Université de Toulouse

LAAS-CNRS

Safety MOnitoring Framework (SMOF)

https://www.laas.fr/projects/smof/

Jérémie Guiochet

LAAS-CNRS

Université de Toulouse

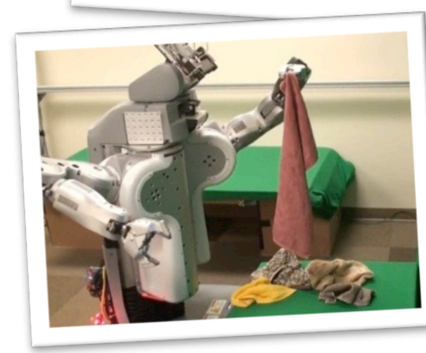
Jeremie.guiochet@laas.fr

http://homepages.laas.fr/guiochet

4th Scandinavian Conference - System and Software Safety, Stokholm, SW, 16-17 of March

Dependable autonomous robots

- Autonomous applications : Complex, evolving in unstructured environment, versatile, networked
- Fault model
  - Development Faults (e.g.,in autonomous SW)
  - Physical Faults (e.g., hardware)
  - Interaction Faults (e.g.,human-robot interactions)
  - Other « faults »:
    - Uncertainties (e.g., in perception, heuristics)
    - Adverse situations (e.g., unexpected hazards)



Fault **Avoidance**

Fault **removal** & prevention

→ Residual faults →

Fault Acceptation

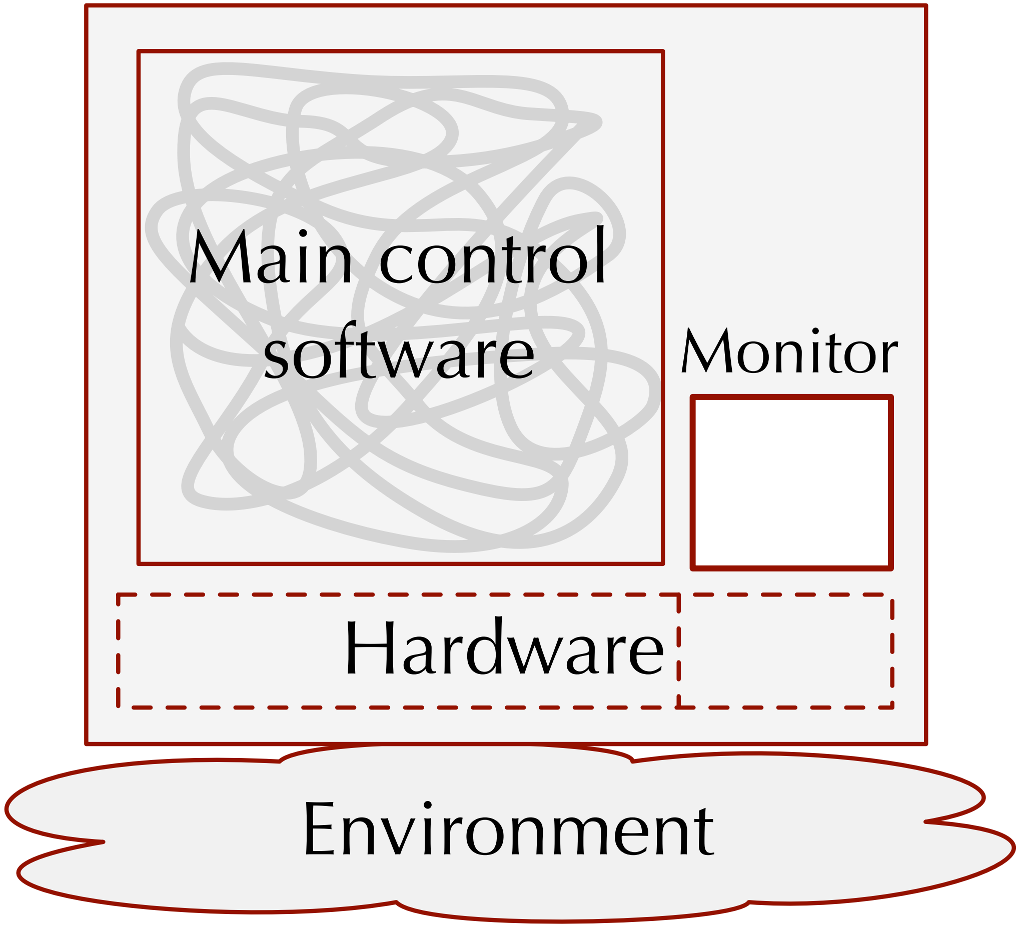
Fault forecasting & tolerance

Dependable robots@laas

- Phds :
  - Execution Monitoring (2005) , Diverse task planning (2007), Robustness testing (2011), Safety monitoring (2012), Safety analysis for human-robot interactions (2015), Safety monitoring (with synthesis) (2015), Testing autonomous robots in virtual worlds, Multi-level safety monitoring

- Recent collaborative European projects :
  - **CPS Engineering Labs**: cyber physical systems, European H2020-ICT, 2015-2018
  - **SAPHARI** : Safe and Autonomous Physical Human-Aware Robot Interaction, FP7 European Project, 2011-2014
  - **PHRIENDS**: Physical Human-Robot Interaction: depENDability and Safety, FP6 European project, 2006-2009

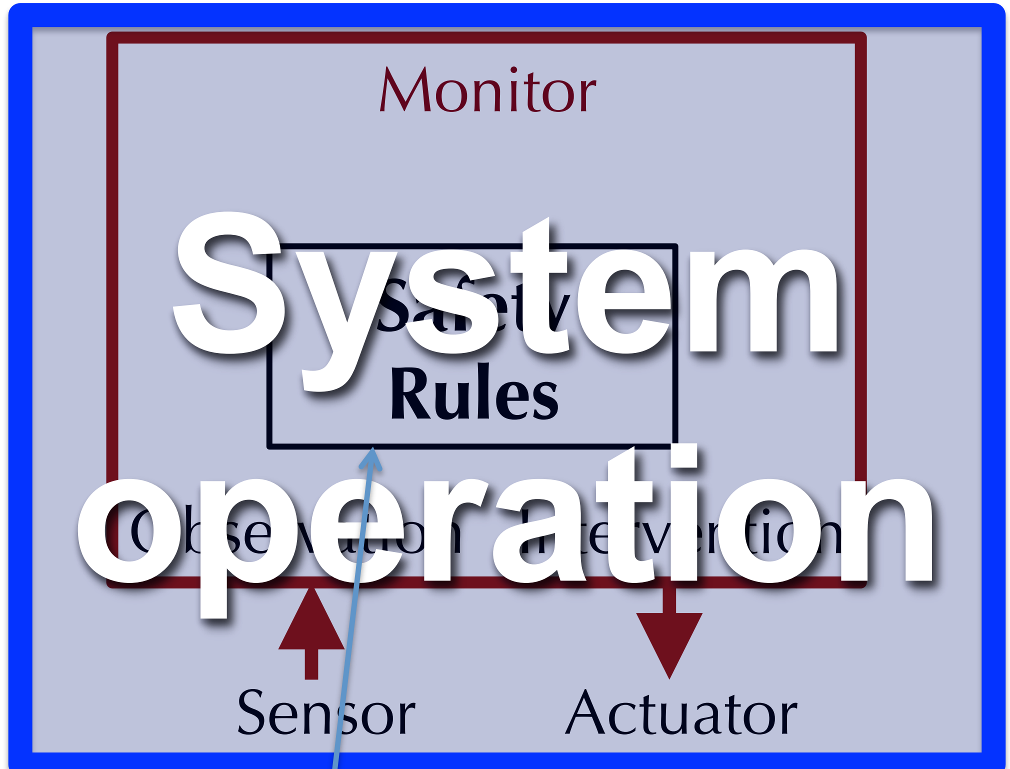
Active safety monitor



Safety Rules

Properties required from the monitor:

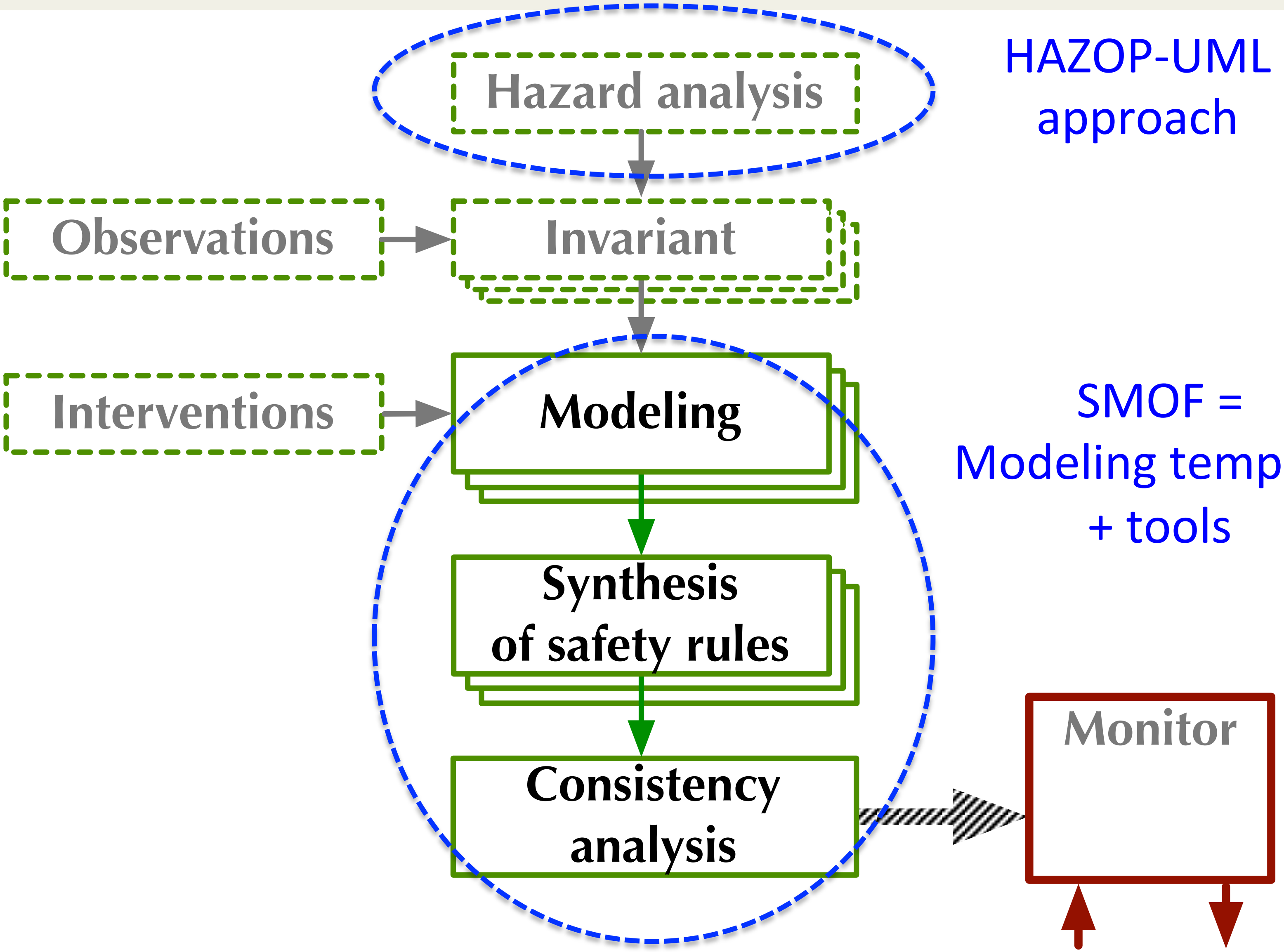
- Safety
- Permissiveness



⇒ Specification of the safety rules

System design

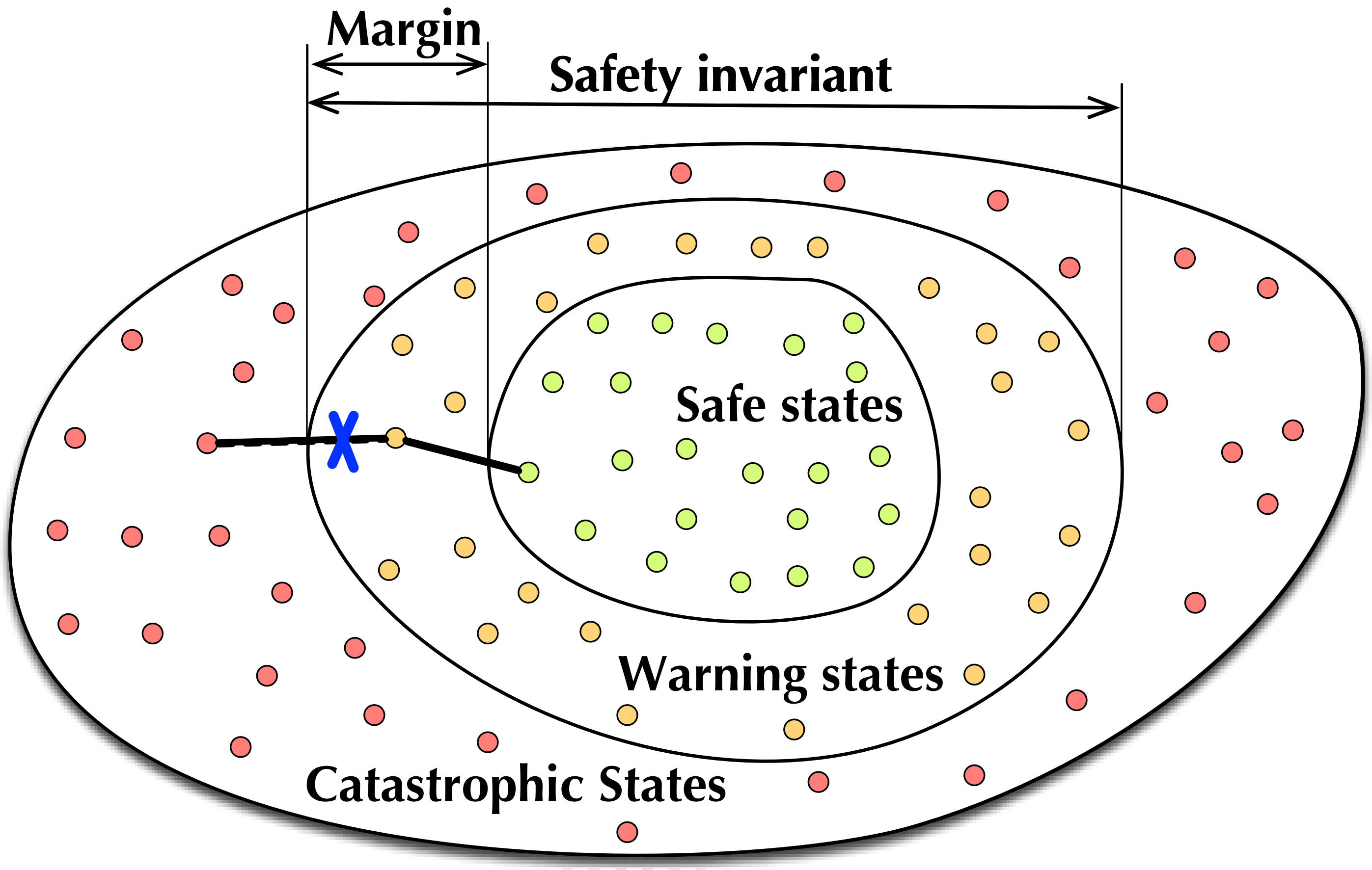
Method



HAZOP-UML approach

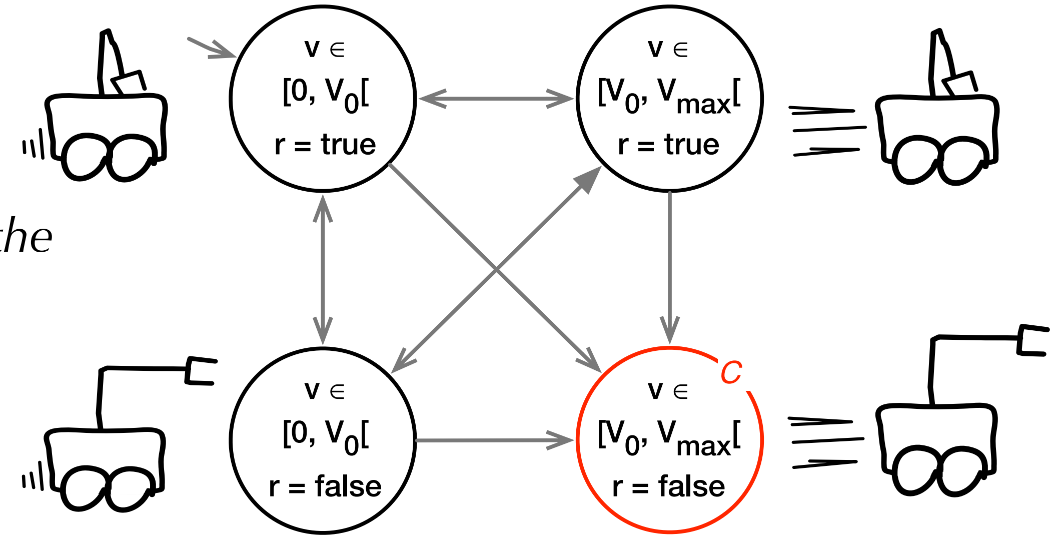
SMOF = Modeling template + tools

Concepts: margin, warning states



- A safety rule assigns interventions to warning states
- A **strategy** is a set of safety rules intended to ensure an invariant

Toy example

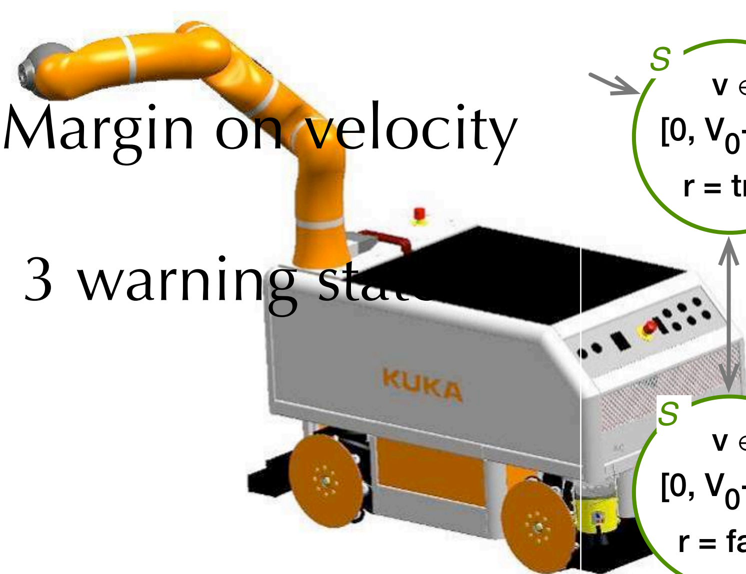


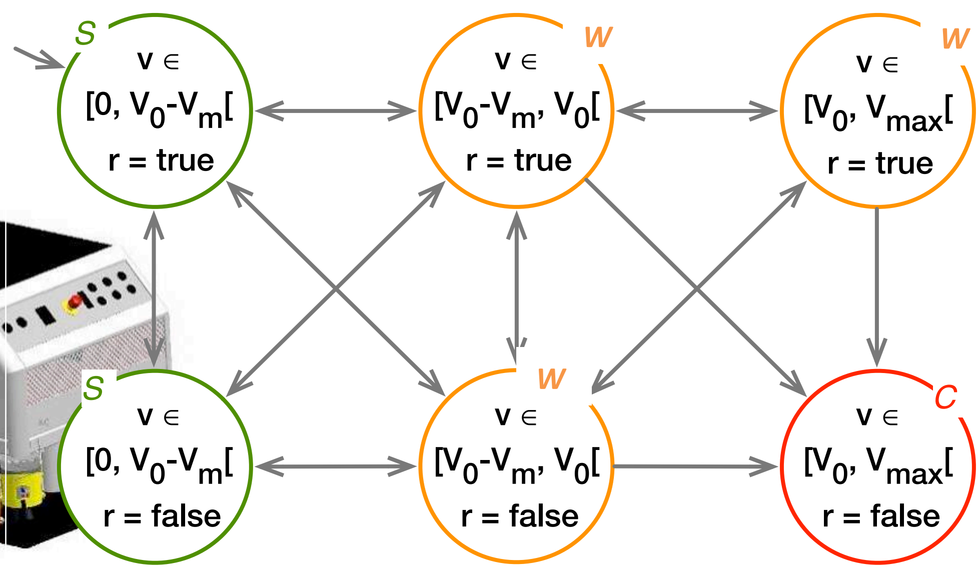
The robot arm must be folded when the platform velocity is greater than V_0

$(r = \text{true}) \vee (v < V_0)$

Margin on velocity

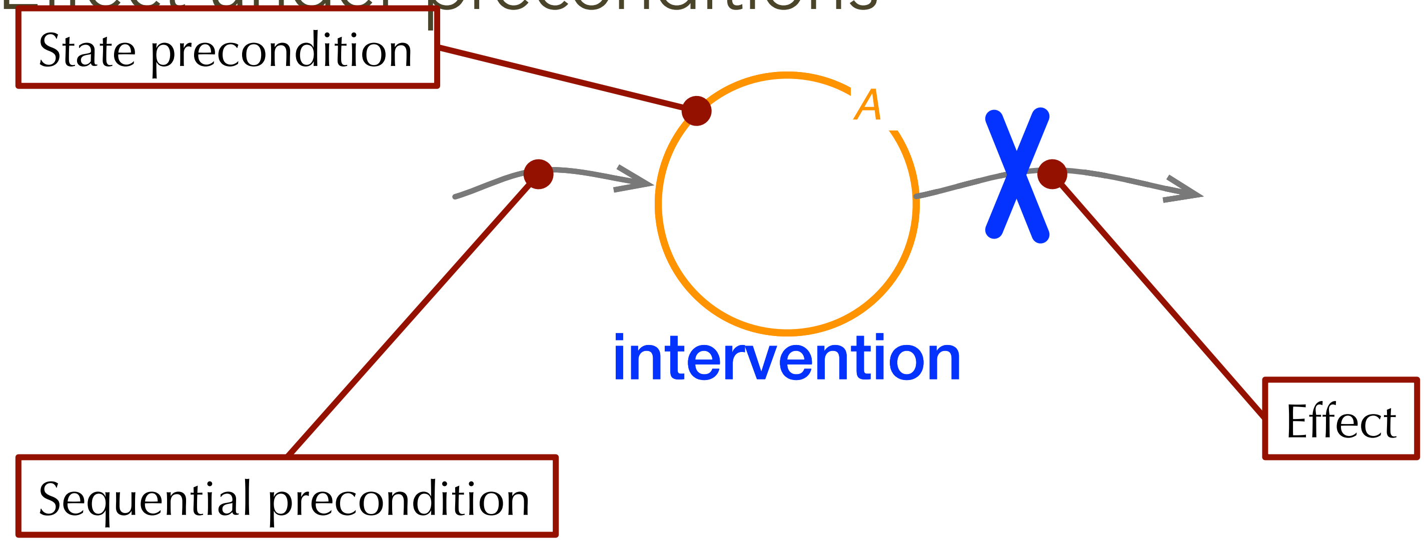
3 warning sta…





Interventions

- Ability of the monitor to constrain the system behavior
- E.g.: engage platform brakes, lock the arm position
- Effect under preconditions



Modeling with SMOF

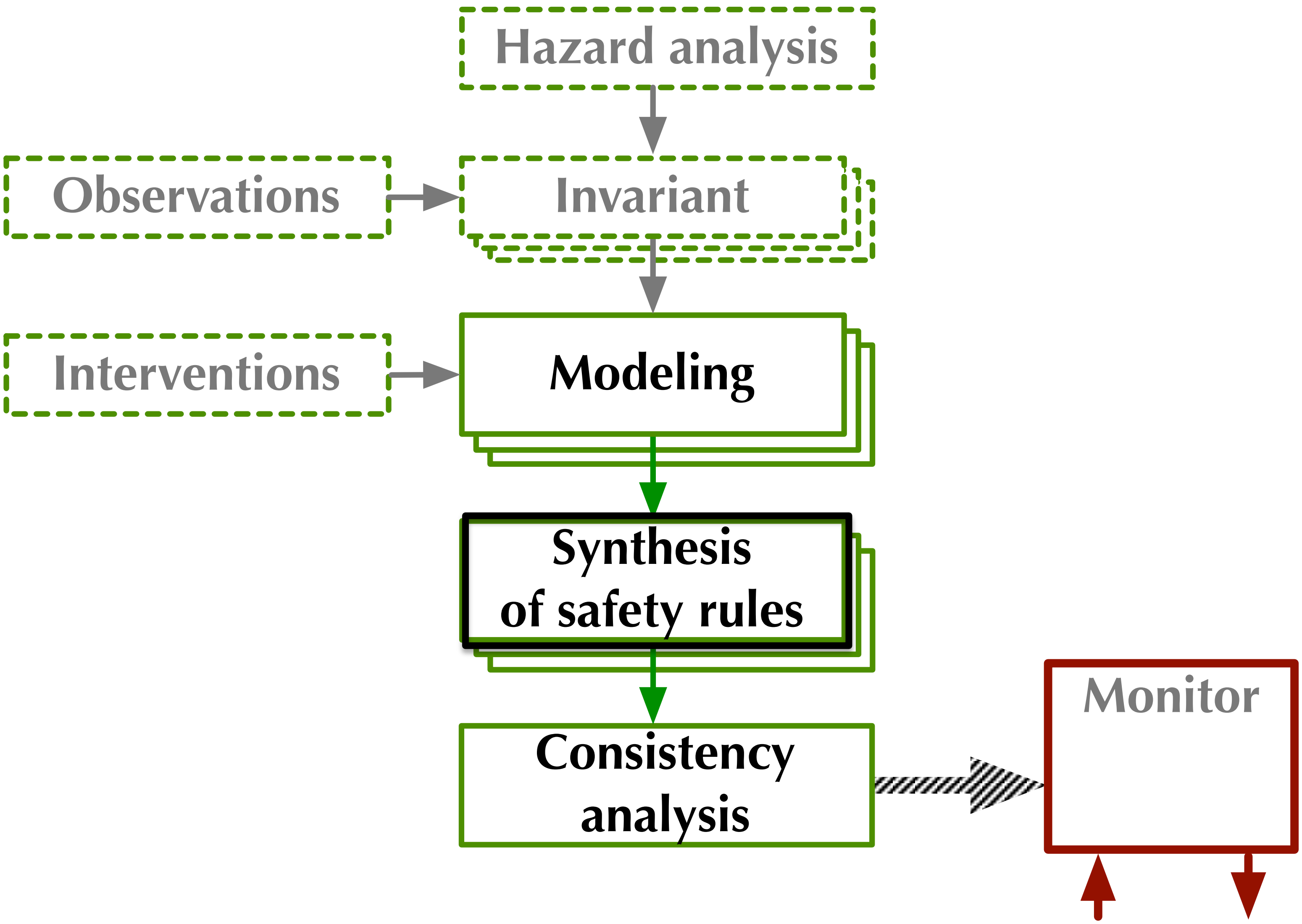
- NuSMV
- Modeling template:
    - Predefined parts
    - Parts to be edited by the user
    - Generated parts

```
VAR
pf_vel: Continuity(0,2,0);
arm_pos : Continuity(0,1,1);

DEFINE cata:= (pf_vel=2 & arm_pos=0);

VAR
brake : Intervention(TRUE, pf_vel!=0, flag_brake, next(pf_vel)=pf_vel!=2);
lock_arm : Intervention(arm_pos=1, TRUE, flag_lock_arm, next(arm_pos)=1);
```

Method



Hazard analysis
Observations
Invariant
Interventions
Modeling
Synthesis of safety rules
Consistency analysis
Monitor

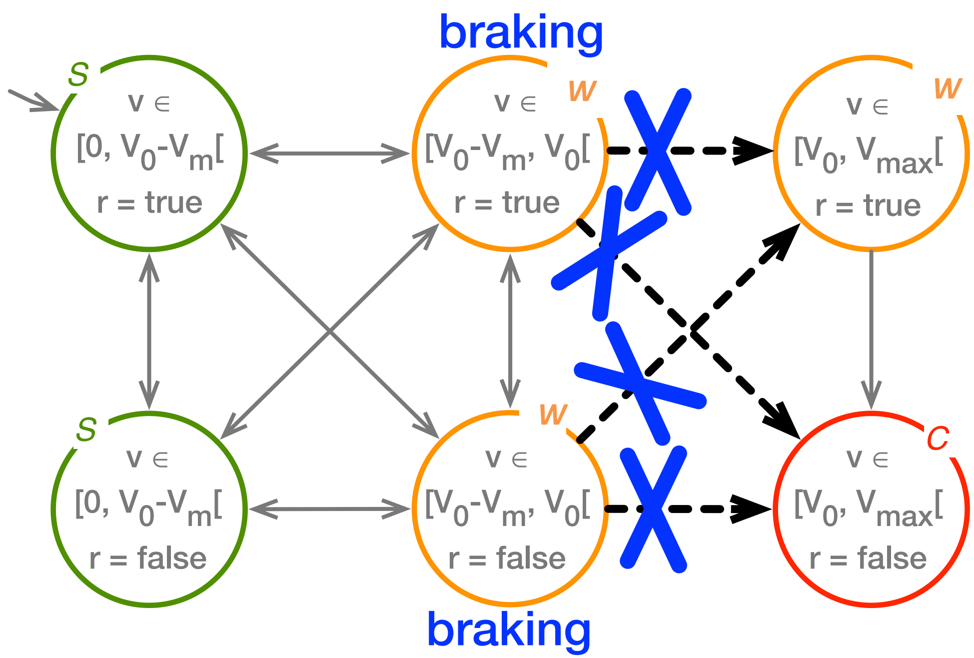
Strategies

- Association

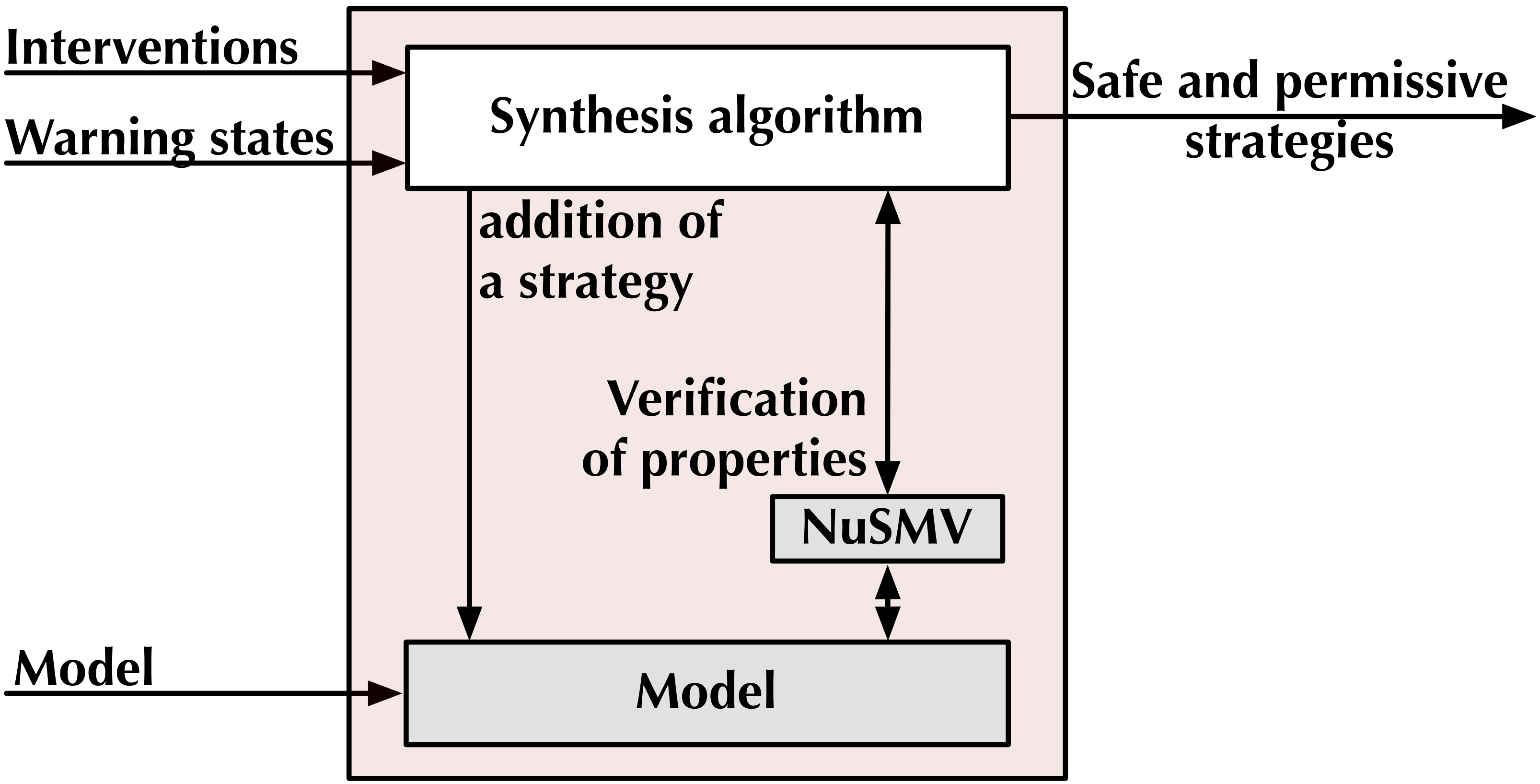
  Warning state – combination of interventions

- Required properties:
  - **Safe**: catastrophic states are not reachable
  - **Permissive**: non-catastrophic states are reachable

This strategy is safe, but not permissive !



Synthesis of strategies



Examplary result

```
VAR
pf_vel: Continuity(0,2,0);
arm_pos : Continuity(0,1,1);

DEFINE cata:= (pf_vel=2 & arm_pos=0)
--Safety property
INVARSPEC !cata

-- Intervention(precondition, flag,
VAR
brake : Intervention(TRUE, pf_vel!=0
lock_arm : Intervention(arm_pos=1, T
```

```
-- Warning states
DEFINE flag_st_1 := arm_pos = 0 & pf_vel=1;
DEFINE flag_st_2 := arm_pos = 1 & pf_vel=1;
DEFINE flag_st_3 := arm_pos = 1 & pf_vel=2;
------------------------------------------------------------------


-- Strategy definition
DEFINE flag_brake := flag_st_2 | flag_st_3 ;
DEFINE flag_lock_arm := flag_st_1 ;
```

A case study from Kuka

- Mobile platform with an articulated arm
  KUKA GmbH
  SAPHARI-FP7

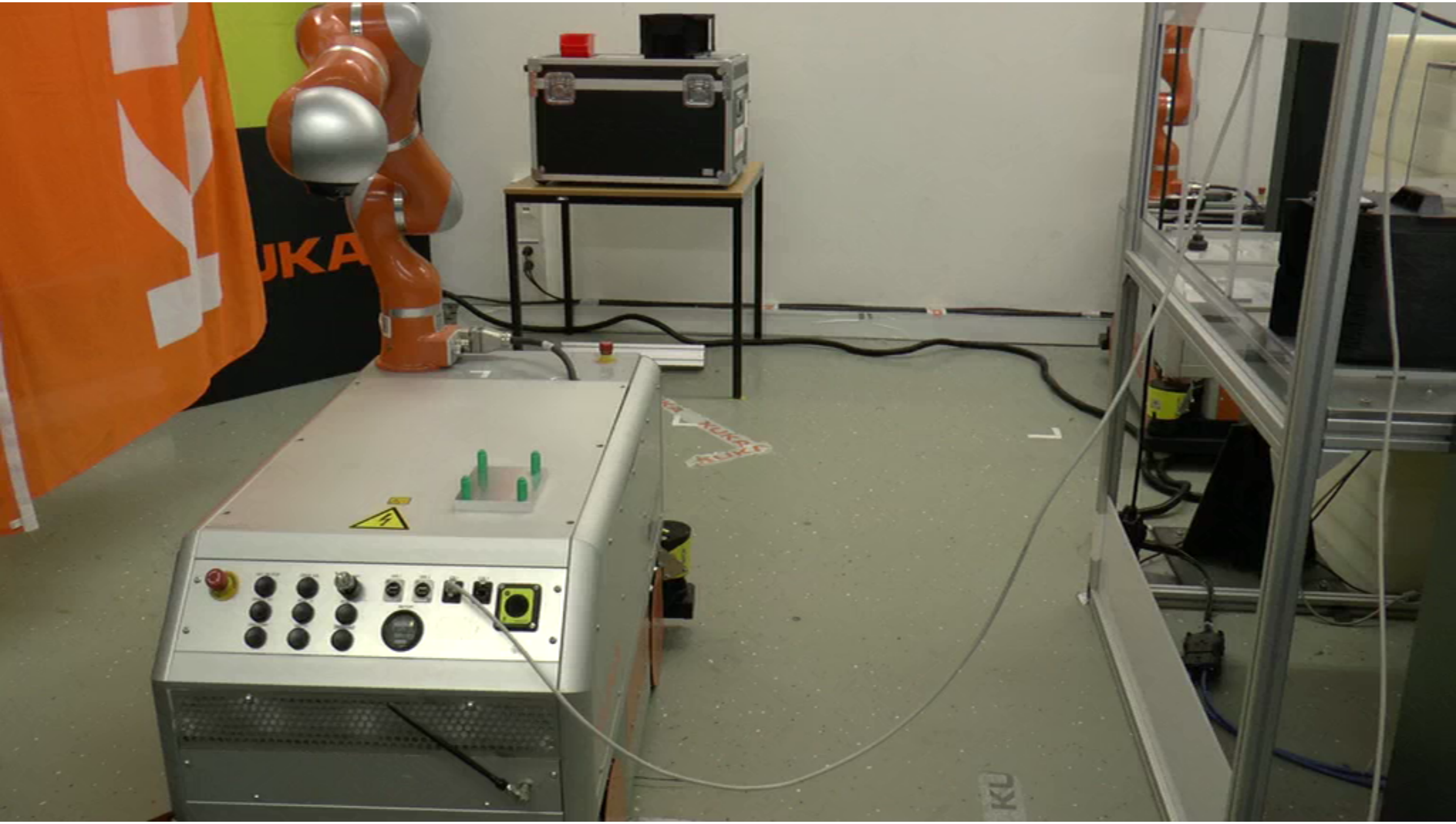
- Safety Monitor can:
  - Block the arm
  - Engage the platform brakes
- HAZOP Analysis
  - 100 lines with a non-zero severity
  - 13 invariants, including:

"The robot arm must not be extended beyond the platform footprint when the platform moves."

Case study safety invariants

SI1	The velocity of robot arm must not be greater than V_0.
SI2	The velocity of robot platform must not be greater than V_1.
SI3	The robot must not enter the restricted area.
SI4	The robot platform must not collide with a human.
SI5	The robot arm must not be extended beyond the platform footprint when the platform moves.
SI6	A gripped box must not be tilted more than α_0.
SI7	A collision between a human and the robot arm must not hurt the human.
SI8	The velocity of any point of the robot must not be greater than V_2.
SI9	The robot arm must not drop a box.
SI10	The robot arm must not clamp human parts.
SI11	The robot gripper must not clamp human parts.
SI12	The robot must not override boxes laid on tables, shelves and robot storage.
SI13	The robot must follow the hand-guiding.

The safety monitor in action



Conclusion

+ SMOF provides a systematic and formal approach for the expression of safety rules
+ Dev. of a tool (no combinatorial explosion of the algorithm with acceptable performance)

- Level of expertise impact model expression, and thus synthesis
- Monitoring limited to the functional level

Future directions : several warning regions, interventions and observation located at different layers (hardware and software) with different integrity levels