Reconfigurable graphs for event structures

José Proença
based on work with Alexandre Madeira, Manuel Martins, David Tinoco @ Univ. Aveiro, Portugal

APM Workshop 2024, Turin, 2-4 October 2024

CISTER & U.Porto, Porto, Portugal

CISTER - Research Centre in
Real-Time & Embedded
Computing Systems

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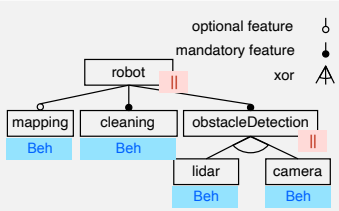
UNIVERSIDADE DO PORTO

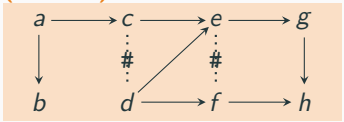
Behavioural Feature Models, Event Structures, and Reconfigurable Graphs

Behavioural feature models



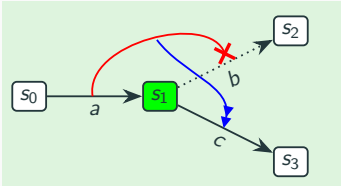
by Pässler, Fortz, ter Beek, Damiani, Mousavi, Johnsen, Tapia Tarifa [UNPUBLISHED]

(Bundle) Event structures



by Nielsen, Plotkin, and Winskel [TCS'81] *and Langerak* [FORTE'92]

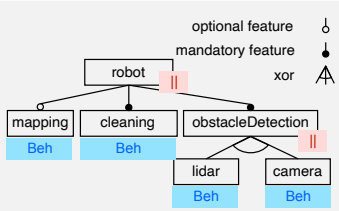
Reconfigurable graphs



by Tinoco, Madeira, Martins, Proença [FACS'24]

Behavioural Feature Models, Event Structures, and Reconfigurable Graphs

Behavioural feature models



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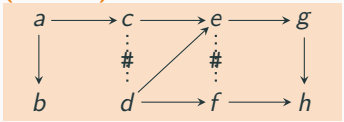

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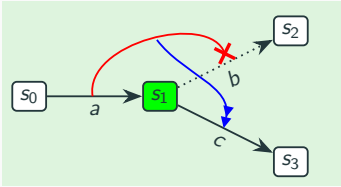
Reconfigurable graphs

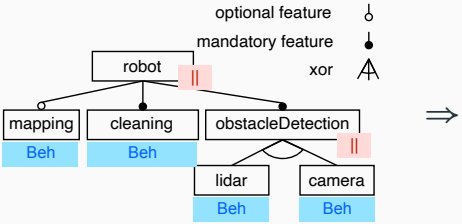


by Tinoco, Madeira, Martins, Proença [FACS'24]

Goal: Investigate dependencies & conflicts in (Networks of) Reconfigurable graphs

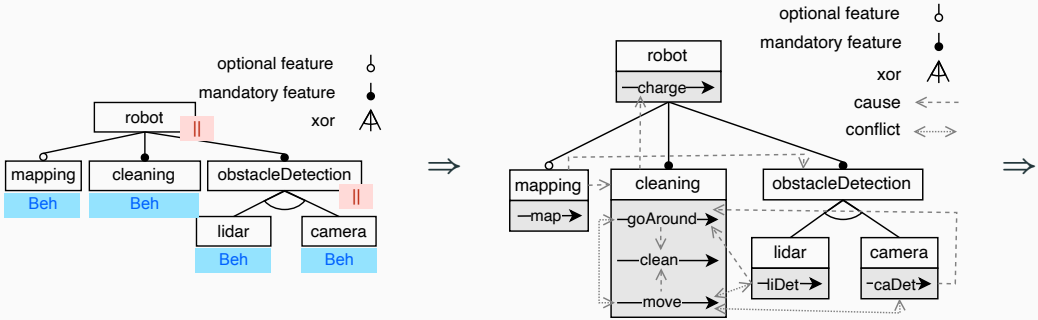
Behavioural Feature Models

Behavioural Feature Model of a Cleaning Robot

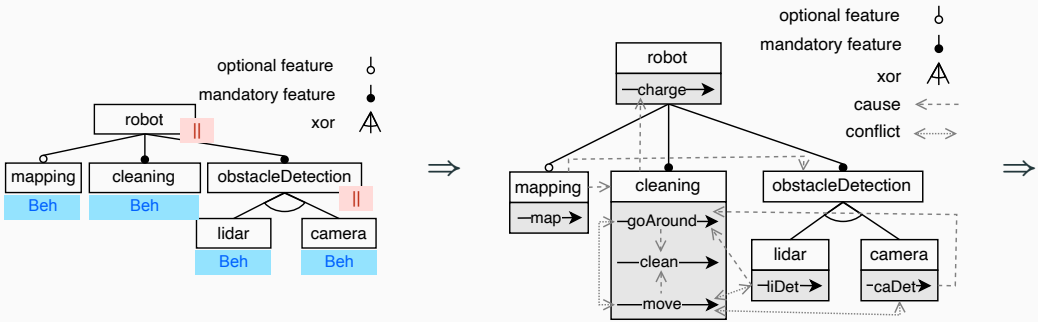


$\Rightarrow$

Behavioural Feature Model of a Cleaning Robot



Behavioural Feature Model of a Cleaning Robot



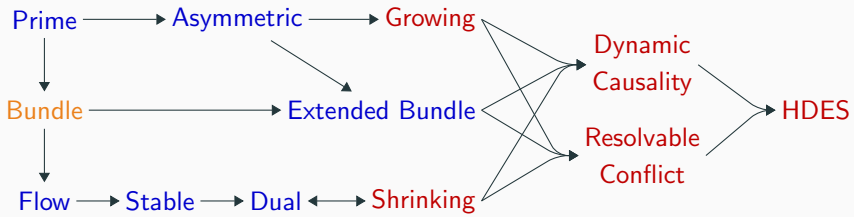
Family of Event Structures

- called *Featured Event Structure*
- Events labelled with feature conditions
- Similar to featured transition systems (more traditional)

Event Structures

Event structures

Landscape (partial): static and dynamic classes of event structures.

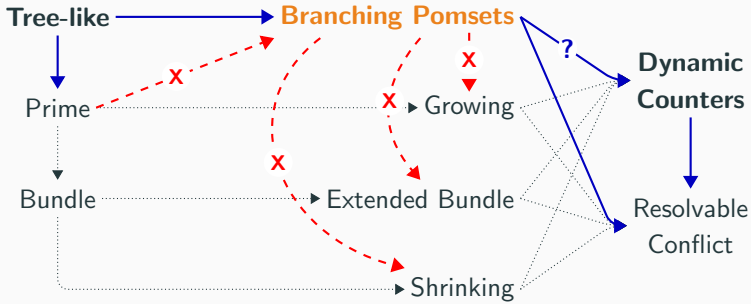


Arrows represent (strict) inclusion in terms of expressiveness

Arbach, Karcher, Peters, Nestmann, Dynamic causality in event structures [FORTE 2015/LMCS 2018]

Event structures

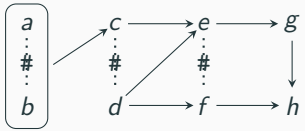
Landscape (partial): static and dynamic classes of event structures.



Arrows represent (strict) inclusion in terms of expressiveness

Used also to relate branching pomsets – *Edixhoven, Jongmans, Proença, Castellani, Branching pomsets: design, expressiveness and applications to choreographies* [JLAMP 2024]

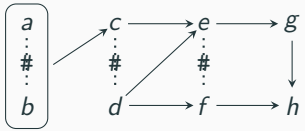
Bundle event structures by Example



Valid traces

- a·c·e·g·h
- d·b·e·g·h
- d·f·a·h
- ...

Bundle event structures by Example



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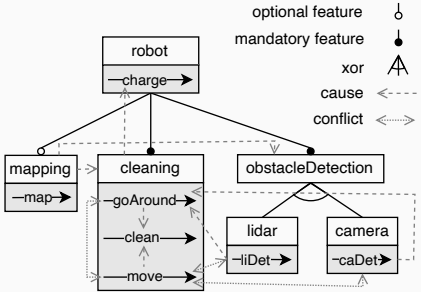


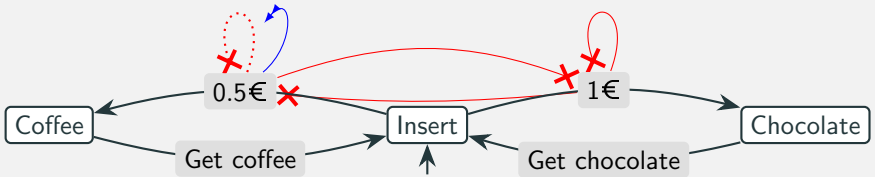
Valid traces

- (map)? · move · clean · charge
- (map)? · liDet · goAround · clean · charge
- (map)? · caDet · goAround · clean · charge

Reconfigurable Graphs

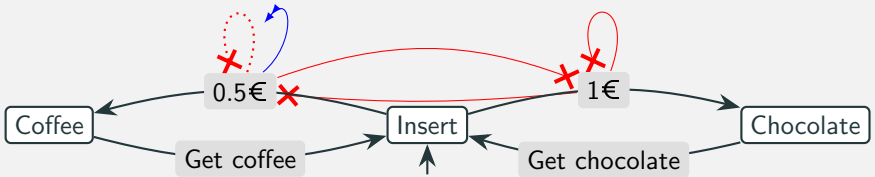
Reconfigurable Coffee Machine

The reconfigurable graph

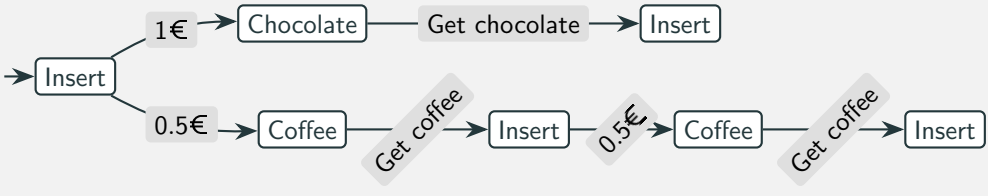


Reconfigurable Coffee Machine

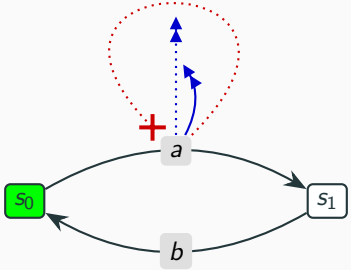
The reconfigurable graph



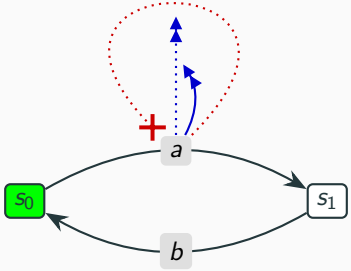
can be encoded as



Reconfigurable Counter



Reconfigurable Counter

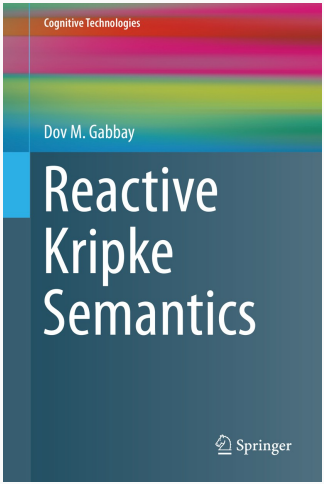


When can these be useful?

Tool to experiment with semantics/compositions:

https://fm-dcc.github.io/marge

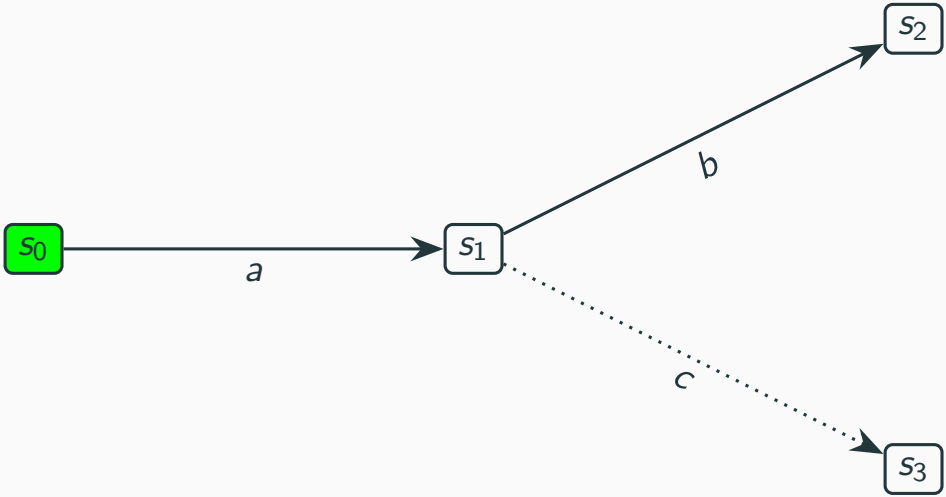
Reactive graphs: A reconfigurability dimension on LTS

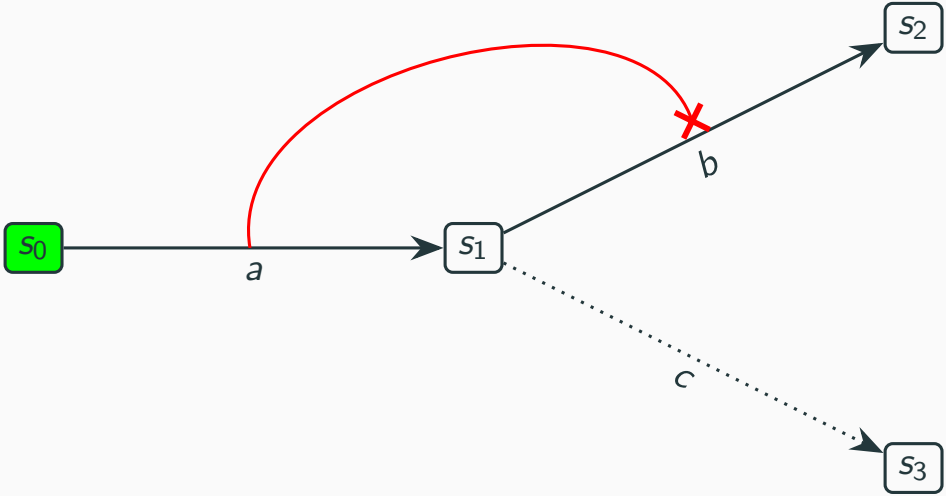


"In computer science the word reactivity has been used to denote systems that react to their environment and are not meant to terminate, as coined by Pnueli and Harel in [On the development of reactive systems, 1985]. In this work the word has a different meaning, reactive systems are history-dependent relational structures, where the accessibility relation is determined not only by the point where one is, but also by the previous transitions"

Dov M. Gabbay (2013)

I call Reconfigurable Graph instead of Reactive Graph in this talk


s_0
s_1
s_2
s_3
a
b
c


s_0
s_1
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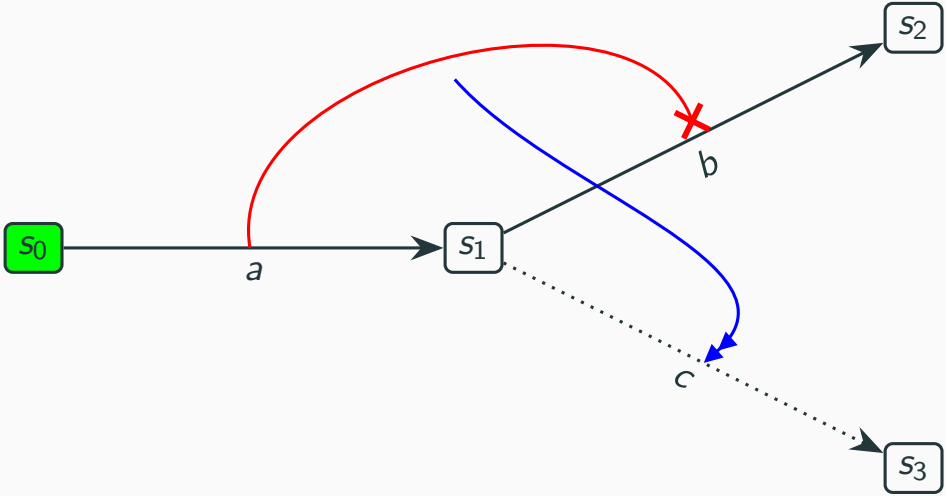
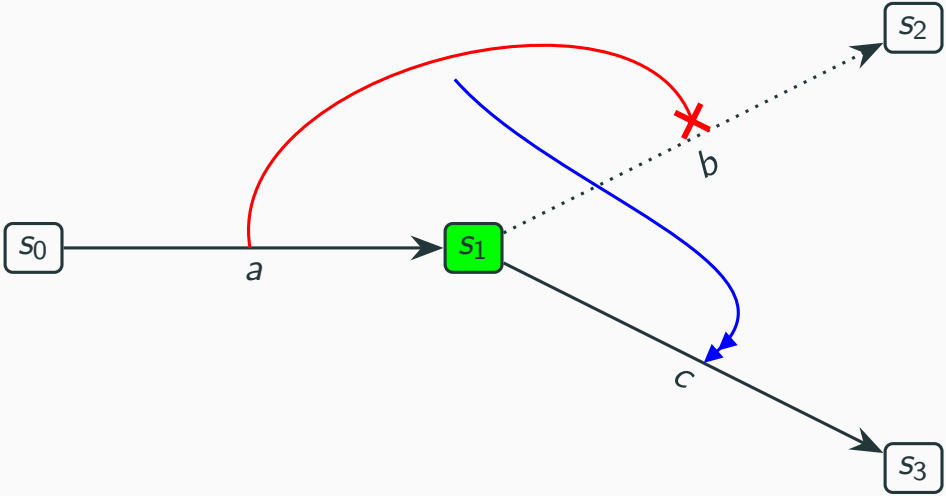
a
b
c


s_0
s_1
s_2
s_3
a
b
c

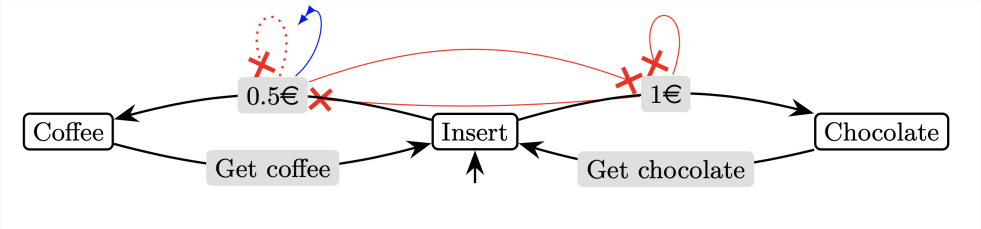

s_2
b
s_0
a
s_1
c
s_3

A labelled version of a reactive graph

A Multi-Actions Reactive Graph is a tuple $M = (W, Act, E, \rightarrow, \twoheadrightarrow, \multimap, \dot{\cdot}, w_0, \alpha_0)$ where:

- W – states
- Act – actions
- E – edges
- $w_0 \in W$ – initial state;
- $\alpha_0 \subseteq E$ – initially active edges

- $\rightarrow \subseteq W \times Act \times W$ – ground edges
- $\twoheadrightarrow \subseteq E \times E$ – activating edges
- $\multimap \subseteq E \times E$ – deactivating edges
- $\dot{\cdot} : E \longrightarrow (\rightarrow \cup \twoheadrightarrow \cup \multimap)$ – internal details of edges



Semantics

A reconfigurable graph M can evolve its configuration $\langle w_0, \alpha_0 \rangle$ by the rule

$$\frac{\exists e \in \alpha \quad \cdot \quad \overline{e} = w \xrightarrow{a} w' \quad \wedge \quad \alpha' = \big(\alpha \cup \mathsf{on}(e, \alpha)\big) \backslash \mathsf{off}(e, \alpha)}{\langle w, \alpha \rangle \quad \xrightarrow{a}_M \quad \langle w', \alpha' \rangle}$$

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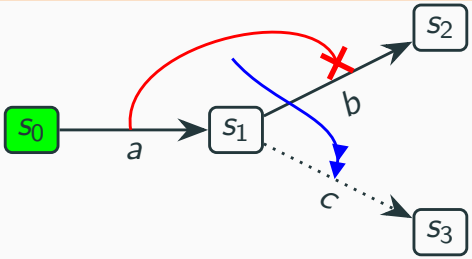

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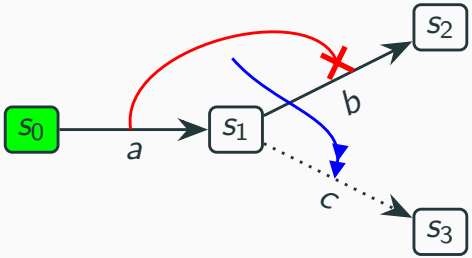

$\langle s_0, \{ s_0 \xrightarrow{a} s_1, s_1 \xrightarrow{b} s_2, \ldots \} \rangle \quad \xrightarrow{a}$

Semantics

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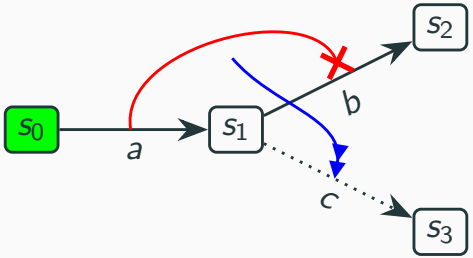

$$\langle s_0, \{s_0 \xrightarrow{a} s_1, s_1 \xrightarrow{b} s_2, \ldots\} \rangle \quad \xrightarrow{a} \quad \langle s_1, (\{s_0 \xrightarrow{a} s_1, s_1 \xrightarrow{b} s_2, \ldots\} \cup \{s_1 \xrightarrow{c} s_3\}) \setminus \{s_1 \xrightarrow{b} s_2\} \rangle$$

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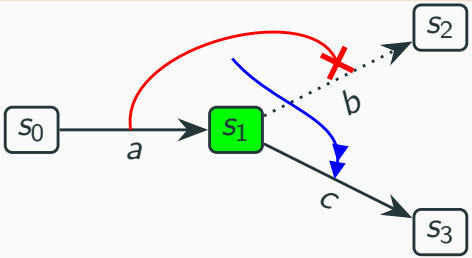
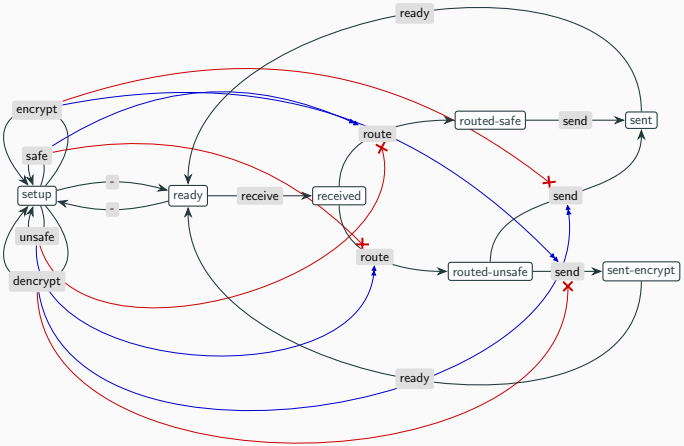


$$\langle s_0, \{s_0 \xrightarrow{a} s_1, s_1 \xrightarrow{b} s_2, \ldots\} \rangle \quad \xrightarrow{a} \quad \langle s_1, (\{s_0 \xrightarrow{a} s_1, s_1 \xrightarrow{c} s_3, \ldots\} \rangle$$

Applicable in dynamic software product lines?



Example adapted from Cordy, Classen, Heymans, Legay, Schobbens: *Model checking adaptive software with featured transition systems* (ASAS 2013).

Composition of models

Composition of reactive graphs

Goal

Help building complex systems by composing simpler modules.

Composition of reactive graphs

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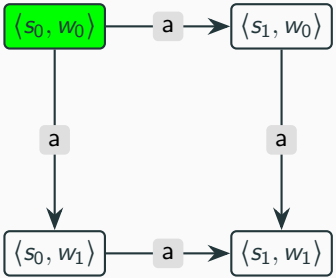
Help building complex systems by composing simpler modules.

Four products of reactive graphs

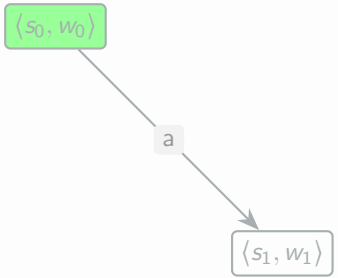
- asynchronous and synchronous
- with and without intrusive transitions

Traditional composition

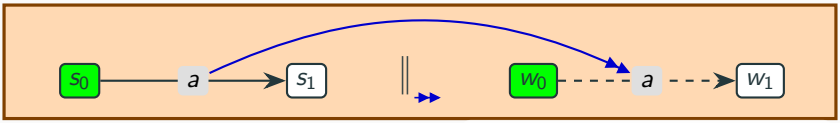
Asynchronous (interleaving)



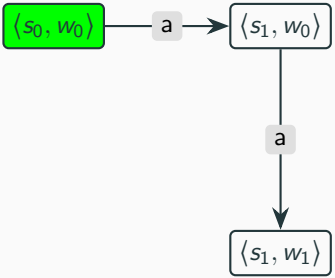
Synchronous (communicating)



Composition with intrusive transitions (example 1)

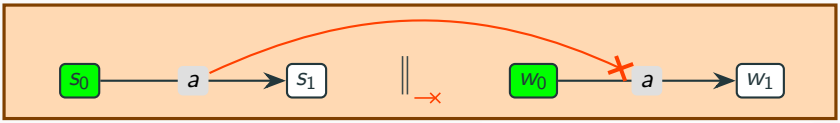


Asynchronous (interleaving)

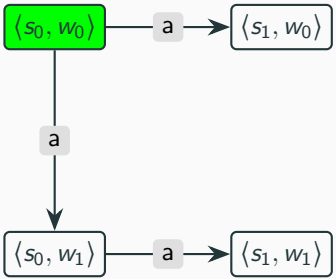


Synchronous (communicating)

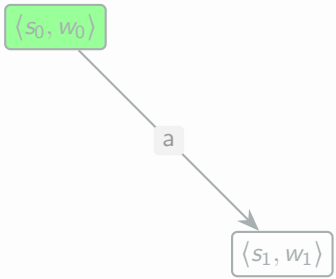
Composition with intrusive transitions (example 2)



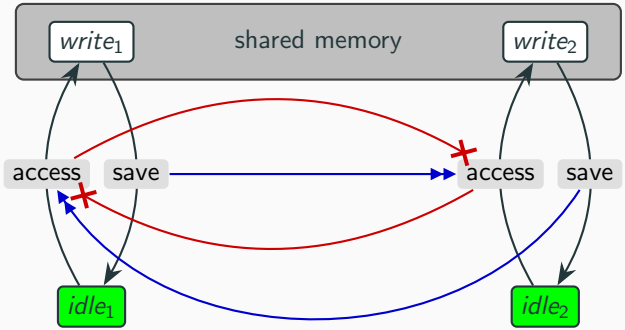
Asynchronous



Synchronous



Intrusive transitions – a different way to communicate



Products – formally

Asynchronous product with intrusive transitions

Given $c_1 = \langle s_1, \alpha_1 \rangle$ and $c_2 = \langle s_2, \alpha_2 \rangle$, the product, $c_1 \parallel_{\Gamma^{\oplus}, \Gamma^{\ominus}} c_2$ is defined as follows:

$$\alpha_i(\Gamma^{\oplus}, \Gamma^{\ominus}, e) \quad = \quad \big(\alpha_i \cup \mathsf{on}(e, \alpha_i) \cup \Gamma^{\oplus}(e)\big) \setminus \big(\mathsf{off}(e, \alpha_i) \cup \Gamma^{\ominus}(e)\big)$$

$$\frac{\exists\ e \in \alpha_1 \quad \cdot \quad \overline{e} = s_1 \xrightarrow{a} s_1' \quad \wedge \quad \alpha_1' = \big(\alpha_1 \cup \mathsf{on}(e, \alpha_1)\big) \backslash \mathsf{off}(e, \alpha_1) \quad \wedge \quad \alpha_2' = \alpha_2(\Gamma^{\oplus}, \Gamma^{\ominus}, e)}{\langle s_1, \alpha_1 \rangle \parallel_{\Gamma^{\oplus}, \Gamma^{\ominus}} \langle s_2, \alpha_2 \rangle \quad \xrightarrow{a} \quad \langle s_1', \alpha_1' \rangle \parallel_{\Gamma^{\oplus}, \Gamma^{\ominus}} \langle s_2, \alpha_2' \rangle}$$

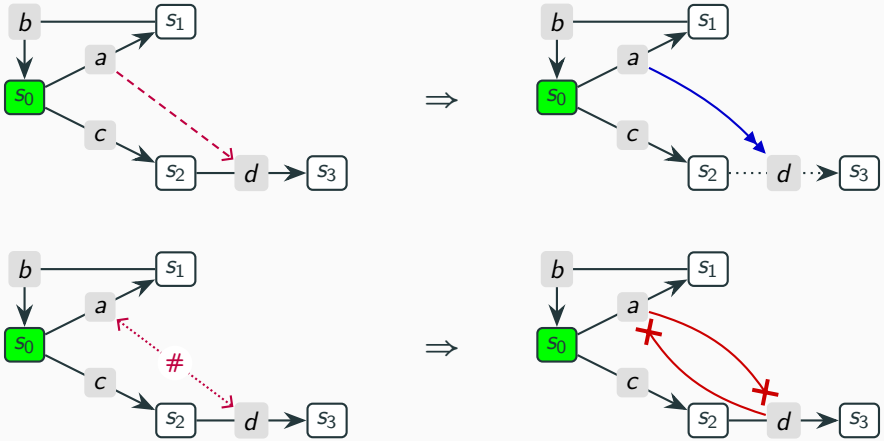
$$\frac{\exists\ e \in \alpha_2 \quad \cdot \quad \overline{e} = s_2 \xrightarrow{a} s_2' \quad \wedge \quad \alpha_2' = \big(\alpha_2 \cup \mathsf{on}(e, \alpha_2)\big) \backslash \mathsf{off}(e, \alpha_2) \quad \wedge \quad \alpha_1' = \alpha_1(\Gamma^{\oplus}, \Gamma^{\ominus}, e)}{\langle s_1, \alpha_1 \rangle \parallel_{\Gamma^{\oplus}, \Gamma^{\ominus}} \langle s_2, \alpha_2 \rangle \quad \xrightarrow{a} \quad \langle s_1, \alpha_1' \rangle \parallel_{\Gamma^{\oplus}, \Gamma^{\ominus}} \langle s_2', \alpha_2' \rangle}$$

Tool support: `https://fm-dcc.github.io/MARGe`

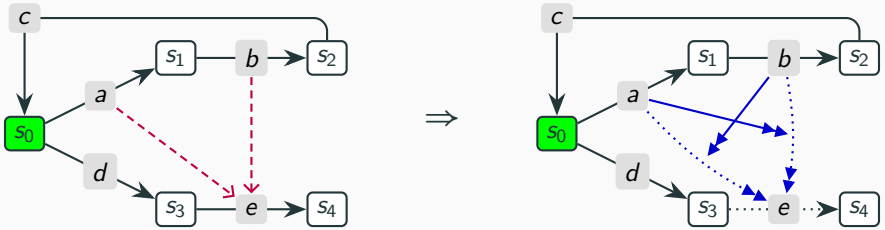
Dependencies as reconfigurations

Dependencies as reconfigurations

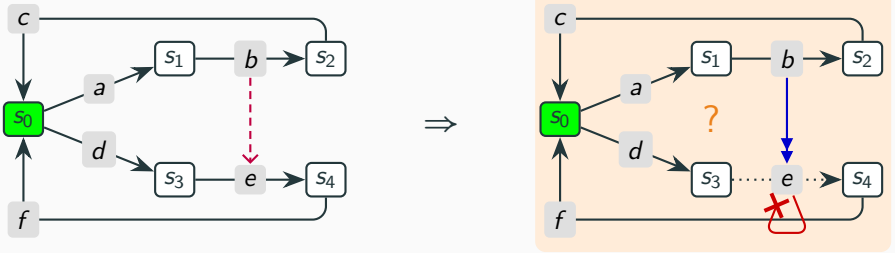
Dependencies as reconfigurations



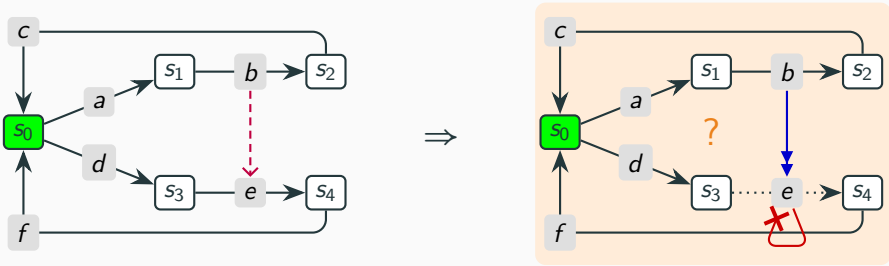
Too many reconfigurations?



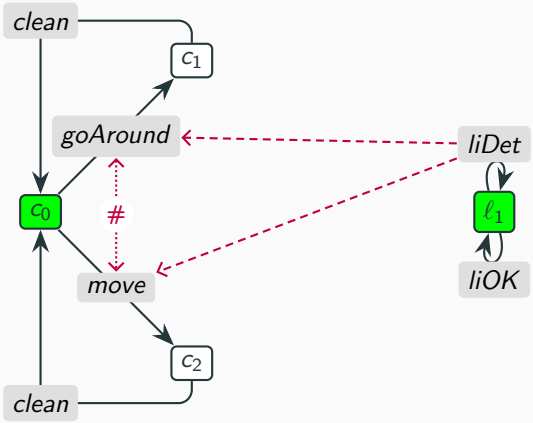
Loops and reset?



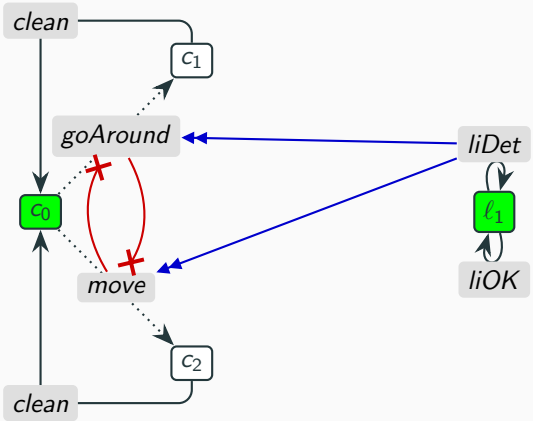
Loops and reset?



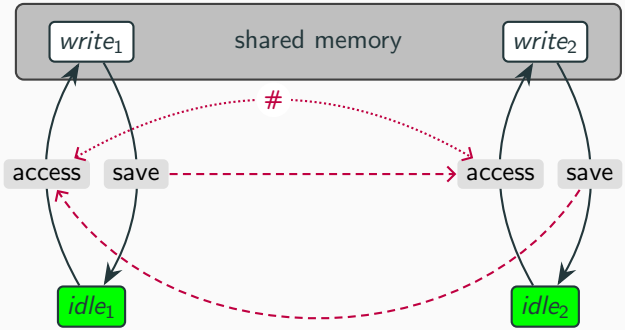
Composing with dependencies?



Composing with dependencies – what should be the interpretation?



Composing with dependencies (revisiting example)



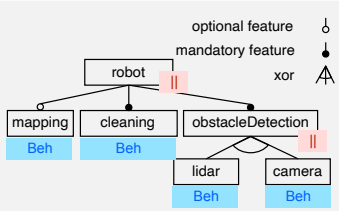
Other possible challenges and directions of work?

- When to reset a dependency/conflict?
- Different dependency notions (e.g., from different event structures)?
- Should dependability/conflict be a primitive in the model?
- How compositional are these operators?
- Semantics for reconfigurable graphs (or variation) with Petri nets?

Wrap up – towards dependable graphs

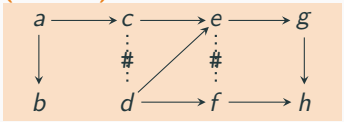
Wrap up – towards dependable graphs

Behavioural feature models



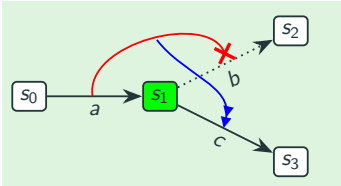
Pässler, Fortz, ter Beek, Damiani, Mousavi, Johnsen, Tapia Tarifa [UNPUBLISHED]

(Bundle) Event structures



by Nielsen, Plotkin, and Winskel [TCS'81] *and Langerak* [FORTE'92]

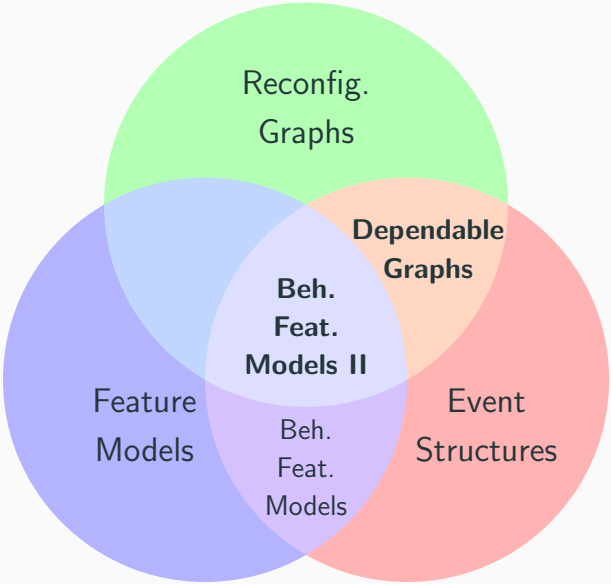
Reconfigurable graphs



Tinoco, Madeira, Martins, Proença [FACS'24]

Experiments:

Modelling dependencies & conflicts
using (Networks of) Reconfigurable graphs

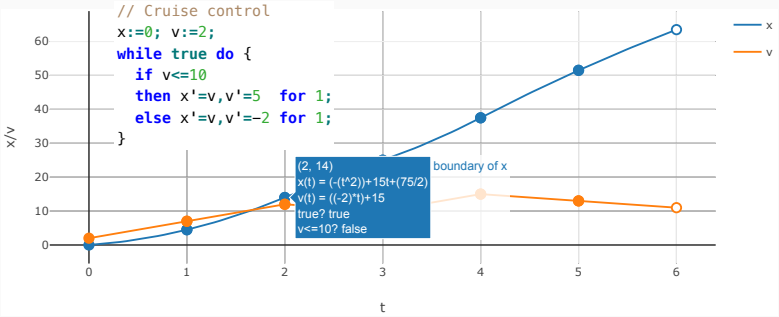


"...I was told that every good presentation must have a Venn diagram" [Einar, Lima, ICTAC 2023]

Advertisement of other work – on hybrid programs

Lince (prototype tool – http://arcatools.org/lince)

- Simple while-language with differential equations
- Precise simulation using a symbolic solver (SageMath)



Improved Lince accepted at FMAS @ iFM'24

- More operators outside differential equations
- Complex examples (following a target, overtake an object, oscillation, etc.)
- Custom visualisations (2D/3D path, etc.)
- New approximated simulator