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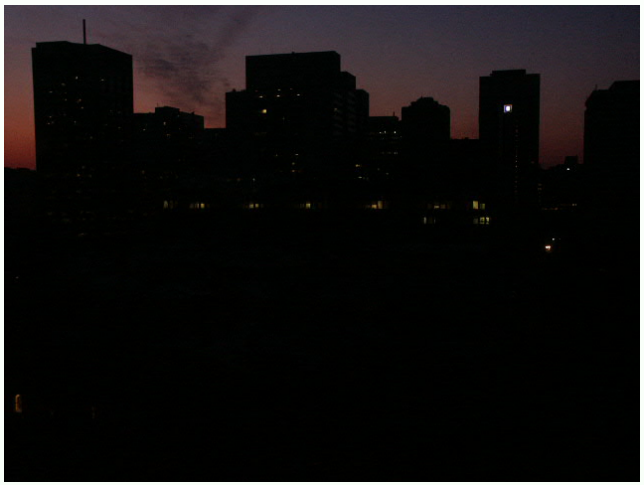
Formalizing Non-Concurrent UML State Machines Using Colored Petri Nets

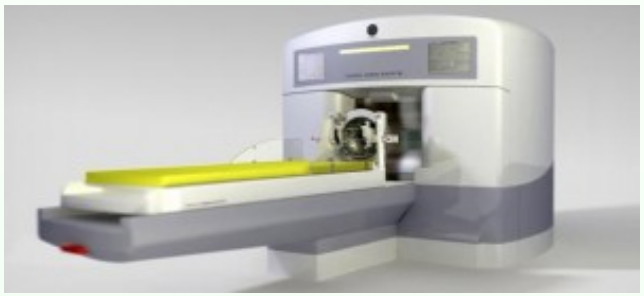
Étienne André, Christine Choppy, Kaïs Klaï

Laboratoire d'Informatique de Paris Nord
Université Paris 13, Sorbonne Paris Cité, France

Context: Verification of Complex Systems

- Need for early bug detection
  - Bugs discovered when final testing: expensive
  - Need for a thorough modeling phase

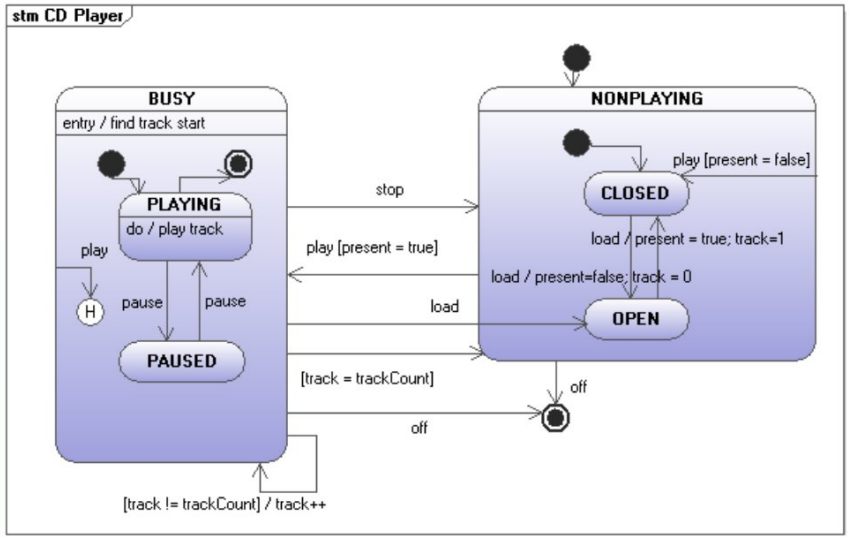




UML Behavioral State Machines

- Transition systems used to express the behavior of dynamic systems
- Specified in [OMG, 2009] (version 2.2)
- Widely used in the industry
- Semantics not formally expressed
  - Informal specification in [OMG, 2009]
  - Not directly suitable for formal methods

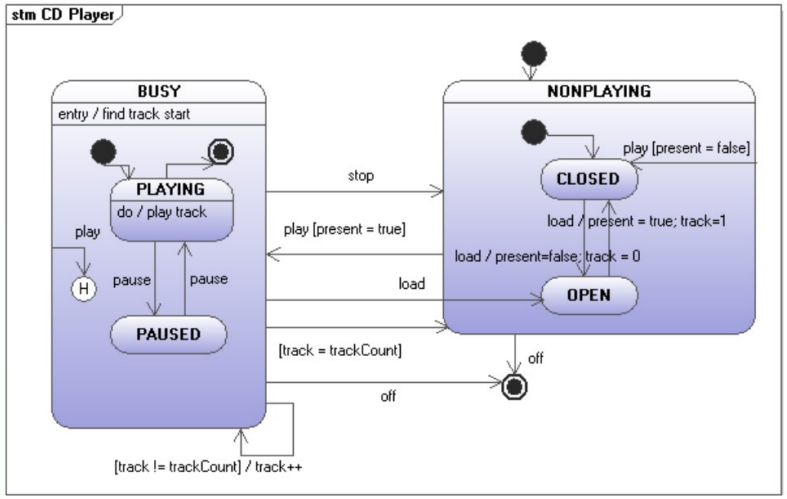
Example of a CD Player [Zhang and Liu, 2010]



- Features
  - A hierarchy of simple and composite states
  - Transitions (including inter-level) with events
  - Entry (`find track start`) and do (`play track`) behaviors
  - 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 concurrency
  - No exit behavior



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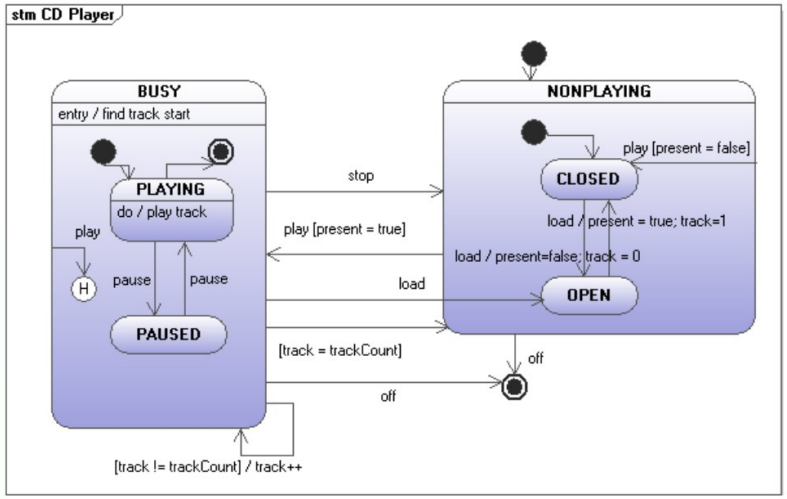

- And still... Can we ensure the following?
  - "When in **PLAYING**, there is a CD in the player"
  - "When in **PLAYING**, the track number is always between 1 and `trackCount`"

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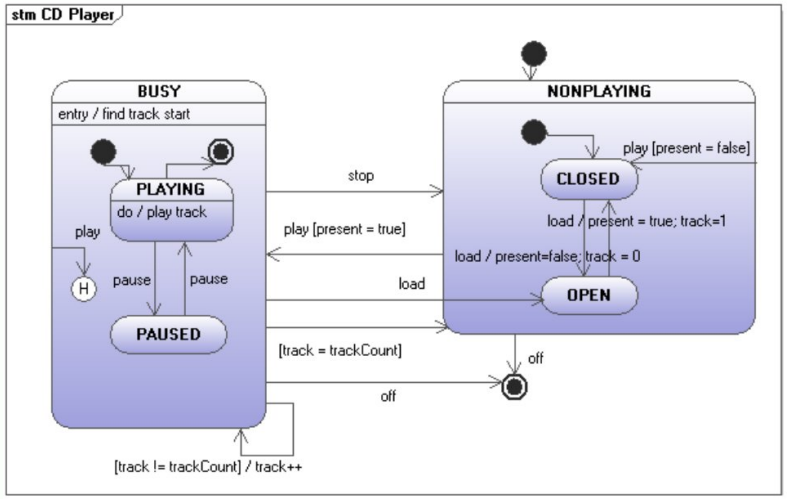

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  - "When in **PLAYING**, there is a CD in the player"
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- Not easy to guarantee!
  (So what about larger case studies...)

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"Give a semantics to UML state machines so as to allow for formal verification."

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- We choose here to automatically translate UML state machines to colored Petri nets (CPNs)
- Set of considered constructs
  - Hierarchy of composite states
  - Inter-level transitions
  - Entry, do, exit behaviors with global variables
  - History pseudostates
  - No concurrency (no fork, join, synchronization)

Related Works

- Semantics directly defined
  - [Jin et al., 2004, Dubrovin and Junttila, 2007]
- Translations of ULM state machines to CPNs
  - [Pettit IV and Gomaa, 2006, Lian et al., 2008, Choppy et al., 2011]
- Translations of ULM state machines to other formalisms
  - SPIN [Latella et al., 1999], SMV [Clarke and Heinle, 2000], CSP# [Zhang and Liu, 2010], etc.

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- Limitations
  - Almost always restrictive subset of syntactic constructs
  - Often limited specification of properties

Outline

1. Colored Petri Nets
2. Translation
3. Application to the CD Player
4. Perspectives

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1 Colored Petri Nets

2 Translation

3 Application to the CD Player

4 Perspectives

Petri Nets [Petri, 1962]

- Advantages of Petri nets
  - Detailed view of the process with an expressive graphical representation
  - A formal semantics
  - Powerful tools to test and check the model

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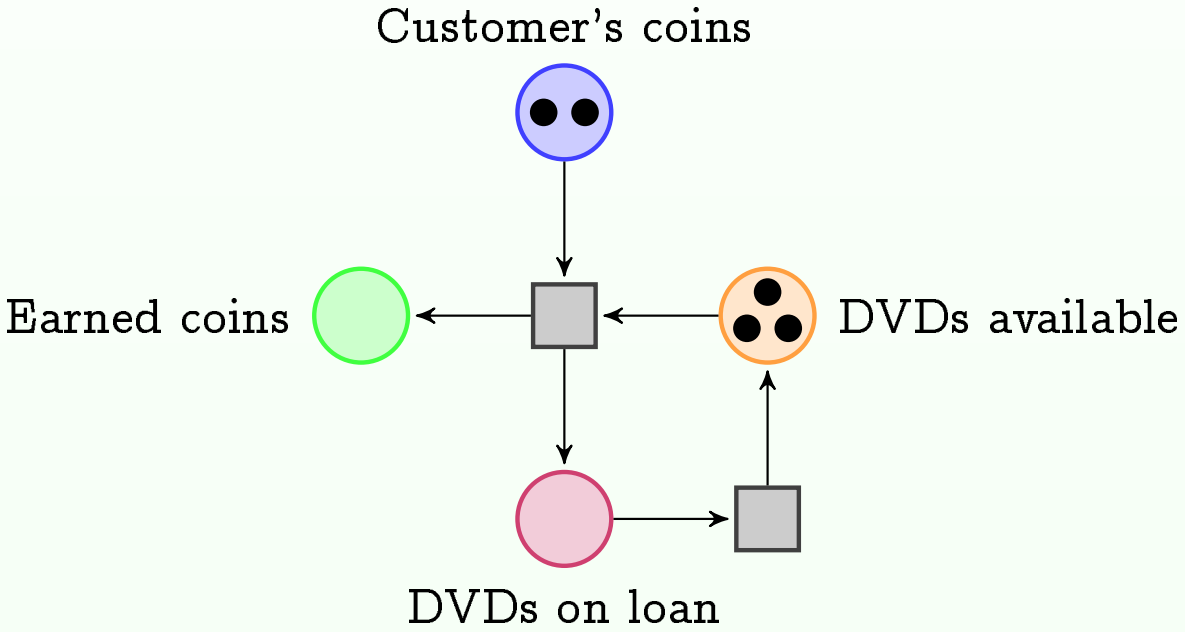

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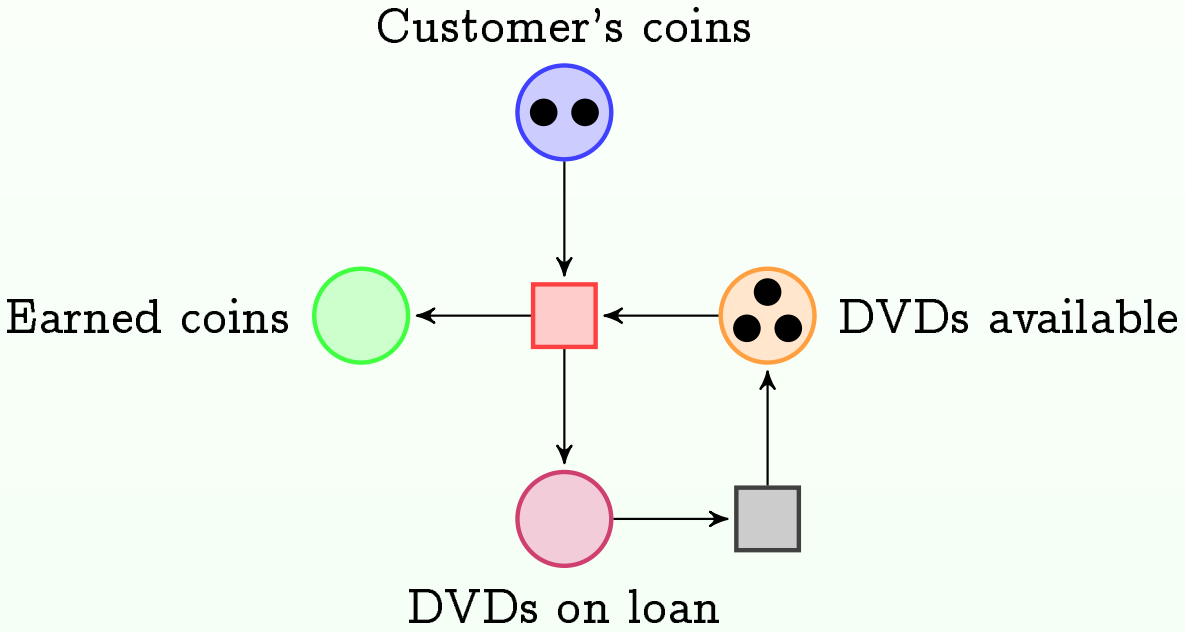

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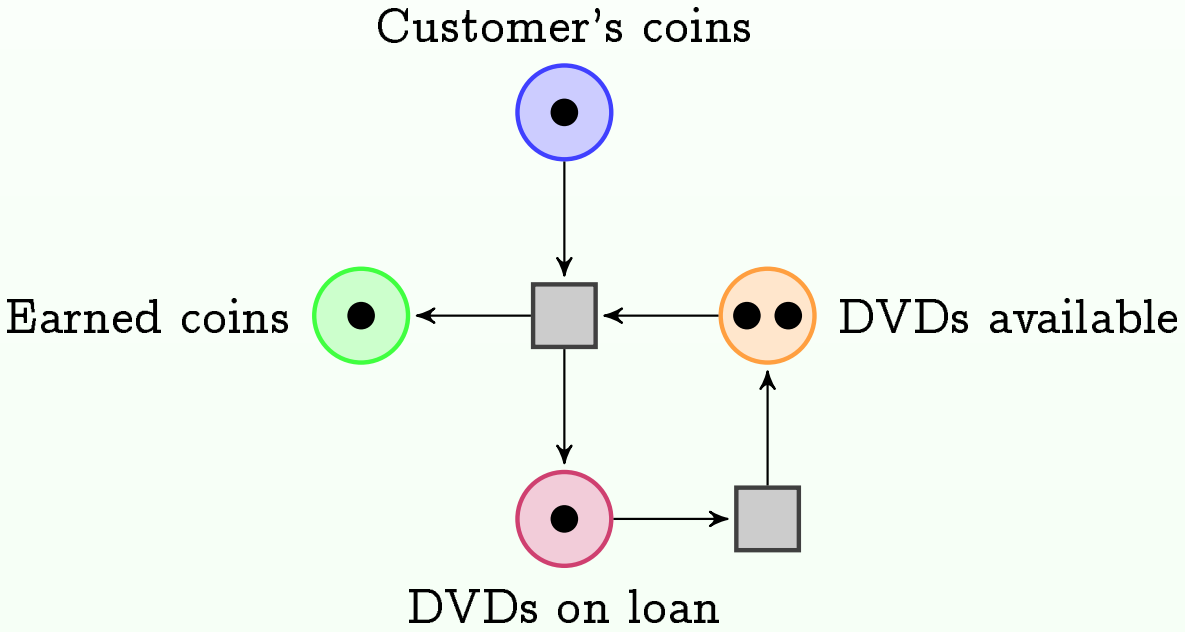

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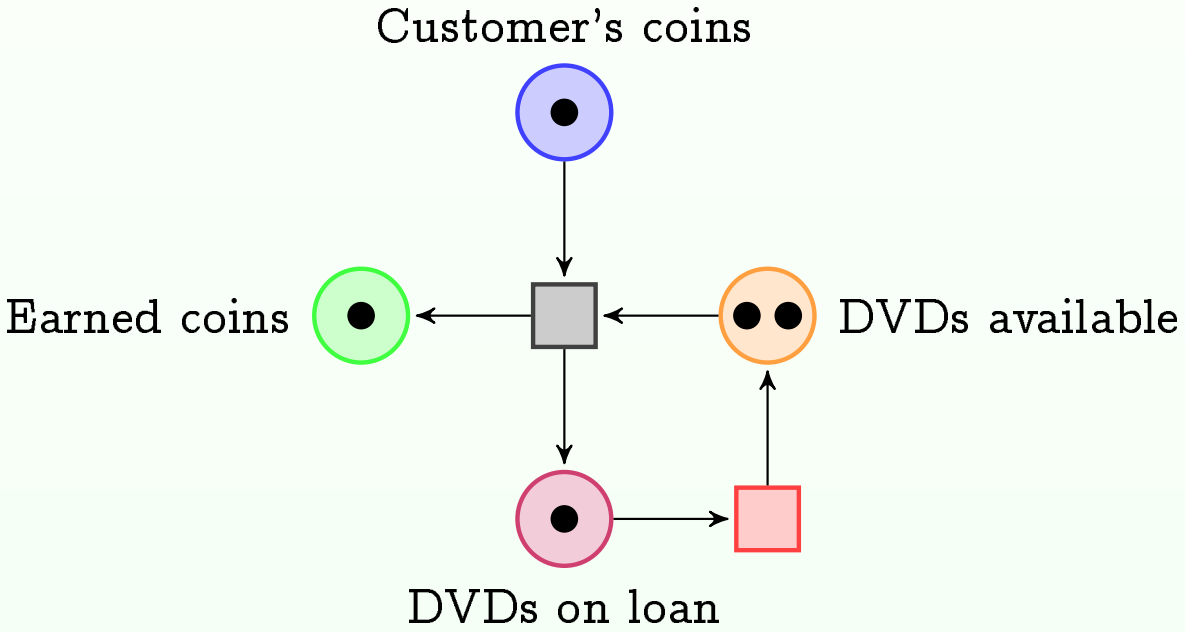

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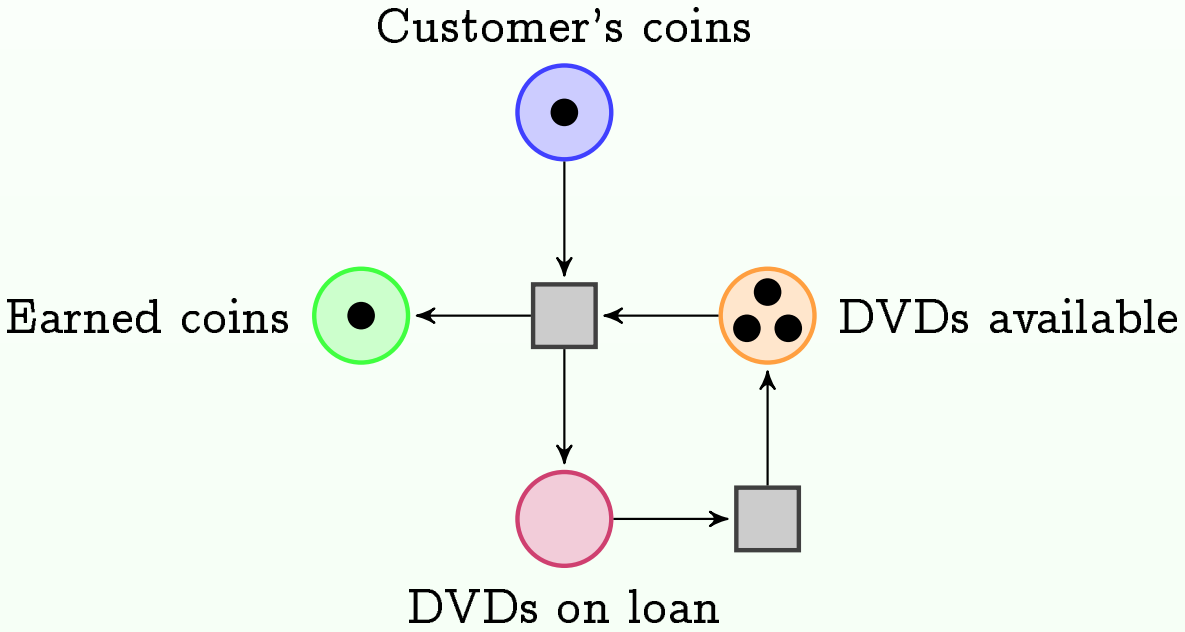

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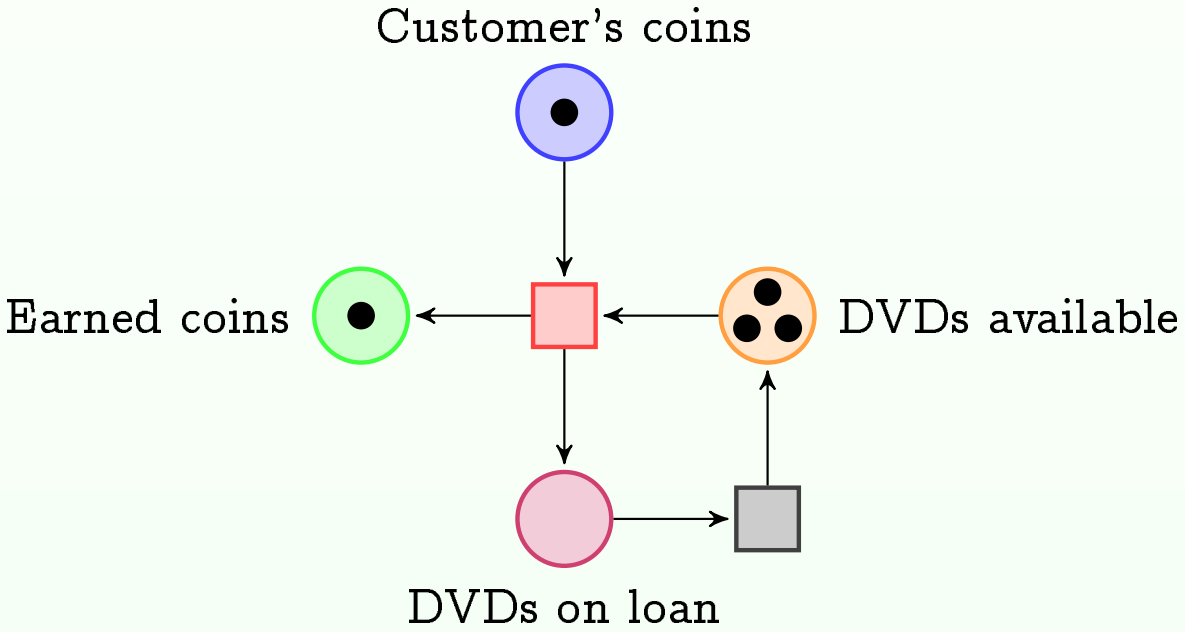

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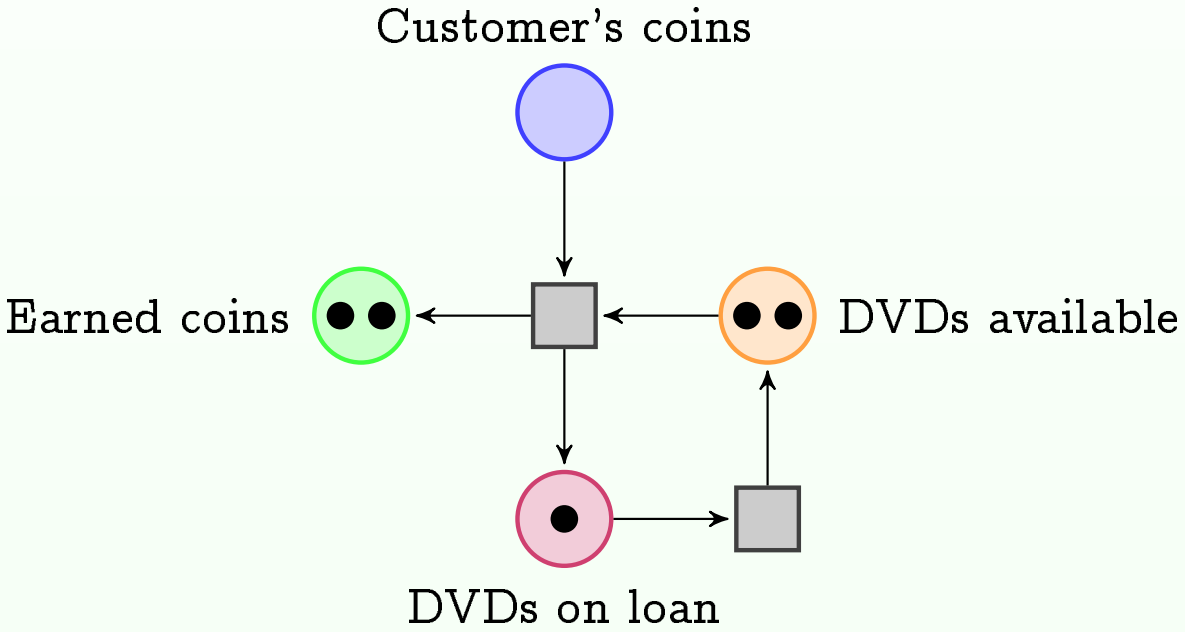

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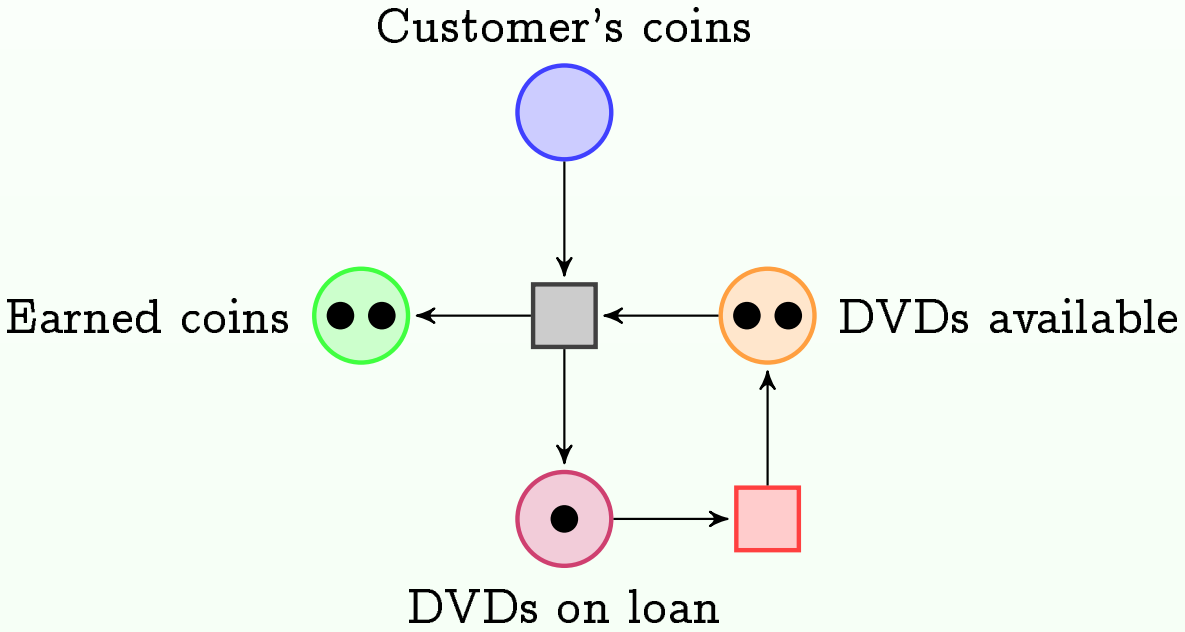

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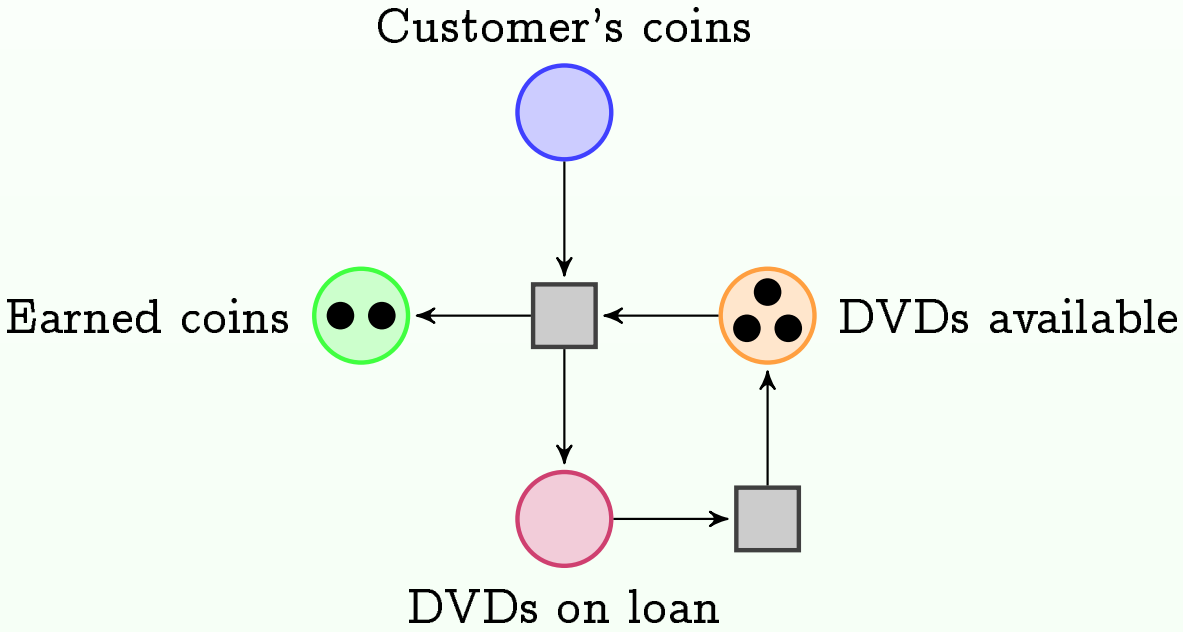

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- Extension of Petri nets with colors
  - Tokens and places have a type ("color set")
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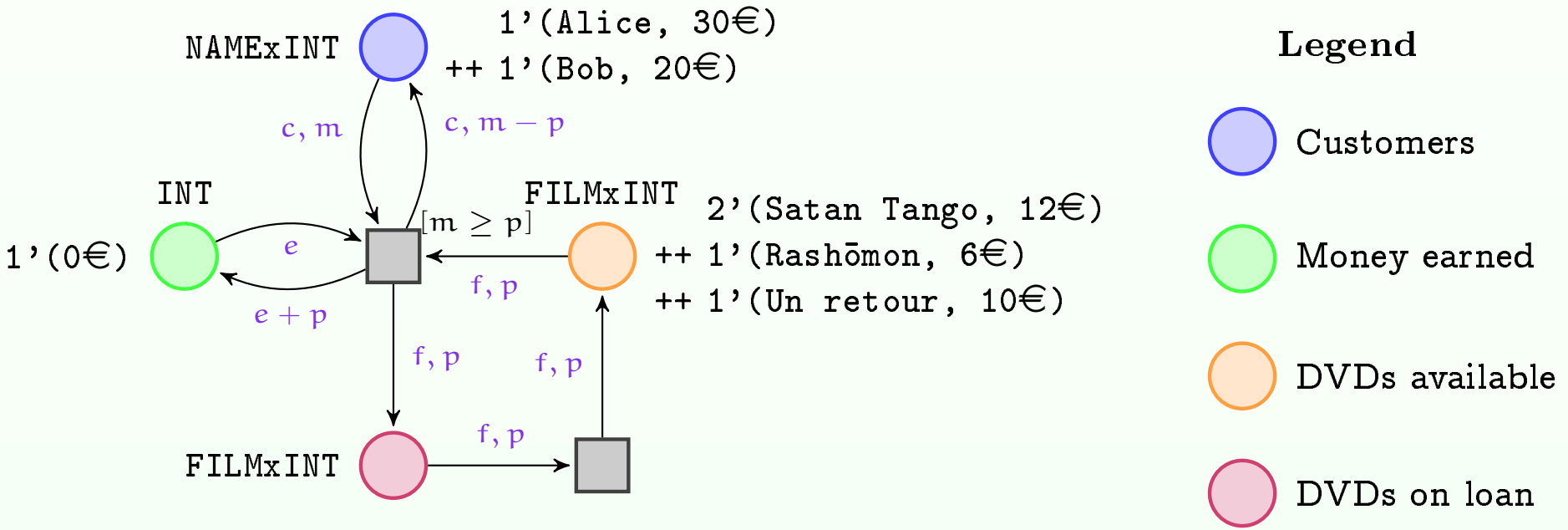

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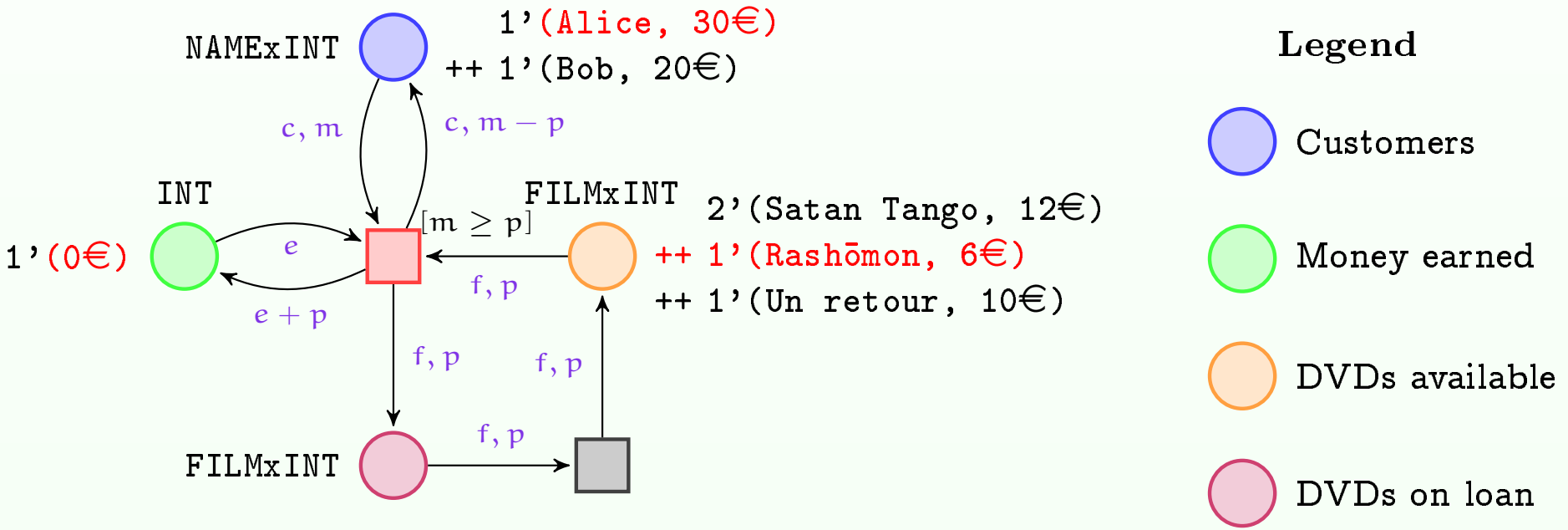

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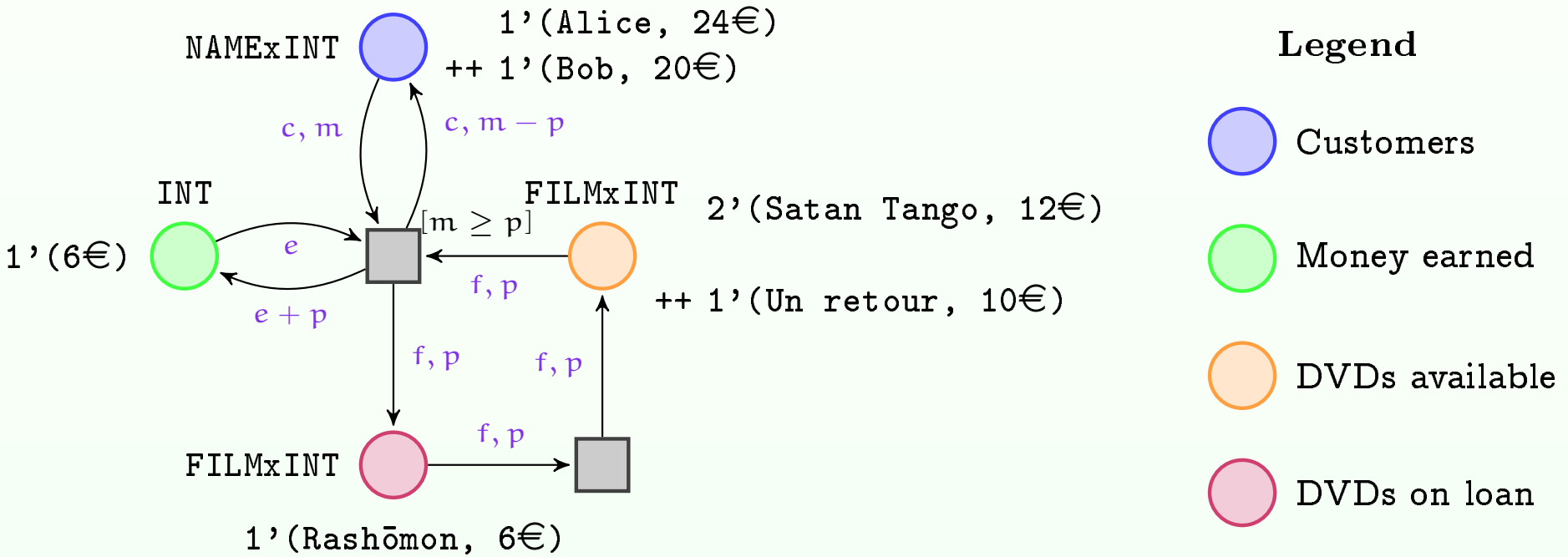

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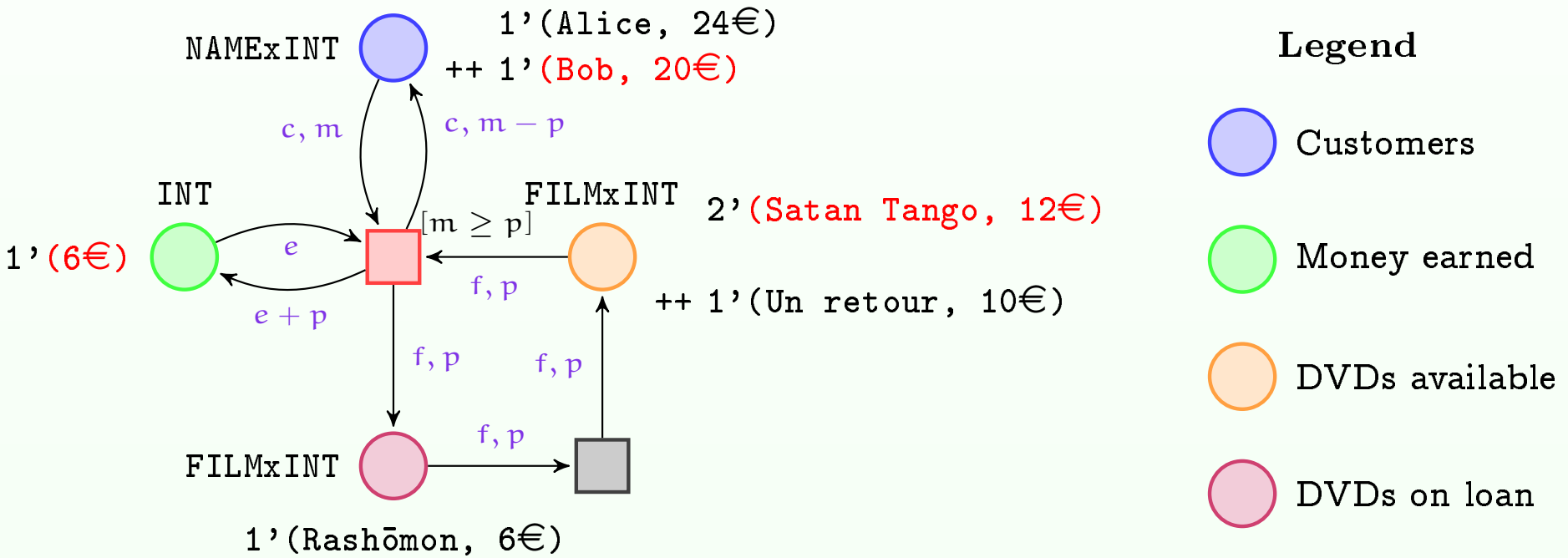

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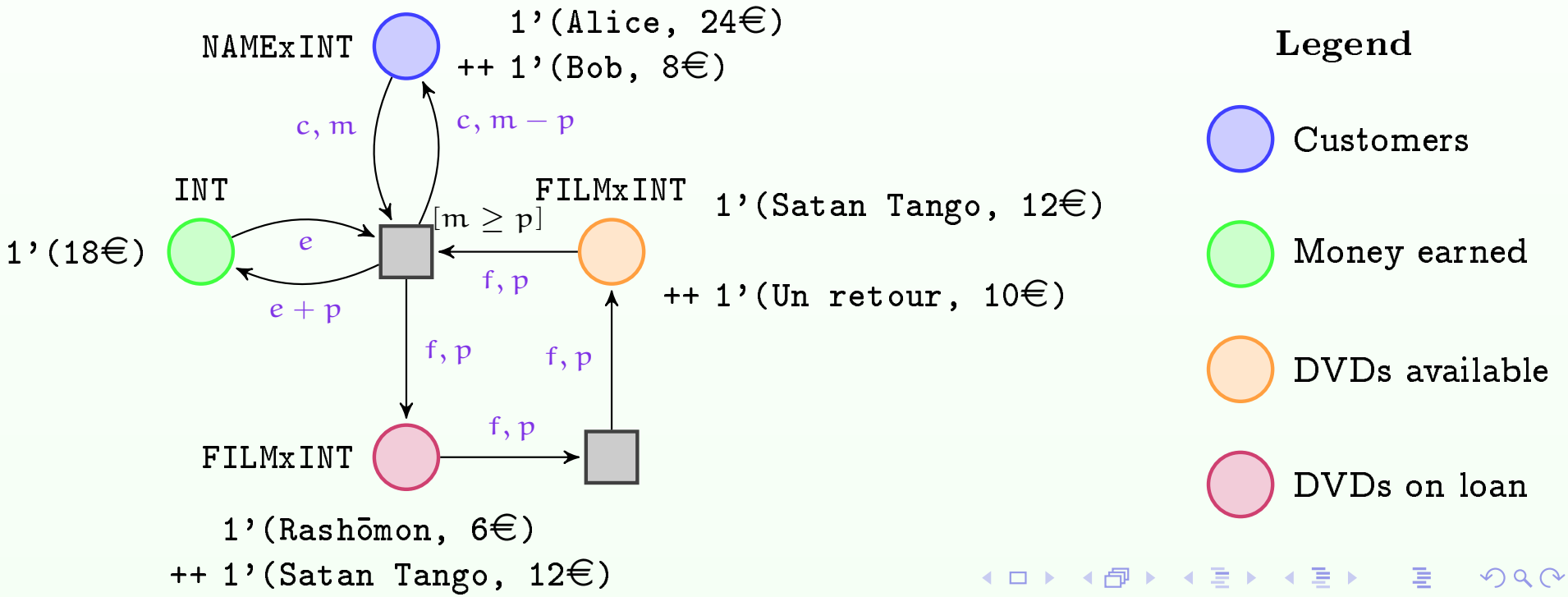

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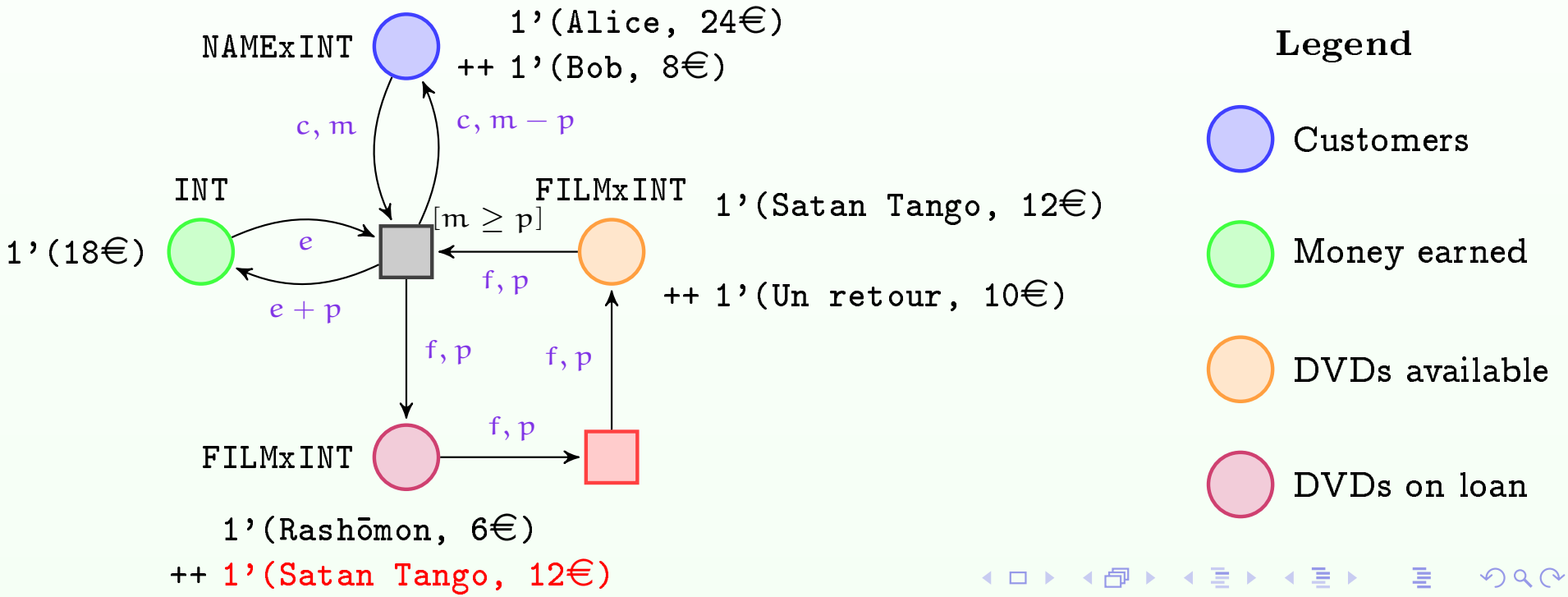

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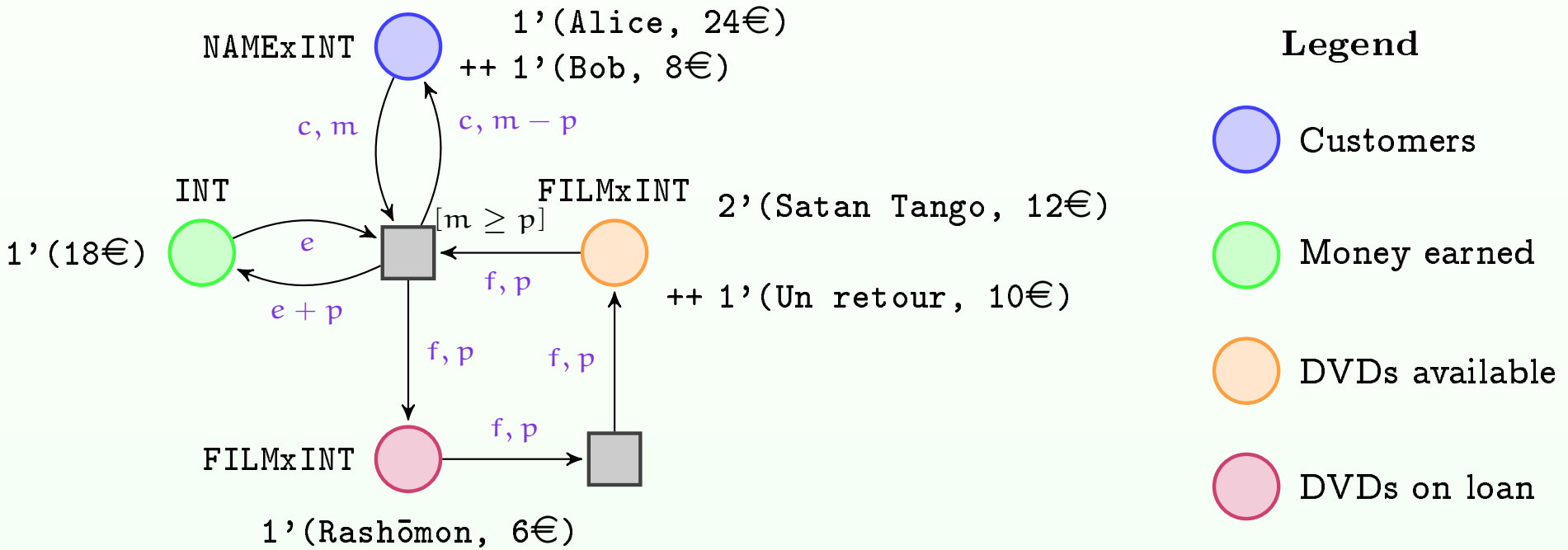


Outline

1 Colored Petri Nets

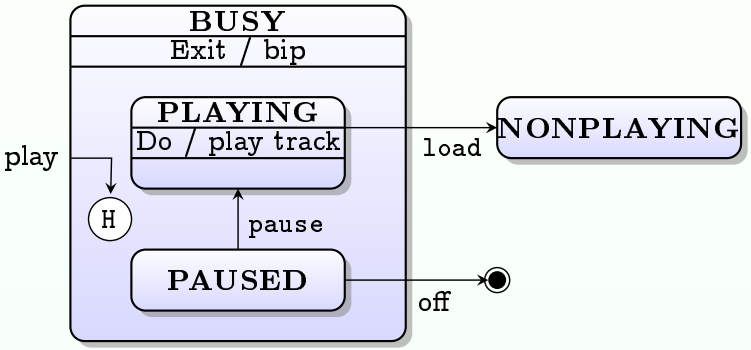
2 Translation

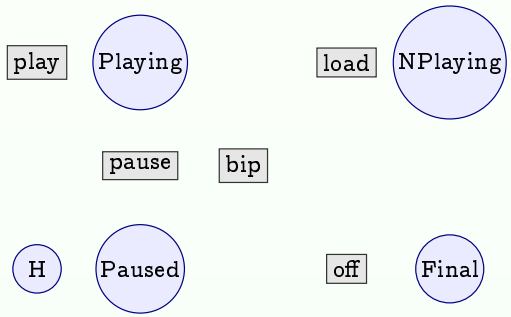
3 Application to the CD Player

4 Perspectives

Translating States and Behaviors

- Each simple state, final state, and history pseudostate is translated into a CPN place
  - Composite states not translated, only their simple substates are
- Each event and behavior is translated into a CPN transition





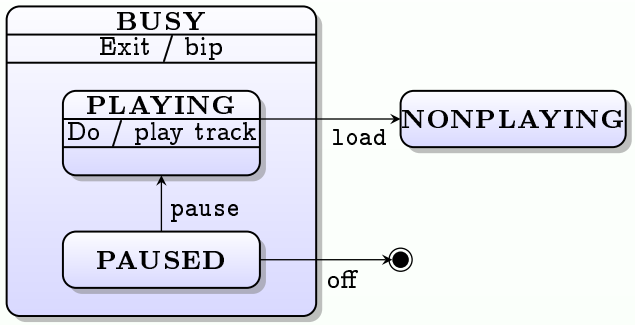
- Additional CPN places, transitions and arcs needed
  - Link between behaviors and states, etc.
  - Transitions

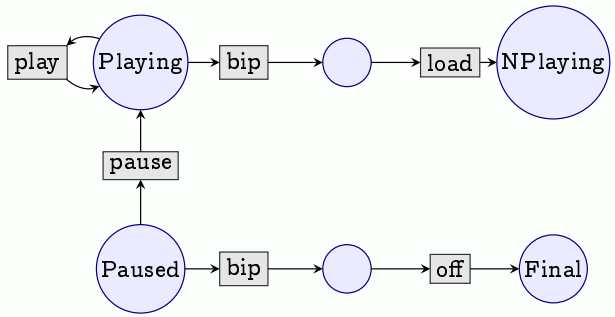
Typing

- Only one (colored) token in the resulting CPN
  - Possible because of non-concurrency
- This token carries:
  - The value of the global variables
  - The name of the latest substate for states containing a history pseudostate
- Example: CD Player
  - 2 global variables (present and track), one history pseudostate
  - Type of the token: $\{\texttt{true}, \texttt{false}\} \times \mathbb{N} \times \{\textbf{PLAYING}, \textbf{PAUSED}\}$
  - Example of value: $(\texttt{true}, 2, \textbf{PAUSED})$

Translating Transitions

- A possible translation





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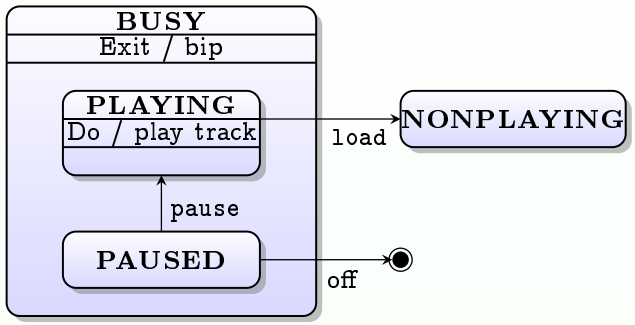
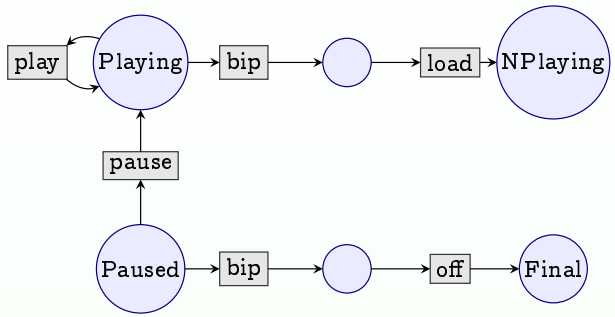
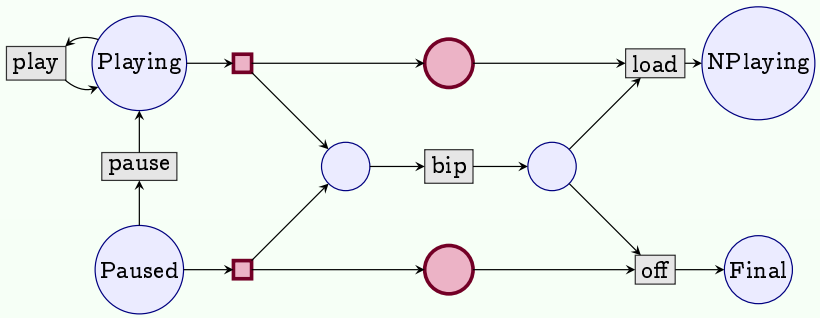


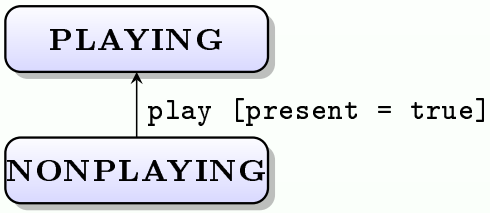


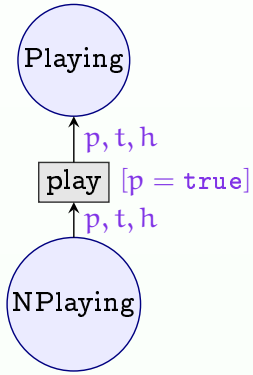
- Main problem: factoring
  - For each behavior in UML, we want only one CPN transition
  - Idea: use synchronization places



Translating Global Variables

- Guards involving variables





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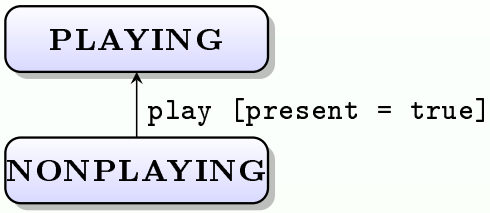
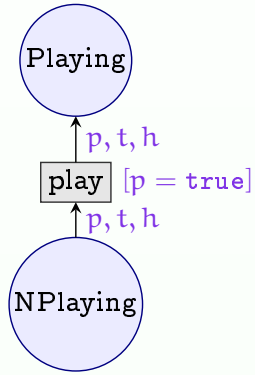
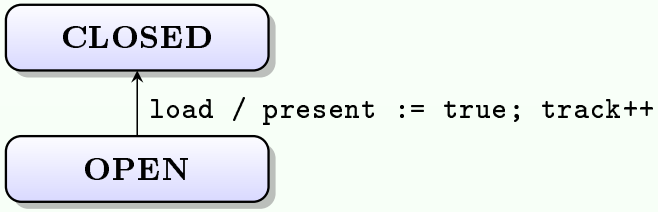
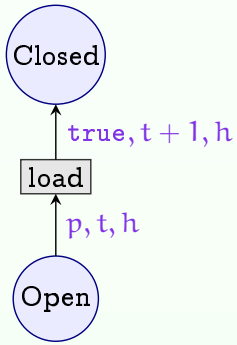




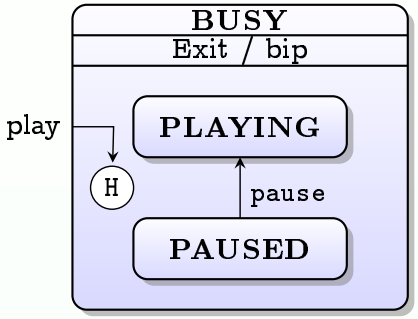
- Transitions updating variables

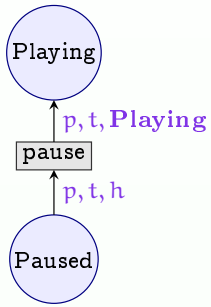




Translating History States

- For each transition leading to a substate, update the token





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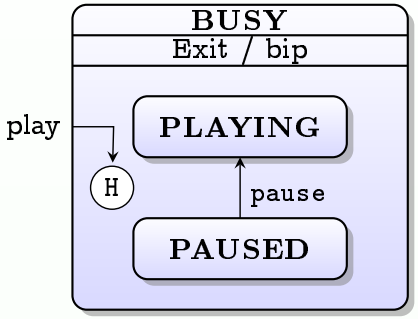
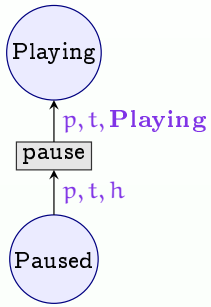
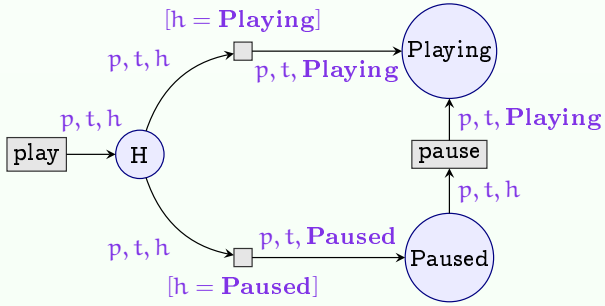




- For each history pseudostate, add CPN transitions to places corresponding to all substates, with the adequate guard



  - Note: this mechanism combines with the mechanism for behaviors (in case entry behaviors should be performed)

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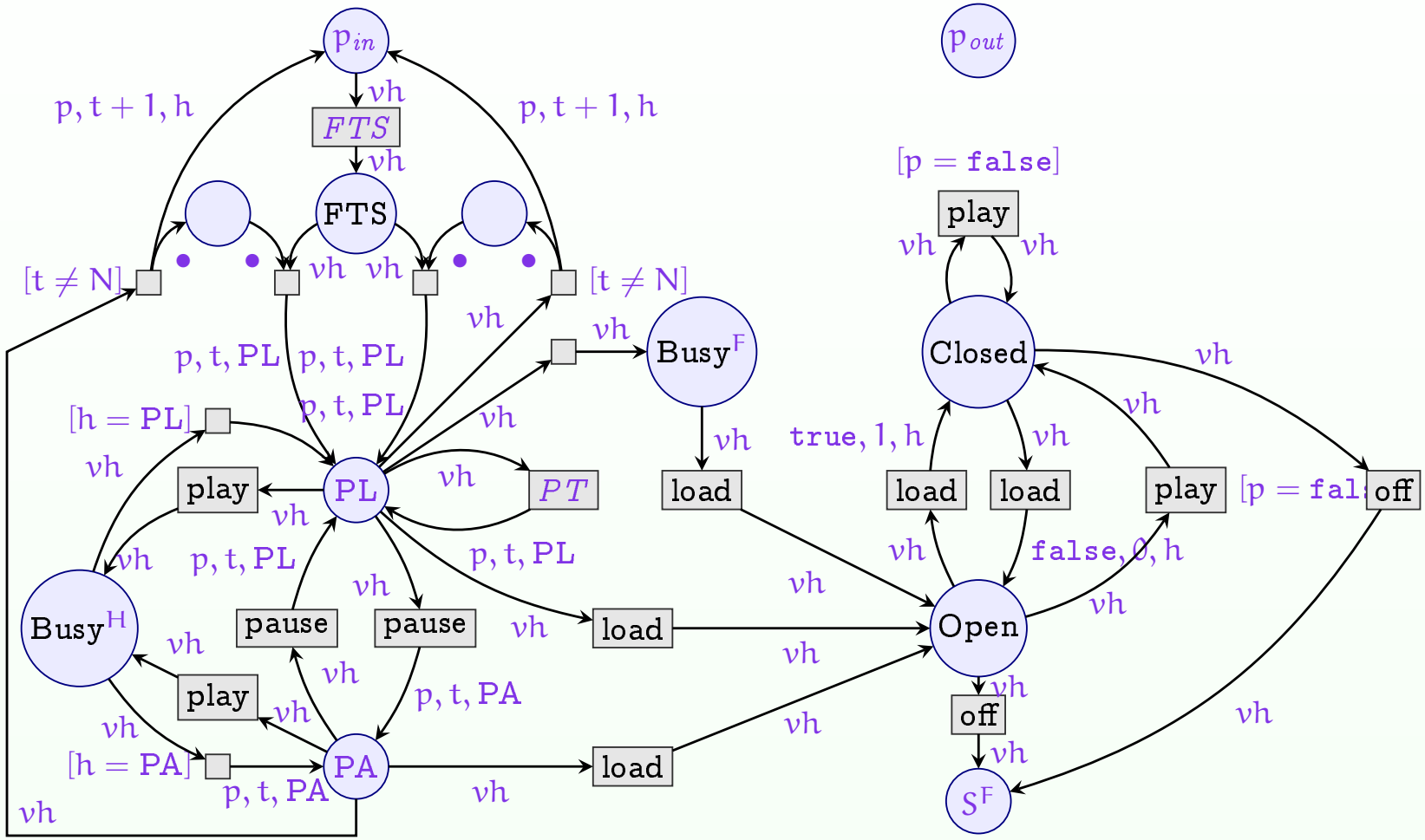
Application to the CD Player (1/2)



where vh stands for p, t, h

Partial scheme

(See full scheme in [André et al., 2012])

Application to the CD Player (2/2)

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  - But still possible to read visually
- ☺ But automated verification now possible

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"When in **PLAYING**, there is a CD in the player"

Application to the CD Player (2/2)

☹ Scheme graphically more complex than the original diagram

- But still possible to read visually

☺ But automated verification now possible

√ "When in **PLAYING**, there is a CD in the player"

Application to the CD Player (2/2)

- ☹ Scheme graphically more complex than the original diagram
  - But still possible to read visually
- ☺ But automated verification now possible
  - √ "When in **PLAYING**, there is a CD in the player"
    "When in **PLAYING**, the track number is always between 1 and `trackCount`"

Application to the CD Player (2/2)

- ☹ Scheme graphically more complex than the original diagram
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Application to the CD Player (2/2)

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√ "When in **PLAYING**, there is a CD in the player"

√ "When in **PLAYING**, the track number is always between 1 and `trackCount`"

(Properties verified using CPN Tools)

Outline

1 Colored Petri Nets

2 Translation

3 Application to the CD Player

4 Perspectives

Future Work

- Implementation and evaluation
- Extension to concurrent UML state machines
  - Use "global places" to encode global variables and history states
  - Use the mechanisms from [Choppy et al., 2011] to encode fork / join constructs
- Extension to full UML state machines 2.3 [OMG, 2010]
  - Including time issues
- Proof of equivalence with a semantics
  - Need to give a formal semantics to UML state machines first

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