UNIVERSITÀ DEGLI STUDI DI MILANO

DIPARTIMENTO DI INFORMATICA

PNemu: an Extensible Modeling Library for Adaptable Distributed Systems

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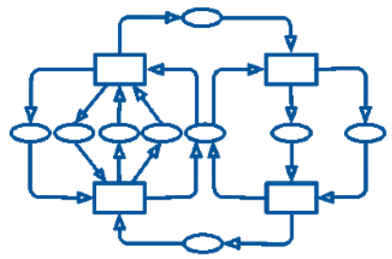

Outline

- Introduction, Motivation, Objective
- A running example
  - self-healing manufacturing system
- PNemu modeling approach
  - Emulator + Primitives + Control-loops
- Validation & Verification
- Conclusion

Motivations

- Distributed SA
  - Engineering distributed self-adaptive systems is hard. Formal reasoning in this context has been recognized as a major challenge in the field of SA [1]
  - Formal methods providing the ability to reason on distributed self-adaptive systems are highly demanded
- Petri Nest
  - Petri Nets represent a sound and expressive formal model for distributed discrete-event systems
  - BUT they cannot specify in a natural way structural changes that are likely to occur in adaptable and evolvable distributed applications (e.g., [2, 3])

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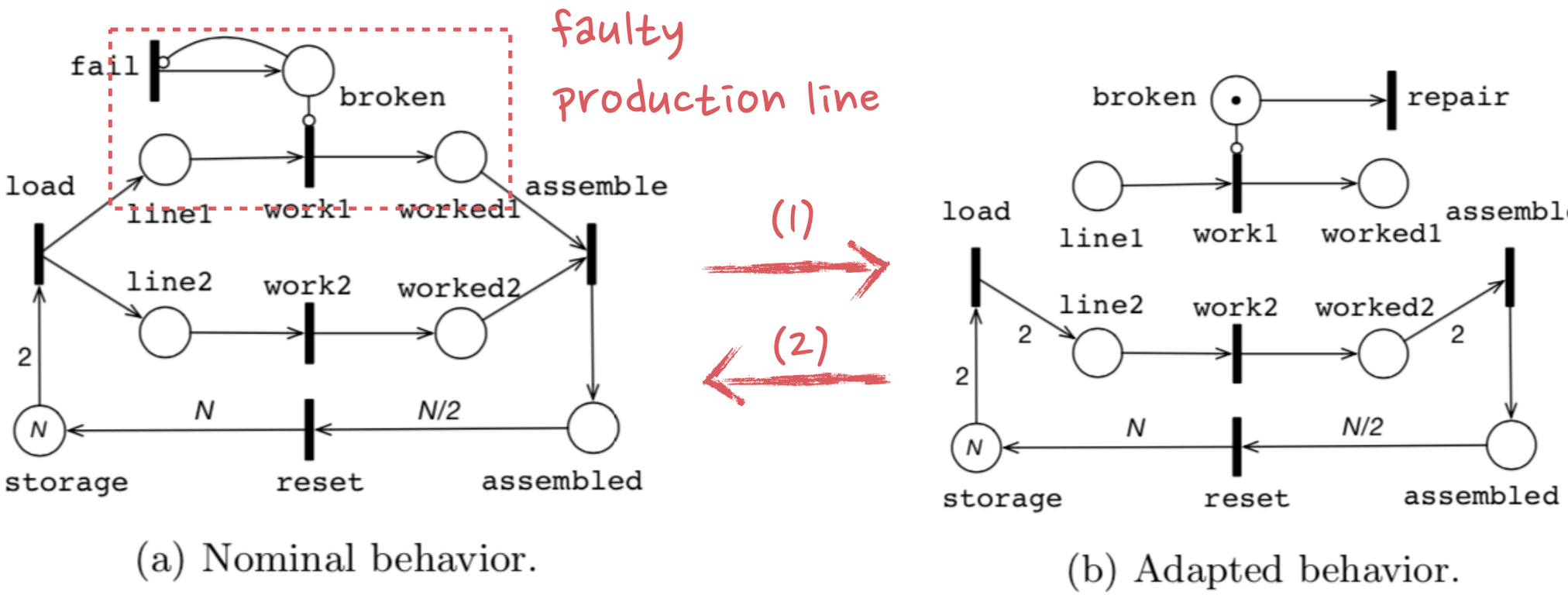
1. P. Arcaini, at al. 2017. Formal Design and Verification of Self-Adaptive Systems with Decentralized Control. ACM Transaction on Autonomous and Adaptive Systems. 11, 4, Article 25 (January 2017)
2. K. Hoffmann and T. Mossakowski. Algebraic higher-order nets: Graphs and petri nets as tokens. 16th International Workshop, WADT 2002, Frauenchiemsee, Germany, September 24-27, 2002, volume 2755 of LNCS, 253–267. Springer.
3. Capra, L. and Cazzola, W. (2006). A petri-net based reflective framework for the evolution of dynamic systems. Electron. Notes Theor. Comput. Sci., 159, 41–59.

A Running Example: the self-healing manufacturing system



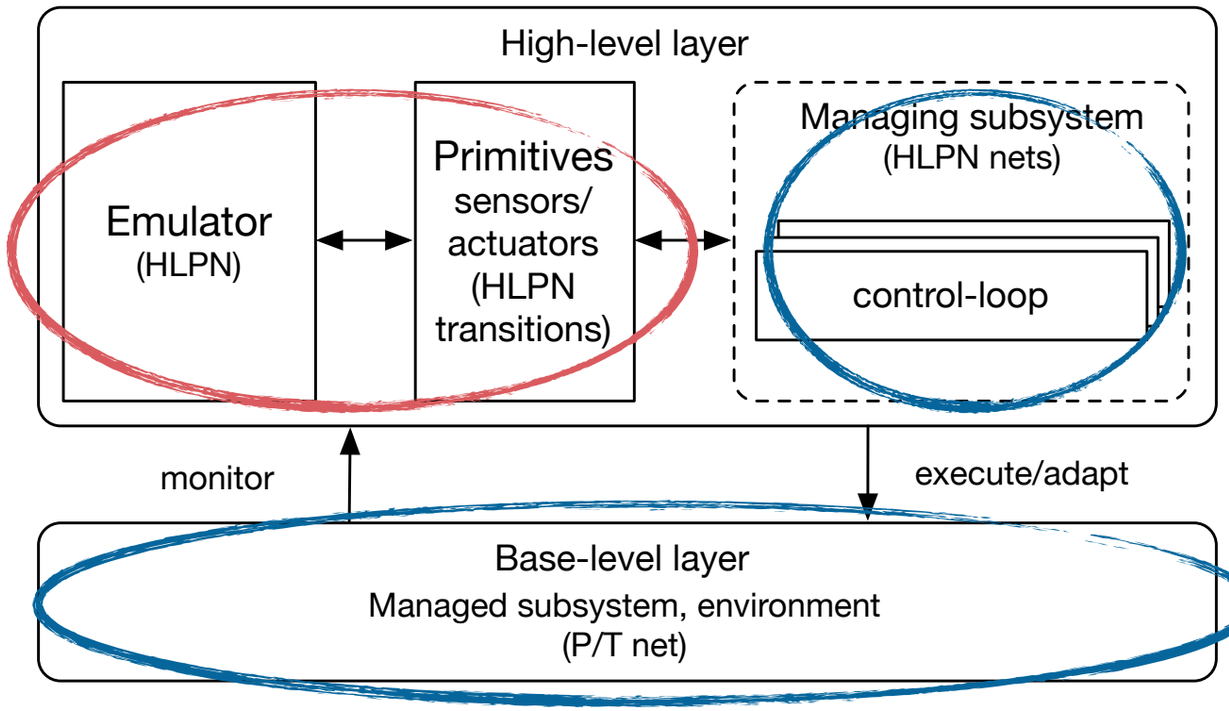
(a) Nominal behavior.

(b) Adapted behavior.

- we want to endow the MS with the ability to change its current state/structure to
  - (1) fault tolerance: detach the faulty line to keep the work going
  - (2) load balancing: distribute the load to all the available production lines
- mixing functional and adaptation aspects is HARD!
  - it often results in very complex P/T nets

PNemu: Framework Overview

fixed



user defined

- High-level layer:
  - Emulator — HLPN [4,5] model able to execute a P/T net
  - Primitives — HLPN transitions that read/change the encoded P/T net model (sensors + actuators)
  - Control-loops (managing subsystem) — HLPNs defining the adaptation aspects

4. Systems and software engineering - High-level Petri nets - Part 1: Concepts, definitions and graphical notation. Standard, International Organization for Standardization, Geneva, CH (Dec 2004), ISO/IEC 15909-1:2004

5. Pommereau, F.: Snakes: A flexible high-level petri nets library (tool paper). In: Devillers, R., Valmari, A. (eds.) Application and Theory of Petri Nets and Concurrency. pp. 254–265. Springer International Publishing, Cham (2015)

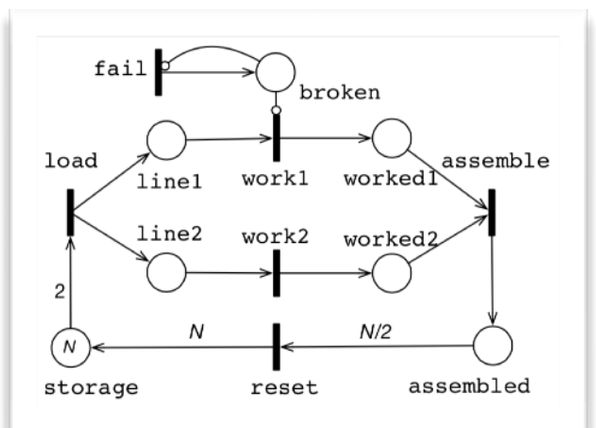
Emulator instance

PNemu code snippet

```
1. from pnemu import PT, Emulator
2.
3. pt = PT('ms', 'ms-nominal.pnml')
4. emulator = Emulator( pt )
5.
6. emulator.get_marking().get( 'mark' )
7. # MultiSet( ['storage'] * 10 )
```

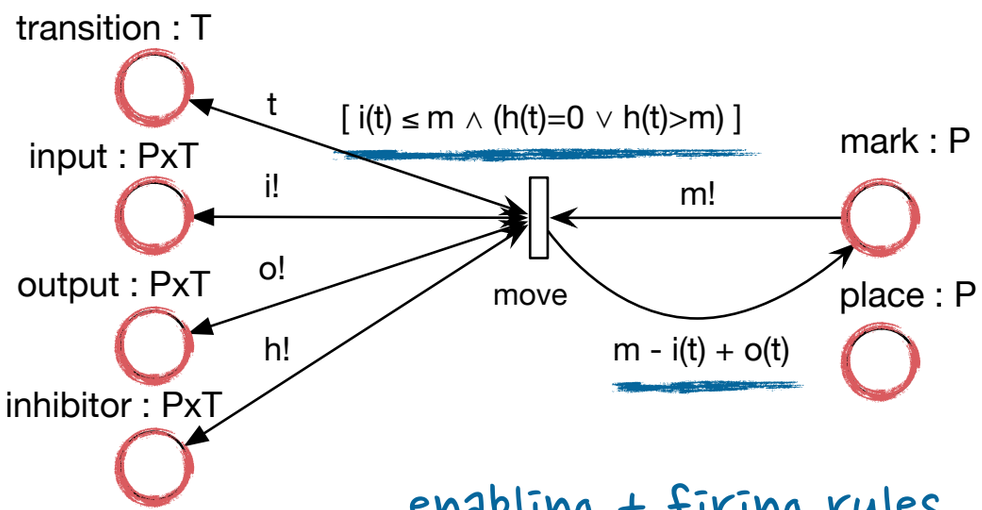
(3)

base-level layer creation



(4)

Emulator instance



enabling + firing rules

Primitives

- HLPN **transitions** connected to specific structural elements of the Emulator
  - read/modify the state/structure of the base-level layer
  - PNemu provides a set of pre-defined **read (sensors)** / **write (actuators)** primitives

- Examples:

Sensor

PNemu code snippet

```
1. signature = "lib.getTokens(p_) -> m(p_)"
2. entry = LibEntry(
3.     signature,
4.     [ Place('M') ],
5.     [ ('M', signature, Flush('m')) ],
6.     [ ('M', signature, Flush('m')) ])
7. READ_LIB.update({function_name(signature) : entry})
```

Actuator

PNemu code snippet

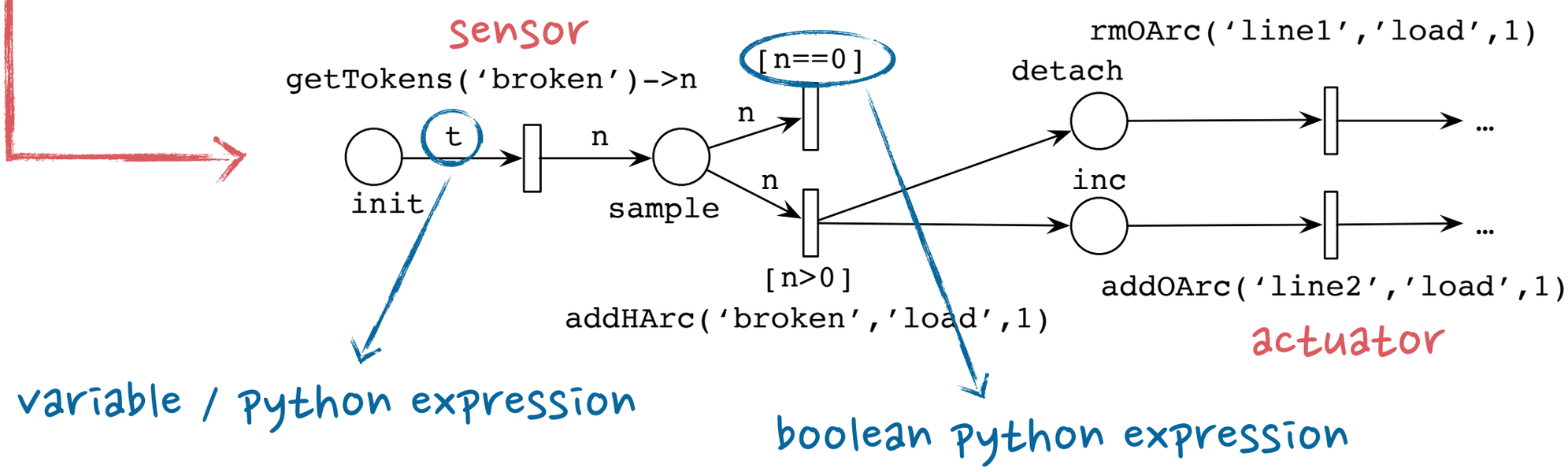
```
1. signature = "lib.addPlace(p_)"
2. entry = LibEntry(
3.     signature,
4.     [ Place('P') ],
5.     [ ],
6.     [ ('P', signature, Expression('p_')) ])
7. WRITE_LIB.update({function_name(signature) : entry})
```

Managing Subsystem

- user-defined HLPNs (one for each **adaptation concern**)

PNemu code snippet

```
1. loop = FeedbackLoop(name='fault-tolerance')
2. loop.add_place(name='init')
3. loop.add_place(name='sample')
4. read_primitive = 'lib.getTokens("broken")->n'
5. loop.add_transition(name=read_primitive)
6. loop.add_input_arc(src='init', dst=read_primitive, Variable('b'))
7. loop.add_output_arc(src=read_primitive, dst='sample', Variable('n'))
8. …
```



Validation and verification activities

PNemu code snippet

```
1. net = AdaptiveNetBuilder(emulator)                                    \
2.     .add_loop(control_loop=loop, initial_places=['init'])    \
3.     .add_loop(control_loop=loop2, initial_places=['init2']) \
4.     .build()
```

- Validation
  - token game by using the PNemu API; step-by-step check:
    - marking/structure of both the managed and the managing systems
    - enabled transitions of both the managed and the managing systems
    - active control-loops
- Formal Verification
  - model checking by using external tools, e.g. the Neco LTL model checker [6]:
    - deadlock freedom $\Box(\neg \texttt{deadlock})$
    - safety + liveness properties + invariants

      $\Box(\texttt{marking}(\texttt{'M'}) >= [\texttt{'broken'}] \rightarrow \neg\Box(\neg\texttt{marking}(\texttt{'M'}) >= [\texttt{'broken'}]))$
    - adaptation integrity constraints

      $\Box(\texttt{card}(\texttt{marking}(\texttt{'init'})) > 0 \rightarrow \Diamond(\texttt{card}(\texttt{marking}(\texttt{'detached'})) > 0))$

6. Fronc, L., Pommereau, F.: Building Petri nets tools around Neco compiler. In: Proceedings of PNSE'13. pp. 1–7 (06 2013)

Conclusion

- We are trying to support design and validation/verification of distributed self-adaptive systems with decentralized adaptation control (recognized as a major challenge in SA)
- We leverage HLPNs applying clear separation of concerns to model SA
- Our approach gets solid foundations from well-established formal methods (HLPNs) and leverages existing analysis techniques and tools (such as SNAKES and Neco)

- PNemu is available at: https://github.com/SELab-unimi/sn-based-emulator 

- Future work
  - DSL to describe the managing subsystem (using directly HLPNs may be tricky)
  - enhance the verification activity providing the ability to check that multiple control loops do not lead to conflicting adaptation decisions

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Thank you

Questions?

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