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Formalising Concurrent UML State Machines Using Coloured Petri Nets

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Motivation: Complex Systems Safety

- Need for early bug detection
  - Bugs discovered when final testing: expensive

  $\leadsto$ Need for a thorough modelling phase
- Critical and complex systems that need verification
- Specification with UML state machines (SMDs) [OMG, 2011]
- Informal description of UML semantics
- No formal verification on UML state machines
- Solution: Provide a formalisation using coloured Petri nets

Outline

1. Concepts (SMDs & CPNs)
2. Translation of Concurrent State Machines
3. Conclusion and Perspectives

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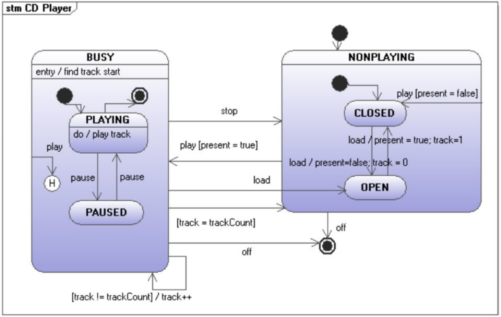
2. Translation of Concurrent State Machines

3. Conclusion and Perspectives

UML Behavioural State Machines

- Transition systems used to express the behaviour of dynamic systems
- Specified in [OMG, 2011]
- Widely used in the industry
- Semantics not formally expressed
  - Informal specification in [OMG, 2011]
  - Not directly suitable for formal methods

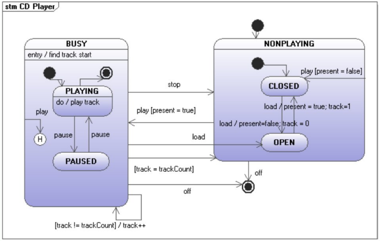
Example of a CD Player [Zhang and Liu, 2010]



- Features
  - A hierarchy of simple and composite states
  - Transitions (including inter-level) with events
  - Entry (`find track start`) and do (`play track`) behaviours
  - Global variables (`present` and `track`)
  - History pseudostate (H)

Example of a CD Player (cont.)

- This example is simple
  - Few states, few events, few variables
  - No exit behaviour



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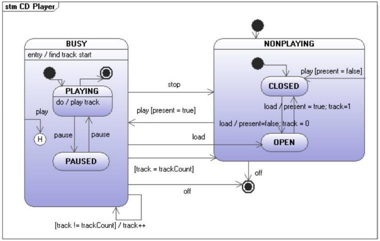

- And still. . . Can we ensure the following?
  - “When in **PLAYING**, there is a CD in the player”
  - “When in **PLAYING**, the track number is always between 1 and trackCount”

Example of a CD Player (cont.)

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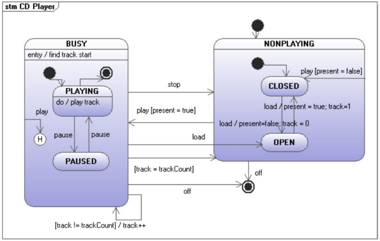

- And still... Can we ensure the following?
  - "When in **PLAYING**, there is a CD in the player"
  - "When in **PLAYING**, the track number is always between 1 and `trackCount`"

- Not easy to guarantee!
  (So what about larger case studies...)

Main Goal

- We translate UML state machines to coloured Petri nets (CPNs)
- Set of considered constructs
  - Hierarchy of composite states
    - simple
    - orthogonal (with regions)
  - Inter-level transitions
  - Entry, do, exit behaviours with global variables
  - History pseudostates
  - Concurrency (fork, join, synchronization)

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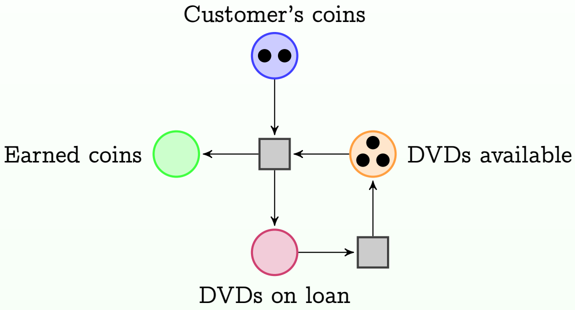
Petri Nets [Petri, 1962]

- A kind of automaton
  - Bipartite graph with places and transitions
  - Tokens can be added to places
    - Represent data or control
  - A state (configuration) of the Petri net: a marking
    - Number of tokens in each place
    - Evolves when firing transitions
  - Initial state: initial marking

- Advantages of Petri nets
  - Detailed view of the process with an expressive graphical representation
  - A formal semantics
  - Powerful tools to simulate and verify the model w.r.t. various properties (reachability, boundedness, invariants, deadlock-freeness, etc.)

Petri Nets: An Example

A DVD renting machine



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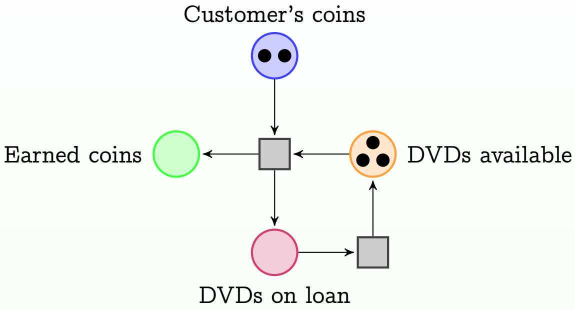

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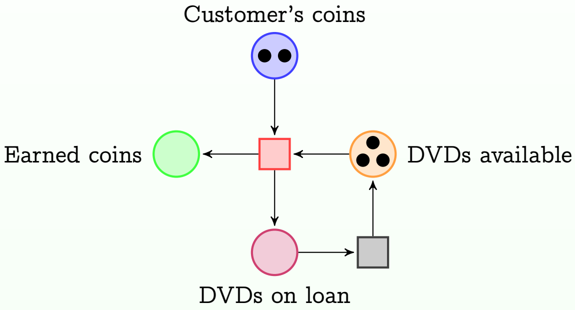

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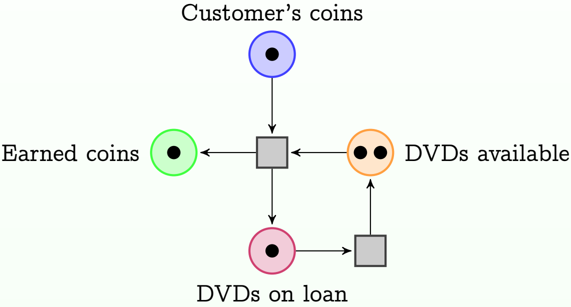

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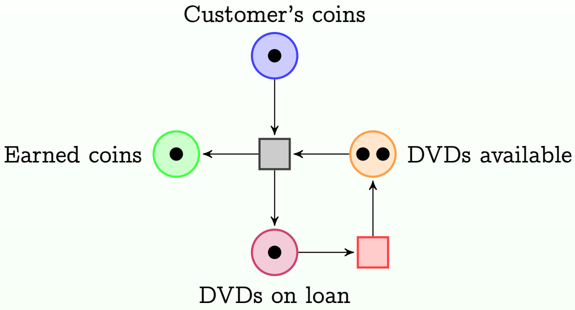

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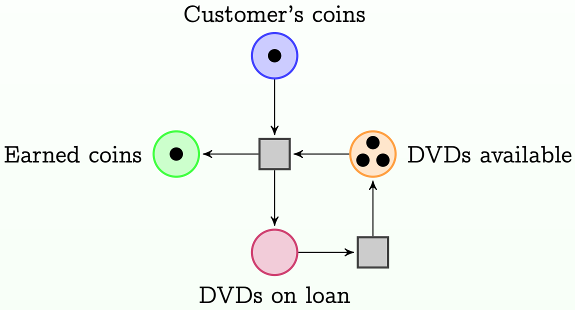

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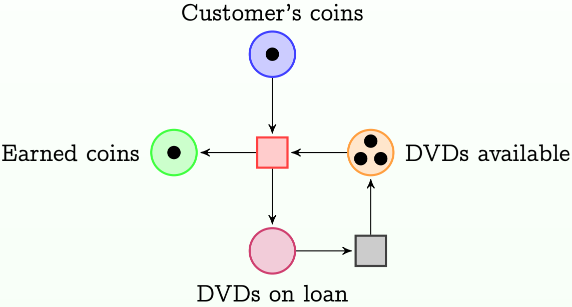

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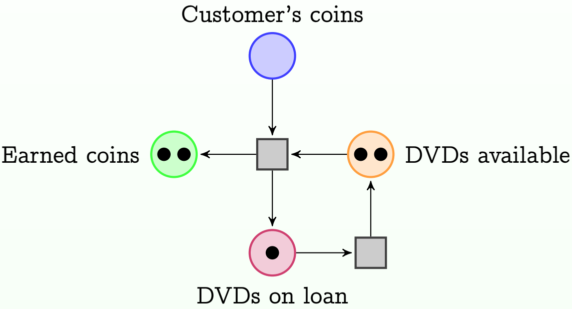

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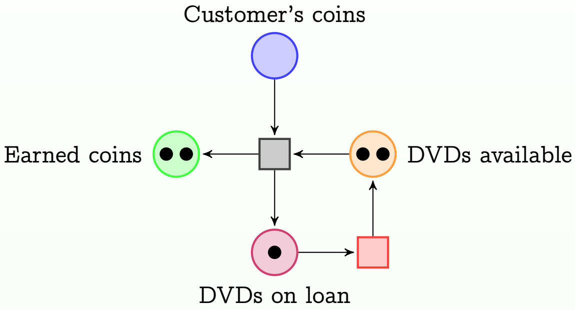

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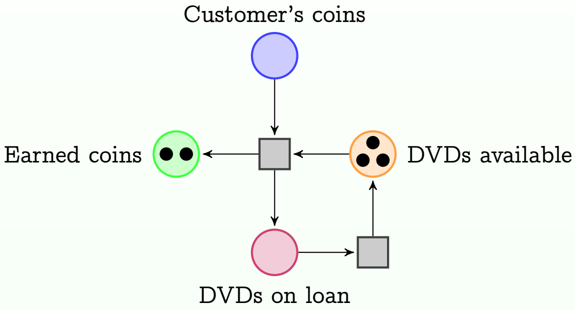

Coloured Petri Nets [Jensen and Kristensen, 2009]

- Extension of Petri nets with colours
  - Tokens and places have a type (“colour set”)
  - Arcs are labelled with expressions
  - Transitions can have a guard

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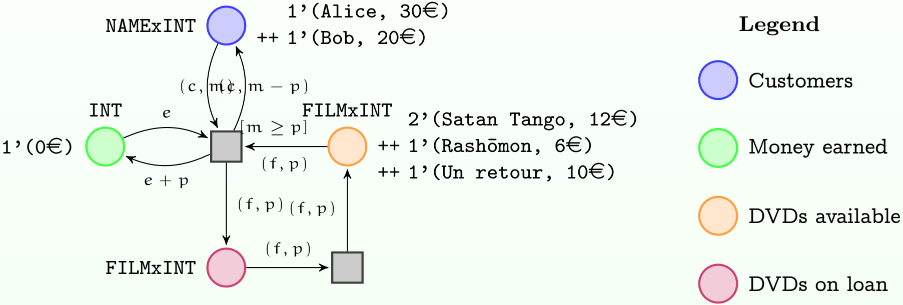

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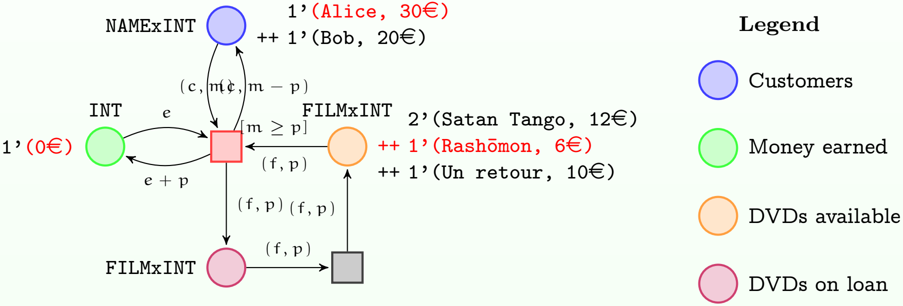

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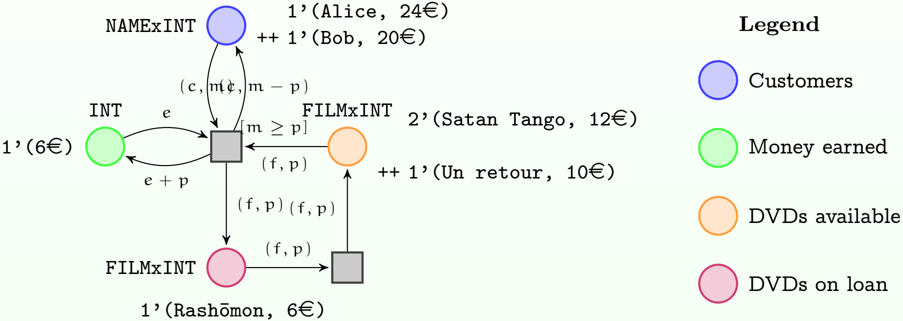

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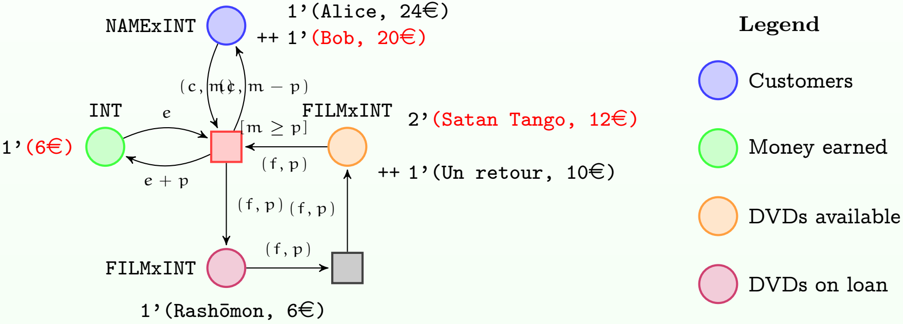

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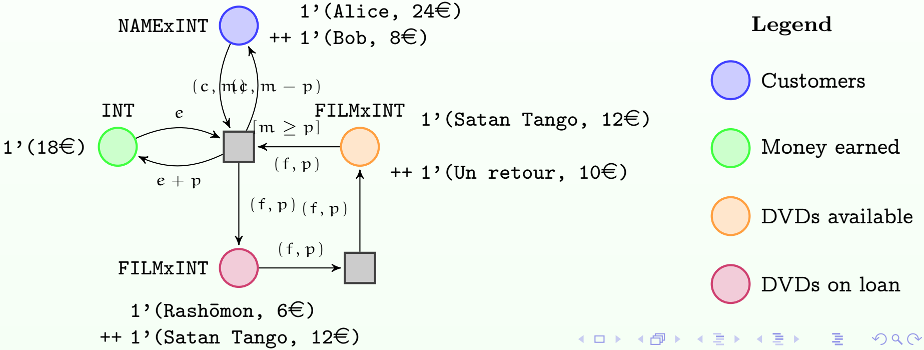

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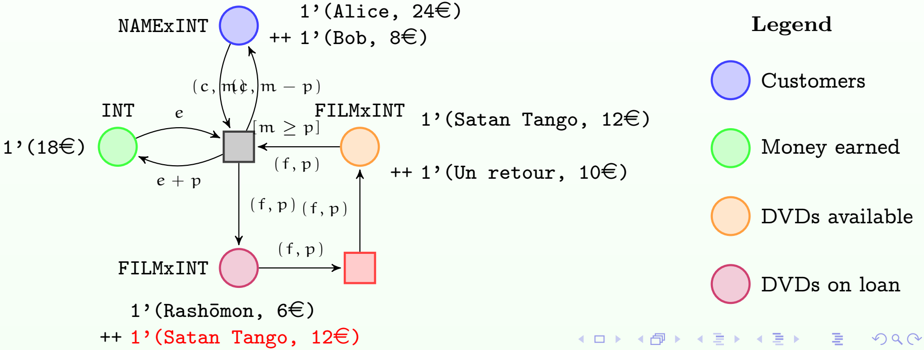

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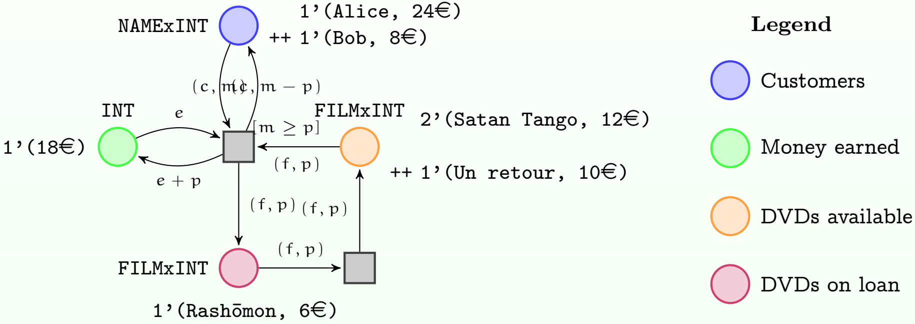
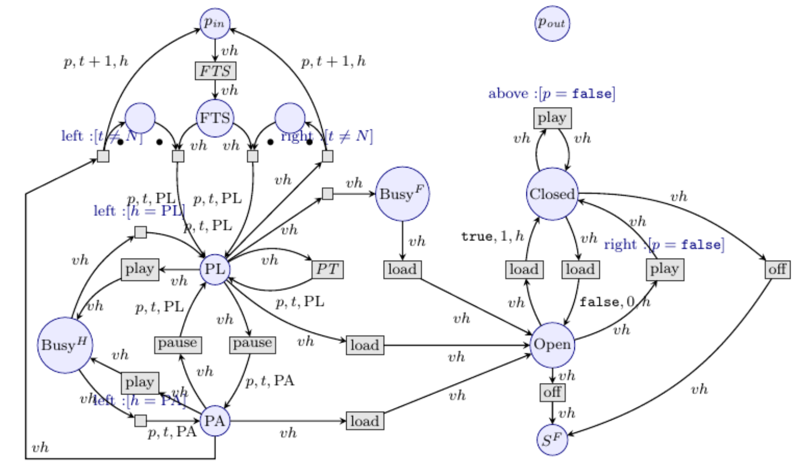


An Example of a CPN

(Partial) translation of the CD player

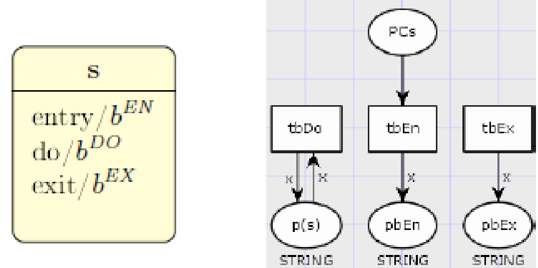


General translation Scheme

- Deeply revise & extend translation from SMDs to CPNs proposed in [André, Choppy, Klai, 2012]
- Tricky: ways to get a reasonable size for the CPN
- To allow to take into account concurrency, fork and join pseudo-states and orthogonal regions.
- Translation based on three algorithms :
  - Algorithm 1 for states and behaviours
  - Algorithm 2 for transitions
  - Algorithm 3 for history pseudo-states

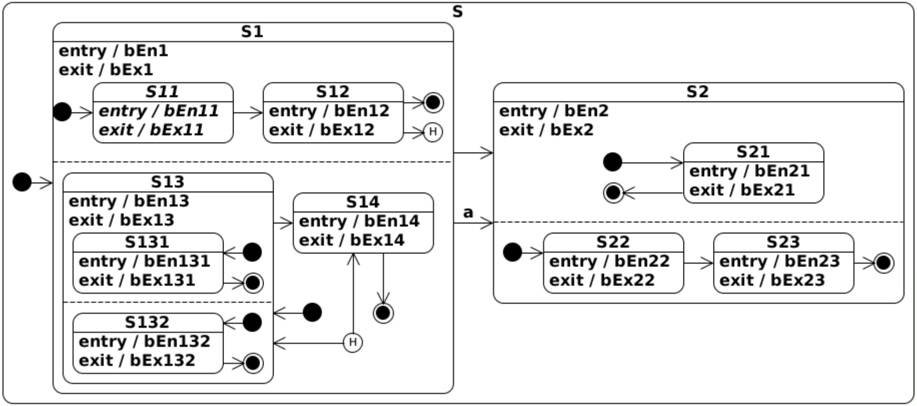
Algorithm 1 -Translation of States and Behaviours

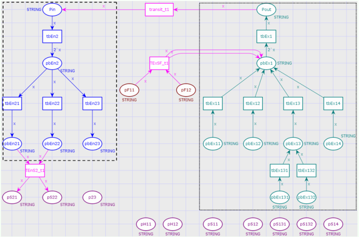
- Each simple, final, history (pseudo) state → one place
- Each behaviour (entry/exit/do) → place, transition & arc
- Hierarchical structure → tree of exit/entry behaviours (used later to connect transitions)



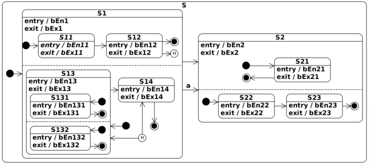
Algorithm 2 - Translation of Transitions

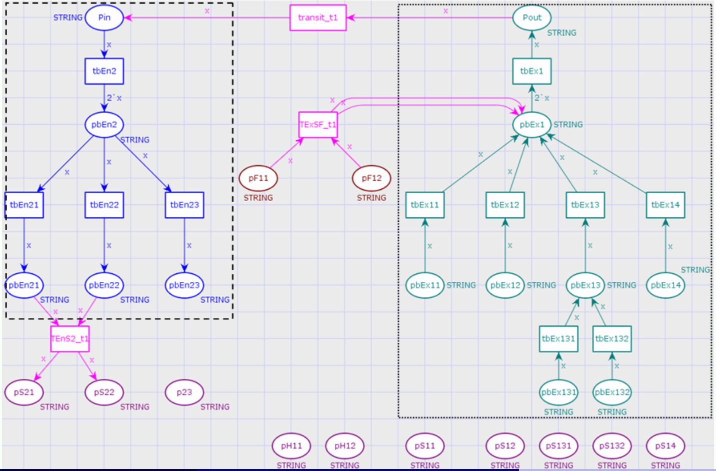
- Establishes connection between source and target of the transition
- Processing differs for simple or composite states (as source and/or target)
- Each UML transition is represented by a CPN transition
- Special processing for concurrent constructs
- Use guards mechanism to guide the tokens in the CPN


S
S1
entry / bEn1
exit / bEx1
S11
entry / bEn11
exit / bEx11
S12
entry / bEn12
exit / bEx12
H
S13
entry / bEn13
exit / bEx13
S131
entry / bEn131
exit / bEx131
S132
entry / bEn132
exit / bEx132
S14
entry / bEn14
exit / bEx14
H
a
S2
entry / bEn2
exit / bEx2
S21
entry / bEn21
exit / bEx21
S22
entry / bEn22
exit / bEx22
S23
entry / bEn23
exit / bEx23


Pin
STRING
x
tbEn2
2`x
pbEn2
tbEn21
tbEn22
tbEn23
pbEn21
pbEn22
pbEn23
TEnS2_t1
pS21
pS22
p23
transit_t1
TExSF_t1
pF11
pF12
Pout
tbEx1
pbEx1
tbEx11
tbEx12
tbEx13
tbEx14
pbEx11
pbEx12
pbEx13
pbEx14
tbEx131
tbEx132
pbEx131
pbEx132
pH11
pH12
pS11
pS12
pS131
pS132
pS14

Example (followed)





Algorithm 3 - History pseudo-states

- Take into account shallow pseudo-states
- Each history is represented by a global variable that contains the last state visited in the region and place/transition
- Variable value updated for each transition fired within a composite state
- Achieved with Algorithm 3 (not represented in the paper for lack of space)

Outline

1 Concepts (SMDs & CPNs)

2 Translation of Concurrent State Machines

3 Conclusion and Perspectives

Element	Considered?
Simple / composite states	Yes
Orthogonal regions	Yes
Initial / final (pseudo)states	Yes
Terminate pseudostate	No (but trivially extensible)
Shallow history states	Identical to [André et al., 2012]
Deep history states	No (but trivially extensible)
Submachine states	No (but trivially extensible)
Entry / exit points	No (but probably easy)
Entry / exit / do behaviours	Yes
Shared variables	Yes
External / local / internal transitions	Yes
Basic fork / joins	Yes
Implicit fork/joins	No (but trivially extensible)
Choices / merges	No (but probably easy)
Deferred events	No
Timing aspects	No

Conclusion and Perspectives

- Extended set of syntactic elements (including hierarchy & concurrency) taken into account
- Developing a tool for implementation of the translation
    - Translation using Acceleo (model to text tool) to implement the translation (done)
    - Home-made tool using Java with parsers to manage the input and the output (partially done)
- Integration of timed events
- Take into account real time specifications
- Prove the formal equivalence between an SMD and its CPN translation

Bibliography

References I

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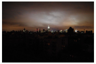
Additional explanation

Explanation for the 4 pictures in the beginning



Allusion to the Northeast blackout (USA, 2003)
Computer bug
Consequences: 11 fatalities, huge cost
(Picture actually from the Sandy Hurricane, 2012)

Allusion to any plane crash
(Picture actually from the happy-ending US Airways Flight 1549, 2009)

Allusion to the sinking of the Sleipner A offshore platform (Norway, 1991)
No fatalities
Computer bug: inaccurate finite element analysis modeling
(Picture actually from the Deepwater Horizon Offshore Drilling Platform)

Allusion to the MIM-104 Patriot Missile Failure (Iraq, 1991)
28 fatalities, hundreds of injured
Computer bug: software error (clock drift)
(Picture of an actual MIM-104 Patriot Missile, though not the one of 1991)

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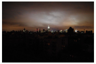

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