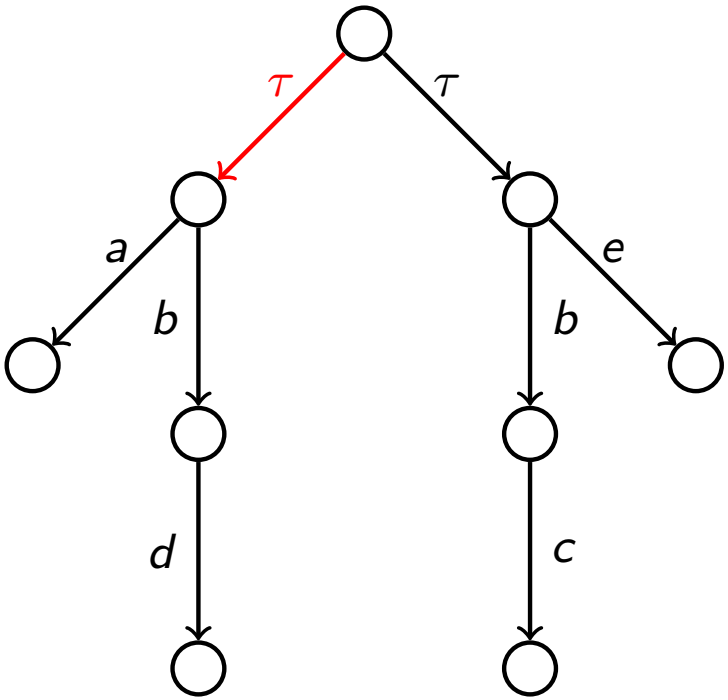

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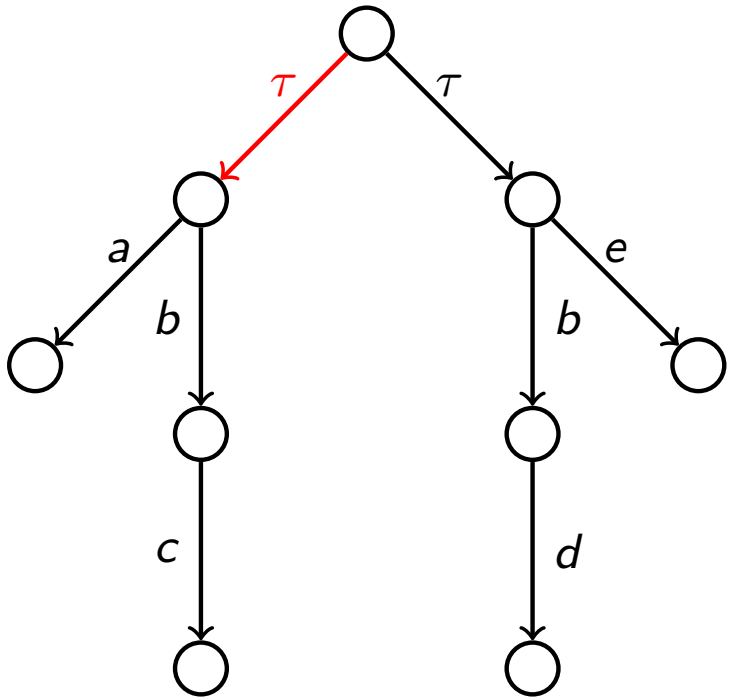
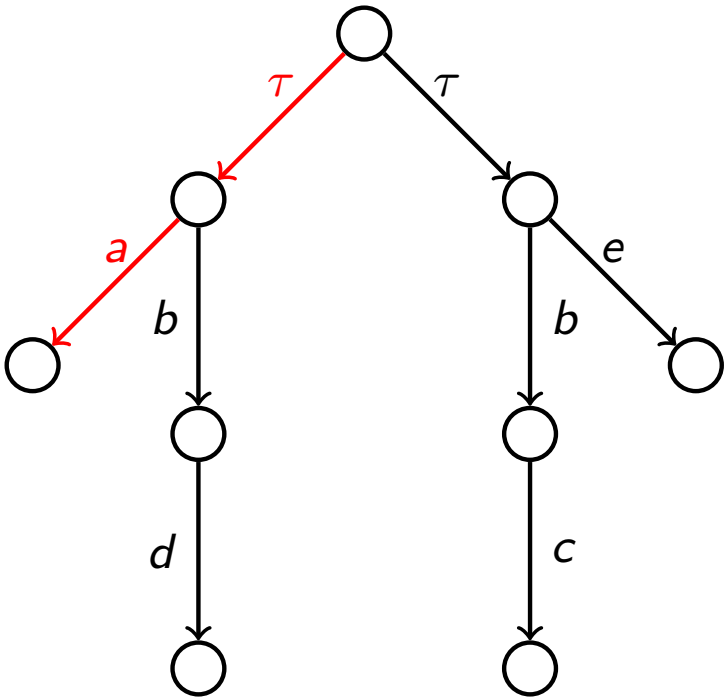


$(\langle\rangle, \{c, d, e\})$, $(\langle a\rangle, \Sigma)$, $(\langle b\rangle, \{a, b, c, e\})$, $(\langle b, d\rangle, \Sigma)$

Stable Failures vs. Refusal Traces



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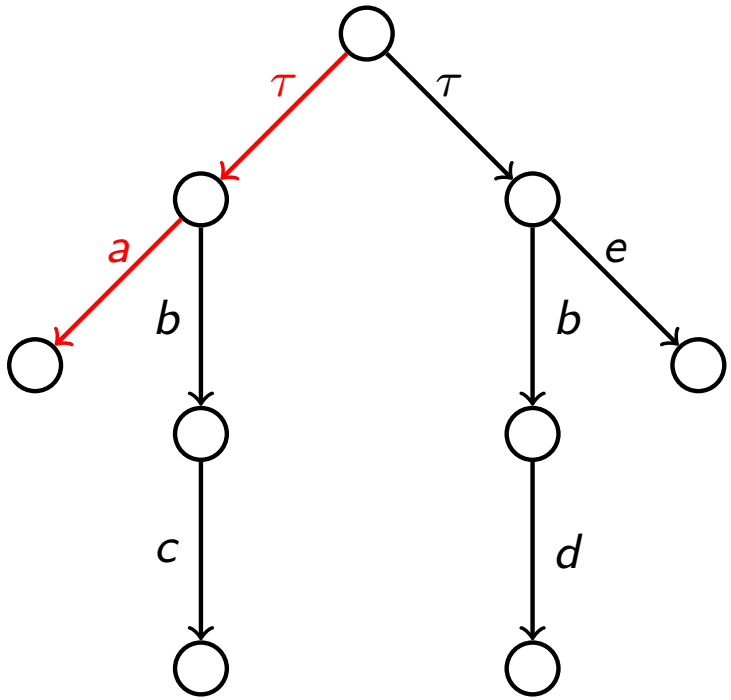

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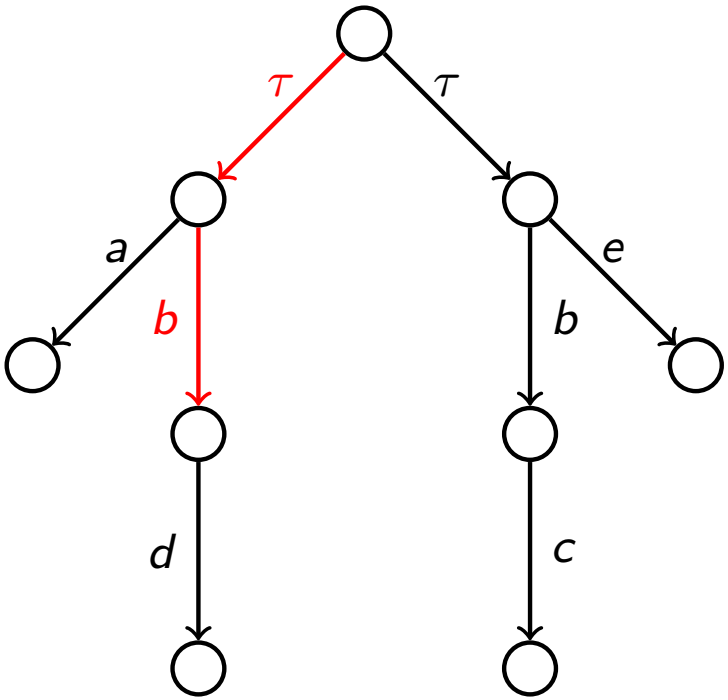
Stable Failures vs. Refusal Traces



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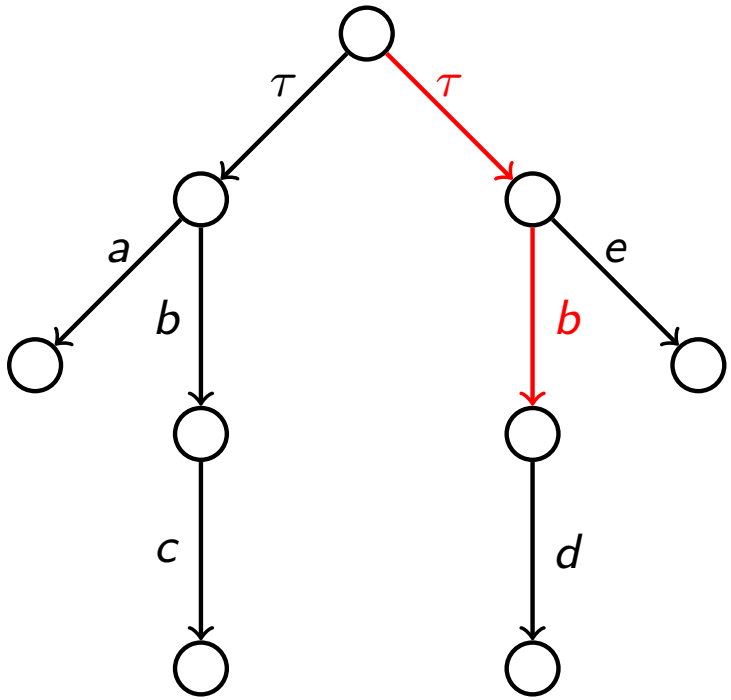
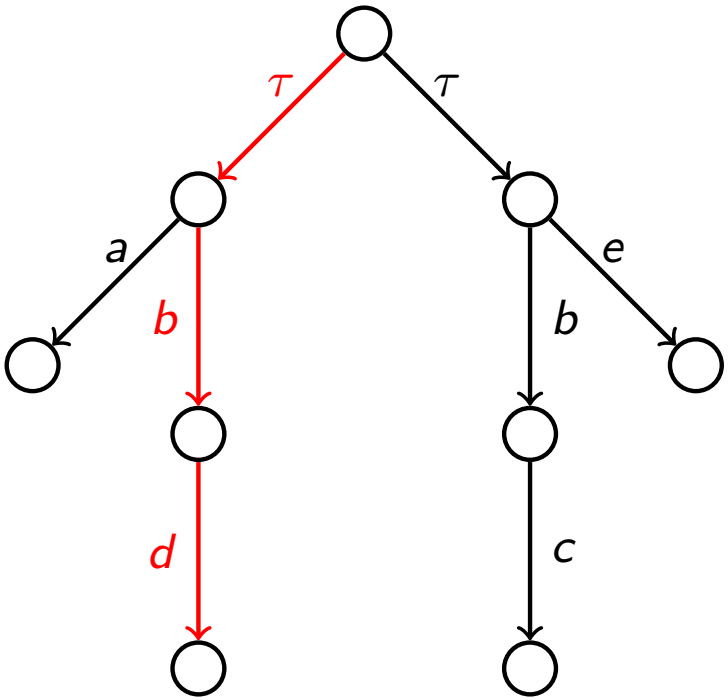


$(\langle\rangle, \{c, d, e\})$, $(\langle a\rangle, \Sigma)$, $(\langle b\rangle, \{a, b, c, e\})$, $(\langle b, d\rangle, \Sigma)$

Stable Failures vs. Refusal Traces



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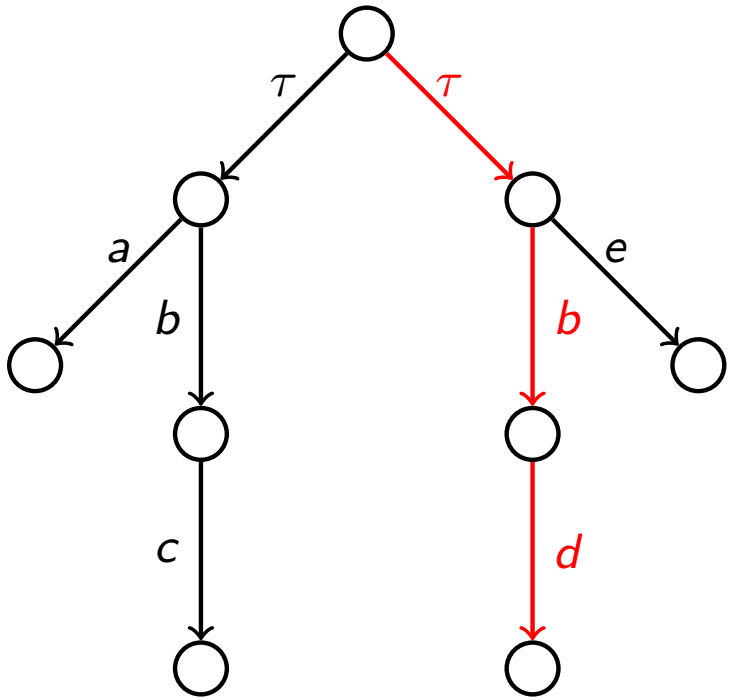
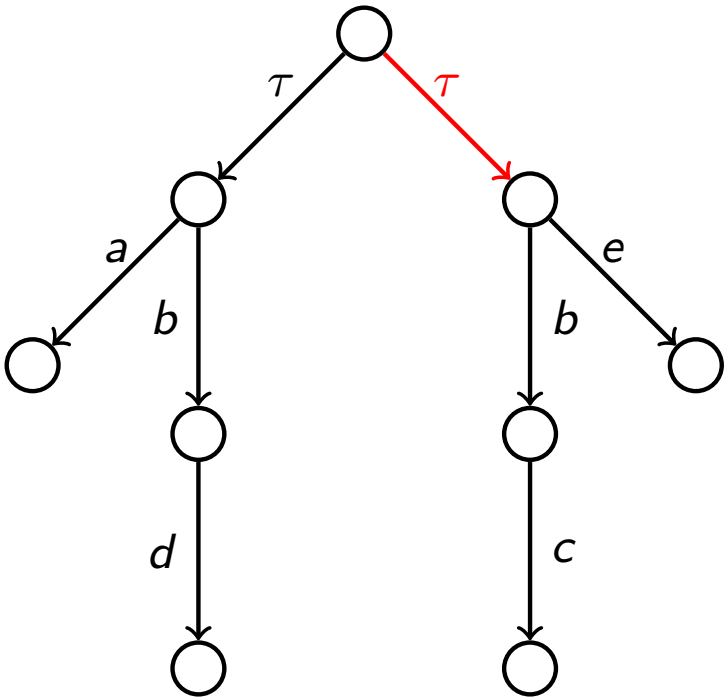


$(\langle\rangle, \{c, d, e\})$, $(\langle a\rangle, \Sigma)$, $(\langle b\rangle, \{a, b, c, e\})$, $(\langle b, d\rangle, \Sigma)$

Stable Failures vs. Refusal Traces



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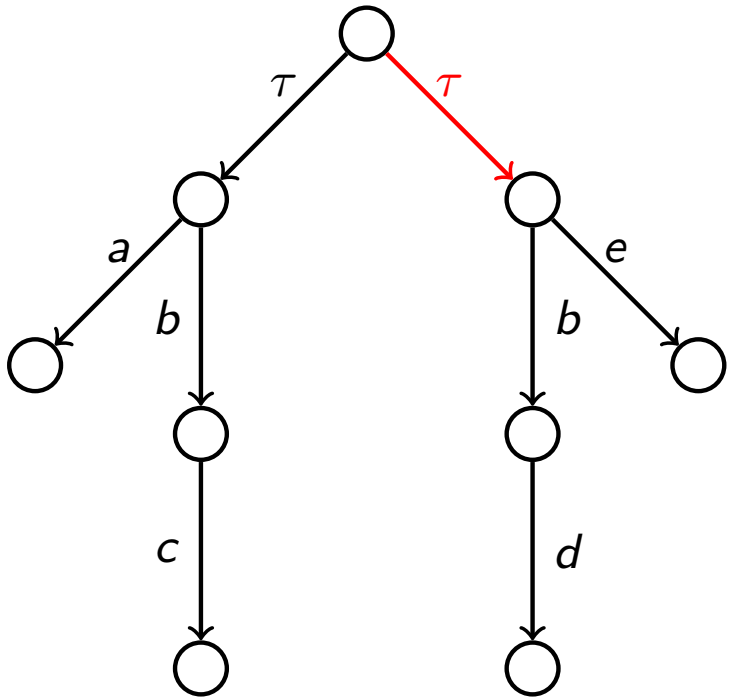
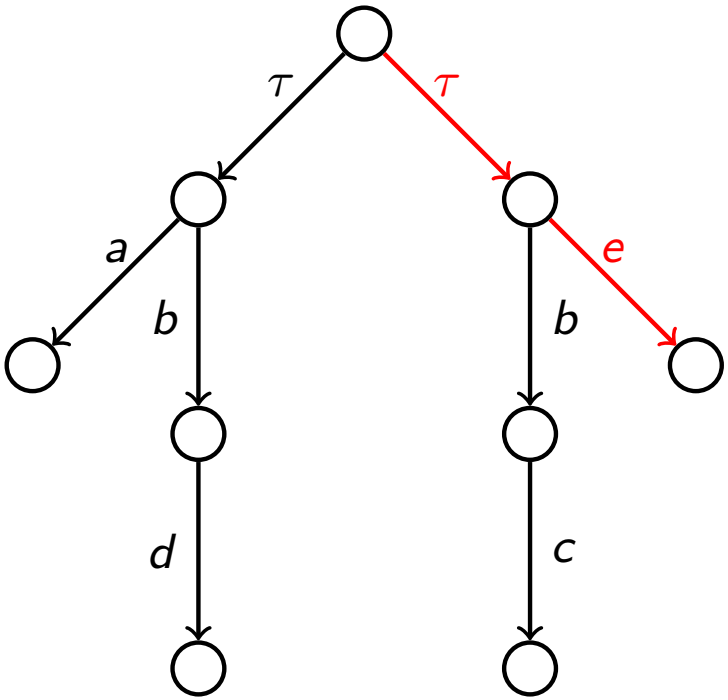


$(\langle\rangle, \{c, d, e\})$, $(\langle a\rangle, \Sigma)$, $(\langle b\rangle, \{a, b, c, e\})$, $(\langle b, d\rangle, \Sigma)$
$(\langle\rangle, \{a, c, d\})$, $(\langle e\rangle, \Sigma)$, $(\langle b\rangle, \{a, b, d, e\})$, $(\langle b, c\rangle, \Sigma)$

Stable Failures vs. Refusal Traces



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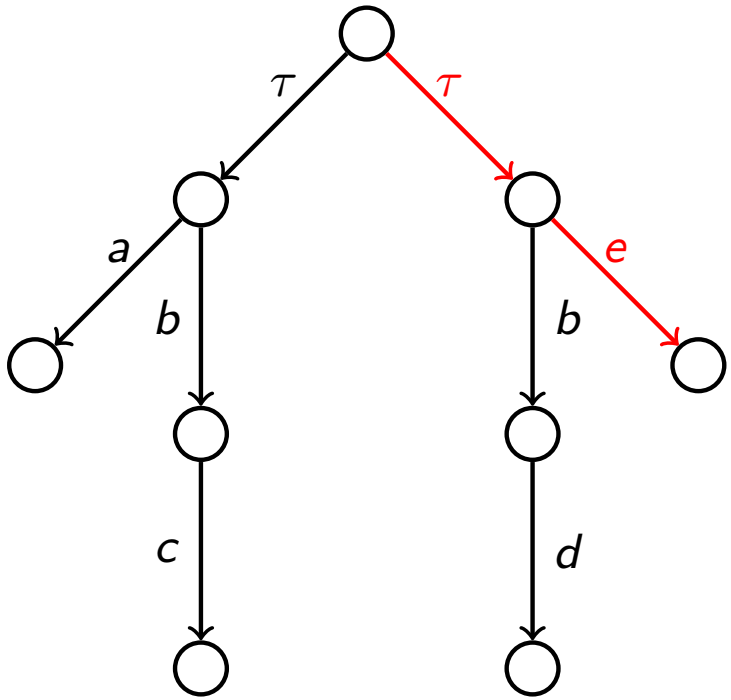

$(\langle\rangle, \{c, d, e\})$, $(\langle a\rangle, \Sigma)$, $(\langle b\rangle, \{a, b, c, e\})$, $(\langle b, d\rangle, \Sigma)$
$(\langle\rangle, \{a, c, d\})$, $(\langle e\rangle, \Sigma)$, $(\langle b\rangle, \{a, b, d, e\})$, $(\langle b, c\rangle, \Sigma)$

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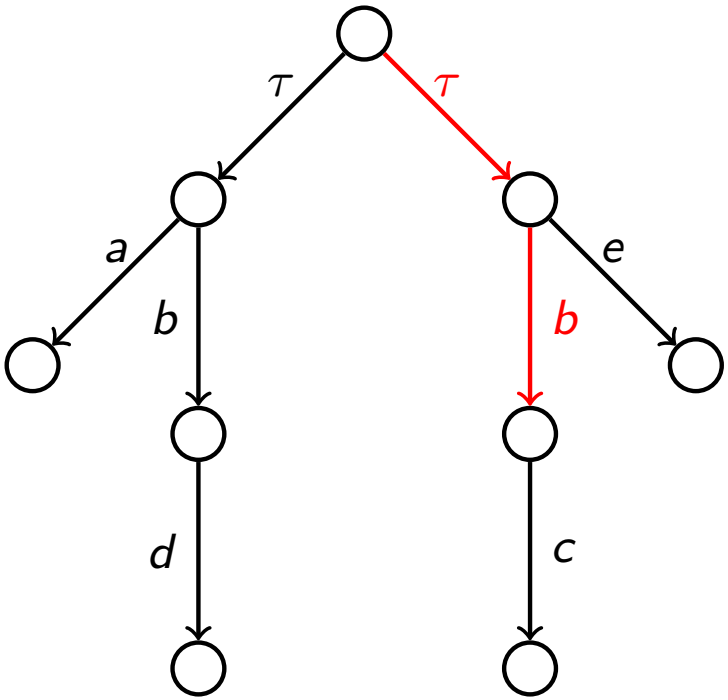

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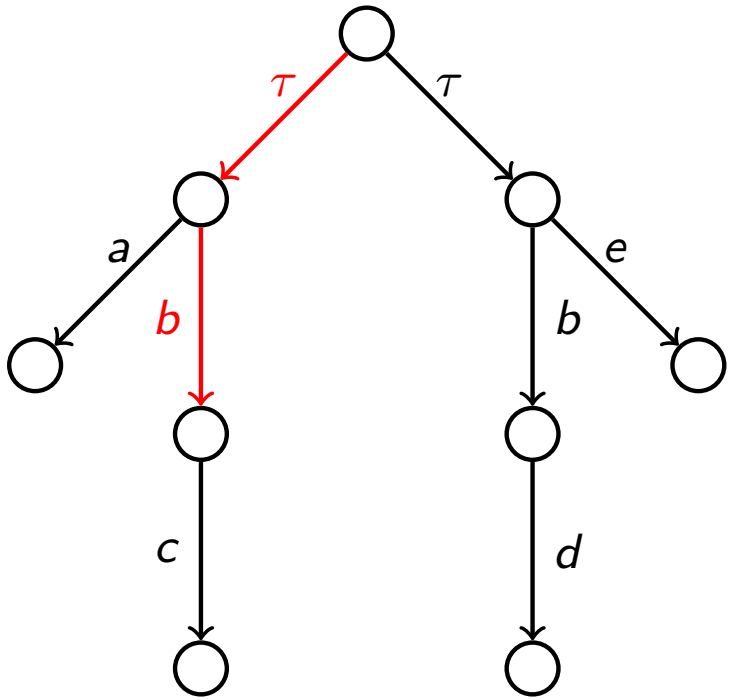

$(\langle\rangle, \{c, d, e\})$, $(\langle a\rangle, \Sigma)$, $(\langle b\rangle, \{a, b, c, e\})$, $(\langle b, d\rangle, \Sigma)$
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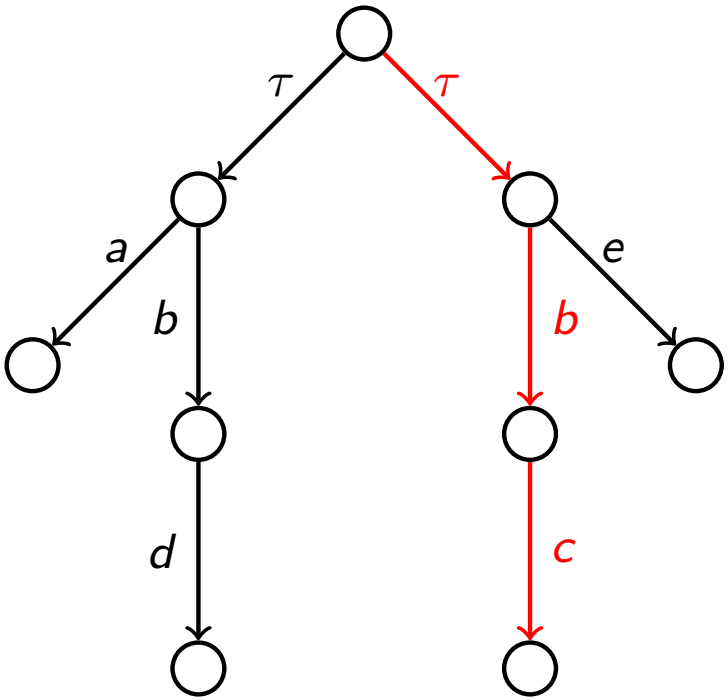

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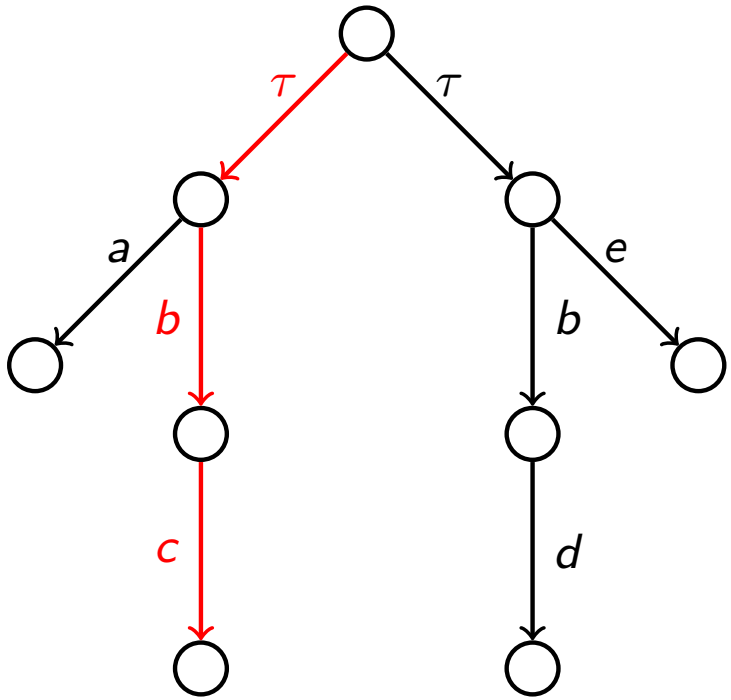

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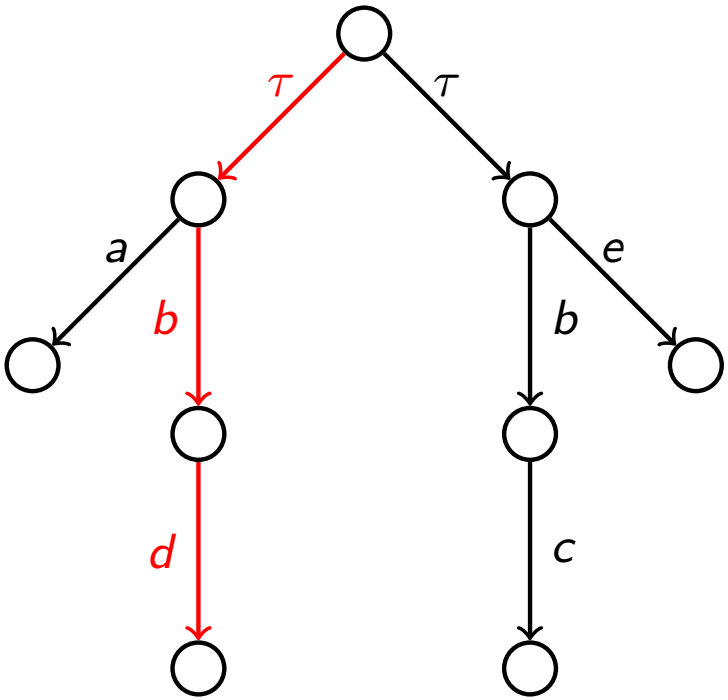

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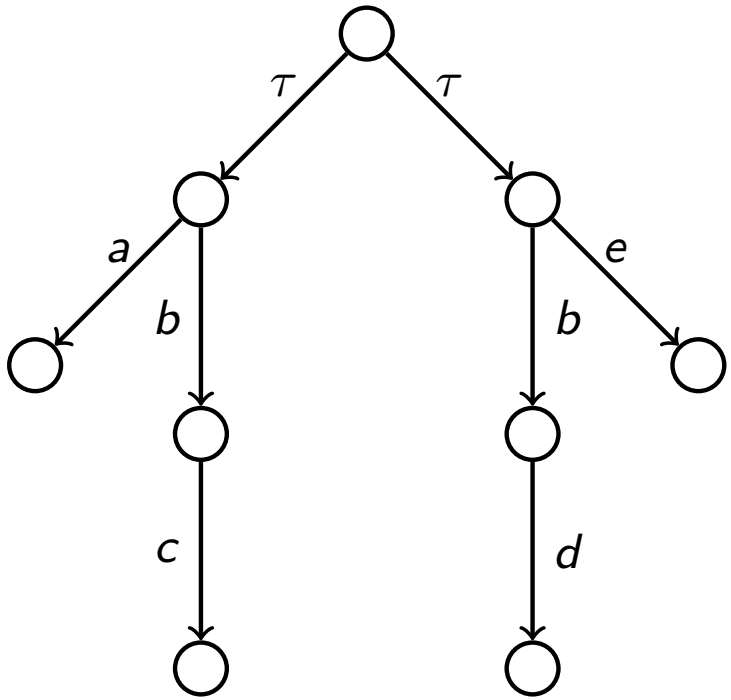
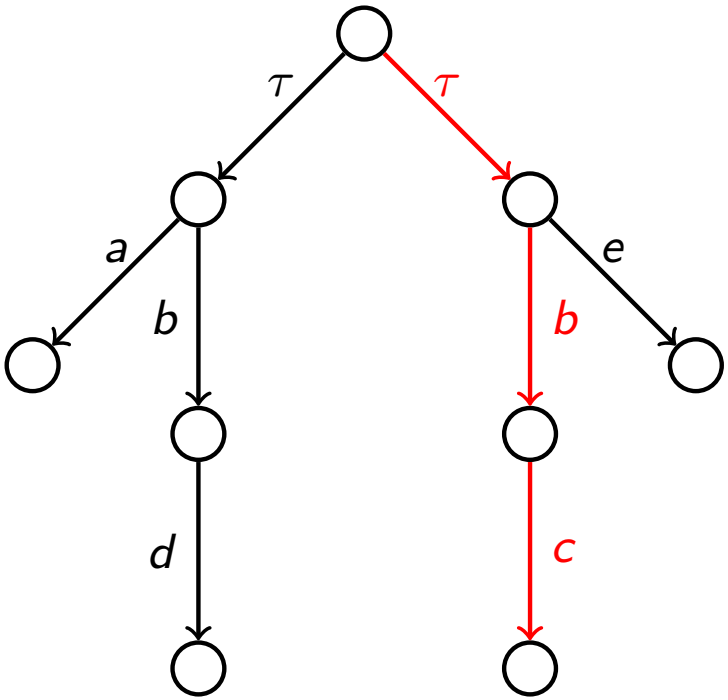


$\langle \{c, d, e\}, b, \{a, b, c, e\}, d, \Sigma \rangle, \langle \{a, c, d\}, b, \{a, b, d, e\}, c, \Sigma \rangle$

Stable Failures vs. Refusal Traces



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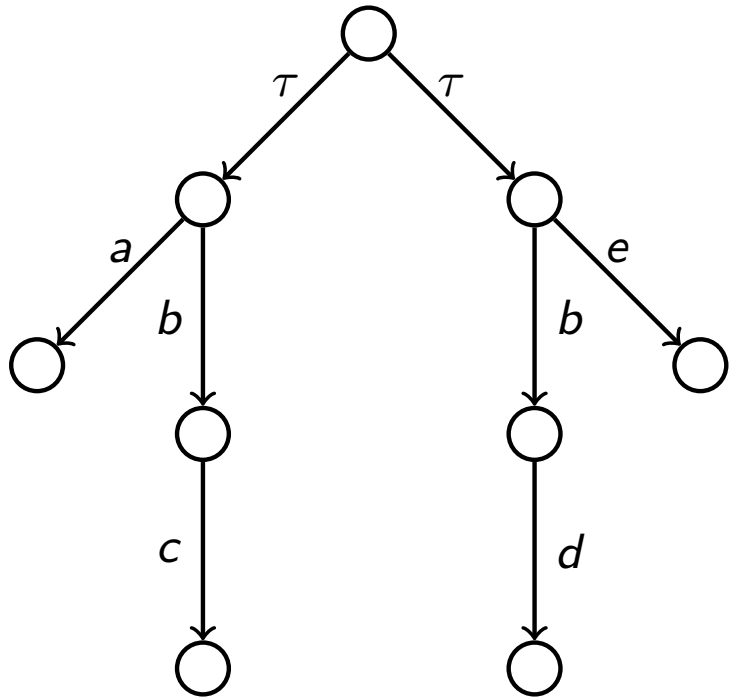

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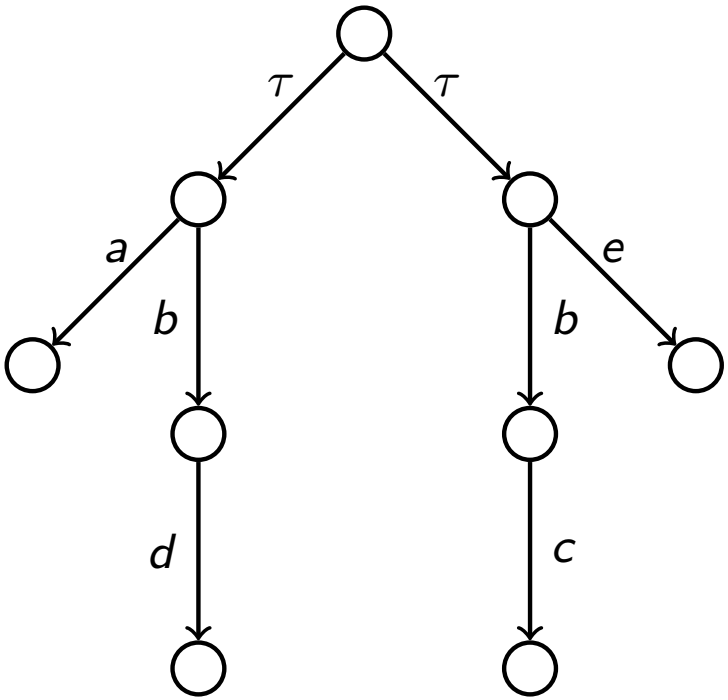

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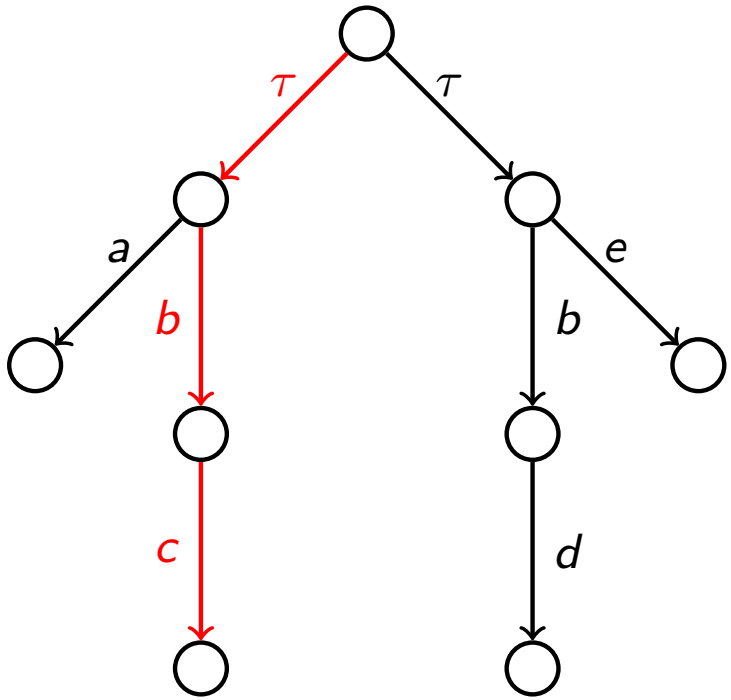

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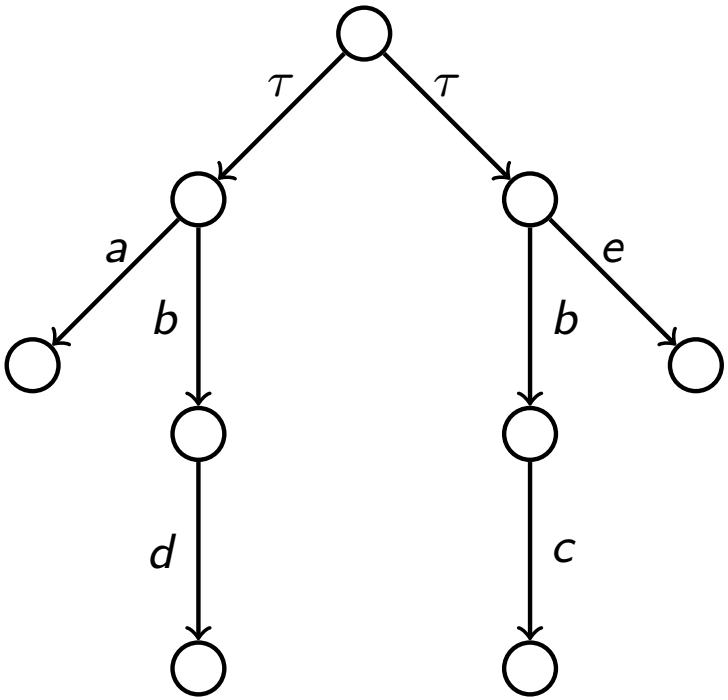

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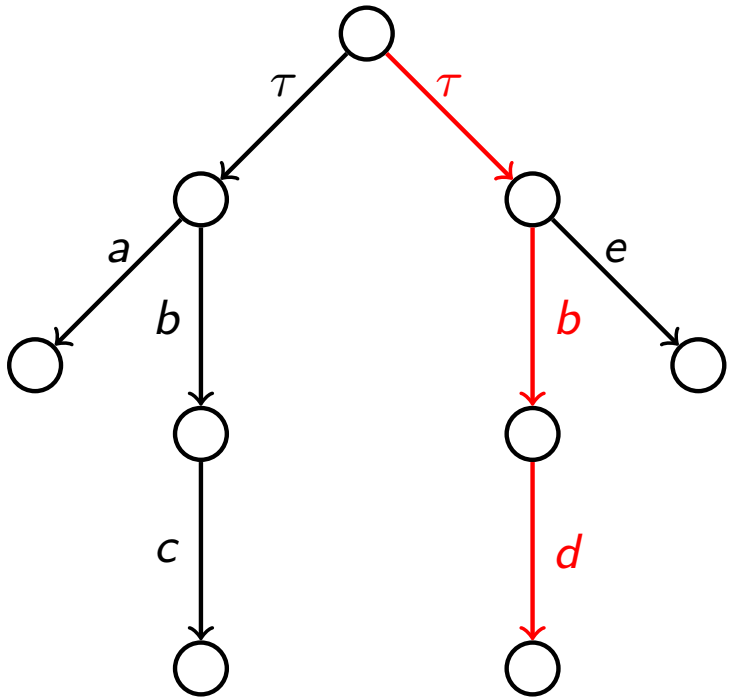

$\langle \{c, d, e\}, b, \{a, b, c, e\}, d, \Sigma \rangle, \langle \{a, c, d\}, b, \{a, b, d, e\}, c, \Sigma \rangle$
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Model Checking CSP

Refinement Checking

$$\frac{S \sqsubseteq_{\mathcal{M}} P \qquad P \sqsubseteq_{\mathcal{M}} Q}{S \sqsubseteq_{\mathcal{M}} Q}$$

Tool Support: FDR or PAT

LTL Model Checking

$$\frac{P \models \phi \qquad P \sqsubseteq_{\mathcal{RT}} Q}{Q \models \phi}$$

Tool Support: ProB and FDR

Fairness

Weak Event Fairness

$$WEF = \bigwedge_{x \in \Sigma} (\Diamond \Box \, enabled\, x \Rightarrow \Box \Diamond x)$$

A constantly often enabled event shall occur infinitely often

Strong Event Fairness

$$SEF = \bigwedge_{x \in \Sigma} (\Box \Diamond \, enabled\, x \Rightarrow \Box \Diamond x)$$

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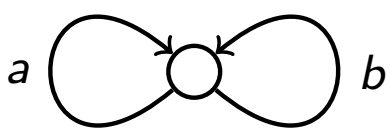

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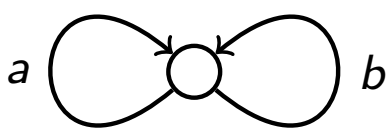

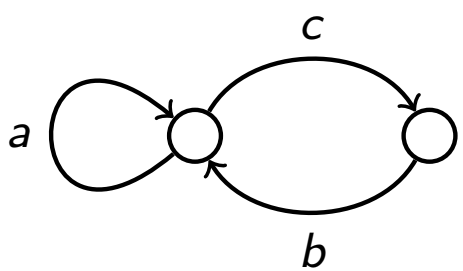

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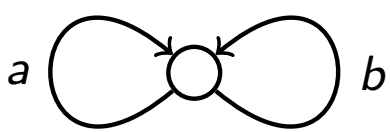

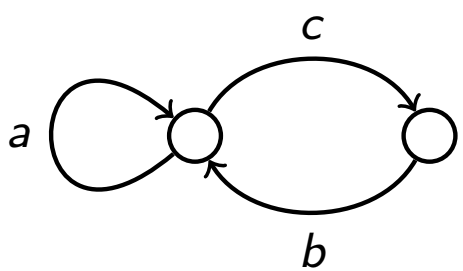

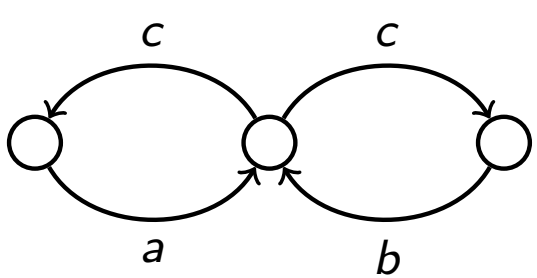

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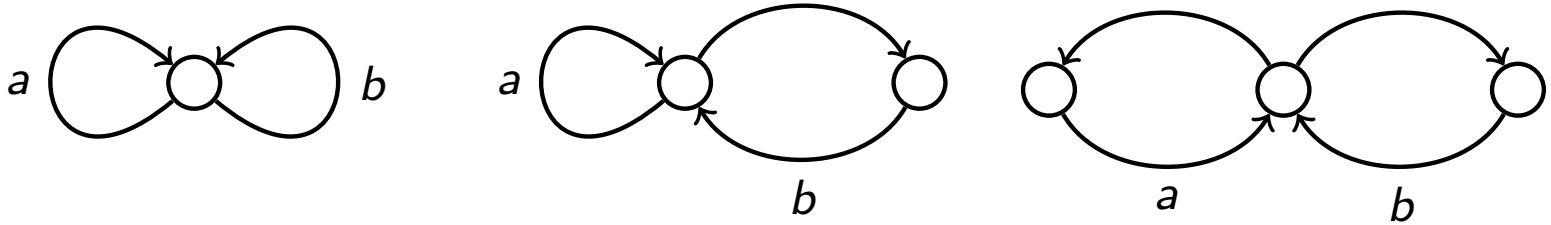

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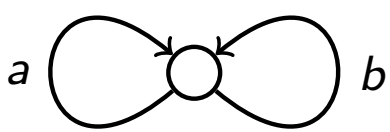

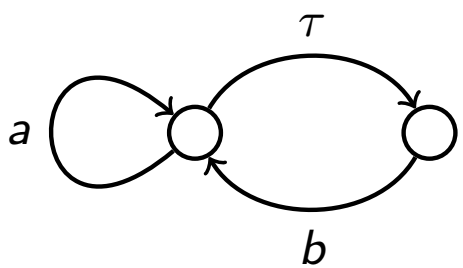

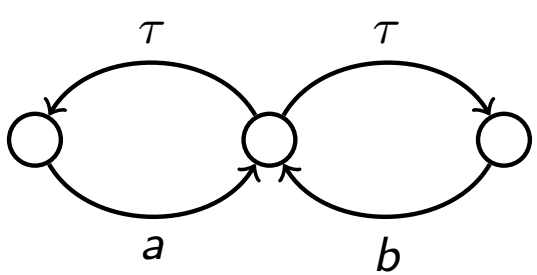

Model Checking CSP

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$$\frac{S \sqsubseteq_{\mathcal{M}} P \qquad P \sqsubseteq_{\mathcal{M}} Q}{S \sqsubseteq_{\mathcal{M}} Q}$$

Tool Support: FDR or PAT

LTL Model Checking

$$\frac{P \models \phi \qquad P \sqsubseteq_{\mathcal{RT}} Q}{Q \models \phi}$$

Tool Support: ProB and FDR

Application to Fair Exchange Protocols

$$SND_2 = snd.A.B.Na \rightarrow SND_2$$
$$RCV_2 = rcv.A.B.Na \rightarrow flag \rightarrow Stop$$
$$SYS_2 = (SND_2 \;|||\; RCV_2) \underset{\{|snd,rcv|\}}{\|} Spy^{L\dagger}$$

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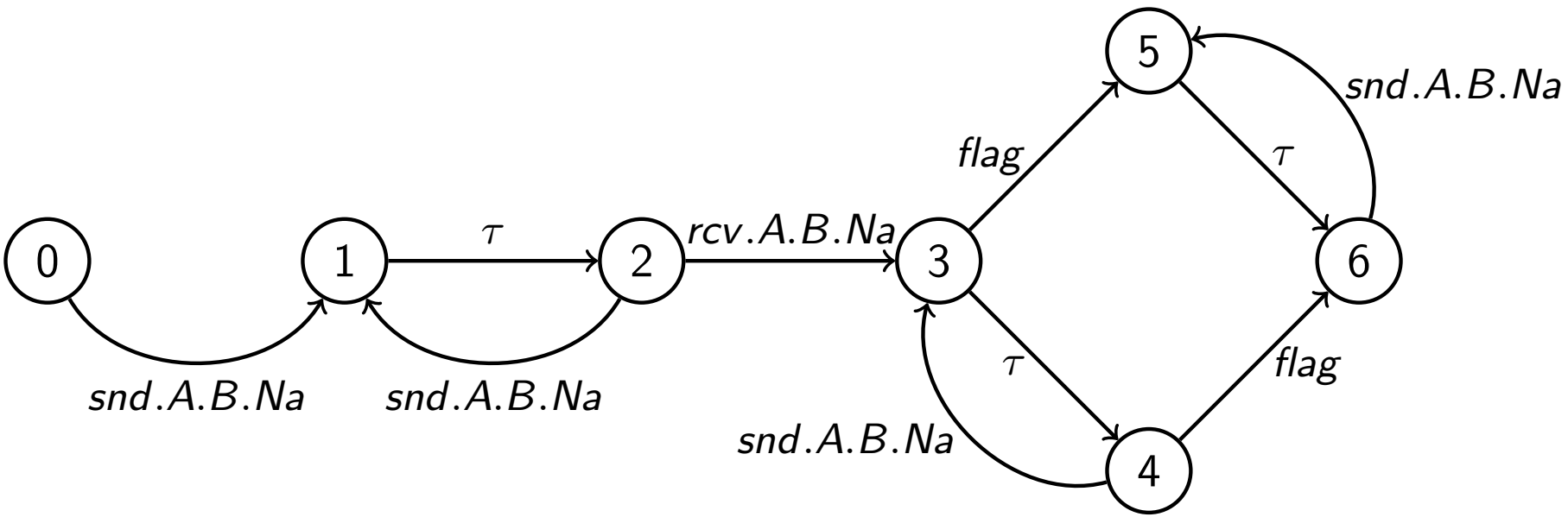

Conclusion

Refinement Checking

$$\frac{S \sqsubseteq_{\mathcal{M}} P \qquad P \sqsubseteq_{\mathcal{M}} Q}{S \sqsubseteq_{\mathcal{M}} Q}$$

Tool Support: FDR or PAT

LTL Model Checking

$$\frac{P \models \phi \qquad P \sqsubseteq_{\mathcal{RT}} Q}{Q \models \phi}$$

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Future Work - Scaling the Approach

Strong Event Fairness

$$SEF = \bigwedge_{x \in \Sigma} (\Box \Diamond \mathit{available}\, x \Rightarrow \Box \Diamond x)$$

An infinitely often enabled event shall occur infinitely often

$$((\Box \Diamond \mathit{available}\, \mathit{snd}.A.B.Na \Rightarrow \Box \Diamond \mathit{snd}.A.B.Na)$$
$$\bigwedge (\Box \Diamond \mathit{available}\, \mathit{rcv}.A.B.Na \Rightarrow \Box \Diamond \mathit{rcv}.A.B.Na))$$
$$\Rightarrow \Box \Diamond \mathit{flag}$$

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$$\begin{aligned}
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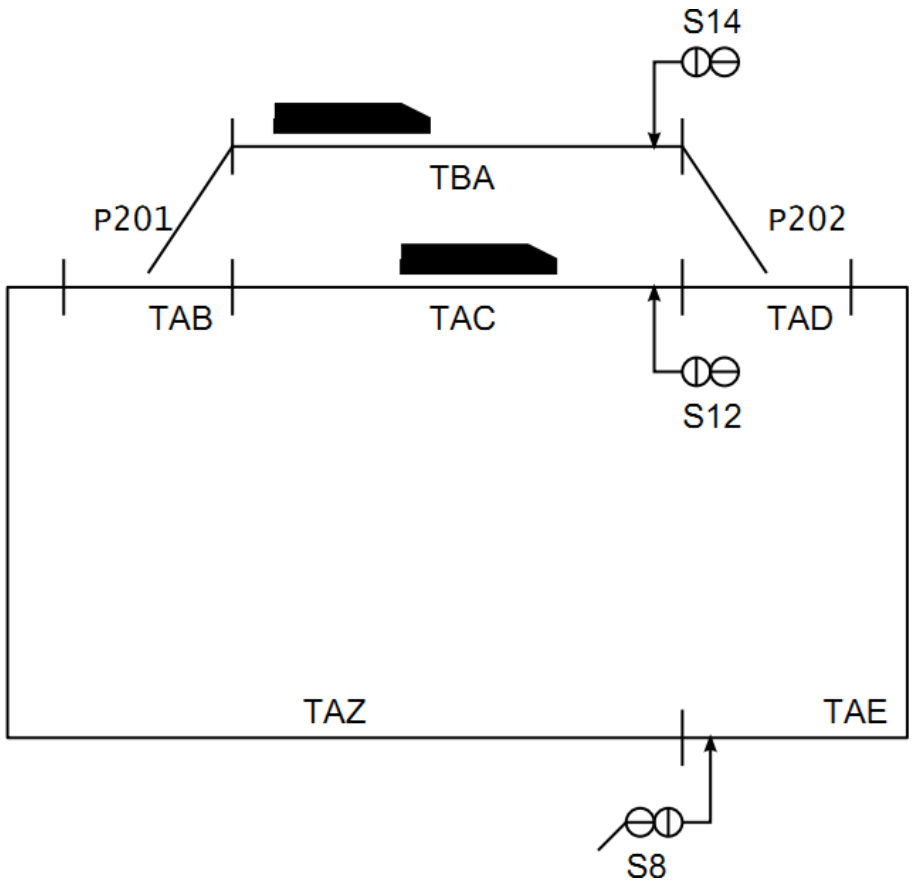
&\bigwedge (\Box \Diamond \mathit{available}\, \mathit{rcv}.A.B.Na \Rightarrow \Box \Diamond \mathit{rcv}.A.B.Na) \\
&\bigwedge (\Box \Diamond \mathit{available}\, \mathit{snd}.A.B.Na' \Rightarrow \Box \Diamond \mathit{snd}.A.B.Na') \\
&\bigwedge (\Box \Diamond \mathit{available}\, \mathit{rcv}.A.B.Na' \Rightarrow \Box \Diamond \mathit{rcv}.A.B.Na')) \\
&\Rightarrow \Box \Diamond \mathit{flag}
\end{aligned}$$

Applications



Conclusion

Any verification using model-based techniques
is only as good as the model of the system.



Our verification approach relates properties of the model to properties of the system along a refinement chain.