Health Monitoring of Hybrid Systems Using Hybrid Particle Petri Nets

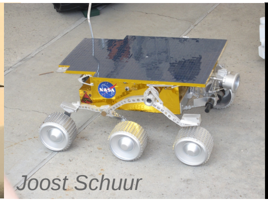
Quentin Gaudel*, Elodie Chanthery*, Pauline Ribot**
LAAS-CNRS, DISCO team, Toulouse, France
University of Toulouse, *INSA, **UPS Toulouse, France
quentin.gaudel@laas.fr
elodie.chanthery@laas.fr
pauline.ribot@laas.fr

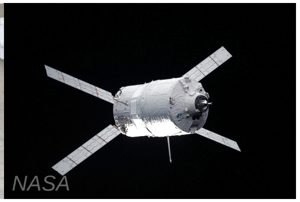
Outline

1. Context
2. Motivations
3. Methodology for behavioral diagnosis
4. Methodology for degradation diagnosis
5. Conclusion & future work

1. Context

- Complex dynamic systems exposed to failures
  - **Maintenance** and repair to reduce cost of products
  - **Reconfiguration** and **replanning** to maximize rewards
  of 'local' missions





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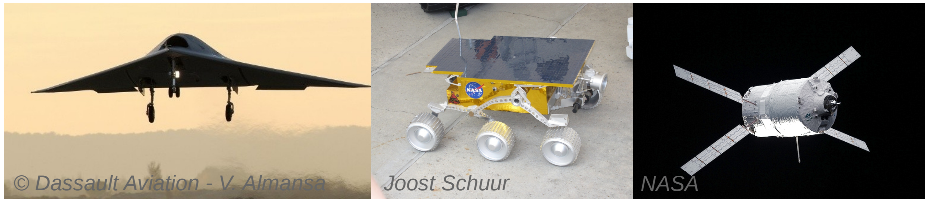
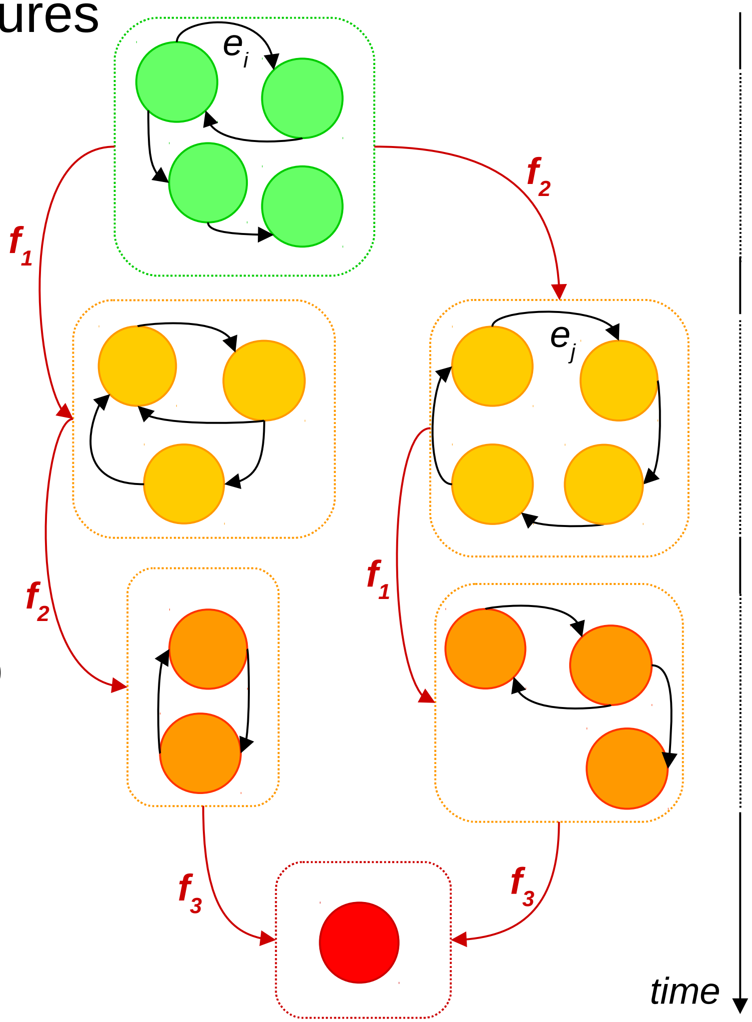
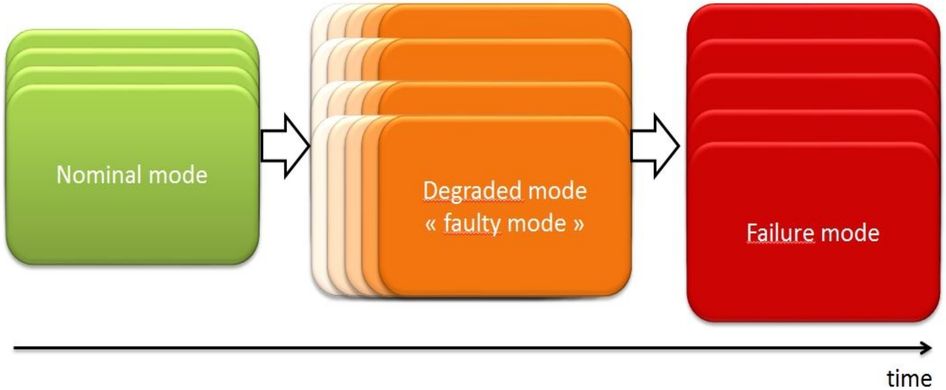




- **Hybrid systems**
  - Continuous and discrete observations
  - Multi-modes systems (continuous and discrete behaviors)



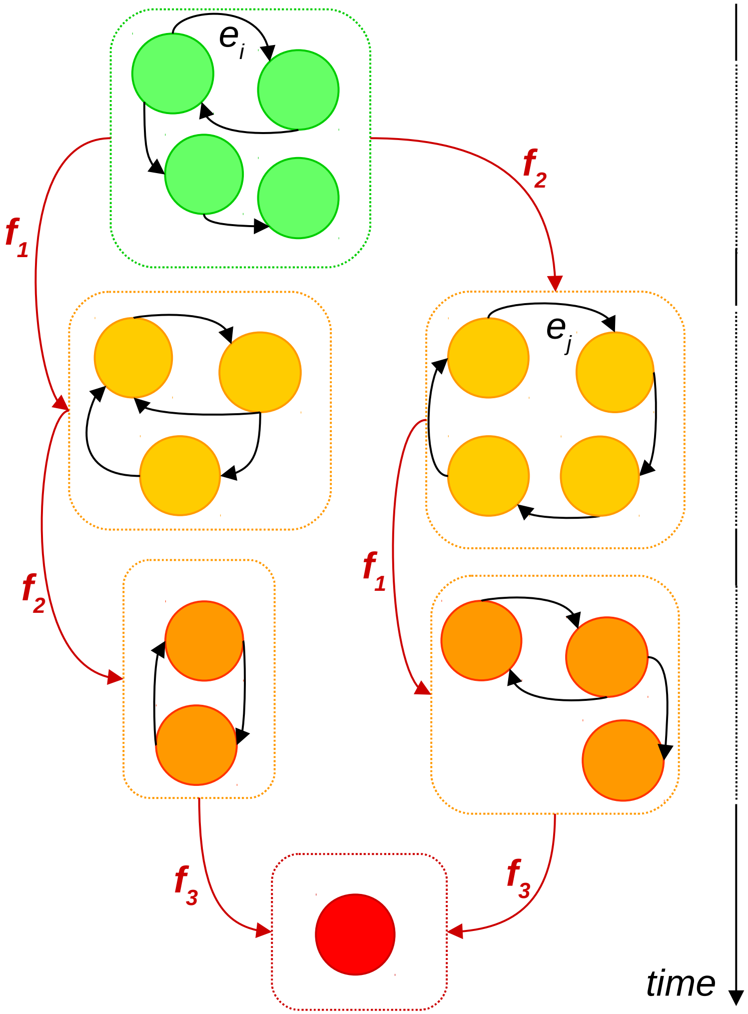
1. Context

Diagnosis

- Determine the current health state of the system

Prognosis

- Determine the future health states of the system
- Often related to the temporal prediction of the date at which the system is not operational anymore
- RUL/EOL prediction



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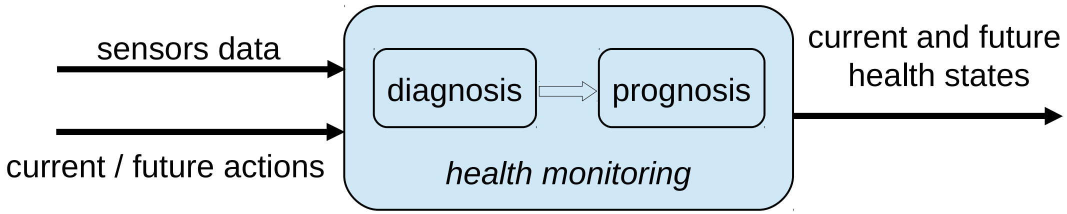
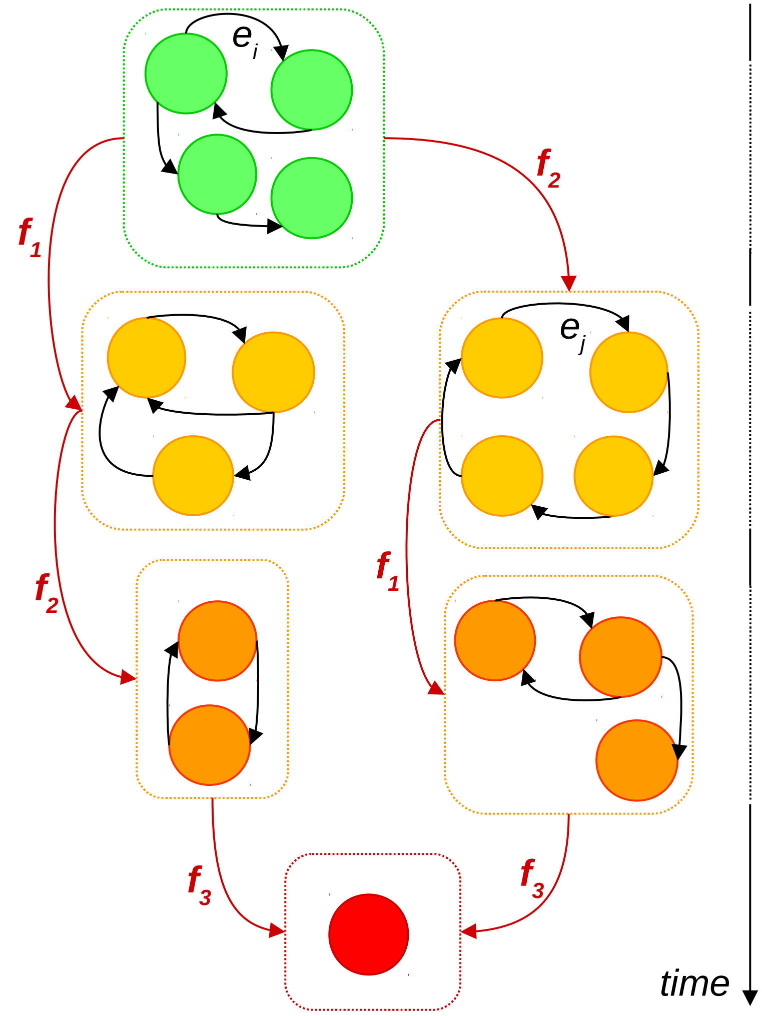
Current approach:





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- **Model-based** diagnosis and prognosis

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  - To perform a more efficient health monitoring [Chanthery & Ribot, 2013]

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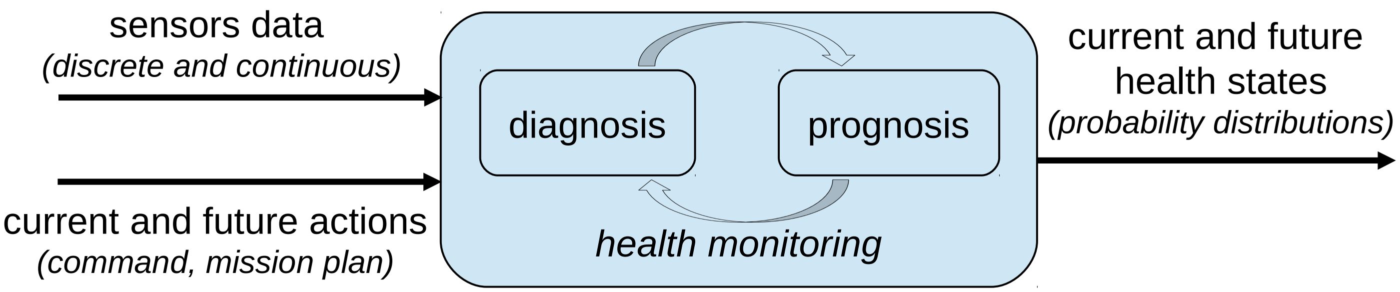

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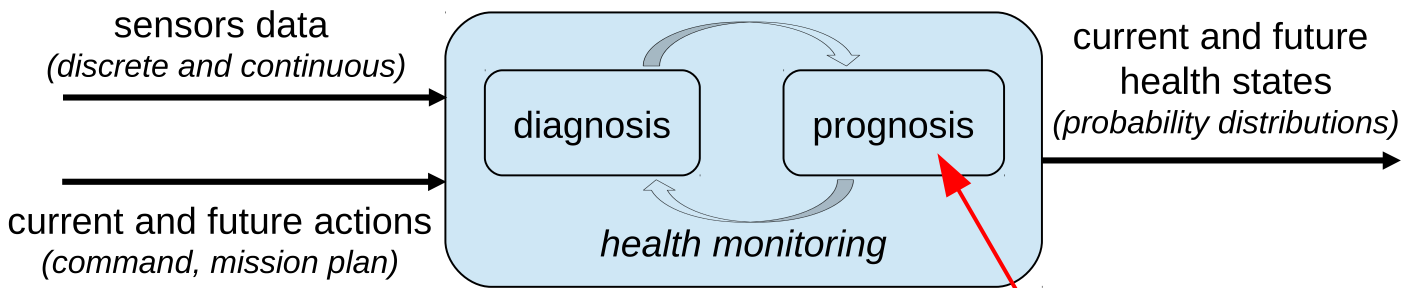

- Use **degradation laws**
- Use **probabilistic tools** *(uncertainty)*

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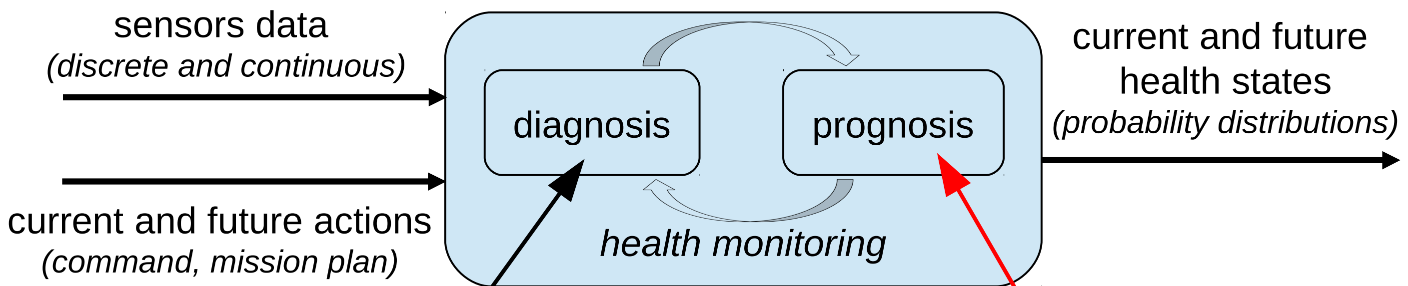

Objectives:

- ***Use probabilistic tools for behavioral diagnosis***
  - ⇒ ***To model uncertainty***
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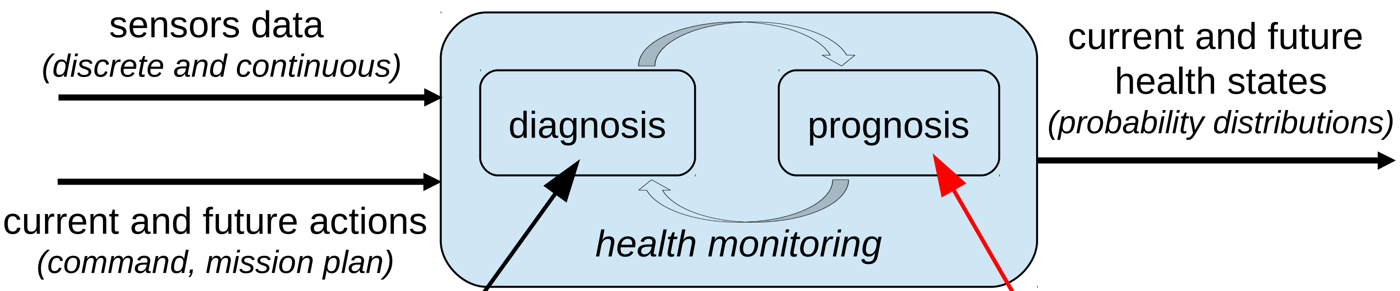

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3. Methodology for behavioral diagnosis

Modified Particle Petri Nets (MPPN)

$$MPPN = (P, T, Pre, Post, X, C, \gamma, \Omega, M_0)$$

Set of places

State space of the continuous state vector

Set of dynamics equations associated with some places

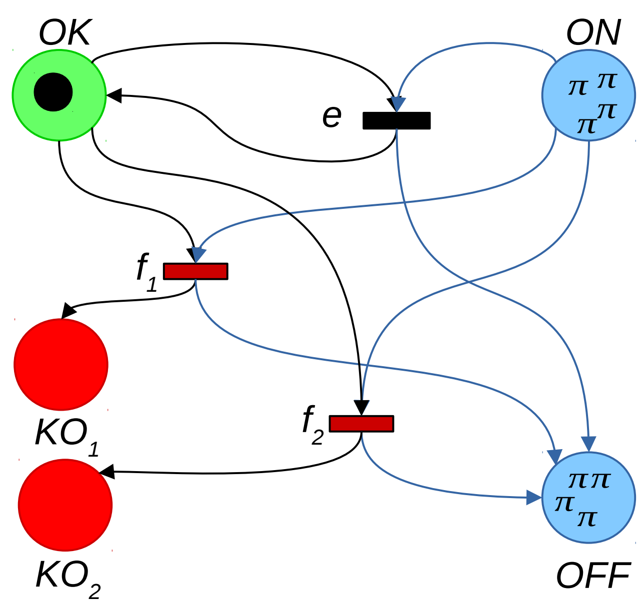
Initial marking

Set of transitions

Incidence matrices

Set of conditions associated with transitions

Application associating tokens with places



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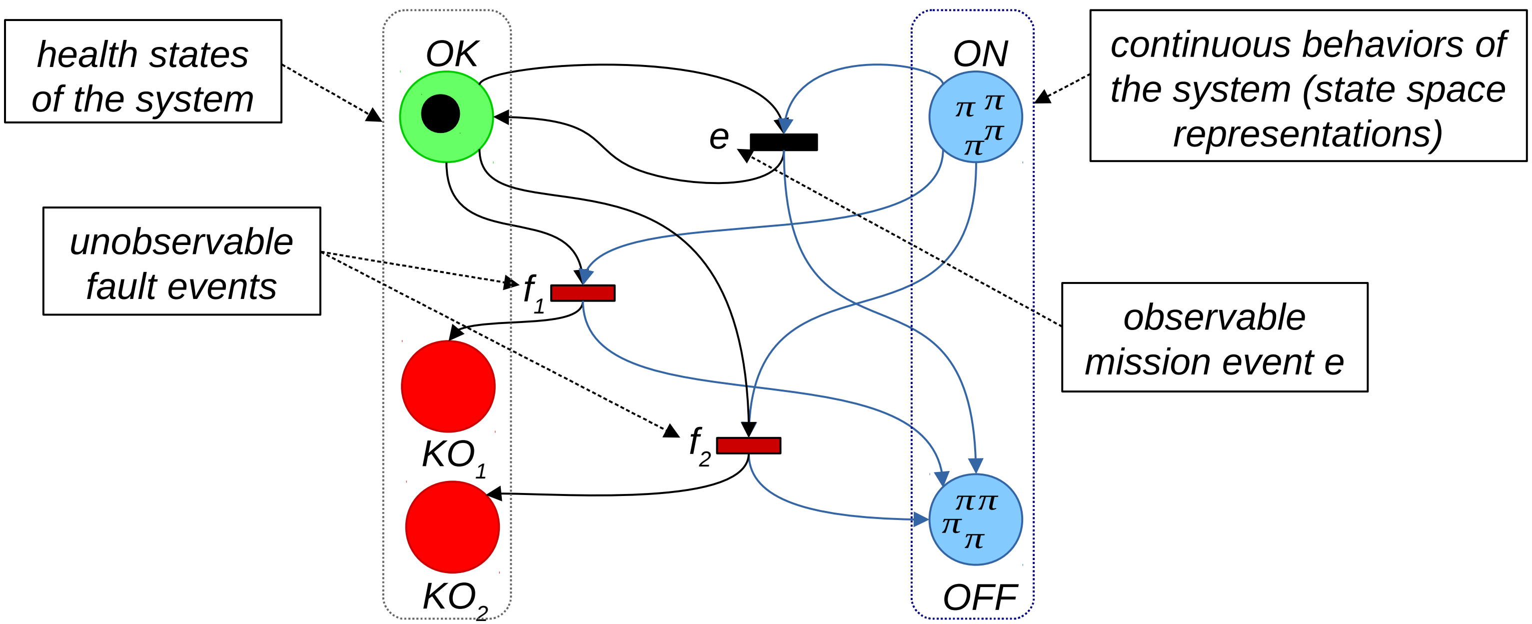

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The **occurrence of an unobservable event** *(supported by continuous observations)*

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MPPN combine **conditioned-firing** and **pseudo-firing** (duplication of tokens)

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MPPN on line process

- Use **particle filters** to model **uncertainty** about:
  - **Model equations**
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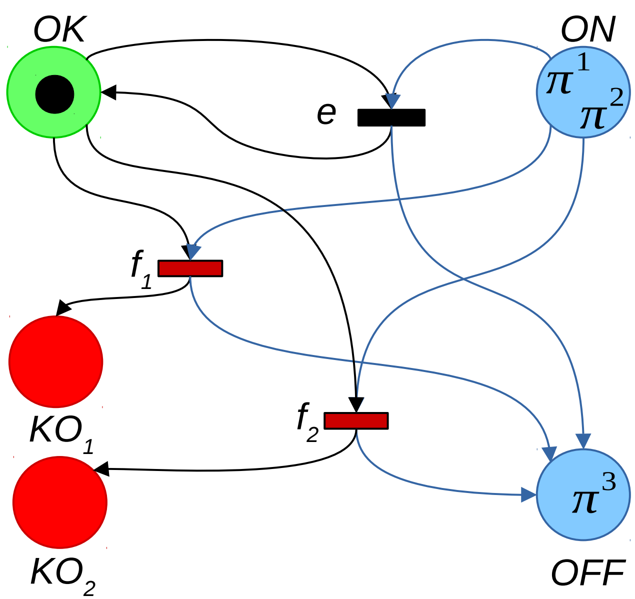

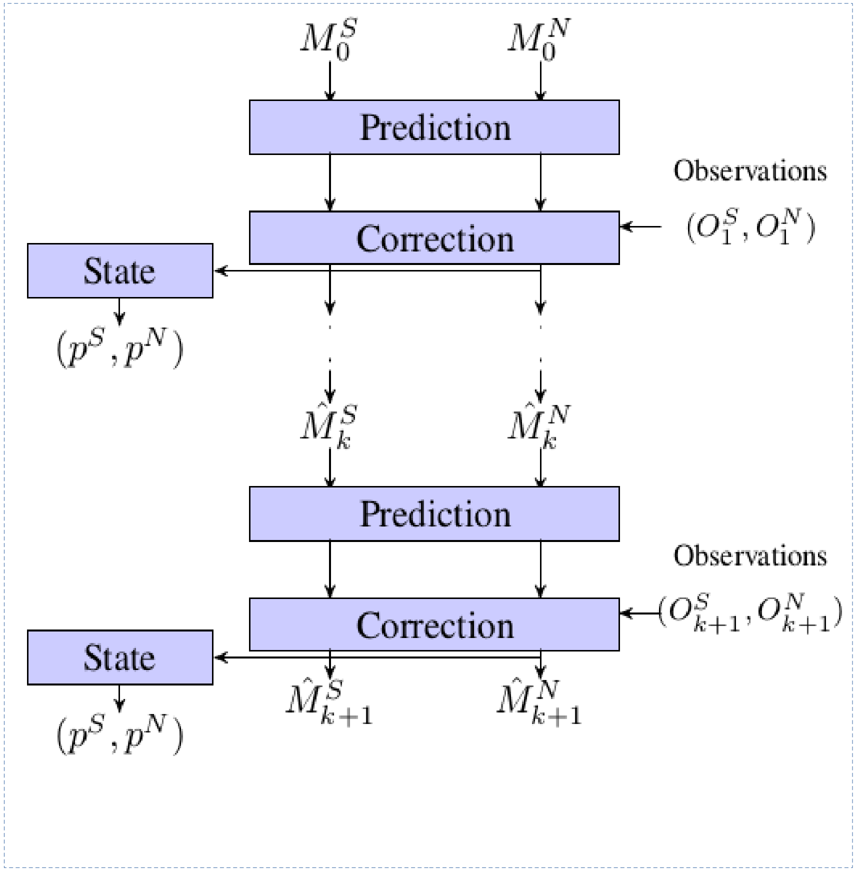

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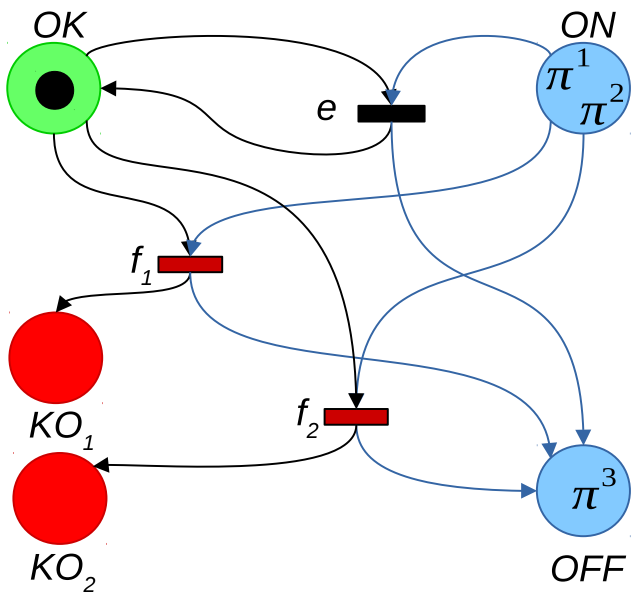
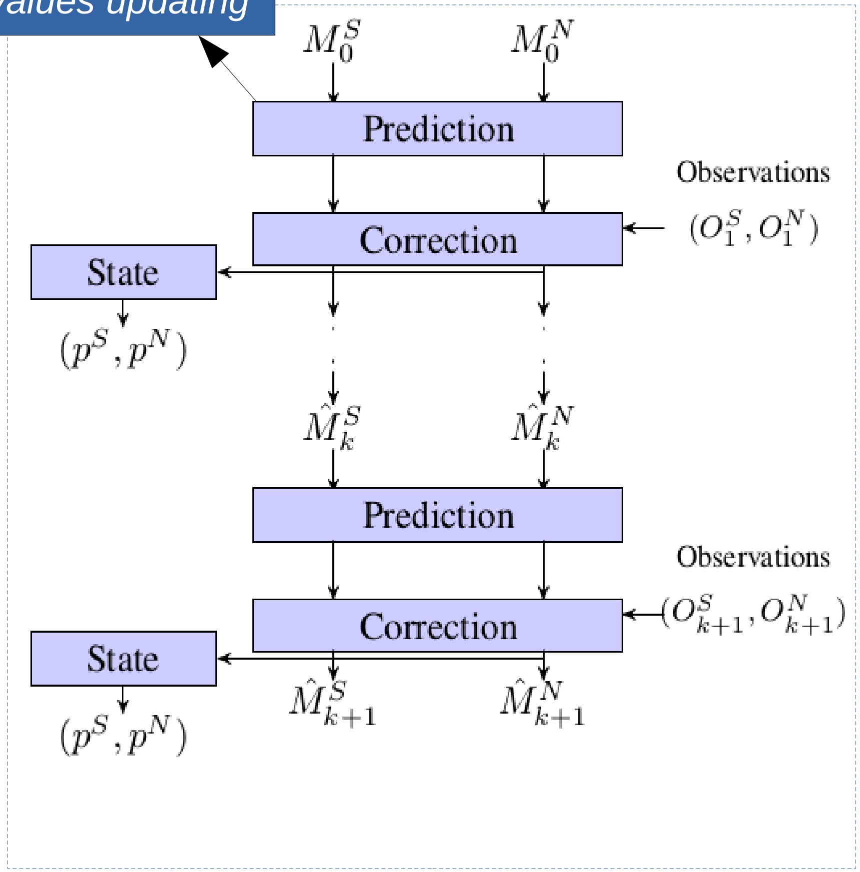
2. particle values updating





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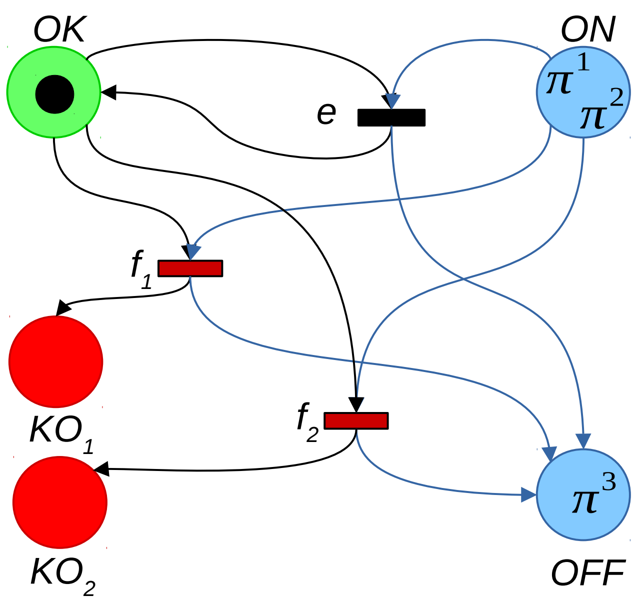

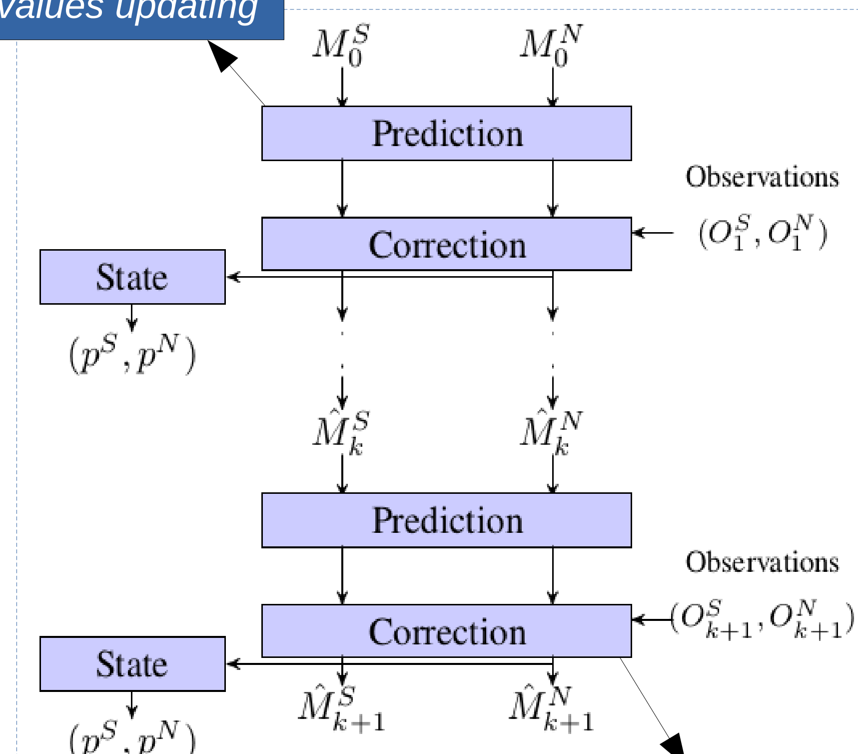

1. particle filtering
2. hybrid mechanism based on numerical belief and discrete observations

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Behavioral diagnosis using MPPN [Gaudel et al. 2014]

- Based on the **generation of a diagnoser**
    - The diagnoser is also a MPPN
    - The diagnoser is an upgrade of the MPPN model

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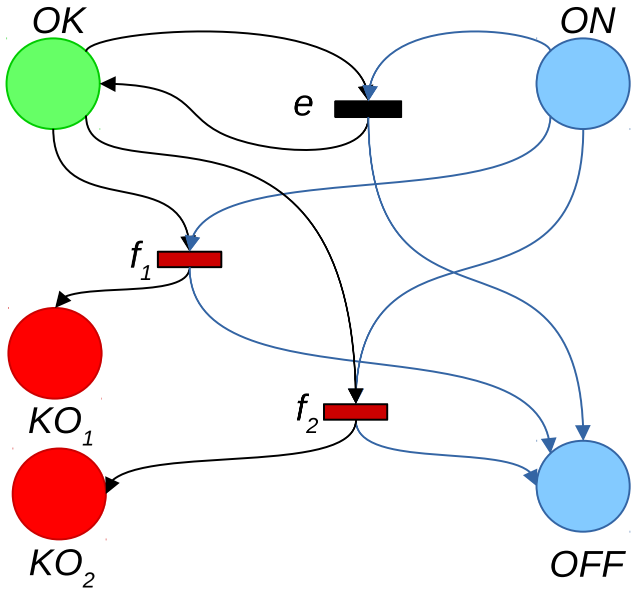

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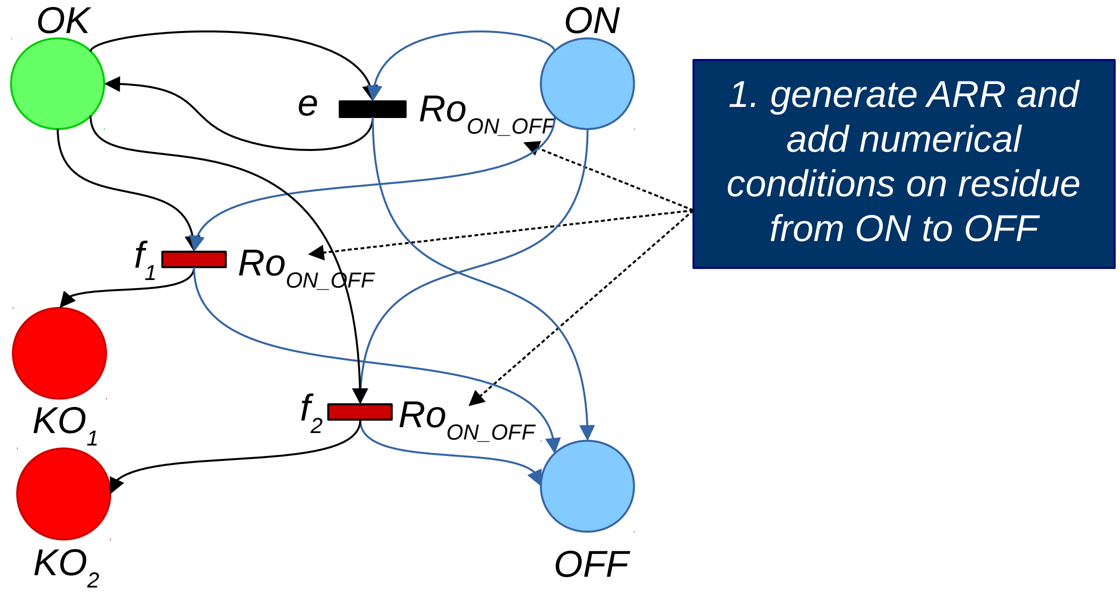

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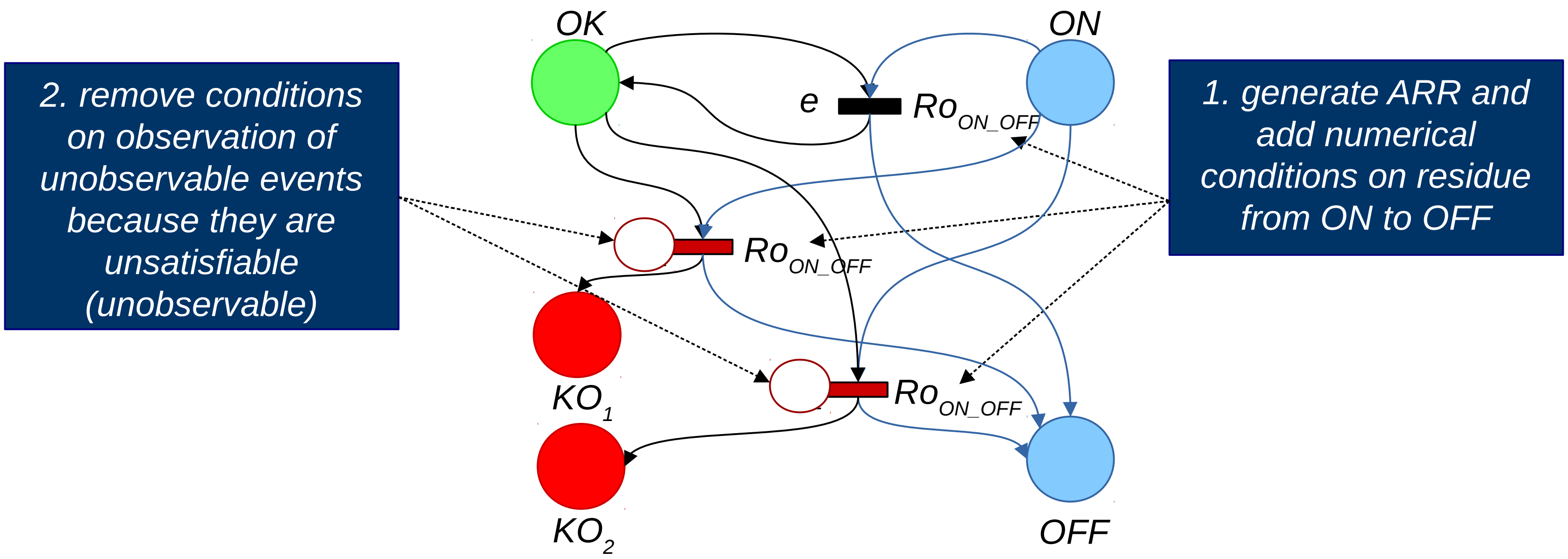

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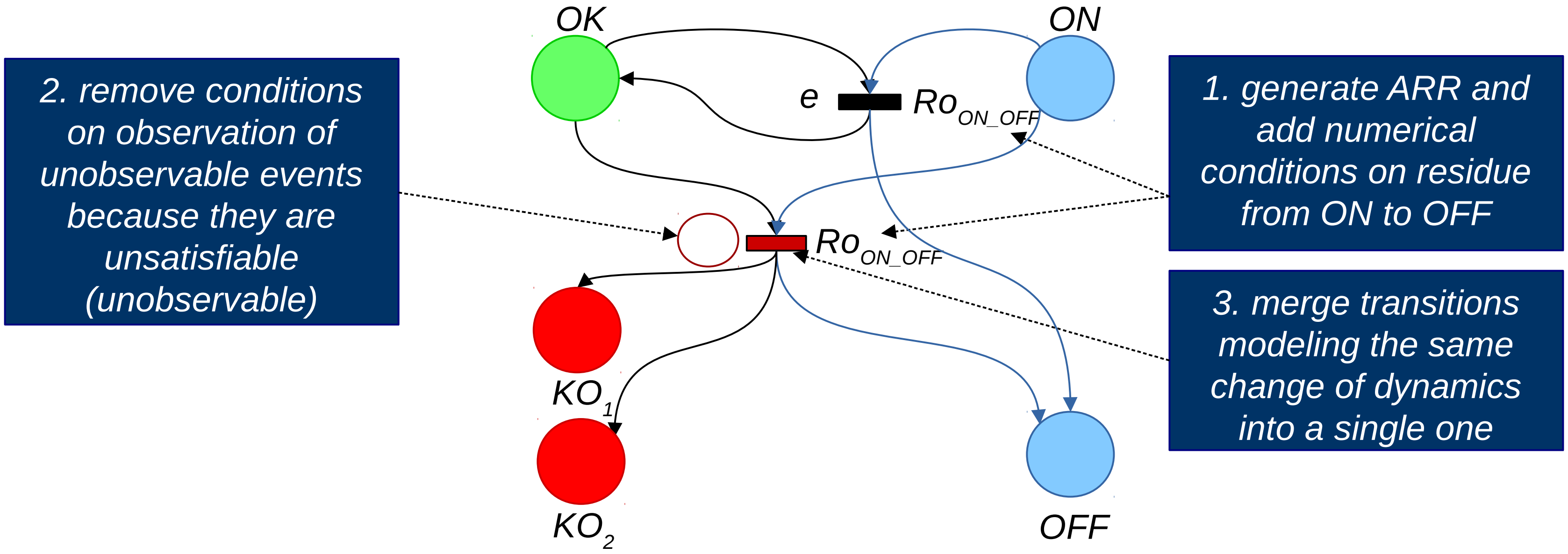

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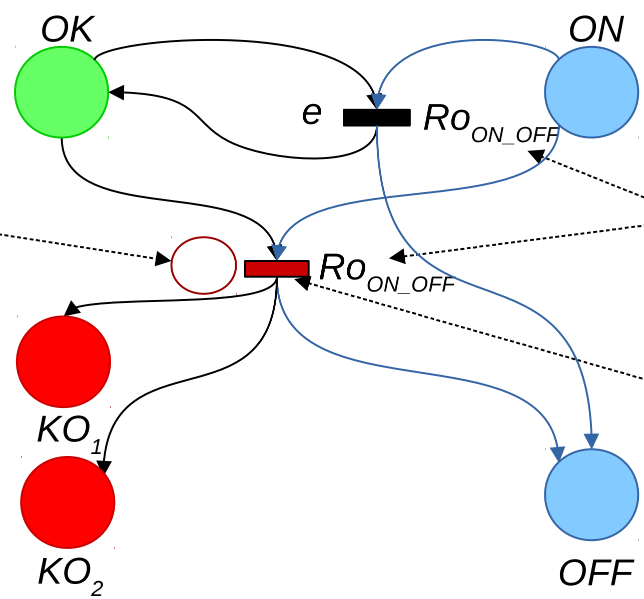
2. remove conditions on observation of unobservable events because they are unsatisfiable (unobservable)



1. generate ARR and add numerical conditions on residue from ON to OFF

3. merge transitions modeling the same change of dynamics into a single one

The **diagnosis results is the marking of the diagnoser** at time *k*

- **Indicates the belief on the fault occurrences** level-headed with particle weights

$$\boxed{\Delta_k = \hat{M}_k}$$

4. Methodology for degradation diagnosis

MPPN behavioral level

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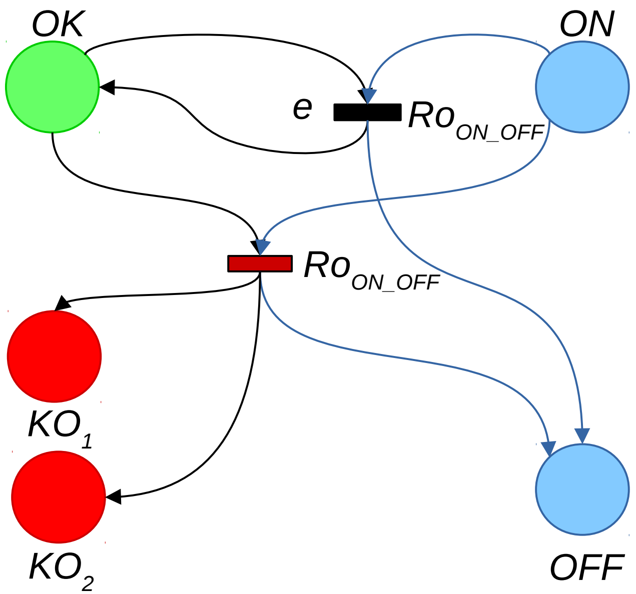

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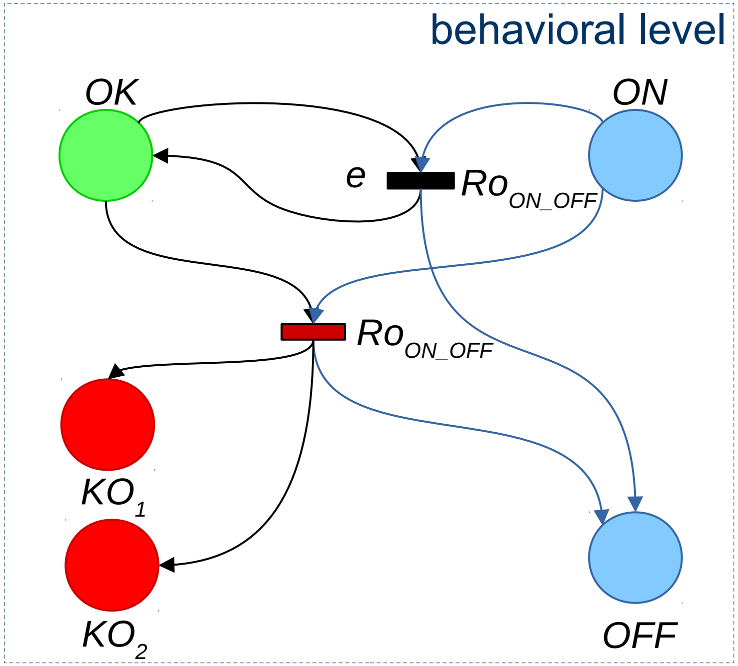

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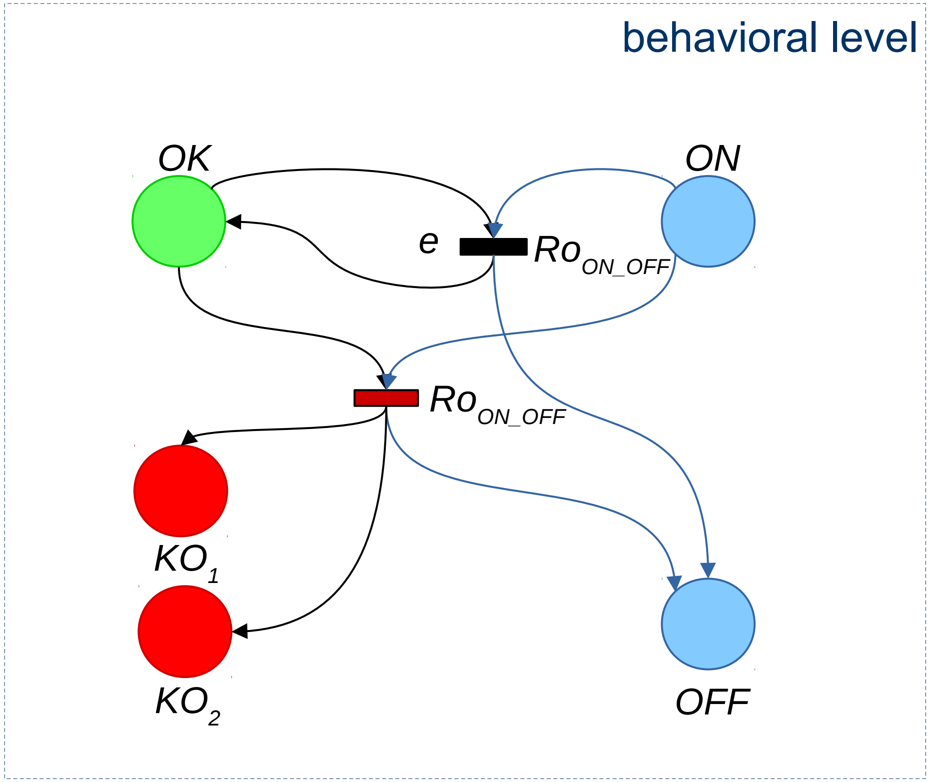
Introduction of health modes

- **Degradation** is an **hybrid information**
- Health modes are composed of one symbolic place and one numerical place



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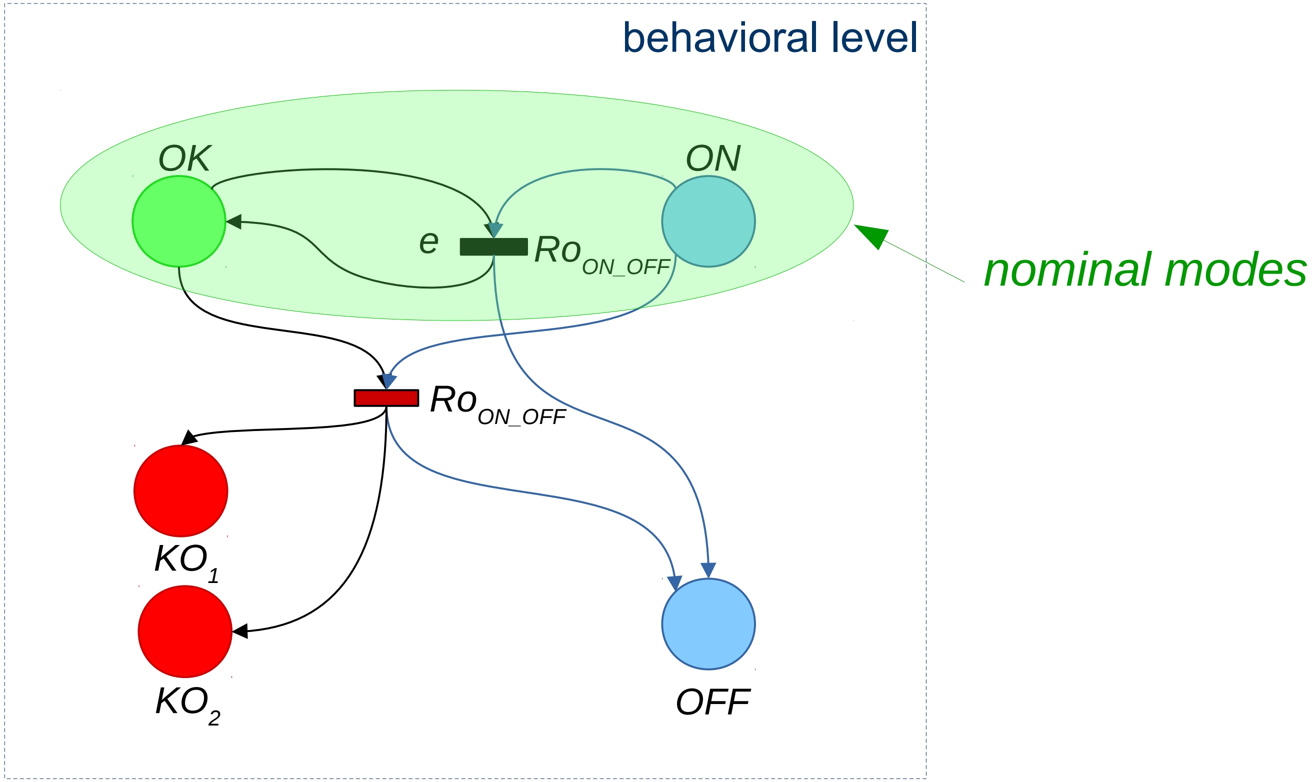

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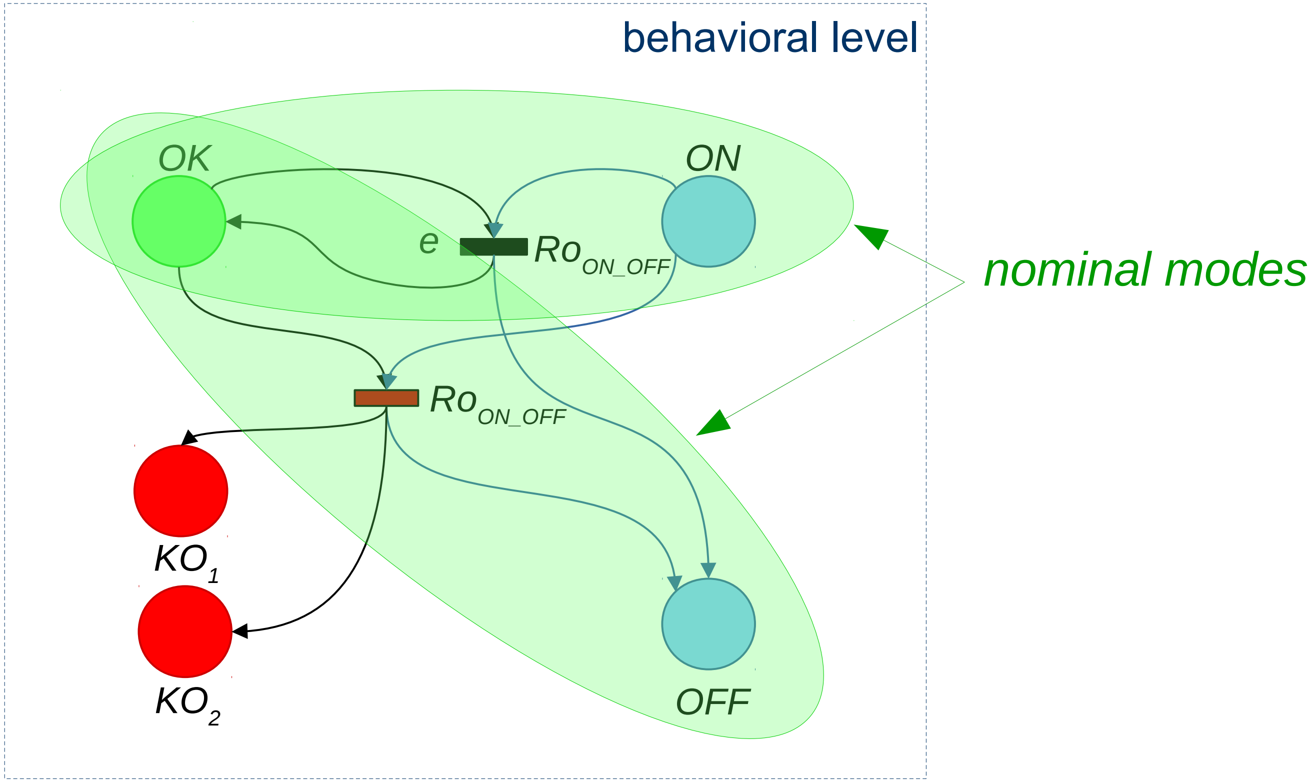

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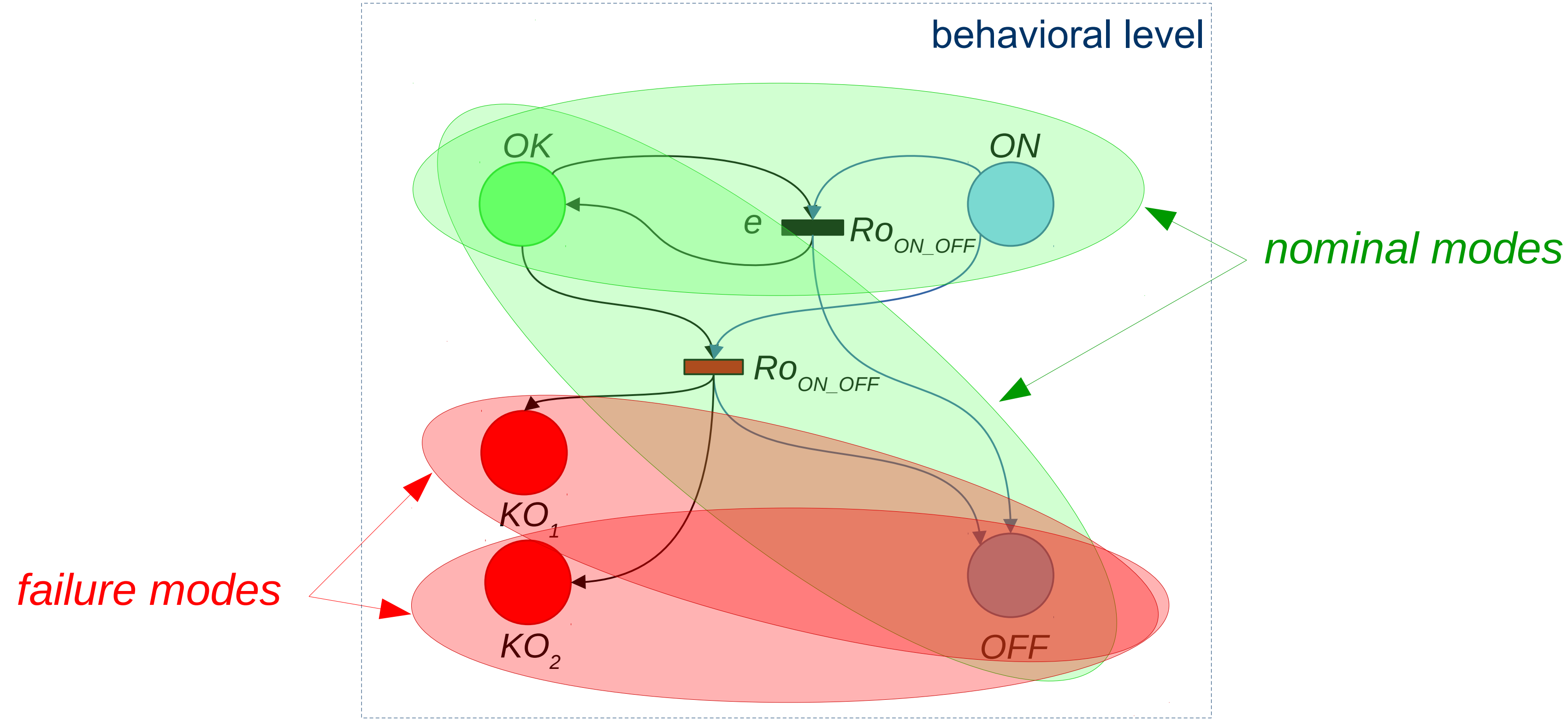

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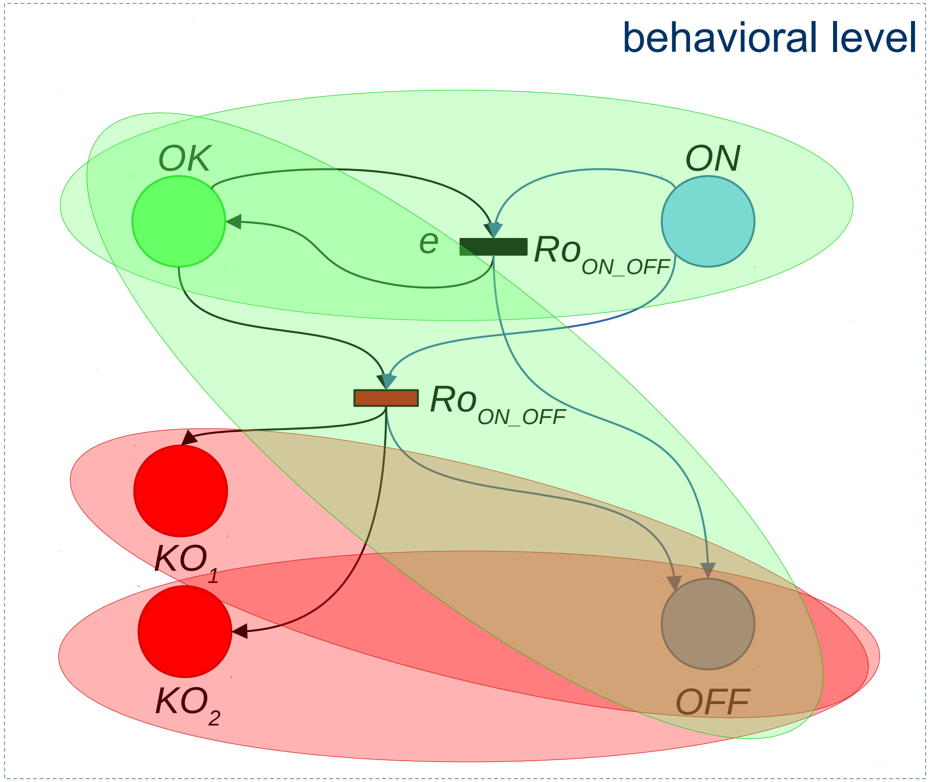
Introduction of a new “hybrid” level

- Creation of hybrid places
- Associate health mode degradation law to corresponding hybrid place
- MPPN are extended in **Hybrid Particle Petri Nets (HPPN)**



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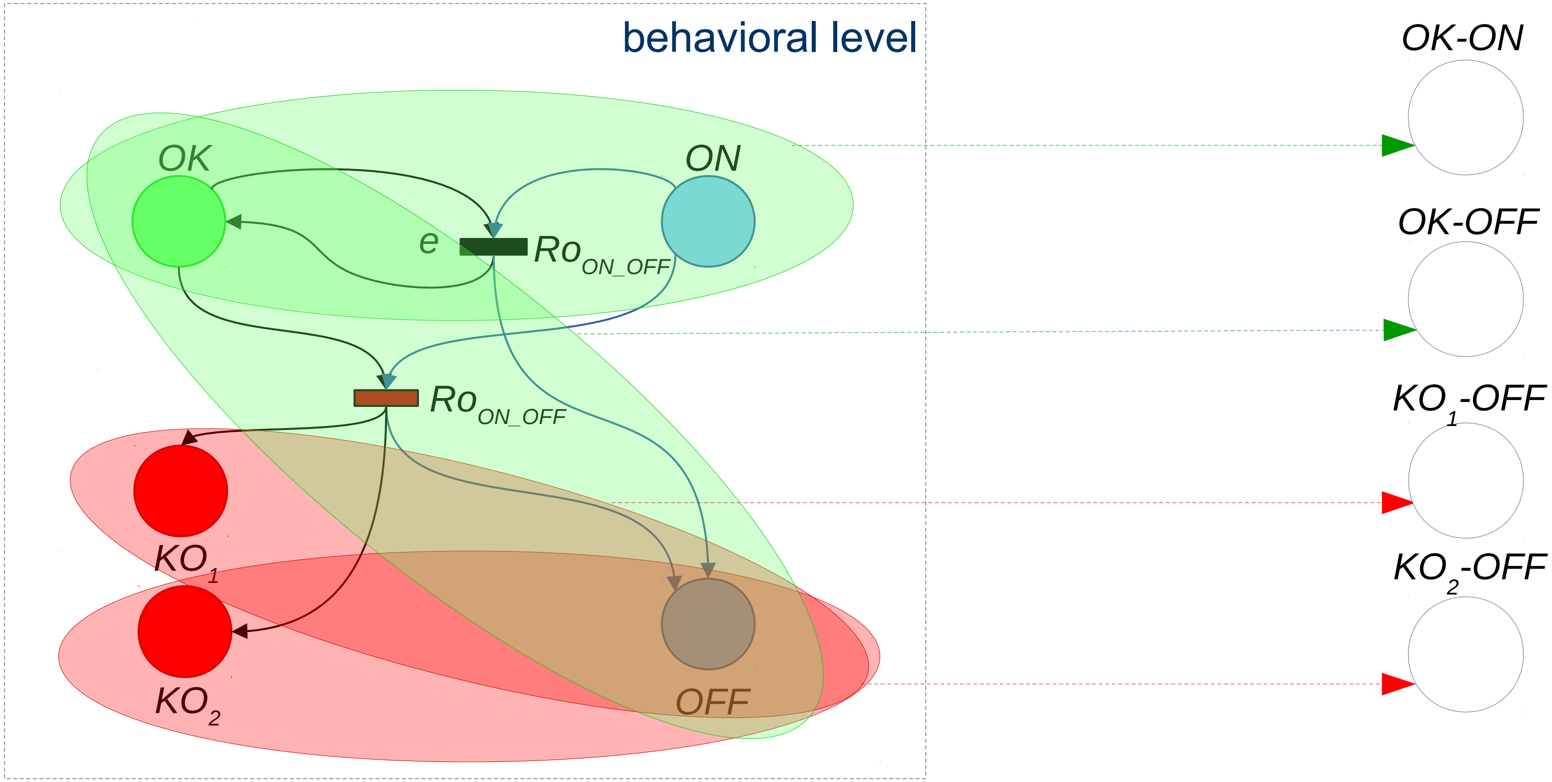

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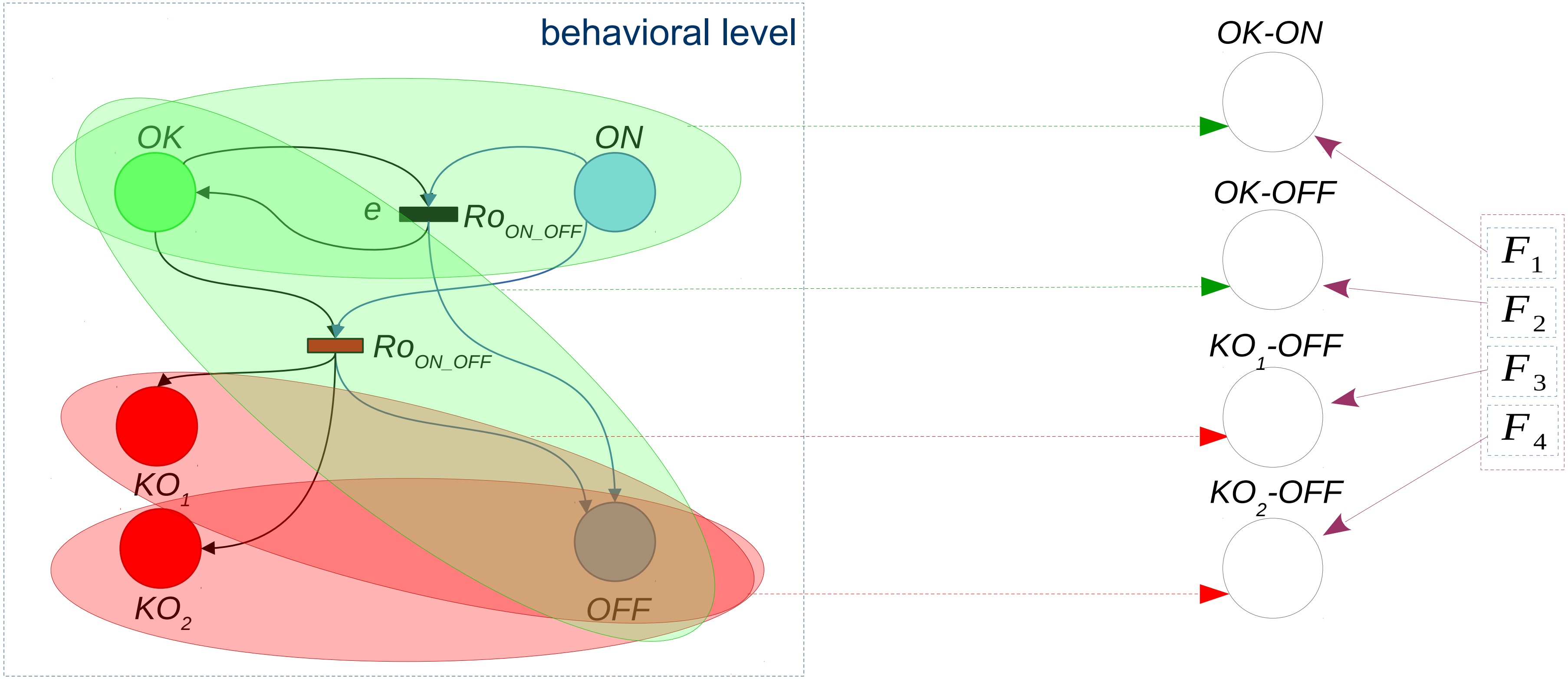

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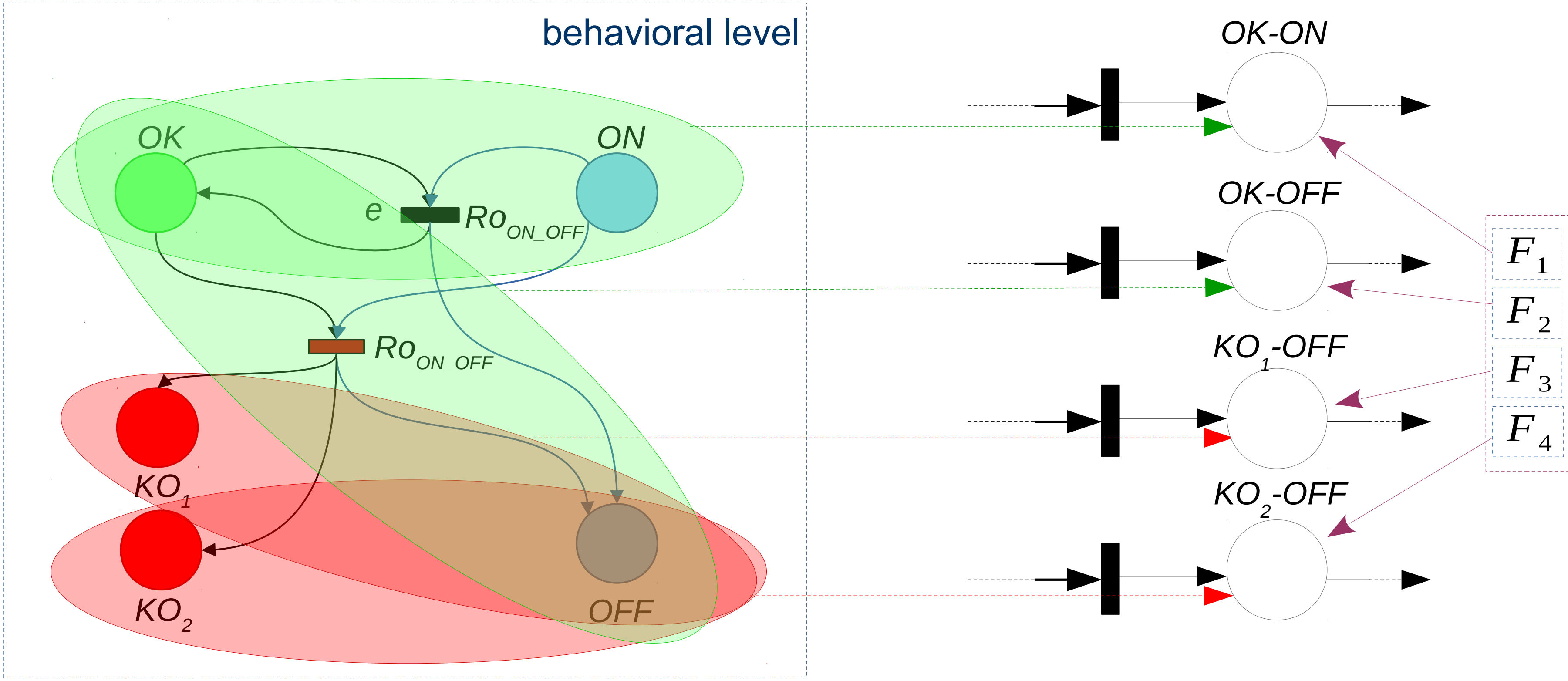

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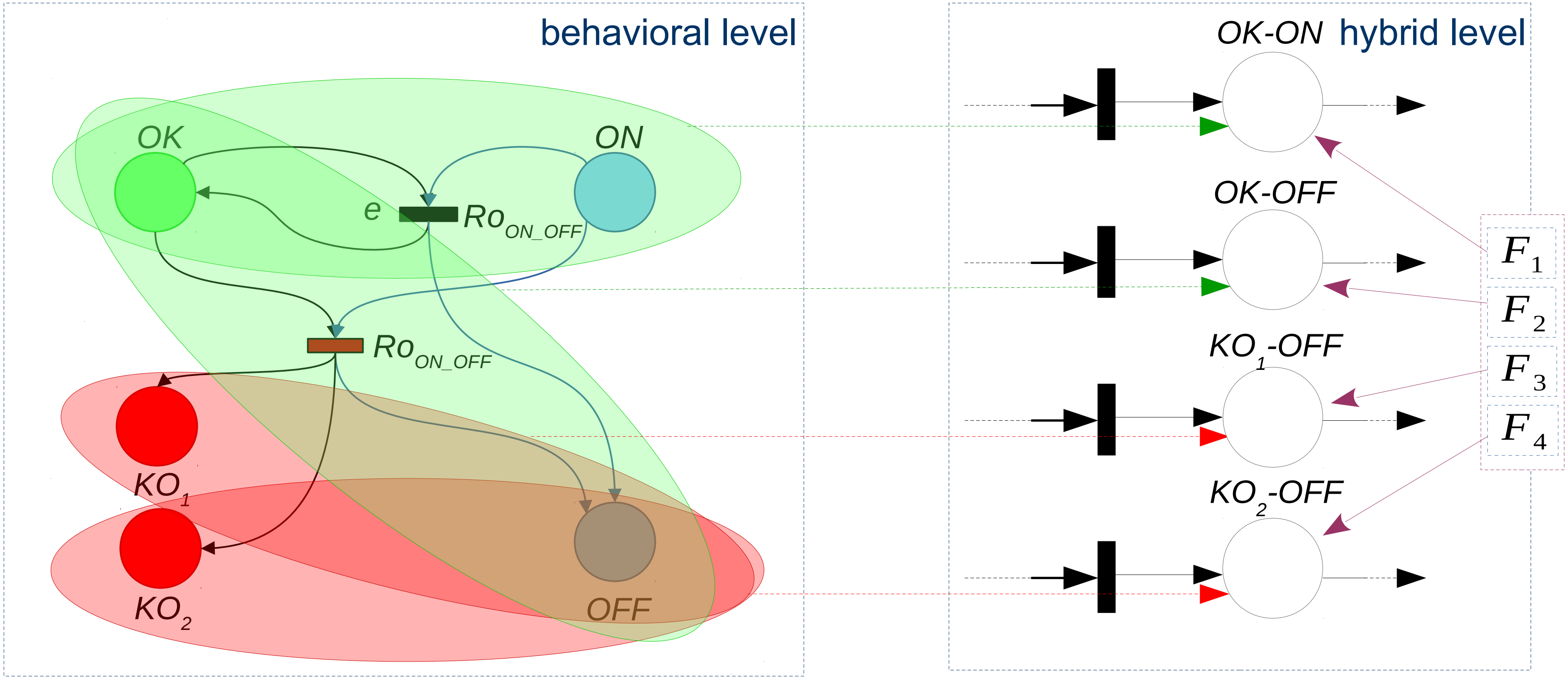

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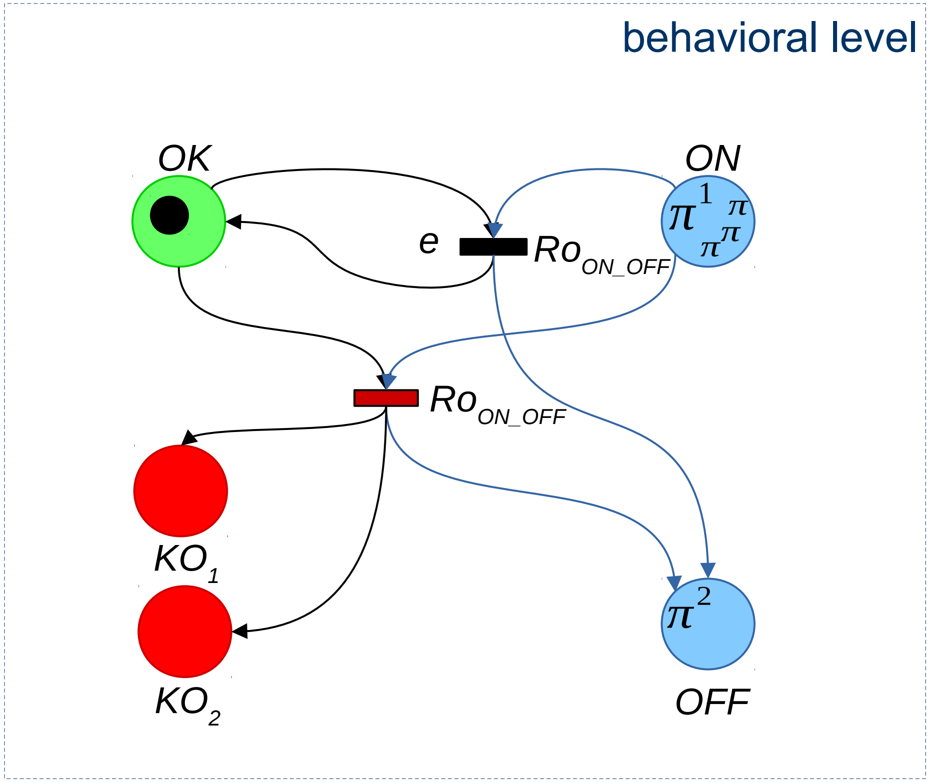
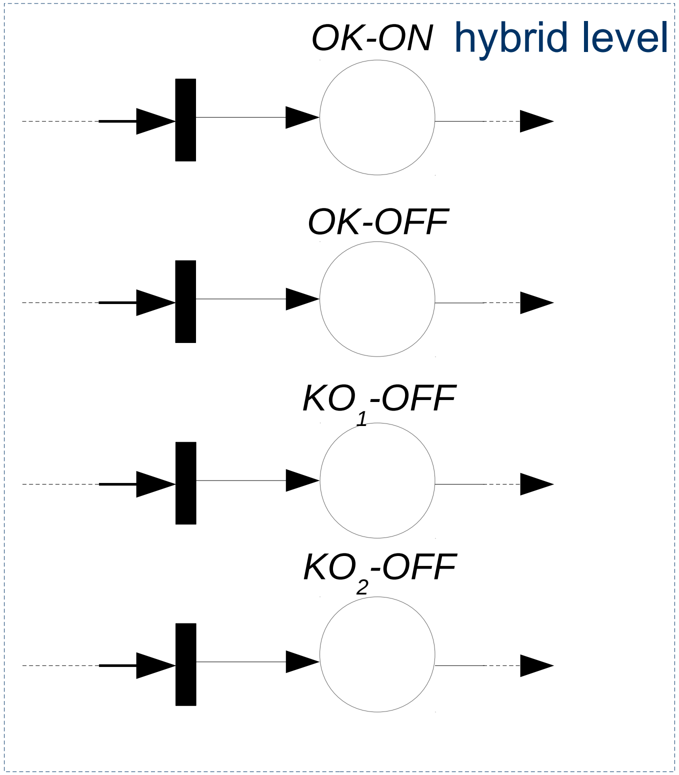
HPPN on line process

- New kind of tokens: hybrid tokens
- Hybrid tokens are associated with two token of the behavioral level





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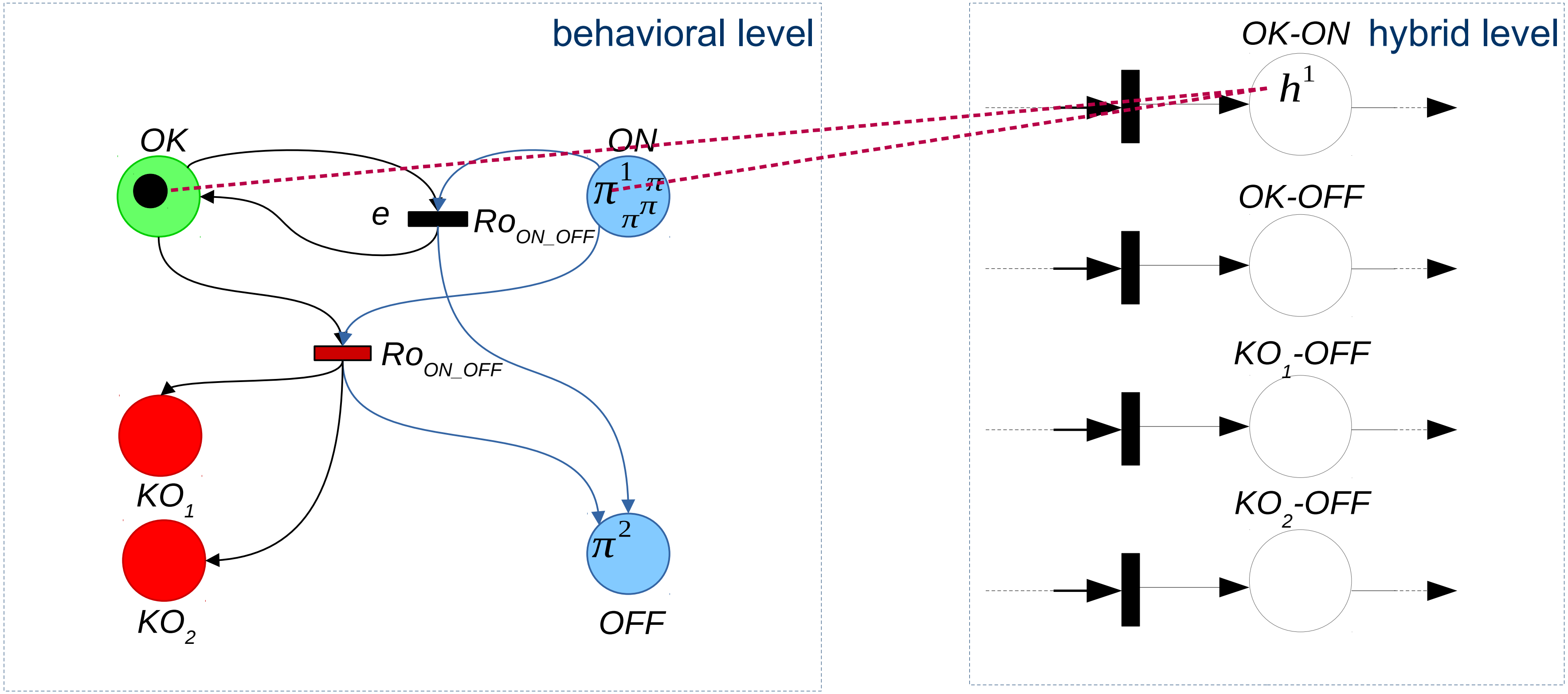

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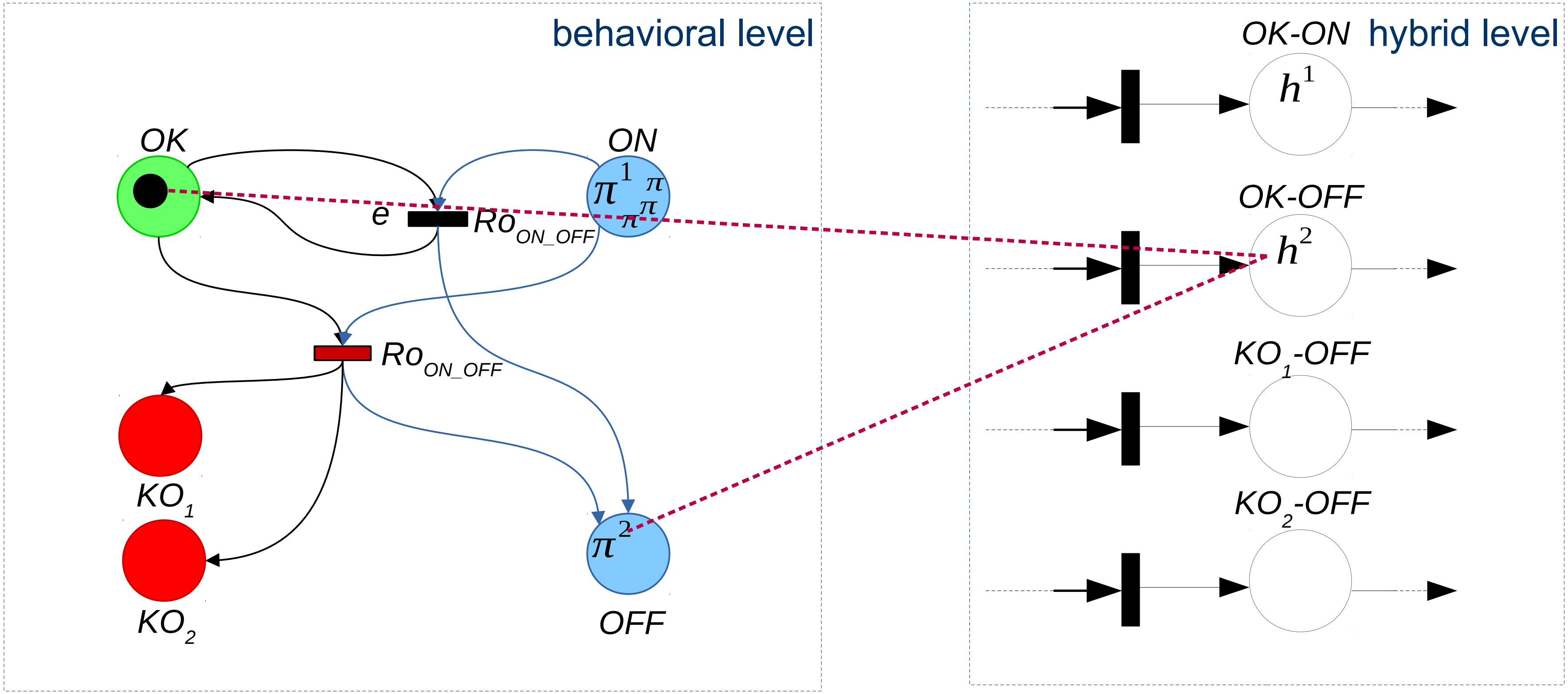

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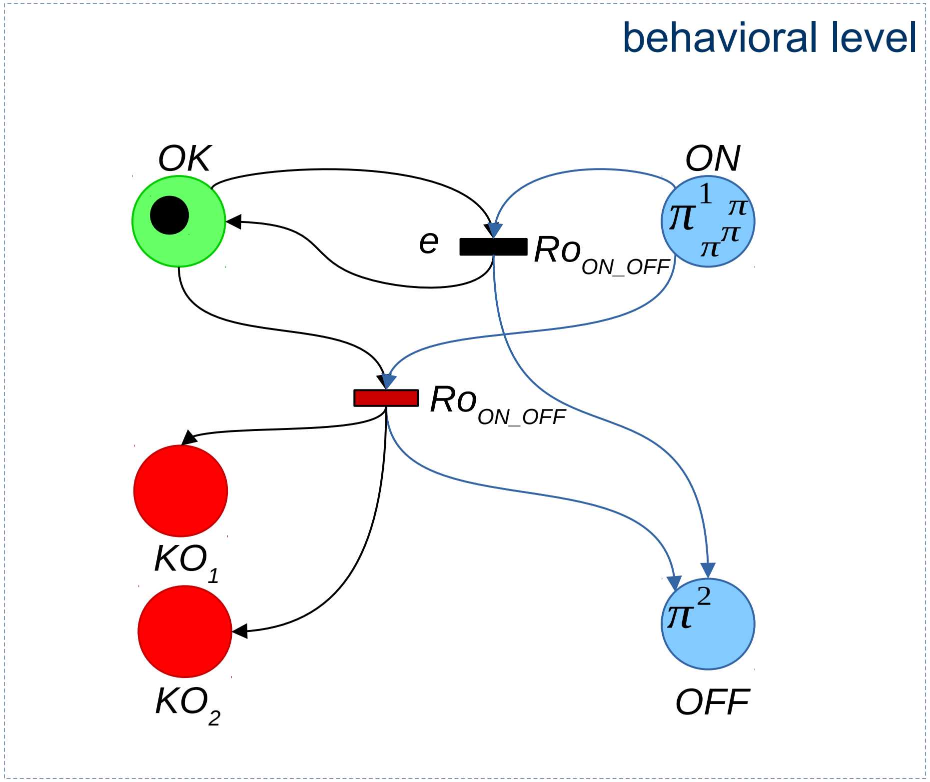

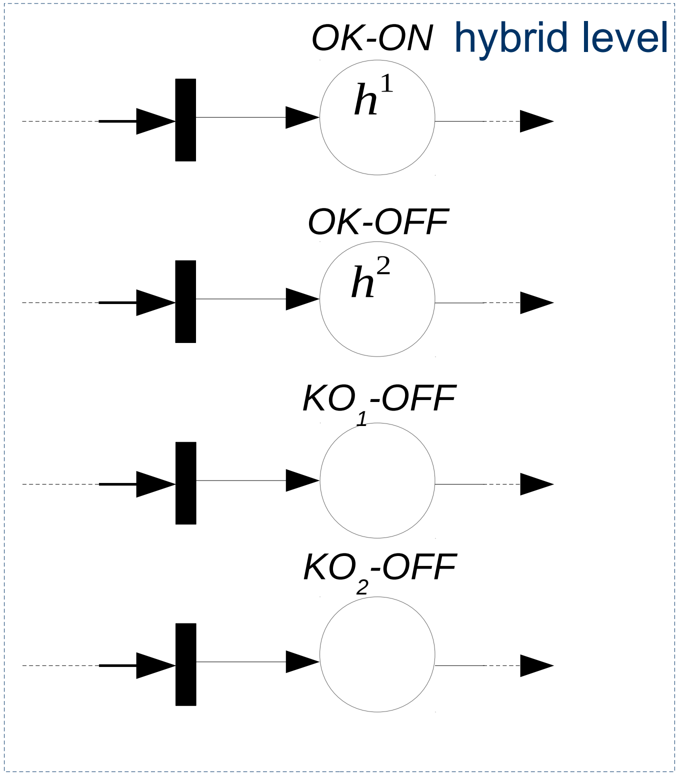

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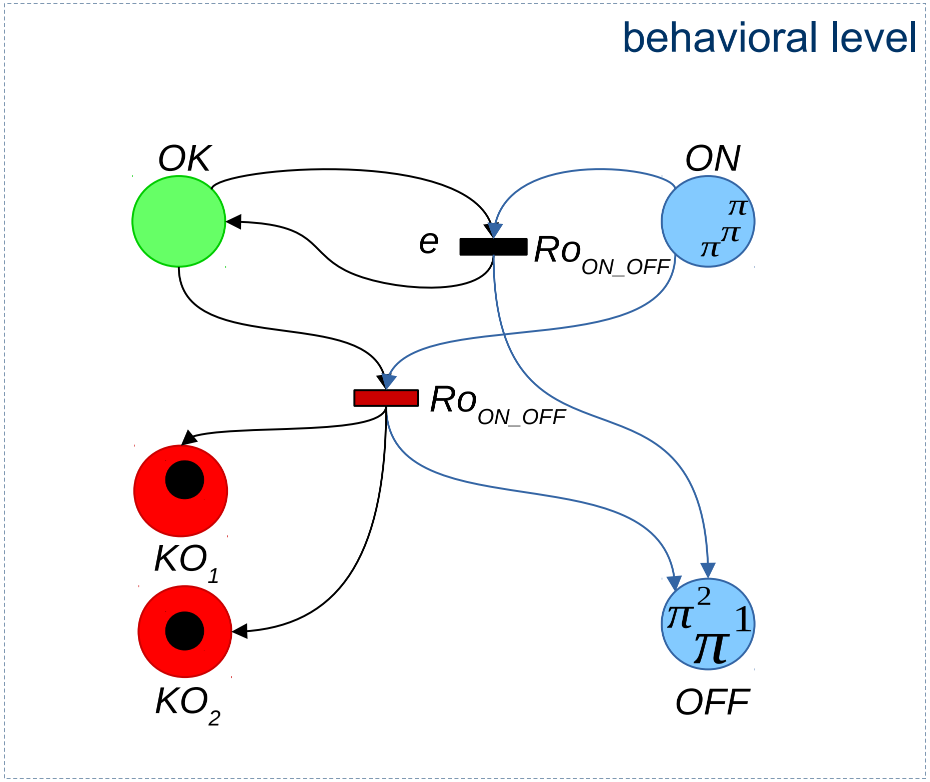

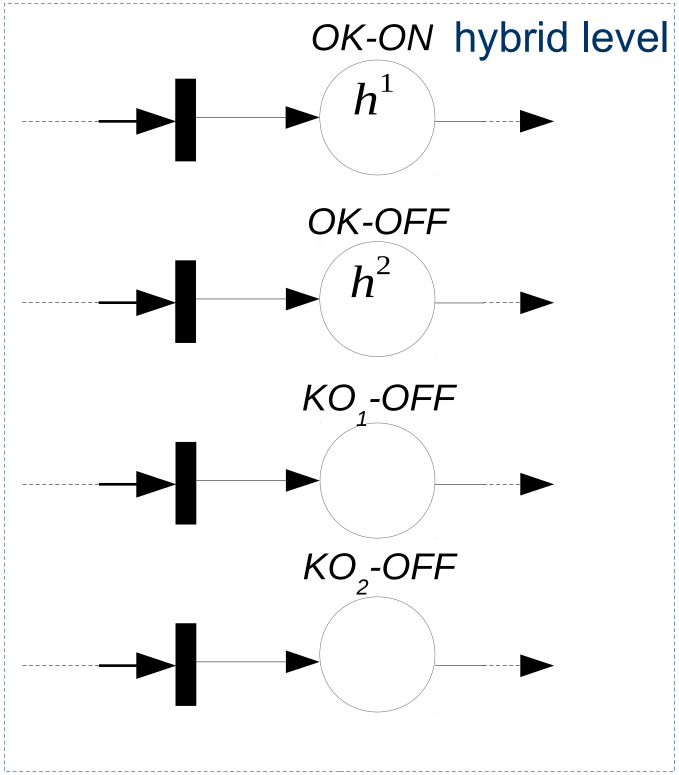

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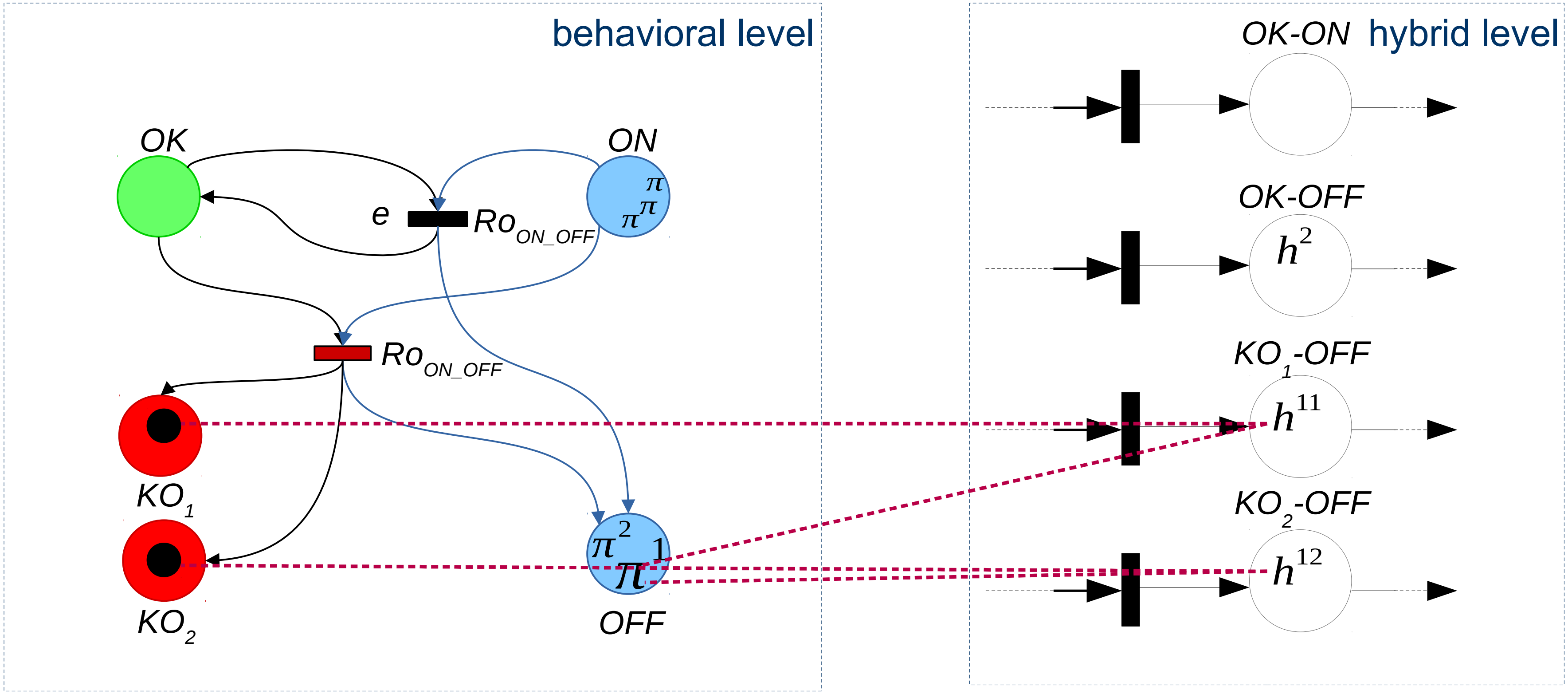

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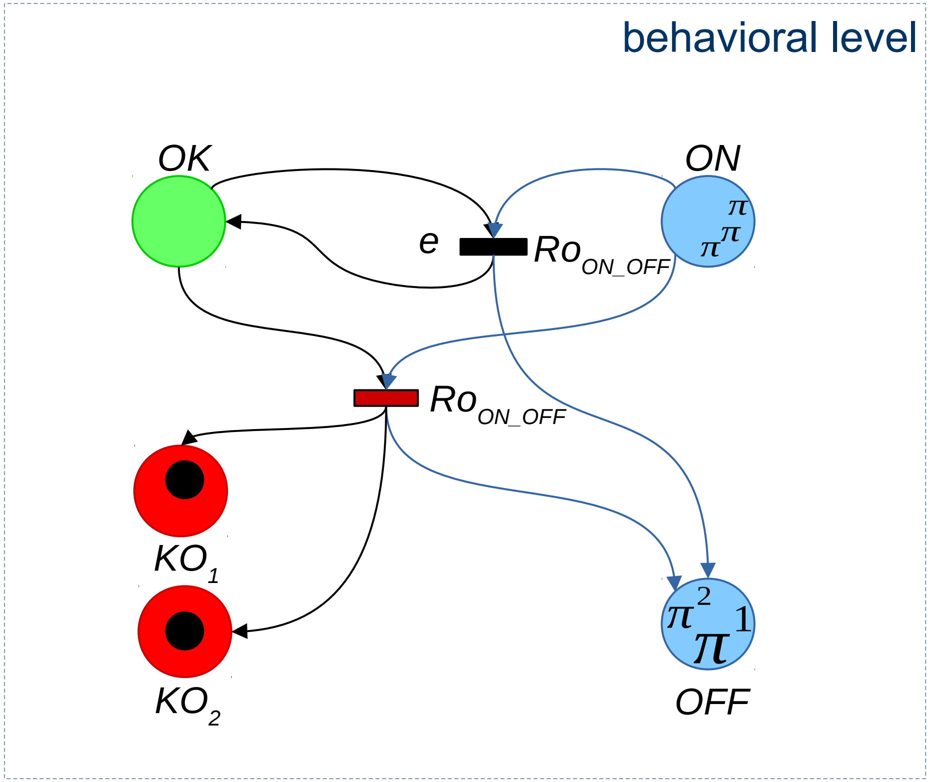

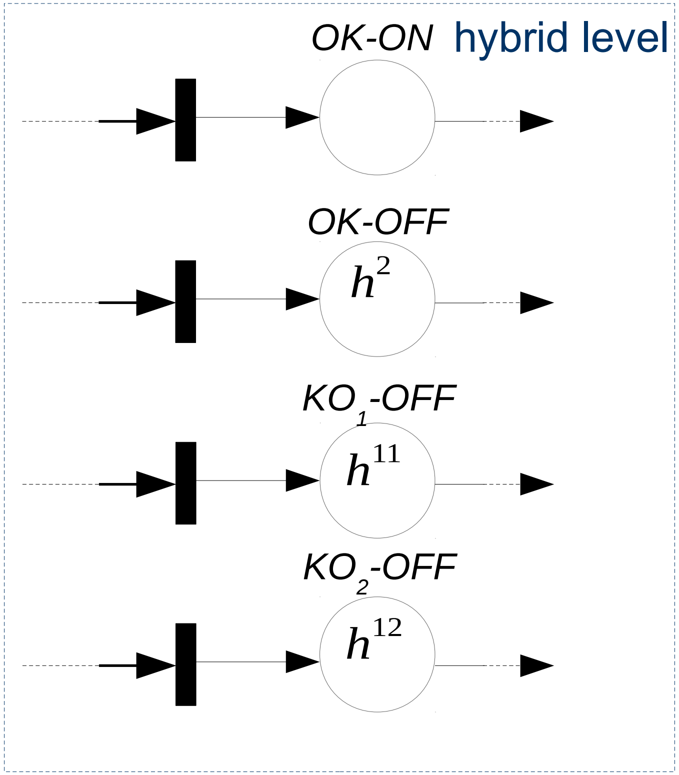

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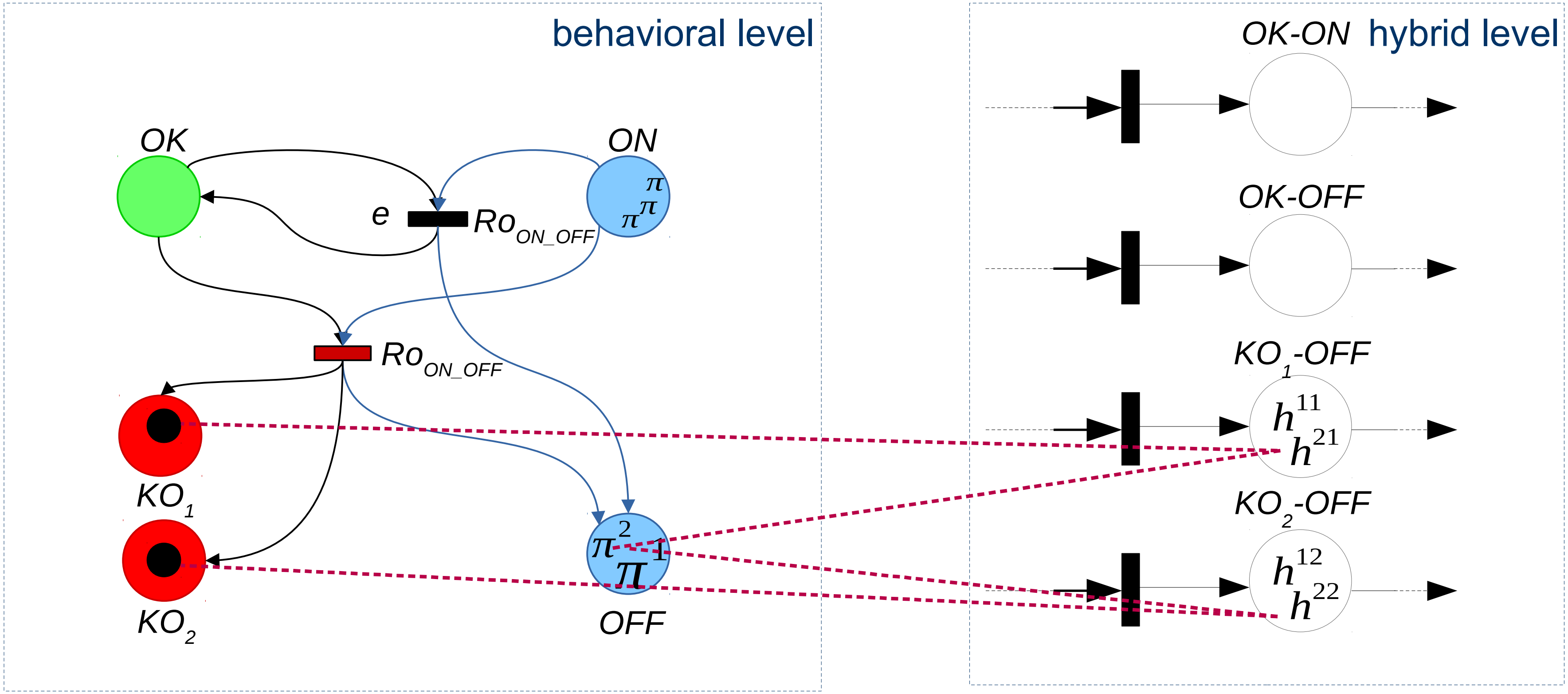

4. Methodology for degradation diagnosis

HPPN on line process

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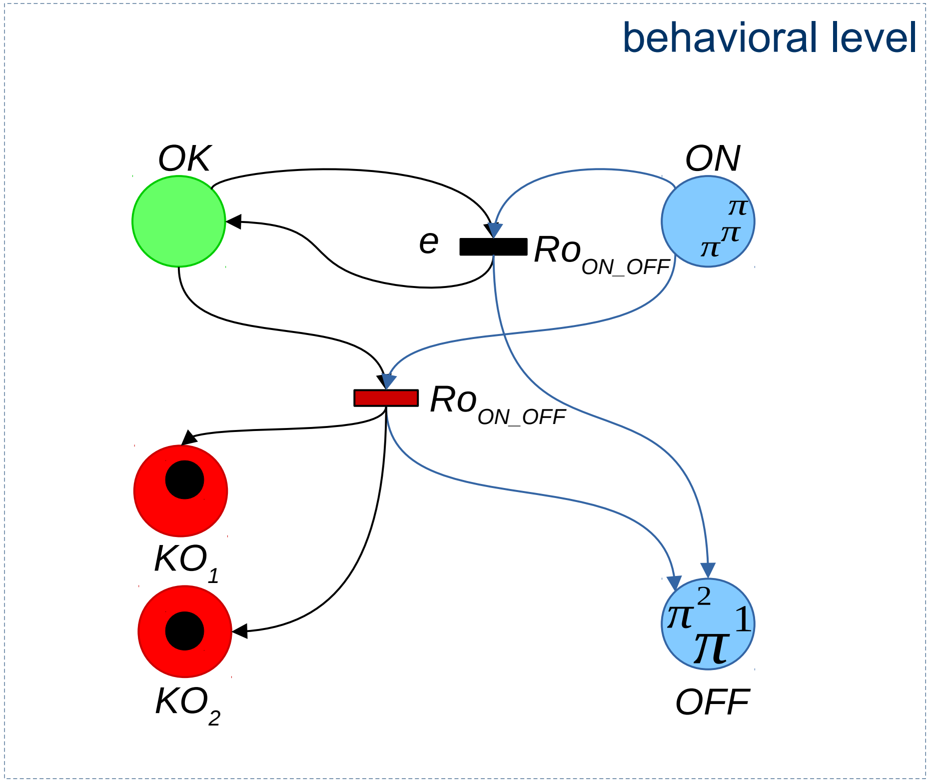

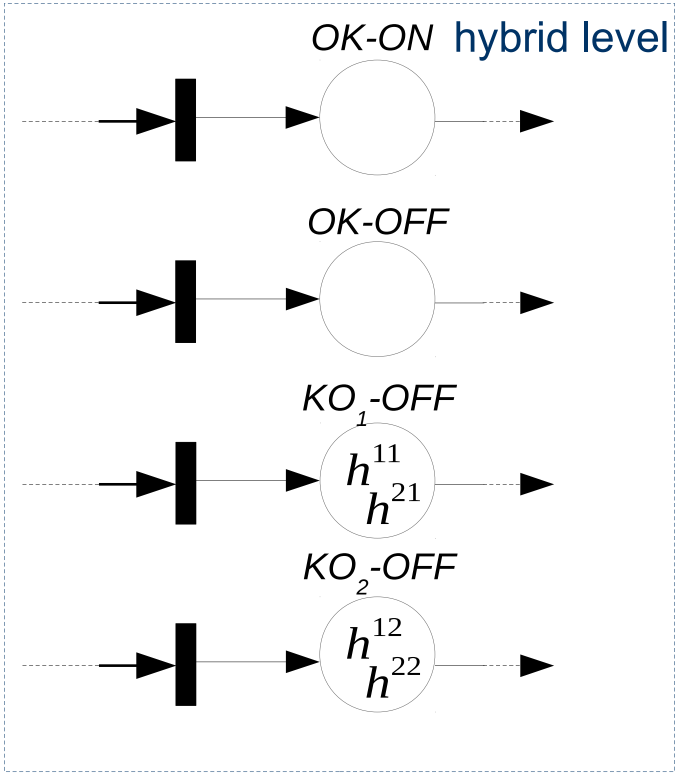

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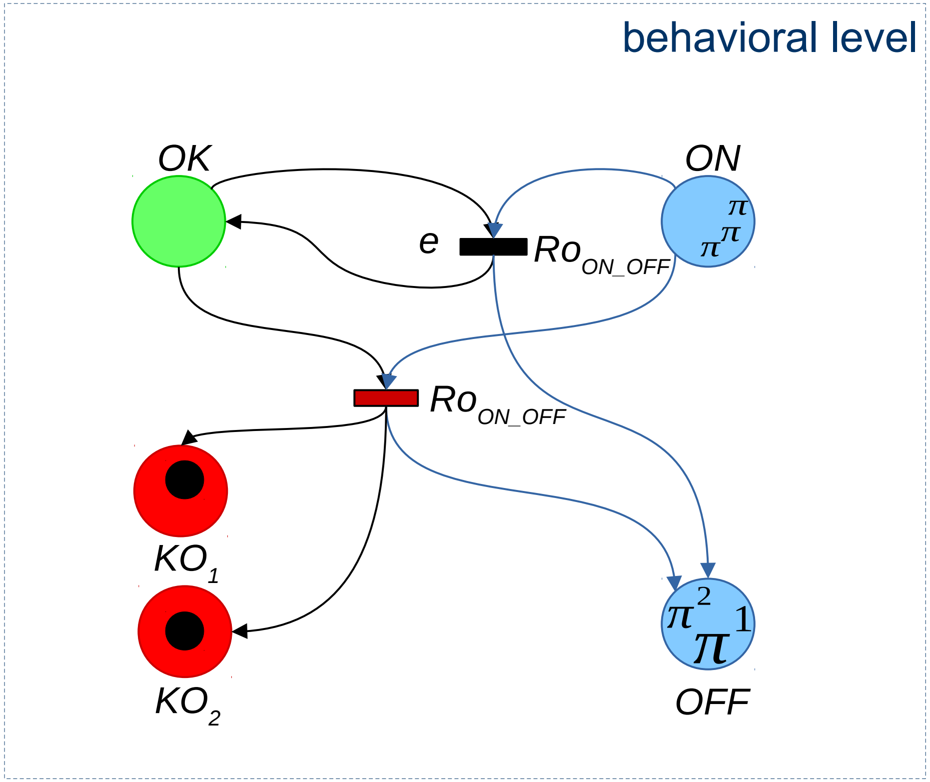
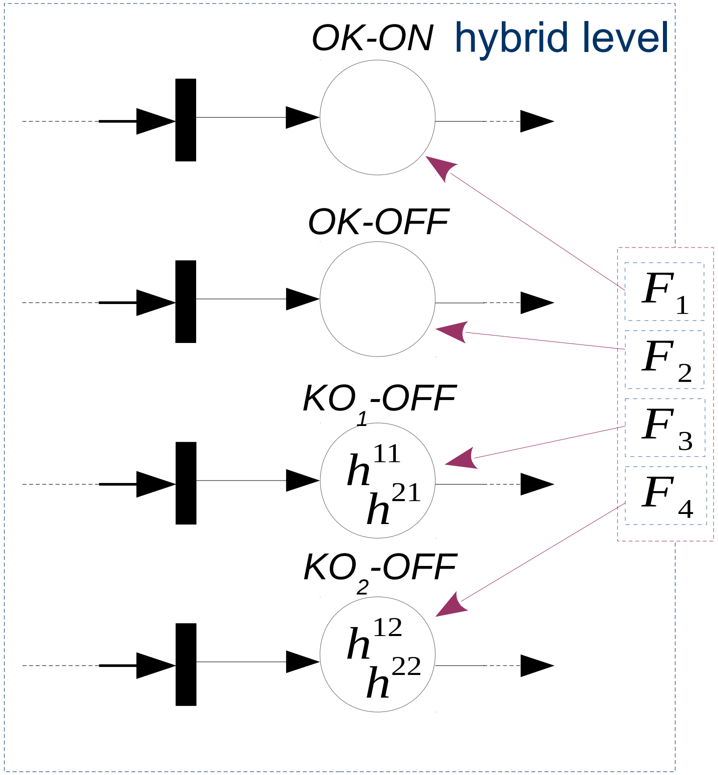
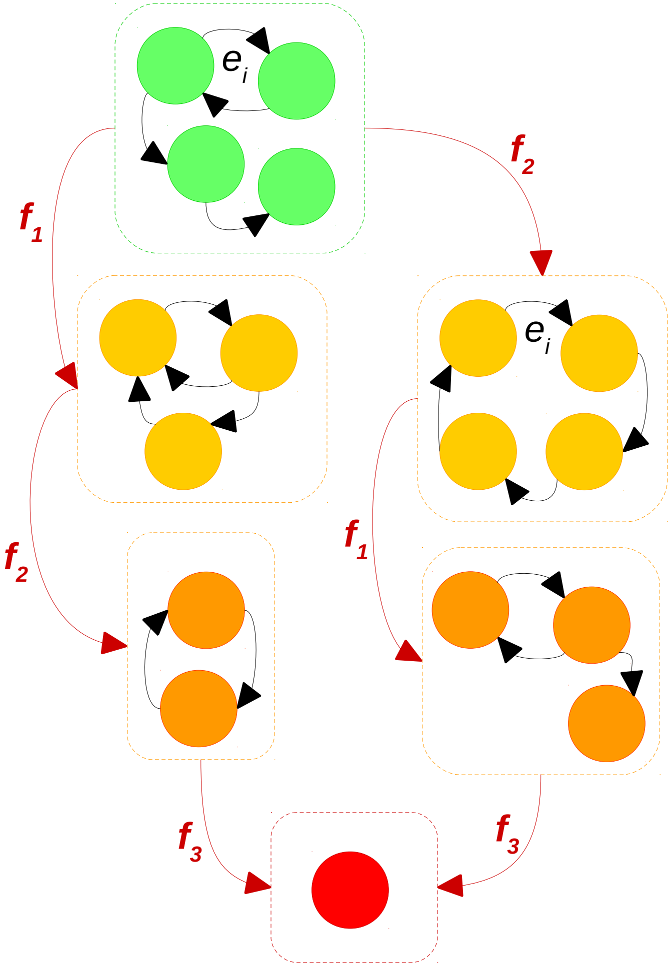




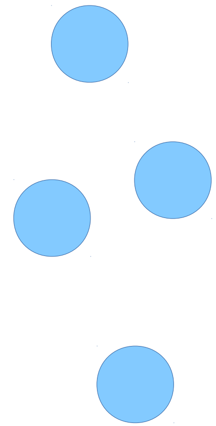
4. Methodology for degradation diagnosis

Hybrid Particle Petri Nets for diagnosis

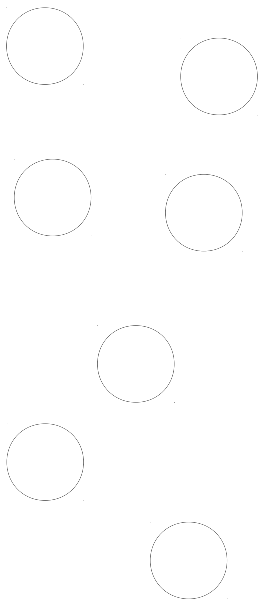
discrete states



continuous behaviors



hybrid dynamics



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Hybrid Particle Petri Nets for diagnosis

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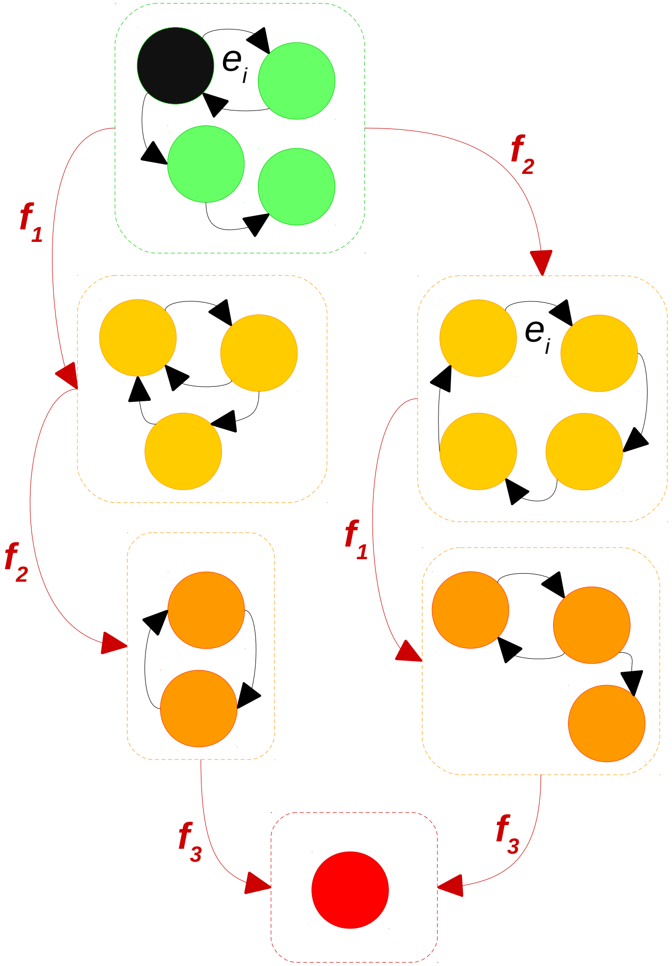

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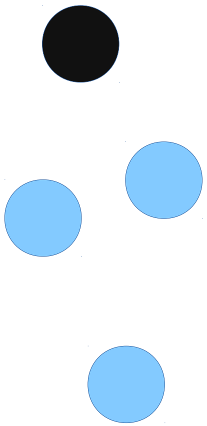

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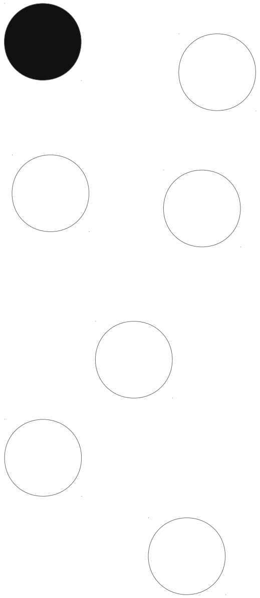
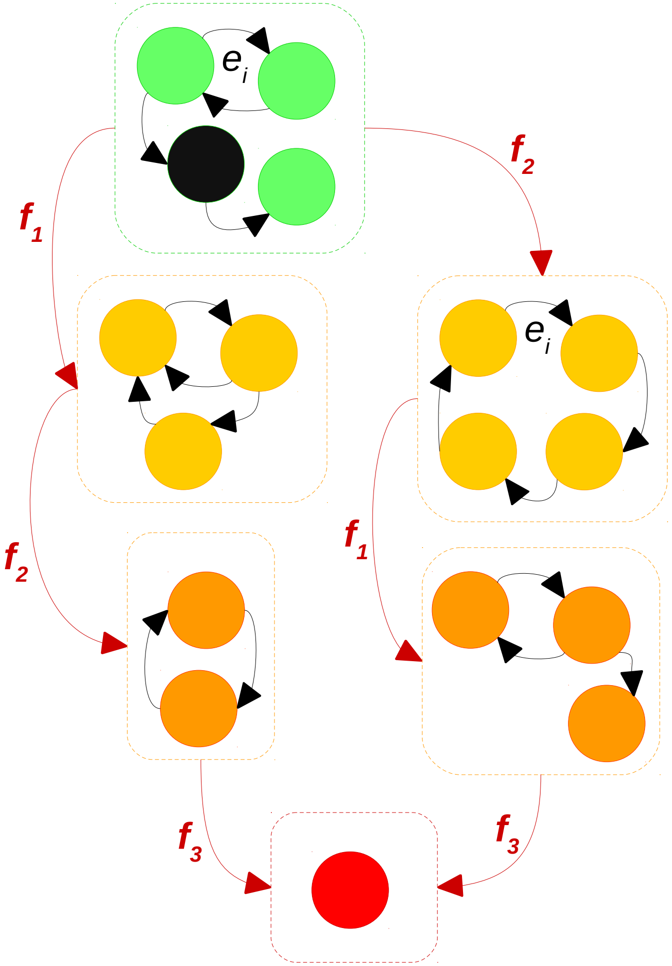


Hybrid Particle Petri Nets for diagnosis

discrete states



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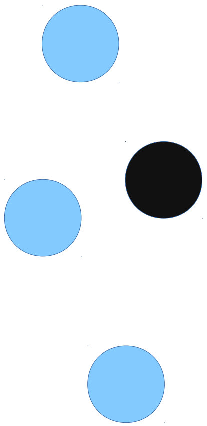
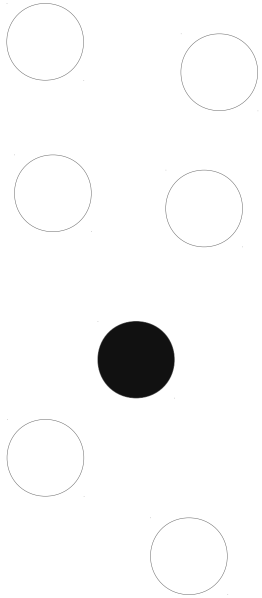


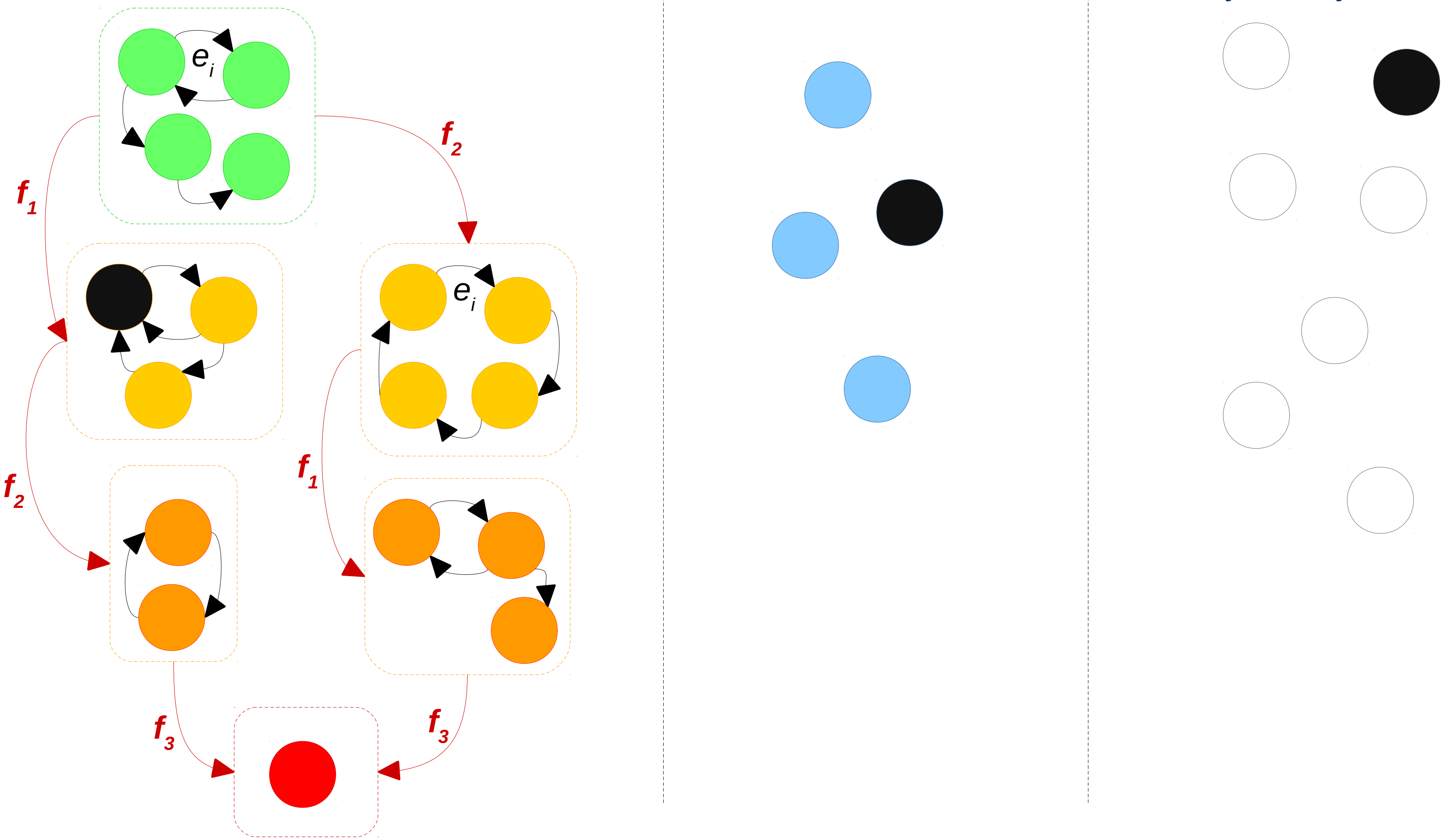
hybrid dynamics



4. Methodology for degradation diagnosis

Hybrid Particle Petri Nets for diagnosis

discrete states | continuous behaviors | hybrid dynamics



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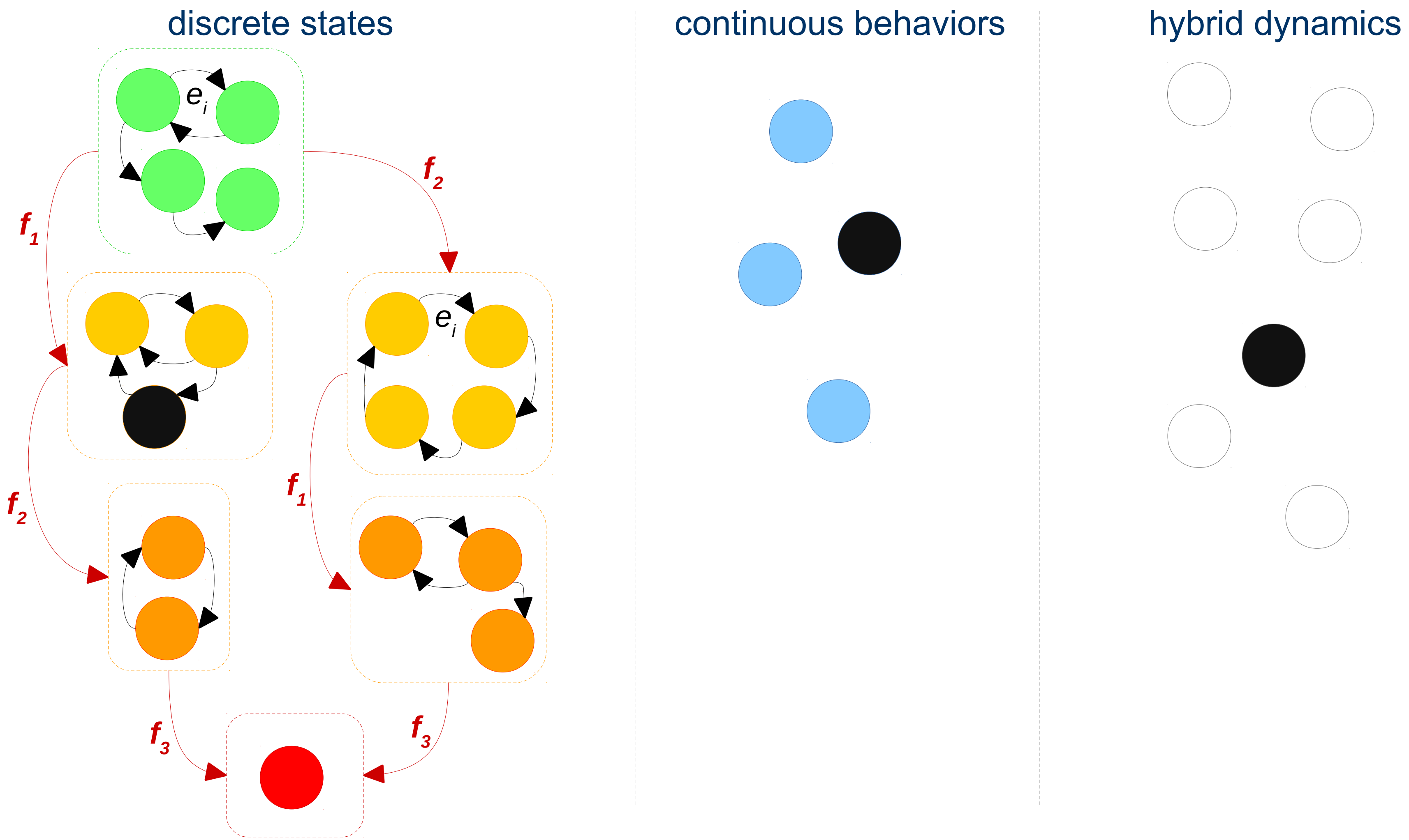
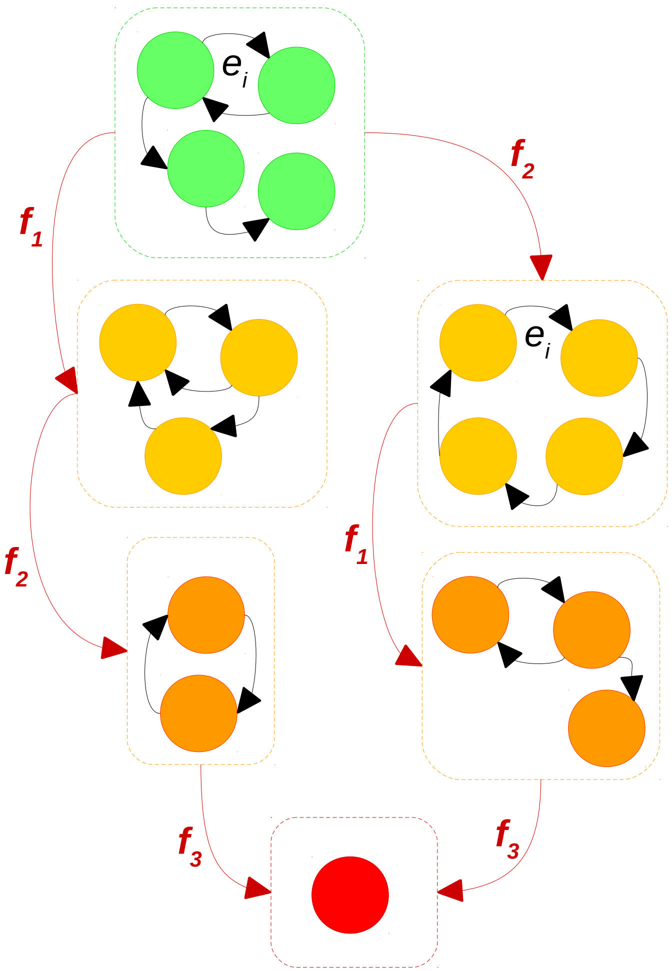
Hybrid Particle Petri Nets for diagnosis



4. Methodology for degradation diagnosis

Hybrid Particle Petri Nets for diagnosis

discrete states



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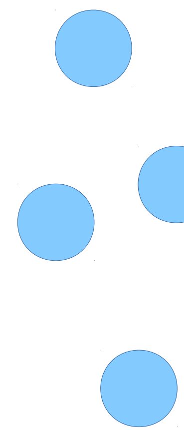
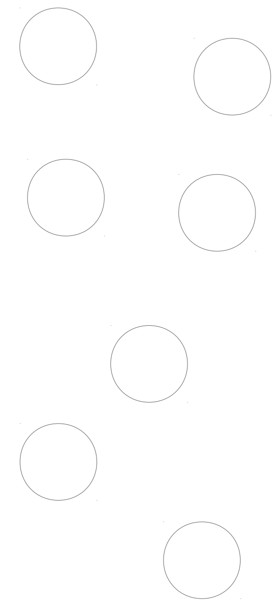


hybrid dynamics



$P^S \cup P^N \cup P^H$

$T^S \cup T^N \cup T^M \cup T^H$

$\Omega^S \cup \Omega^N \cup \Omega^H$

$$HPPN = (P, T, Pre, Post, X, C, H, F, \gamma, \Omega, M_0)$$

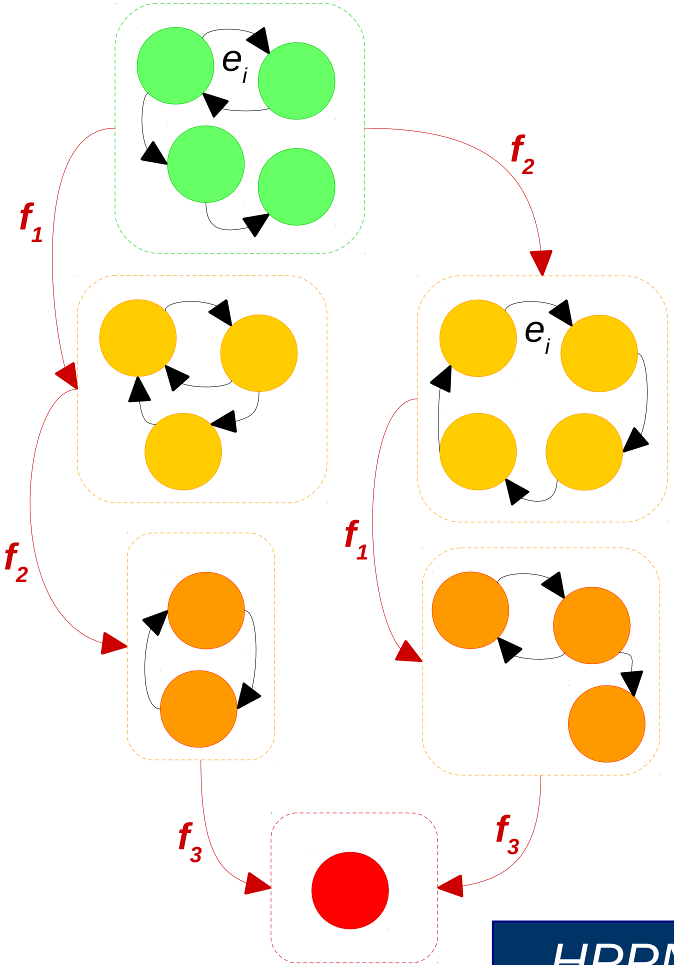
State space of the numerical hybrid vector

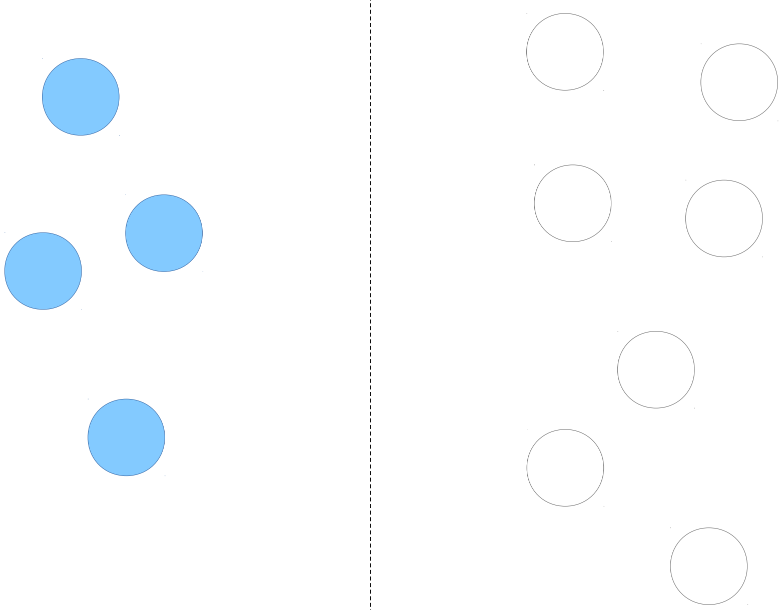
Set of dynamics equations associated with hybrid places

4. Methodology for degradation diagnosis

Hybrid Particle Petri Nets for diagnosis

discrete states | continuous behaviors | hybrid dynamics





$P^S \cup P^N \cup P^H$ $\quad$ $T^S \cup T^N \cup T^M \cup T^H$ $\quad$ $\Omega^S \cup \Omega^N \cup \Omega^H$

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State space of the numerical hybrid vector

Set of dynamics equations associated with hybrid places

HPPN are a nice toolkit for modelers

Conclusion & future work

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- **Definition of a new HPPN formalism to monitor hybrid system** by enriching the MPPN formalism
- Application of the **HPPN for behavioral and degradation diagnosis** of hybrid systems
- Illustration of the proposed method on an academic example

Conclusion & future work

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- Illustration of the proposed method on an academic example

Future work

- Implement and **test** the proposed framework
- **Introduce model-based prognosis** method into the proposed framework
- Test the health management architecture on a **mobile or flying robot**

Related works

Main related work

- Chanthery, E., & Ribot, P. (2013). **An integrated framework for diagnosis and prognosis of hybrid systems**. In *3rd Workshop on Hybrid Autonomous System (HAS)*. Roma, Italy.

- Zouaghi, L., Alexopoulos, A., Wagner, A., & Badreddin, E. (2011a). **Modified particle petri nets for hybrid dynamical systems monitoring under environmental uncertainties**. In *IEEE/SICE International Symposium on System Integration (SII)* (pp. 497–502).

- Gaudel, Q., Chanthery, E., Ribot, P., & Le Corronc, E. (2014). **Hybrid systems diagnosis using modified particle petri nets**. In *Proceedings of the 25th International Workshop on Principles of Diagnosis (DX'14)*. Graz, Austria.

- Gaudel, Q., Chanthery, E., & Ribot, P. (2014). **Health Monitoring of Hybrid Systems Using Hybrid Particle Petri Nets**. In *Proceedings of the Annual Conference of the Prognostics And Health Management Society 2014 (PHM'14)*. Fort Worth, Texas, USA.

Conclusion

Health Monitoring of Hybrid System Using Hybrid Particle Petri Nets

Thank you! Any question?

Key words:

- Hybrid systems
- Model-based diagnosis under uncertainty
- Behavioral diagnosis
- Degradation diagnosis
- Health management architecture
- Hybrid particle Petri nets