UNIVERSITY OF TWENTE.

Formal Methods & Tools.

Why Confluence is More Powerful than Ample Sets in Probabilistic and Non-Probabilistic Branching Time

Mark Timmer

May 23, 2012

Saarbrücken 2012

Joint work with Henri Hansen

The context – probabilistic model checking

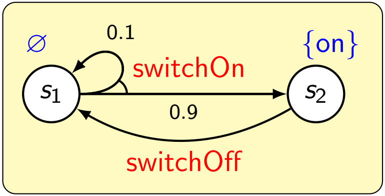
Probabilistic model checking:

- Verifying quantitative properties,
- Using a probabilistic model (e.g., an MDP)

The context – probabilistic model checking

Probabilistic model checking:

- Verifying quantitative properties,
- Using a probabilistic model (e.g., an MDP)

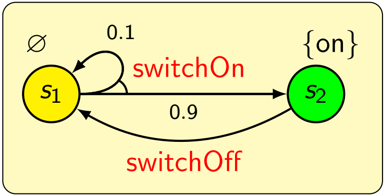


- Non-deterministically choose a transition
- Probabilistically choose the next state

The context – probabilistic model checking

Probabilistic model checking:

- Verifying quantitative properties,
- Using a probabilistic model (e.g., an MDP)

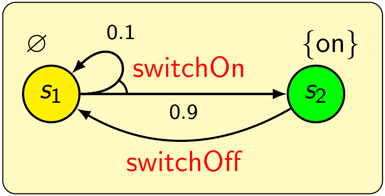


- Non-deterministically choose a transition
- Probabilistically choose the next state

The context – probabilistic model checking

Probabilistic model checking:

- Verifying quantitative properties,
- Using a probabilistic model (e.g., an MDP)

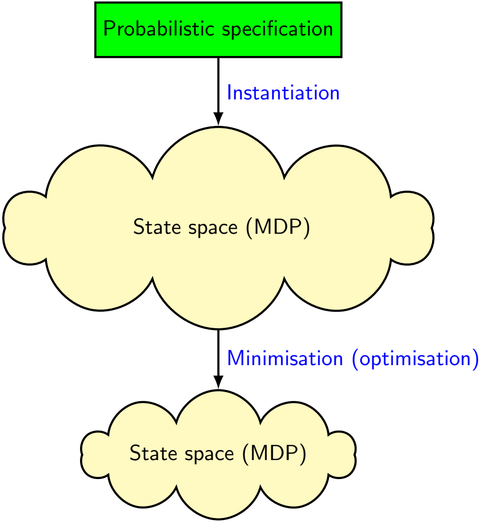


- Non-deterministically choose a transition
- Probabilistically choose the next state

Main limitation (as for non-probabilistic model checking):

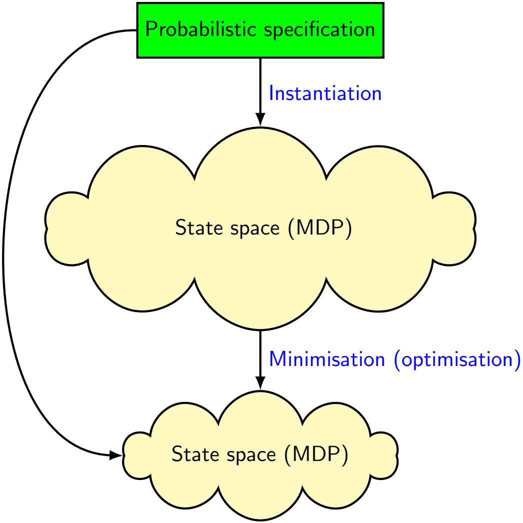
- Susceptible to the state space explosion problem

Combating the state space explosion



Combating the state space explosion

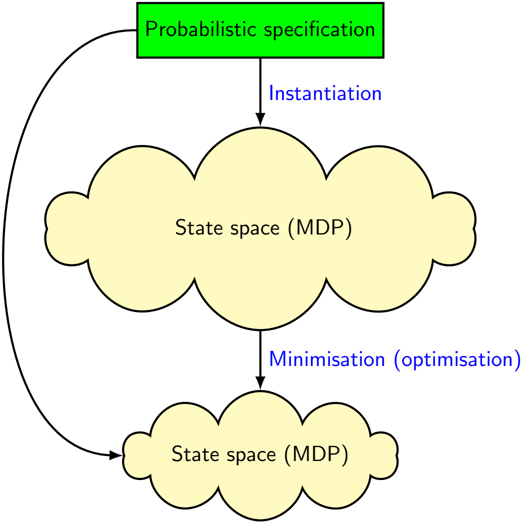
Optimised instantiation



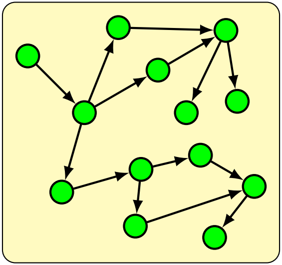
Combating the state space explosion

Optimised instantiation

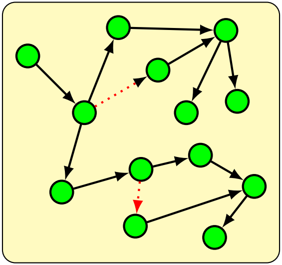
- Partial-order reduction
- Confluence reduction (initially for PAs)



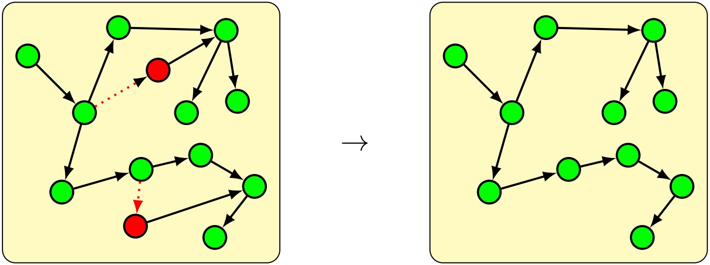
Reductions – an overview



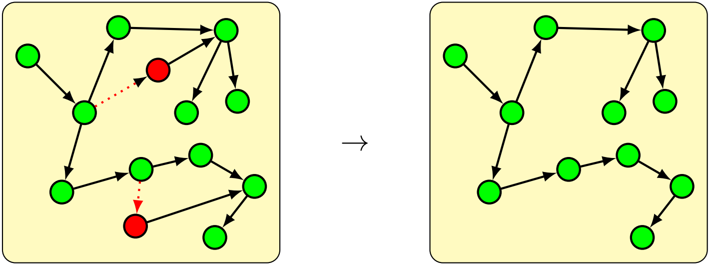
Reductions – an overview



Reductions – an overview



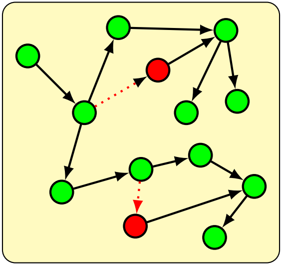
Reductions – an overview



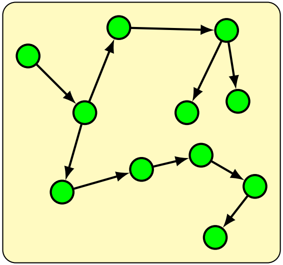
Reduction function:

$R\colon S \to 2^{\Sigma}$

Reductions – an overview



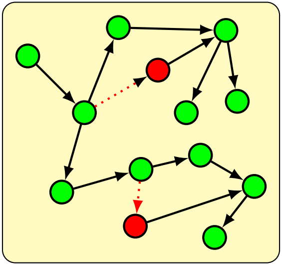
$\rightarrow$



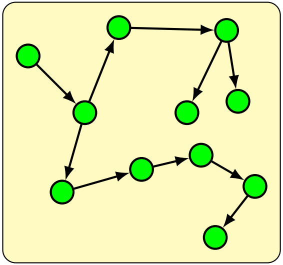
Reduction function:

$R\colon S \rightarrow 2^{\Sigma}$ ($R(s) \subseteq \text{enabled}(s)$)

Reductions – an overview



$\rightarrow$

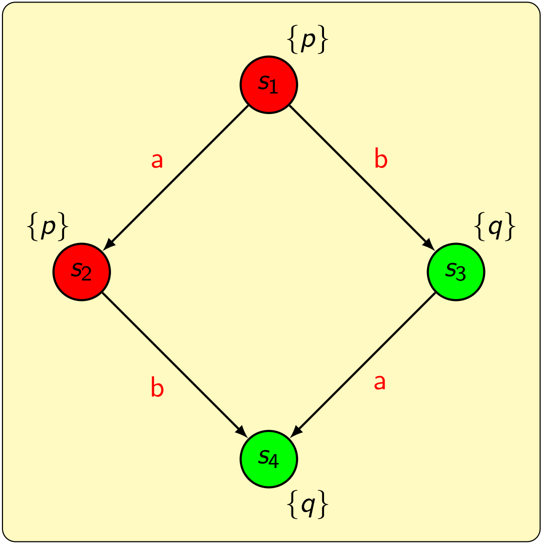


Reduction function:

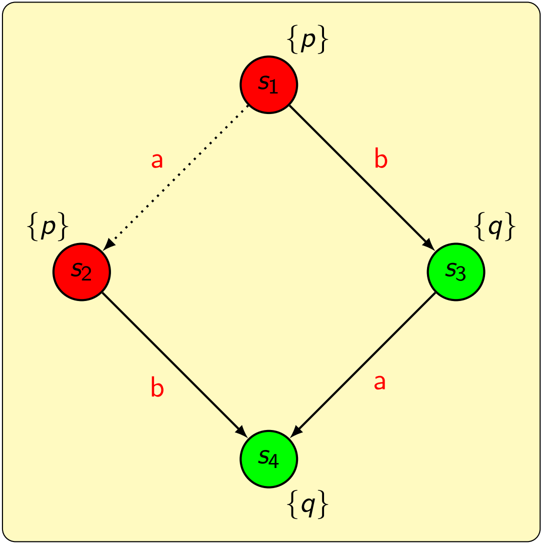
$R\colon S \rightarrow 2^{\Sigma}$ ($R(s) \subseteq \text{enabled}(s)$)

If $R(s) \neq \text{enabled}(s)$, then $R(s)$ consists of remaining transitions.

Basic concepts



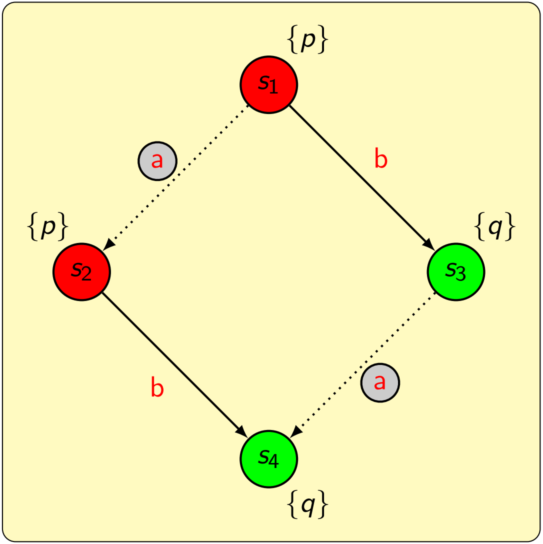
Basic concepts



Stuttering transition:

- No observable change

Basic concepts



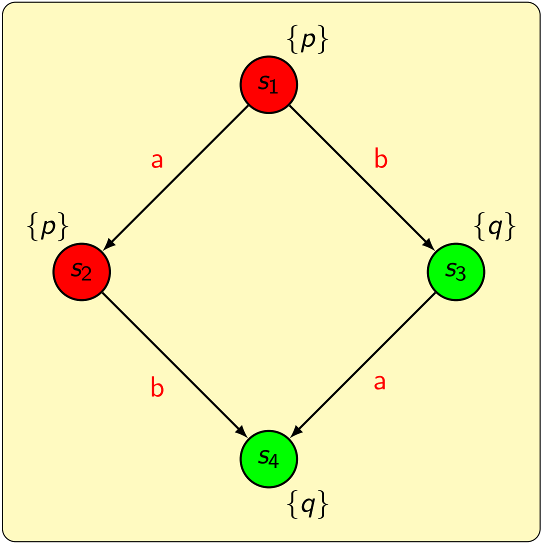
Stuttering transition:

- No observable change

Stuttering action:

- Yields only stuttering transitions

Basic concepts



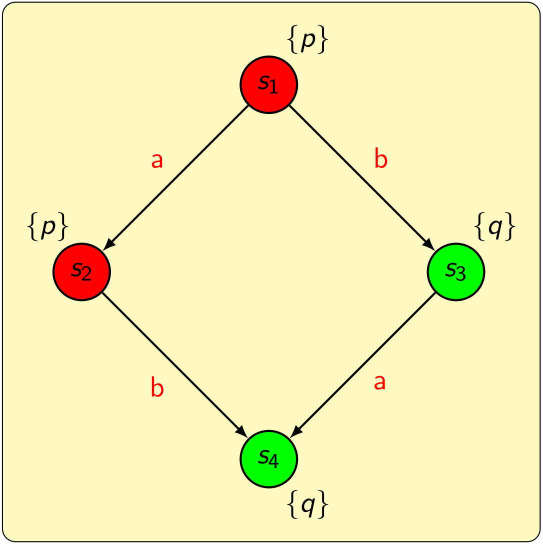
Stuttering transition:

- No observable change

Stuttering action:

- Yields only stuttering transitions

Basic concepts



Stuttering transition:

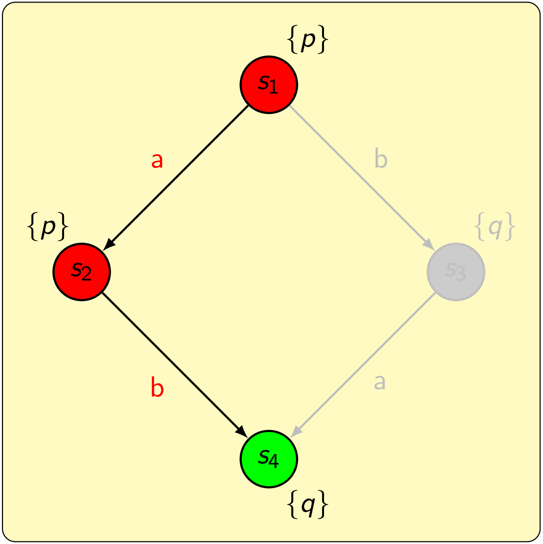
- No observable change

Stuttering action:

- Yields only stuttering transitions

$\{p\}\{p\}\{q\} =_{st} \{p\}\{q\}\{q\}$

Basic concepts



Stuttering transition:

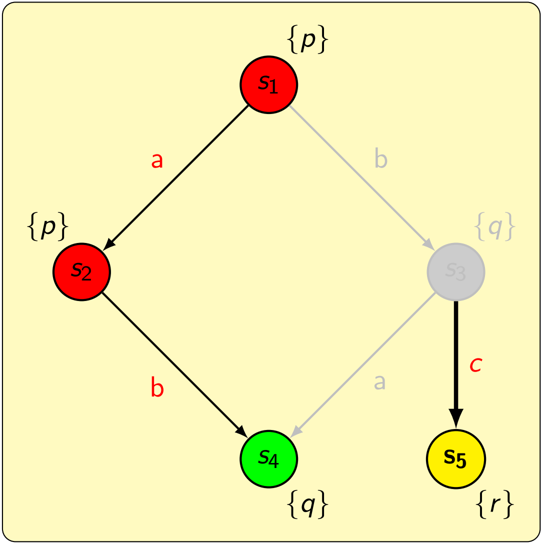
- No observable change

Stuttering action:

- Yields only stuttering transitions

$\{p\}\{p\}\{q\} =_{st} \{p\}\{q\}\{q\}$

Basic concepts



Stuttering transition:

- No observable change

Stuttering action:

- Yields only stuttering transitions

$\{p\}\{p\}\{q\} =_{st} \{p\}\{q\}\{q\}$

Correctness criteria

Correctness criteria for reductions:

- Preservation of $\text{LTL}_{\setminus X}$ (linear time)
- Preservation of $\text{CTL}^*_{\setminus X}$ (branching time)

Correctness criteria

Correctness criteria for reductions:

- Preservation of (quantitative) $\text{LTL}_{\setminus X}$ (linear time)
- Preservation of (P)$\text{CTL}^*_{\setminus X}$ (branching time)

Correctness criteria

Correctness criteria for reductions:

- Preservation of (quantitative) $LTL_{\setminus X}$ (linear time)
- Preservation of $(P)CTL^*_{\setminus X}$ (branching time)

	Partial-order reduction	Confluence reduction
Linear time	[BGC'04, AN'04]	–
Branching time	[BAG'06]	[TSP'11]

Correctness criteria

Correctness criteria for reductions:

- Preservation of (quantitative) $\text{LTL}_{\setminus X}$ (linear time)
- Preservation of $\text{(P)CTL}^*_{\setminus X}$ (branching time)

	Partial-order reduction		Confluence reduction
Linear time	[BGC'04, AN'04]		–
Branching time	[BAG'06]	$\stackrel{?}{\Longleftrightarrow}$	[TSP'11]

Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

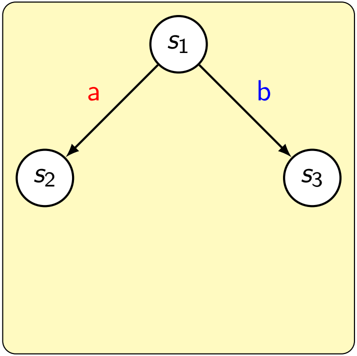
- Based on independent actions and ample sets

Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Independence of *a* and *b*:

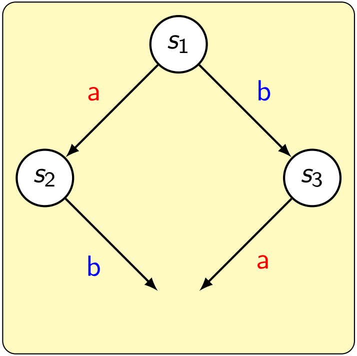


Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Independence of *a* and *b*:

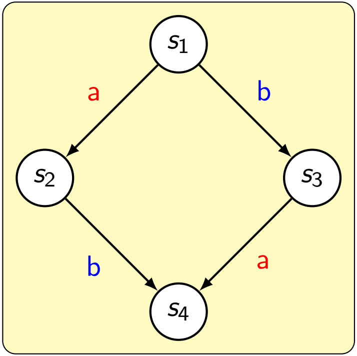


Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Independence of *a* and *b*:

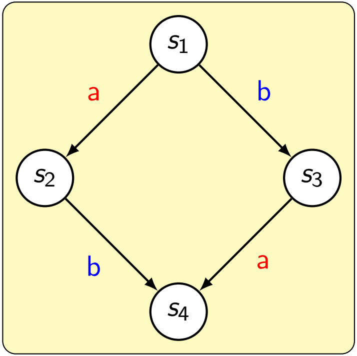


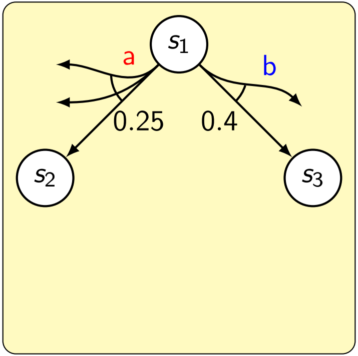
Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Independence of *a* and *b*:



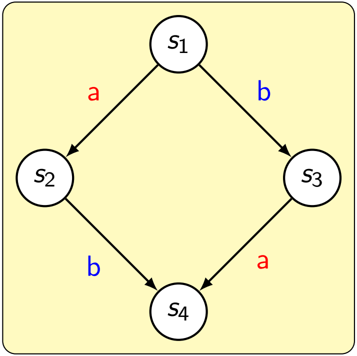


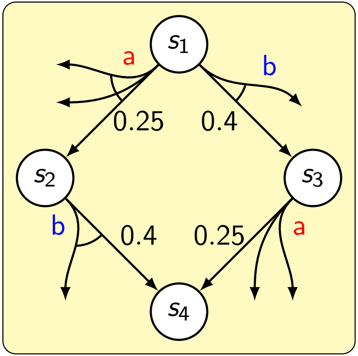
Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Independence of *a* and *b*:



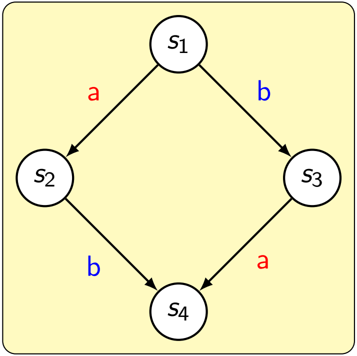


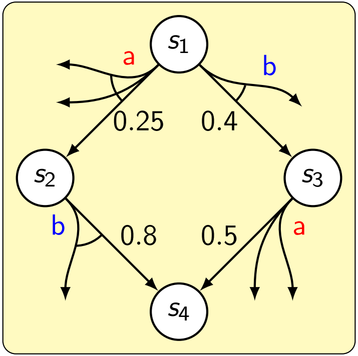
Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Independence of *a* and *b*:



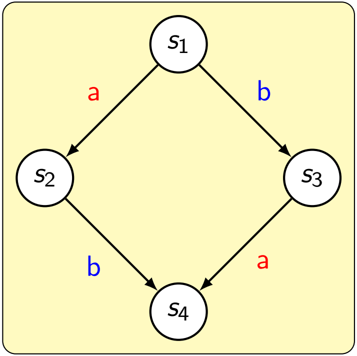


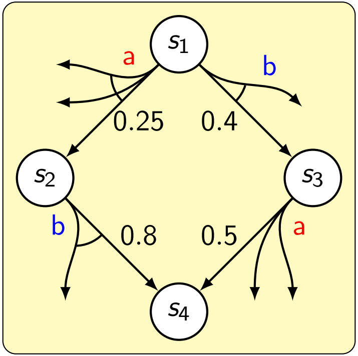
Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Independence of a and b:





$$\mathbb{P}[s_1 \xrightarrow{ab} s] = \mathbb{P}[s_1 \xrightarrow{ba} s],\ \forall s$$

Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

Given a reduction function $R \colon S \to 2^{\Sigma}$, for every $s \in S$

Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

Given a reduction function $R\colon S \to 2^{\Sigma}$, for every $s \in S$

A0 $\varnothing \neq R(s)$

A1

A2

A3

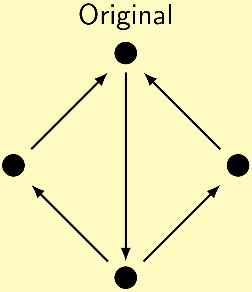
A4

Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

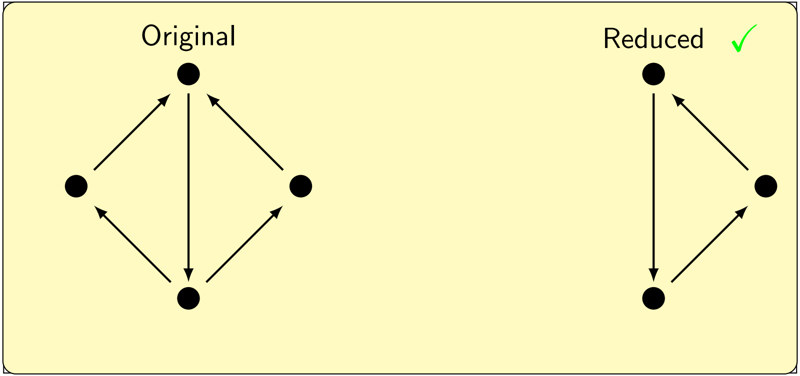


Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

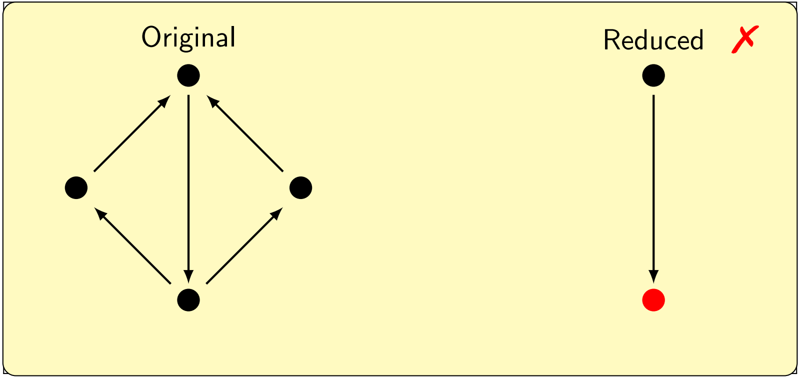


Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:



Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

Given a reduction function $R\colon S \to 2^{\Sigma}$, for every $s \in S$

A0 $\varnothing \neq R(s)$

A1 if $R(s) \neq \text{enabled}(s)$, then $R(s)$ contains only stuttering actions

A2

A3

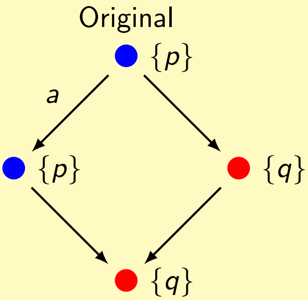
A4

Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

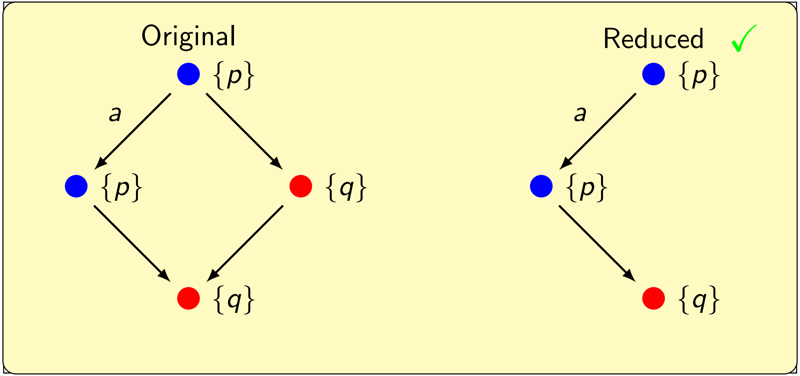


Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

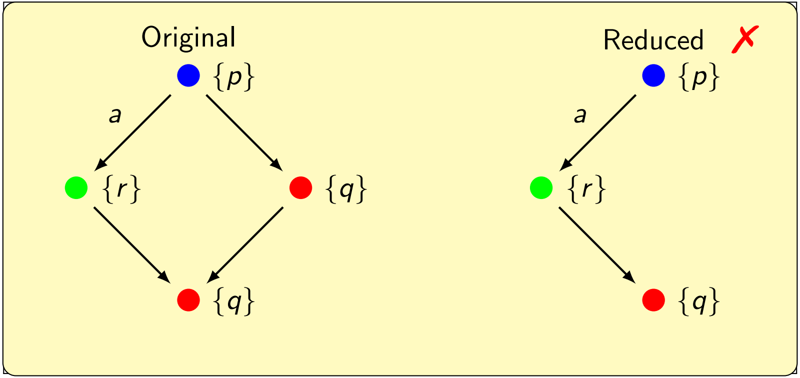


Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:



Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

Given a reduction function $R\colon S \to 2^{\Sigma}$, for every $s \in S$

A0 $\varnothing \neq R(s)$

A1 if $R(s) \neq \text{enabled}(s)$, then $R(s)$ contains only stuttering actions

A2 For every original path $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n \xrightarrow{b} t$ such that $b \notin R(s)$ and b depends on $R(s)$, there exists an i such that $a_i \in R(s)$

A3

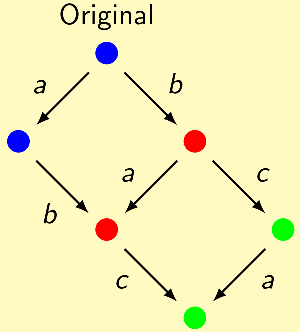
A4

Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

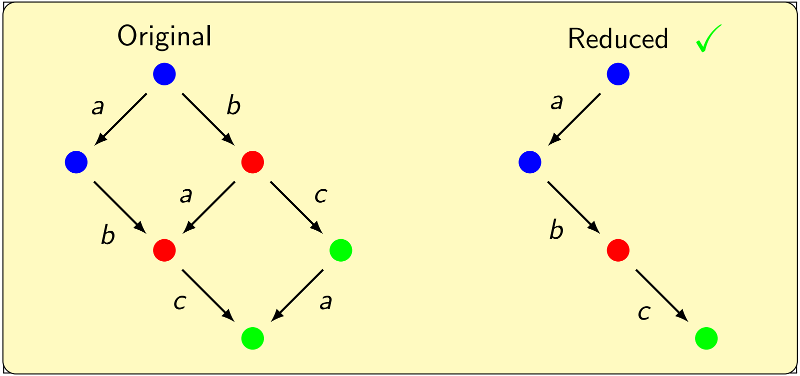


Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

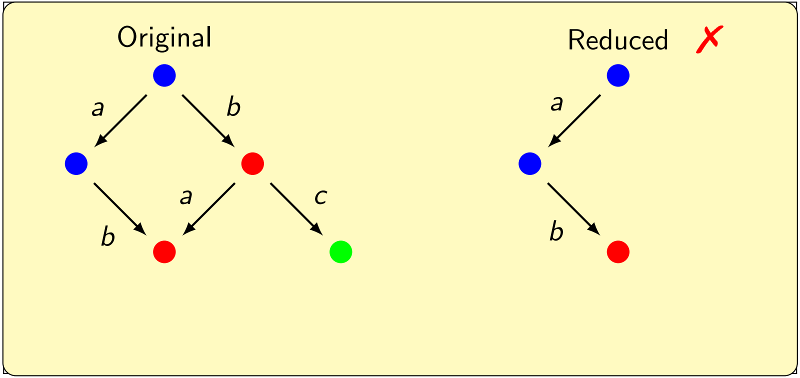


Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:



Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

Given a reduction function $R\colon S \to 2^{\Sigma}$, for every $s \in S$

A0 $\varnothing \neq R(s)$

A1 if $R(s) \neq \text{enabled}(s)$, then $R(s)$ contains only stuttering actions

A2 For every original path $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n \xrightarrow{b} t$ such that $b \notin R(s)$ and b depends on $R(s)$, there exists an i such that $a_i \in R(s)$

A3 Every cycle in the reduced MDP contains a fully-expanded state (if $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n = s$, then $\exists s_i \,.\, R(s_i) = \text{enabled}(s_i)$)

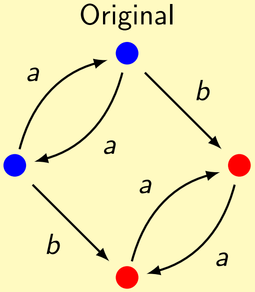
A4

Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

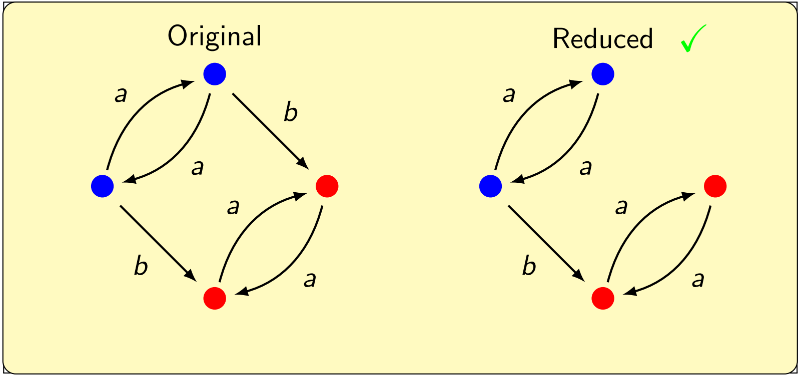


Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

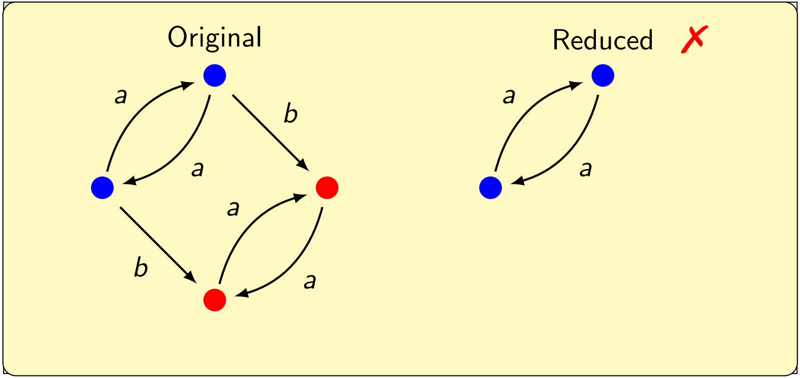


Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:



Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

Given a reduction function $R\colon S \to 2^{\Sigma}$, for every $s \in S$

- A0 $\varnothing \neq R(s)$
- A1 if $R(s) \neq \text{enabled}(s)$, then $R(s)$ contains only stuttering actions
- A2 For every original path $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n \xrightarrow{b} t$ such that $b \notin R(s)$ and b depends on $R(s)$, there exists an i such that $a_i \in R(s)$
- A3 Every cycle in the reduced MDP contains a fully-expanded state (if $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n = s$, then $\exists s_i \,.\, R(s_i) = \text{enabled}(s_i)$)
- A4 if $R(s) \neq \text{enabled}(s)$, then $|R(s)| = 1$ and the chosen action is deterministic

Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

Given a reduction function $R\colon S \to 2^{\Sigma}$, for every $s \in S$

A0 $\emptyset \neq R(s)$

A1 if $R(s) \neq \text{enabled}(s)$, then $R(s)$ contains only stuttering actions

A2 For every original path $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n \xrightarrow{b} t$ such that $b \notin R(s)$ and b depends on $R(s)$, there exists an i such that $a_i \in R(s)$

A3 Every cycle in the reduced MDP contains a fully-expanded state (if $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n = s$, then $\exists s_i \,.\, R(s_i) = \text{enabled}(s_i)$)

A4 if $R(s) \neq \text{enabled}(s)$, then $|R(s)| = 1$ and the chosen action is deterministic

Partial-order reduction: ample sets

Partial-order reduction [Baier, D'Argenio, Größer, 2006]

- Based on independent actions and ample sets

Ample set conditions:

Given a reduction function $R\colon S \to 2^{\Sigma}$, for every $s \in S$

- **A0** $\varnothing \neq R(s)$
- **A1** if $R(s) \neq \text{enabled}(s)$, then $R(s)$ contains only stuttering actions
- **A2** For every original path $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n \xrightarrow{b} t$ such that $b \notin R(s)$ and b depends on $R(s)$, there exists an i such that $a_i \in R(s)$
- **A3** Every cycle in the reduced MDP contains a fully-expanded state (if $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n = s$, then $\exists s_i \,.\, R(s_i) = \text{enabled}(s_i)$)
- **A4** if $R(s) \neq \text{enabled}(s)$, then $|R(s)| = 1$ and the chosen action is deterministic and stuttering

Confluence

Confluence reduction [Timmer, Stoelinga, van de Pol, 2011]

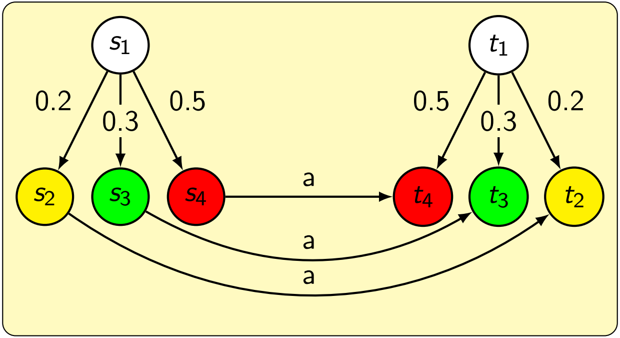
- Based on equivalent distributions and confluent transitions

Confluence

Confluence reduction [Timmer, Stoelinga, van de Pol, 2011]

- Based on equivalent distributions and confluent transitions

T-equivalent distributions

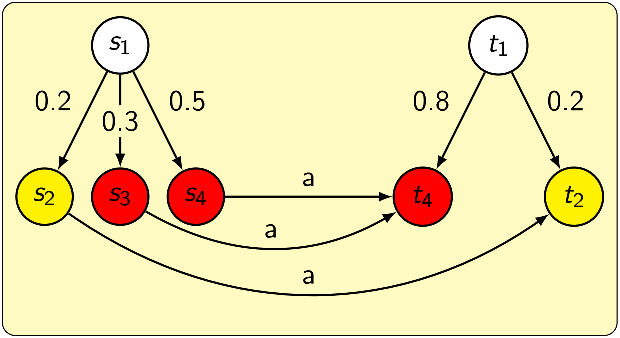


Confluence

Confluence reduction [Timmer, Stoelinga, van de Pol, 2011]

- Based on equivalent distributions and confluent transitions

T-equivalent distributions

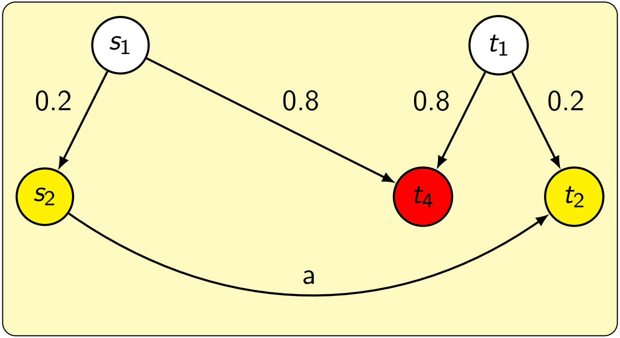


Confluence

Confluence reduction [Timmer, Stoelinga, van de Pol, 2011]

- Based on equivalent distributions and confluent transitions

T-equivalent distributions



Confluence

Confluence reduction [Timmer, Stoelinga, van de Pol, 2011]

- Based on equivalent distributions and confluent transitions

The main idea:

- Choose a set T of transitions
- Make sure all of them are confluent
- $R(s) = \text{enabled}(s)$ or $R(s) = \{a\}$ such that $(s \xrightarrow{a} t) \in T$

Confluence

Confluence reduction [Timmer, Stoelinga, van de Pol, 2011]

- Based on equivalent distributions and confluent transitions

The main idea:

- Choose a set T of transitions
- Make sure all of them are confluent
- $R(s) = \text{enabled}(s)$ or $R(s) = \{a\}$ such that $(s \xrightarrow{a} t) \in T$
- Make sure T is acyclic to prevent infinite postponing

Confluence

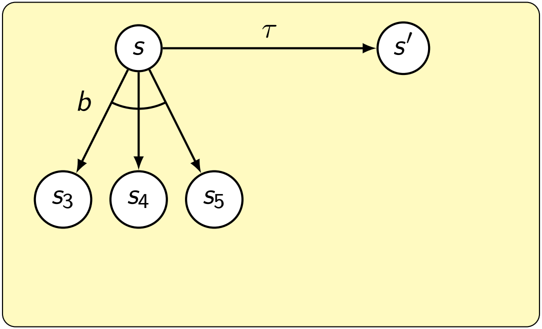
A set of transitions T is confluent if

- Every transition in T is labelled by a deterministic stuttering action
- If $s \xrightarrow{\tau} s' \in T$ and $s \xrightarrow{b} \mu$, then
  1. either $s' \xrightarrow{b} \nu$ and μ is T-equivalent to ν
  2. or $\mu(s') = 1$ (b deterministically goes to s')

Confluence

A set of transitions T is confluent if

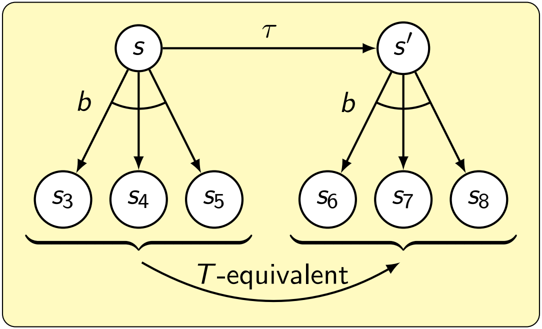
- Every transition in T is labelled by a deterministic stuttering action
- If $s \xrightarrow{\tau} s' \in T$ and $s \xrightarrow{b} \mu$, then
  1. either $s' \xrightarrow{b} \nu$ and μ is T-equivalent to ν
  2. or $\mu(s') = 1$ (b deterministically goes to s')



Confluence

A set of transitions T is confluent if

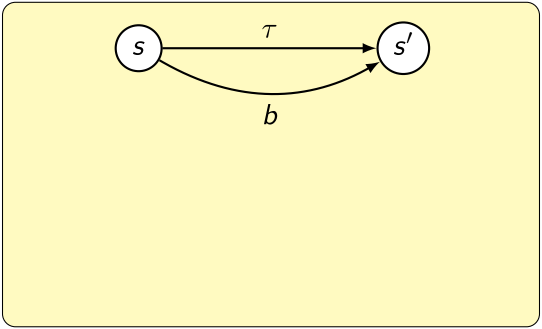
- Every transition in T is labelled by a deterministic stuttering action
- If $s \xrightarrow{\tau} s' \in T$ and $s \xrightarrow{b} \mu$, then
  1. either $s' \xrightarrow{b} \nu$ and μ is T-equivalent to ν
  2. or $\mu(s') = 1$ (b deterministically goes to s')



Confluence

A set of transitions T is confluent if

- Every transition in T is labelled by a deterministic stuttering action
- If $s \xrightarrow{\tau} s' \in T$ and $s \xrightarrow{b} \mu$, then
  1. either $s' \xrightarrow{b} \nu$ and μ is T-equivalent to ν
  2. or $\mu(s') = 1$ (b deterministically goes to s')



Comparison

Similarities among ample sets and confluence:

Comparison

Similarities among ample sets and confluence:

	Requirement
Size of $R(s)$	$R(s) = \text{enabled}(s)$ or $\lvert R(s)\rvert = 1$

Comparison

Similarities among ample sets and confluence:

	Requirement
Size of $R(s)$	$R(s) = \text{enabled}(s)$ or $\lvert R(s)\rvert = 1$
Remaining transitions	Deterministic and stuttering

Comparison

Similarities among ample sets and confluence:

	Requirement
Size of $R(s)$	$R(s) = \text{enabled}(s)$ or $\lvert R(s) \rvert = 1$
Remaining transitions	Deterministic and stuttering
Acyclicity	No cycle of remaining transitions allowed

Comparison

Similarities among ample sets and confluence:

	Requirement
Size of $R(s)$	$R(s) = \text{enabled}(s)$ or $\lvert R(s)\rvert = 1$
Remaining transitions	Deterministic and stuttering
Acyclicity	No cycle of remaining transitions allowed
Preservation	Branching time properties

Comparison

Similarities among ample sets and confluence:

	Requirement
Size of $R(s)$	$R(s) = \text{enabled}(s)$ or $\lvert R(s) \rvert = 1$
Remaining transitions	Deterministic and stuttering
Acyclicity	No cycle of remaining transitions allowed
Preservation	Branching time properties

Differences between ample sets and confluence:

POR For every original path $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n \xrightarrow{b} t$ such that $b \notin R(s)$ and b depends on $R(s)$, there exists an i such that $a_i \in R(s)$

Comparison

Similarities among ample sets and confluence:

	Requirement
Size of $R(s)$	$R(s) = \text{enabled}(s)$ or $\lvert R(s) \rvert = 1$
Remaining transitions	Deterministic and stuttering
Acyclicity	No cycle of remaining transitions allowed
Preservation	Branching time properties

Differences between ample sets and confluence:

POR For every original path $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n \xrightarrow{b} t$ such that $b \notin R(s)$ and b depends on $R(s)$, there exists an i such that $a_i \in R(s)$

Conf If $s \xrightarrow{\tau} t$ and $s \xrightarrow{b} \mu$, then $\mu = \text{dirac}(t)$ or $t \xrightarrow{b} \nu$ and μ is equivalent to ν.

Comparison – POR implies Confluence

Theorem

Let R be a reduction function satisfying the ample set conditions. Then, all remaining transitions are confluent.

Comparison – POR implies Confluence

Theorem

Let R be a reduction function satisfying the ample set conditions. Then, all remaining transitions are confluent.

Or:

Any reduction allowed by partial-order reduction is also allowed by confluence reduction.

Comparison – POR implies Confluence

Theorem

Let R be a reduction function satisfying the ample set conditions. Then, all remaining transitions are confluent.

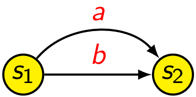
Or:

Any reduction allowed by partial-order reduction is also allowed by confluence reduction.

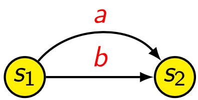
Proof (sketch).

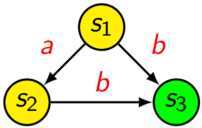
1. Take the set of all remaining transitions of the partial-order reduction.
2. Recursively add transitions needed to complete the confluence diamonds.
3. Prove that the resulting set is indeed confluent. □

Comparison – Confluence does not imply POR

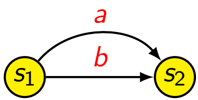


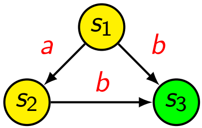
Comparison – Confluence does not imply POR

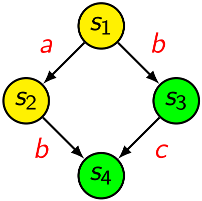




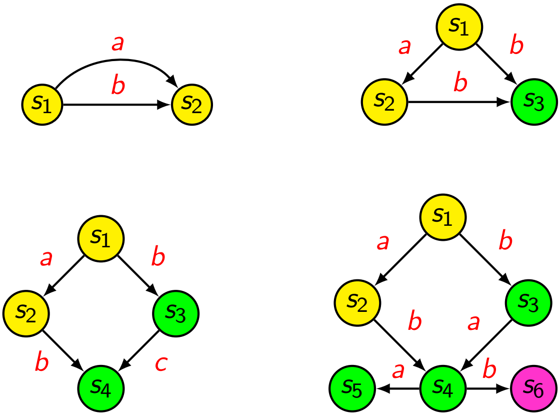
Comparison – Confluence does not imply POR



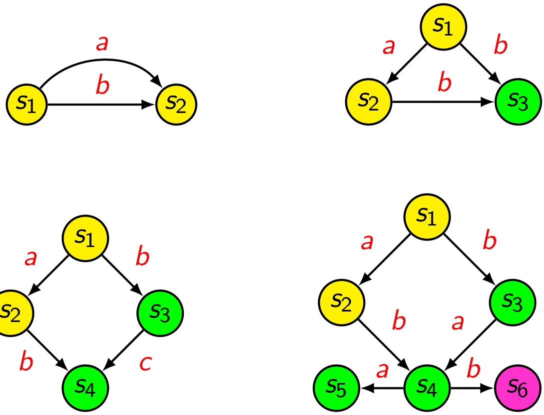




Comparison – Confluence does not imply POR



Comparison – Confluence does not imply POR



POR's notion of independence is stronger than necessary.

Strengthening of confluence

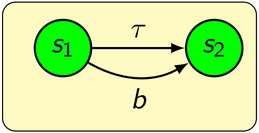
We can change confluence in the following way:

- Do not allow shortcuts

Strengthening of confluence

We can change confluence in the following way:

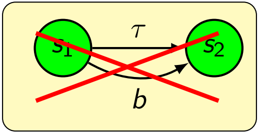
- Do not allow shortcuts



Strengthening of confluence

We can change confluence in the following way:

- Do not allow shortcuts



Strengthening of confluence

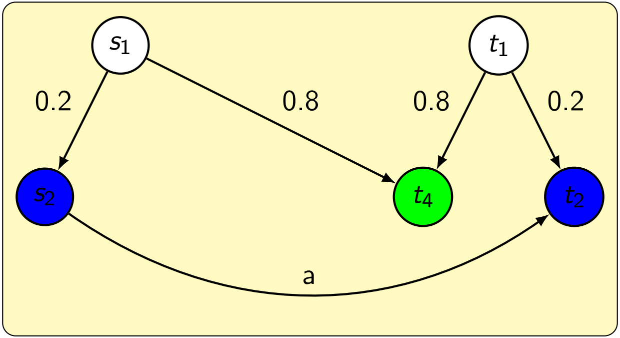
We can change confluence in the following way:

- Do not allow shortcuts
- Do not allow overlapping distributions to be equivalent

Strengthening of confluence

We can change confluence in the following way:

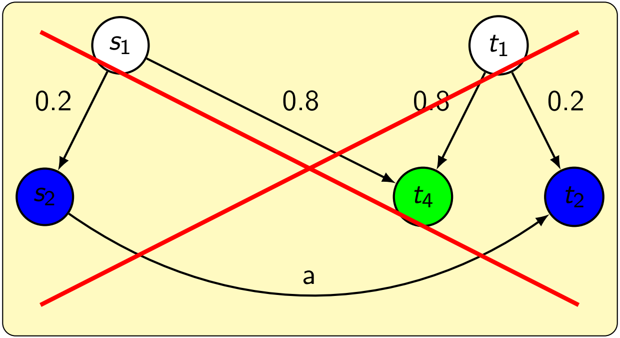
- Do not allow shortcuts
- Do not allow overlapping distributions to be equivalent



Strengthening of confluence

We can change confluence in the following way:

- Do not allow shortcuts
- Do not allow overlapping distributions to be equivalent



Strengthening of confluence

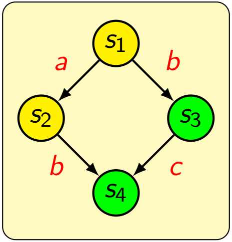
We can change confluence in the following way:

- Do not allow shortcuts
- Do not allow overlapping distributions to be equivalent
- Require action-separability

Strengthening of confluence

We can change confluence in the following way:

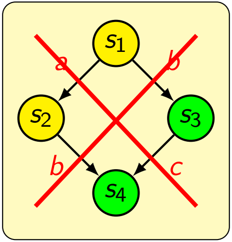
- Do not allow shortcuts
- Do not allow overlapping distributions to be equivalent
- Require action-separability



Strengthening of confluence

We can change confluence in the following way:

- Do not allow shortcuts
- Do not allow overlapping distributions to be equivalent
- Require action-separability



Relaxing of partial-order reduction

We can change partial-order reduction in the following way:

- Relax the dependency condition

Relaxing of partial-order reduction

We can change partial-order reduction in the following way:

- Relax the dependency condition

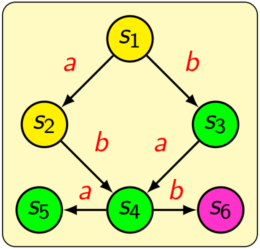
  For every original path $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n \xrightarrow{b} t$ such that $b \neq R(s)$ and $R(s)$ depends on b at s, there exists an i such that $a_i \in R(s)$

Relaxing of partial-order reduction

We can change partial-order reduction in the following way:

- Relax the dependency condition

  For every original path $s \xrightarrow{a_1} s_1 \xrightarrow{a_2} \dots \xrightarrow{a_n} s_n \xrightarrow{b} t$ such that $b \neq R(s)$ and $R(s)$ depends on b at s, there exists an i such that $a_i \in R(s)$



Strengthening of confluence

Theorem

Every acyclic action-separable strengthened confluence reduction is a relaxed ample set reduction and vice versa.

Strengthening of confluence

Theorem

Every acyclic action-separable strengthened confluence reduction is a relaxed ample set reduction and vice versa.

Corollary

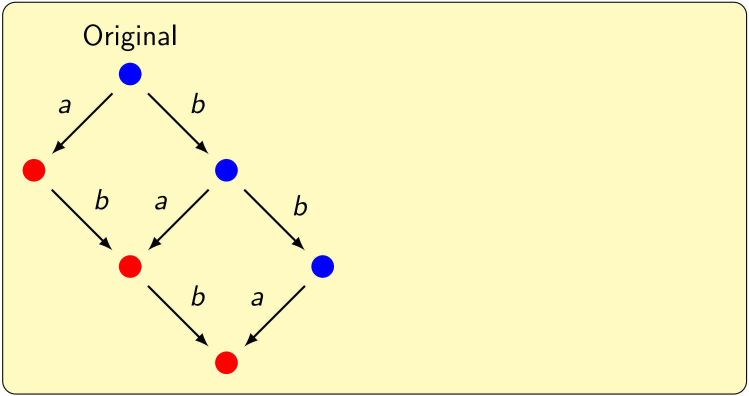
In the non-probabilistic setting, the same statements hold: confluence is stronger than partial-order reduction, and the notions are equivalent for the adjusted definitions.

Implications

State space generation using representatives:

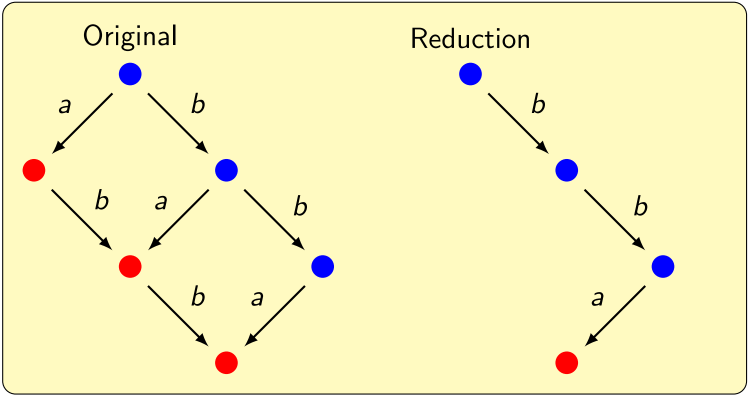
Implications

State space generation using representatives:



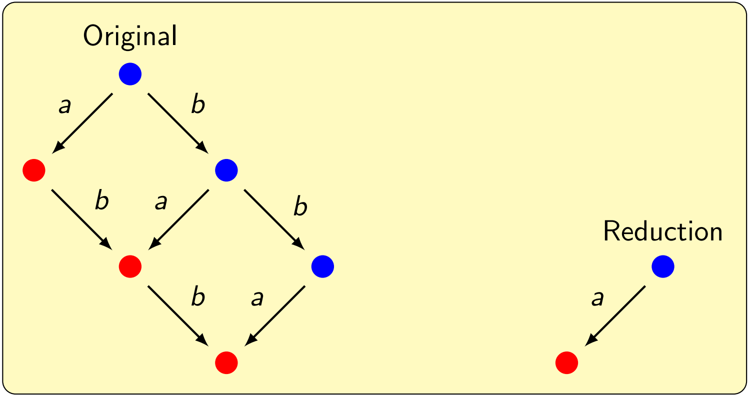
Implications

State space generation using representatives:



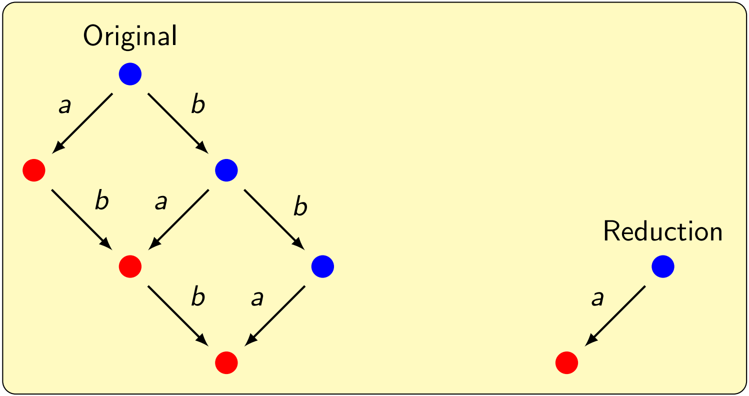
Implications

State space generation using representatives:



Implications

State space generation using representatives:



- Representative in bottom strongly connected component
- Additional reduction of states and transitions
- No need for an explicit cycle condition anymore!

Conclusions

What to take home from this. . .

- We adapted the existing notion of confluence reduction to work in a state-based setting with MDPs.
- We proved that every ample set can be mimicked by a confluent set, but the the converse doesn't always hold.
- We showed how to make ample set reduction and confluence reduction equivalent
- We demonstrated one implication of our results, applying a technique from confluence reduction to POR
- The results are independent of specific heuristics, and also hold non-probabilistically

Questions

Questions?

A paper, containing all details and proofs, can be found at

`http://wwwhome.cs.utwente.nl/~timmer/research.php`