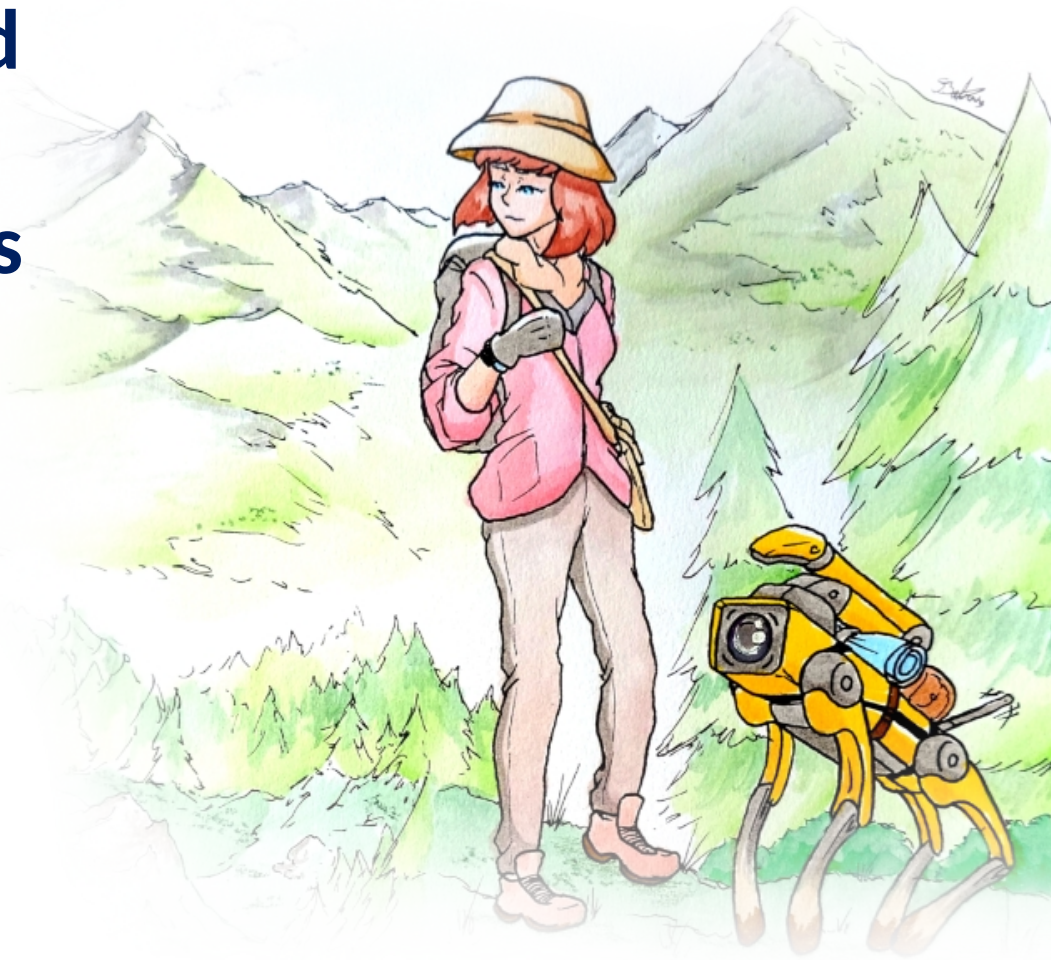
SkiNet : a user-oriented tool for PN-based analysis of robotic skills



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Karen Godary-Dejean (LIRMM)

Petri Nets 25 - 26/06/2025

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Institut Supérieur de l'Aéronautique et de l'Espace
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1. Context
2. SkiNet overview
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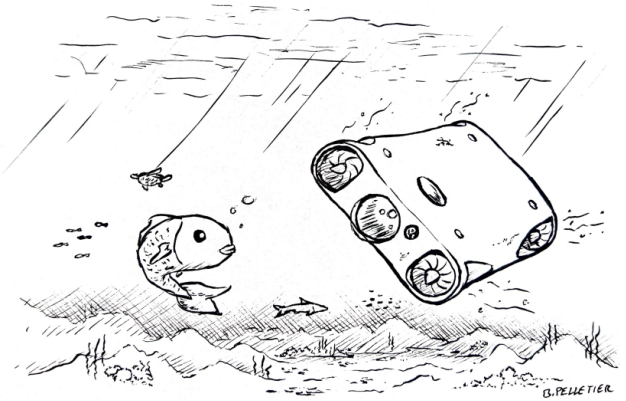
Context : FMs in robotics

Bring trust to autonomous systems – Focus on robotics

Motivations

- Autonomy increases the cost and complexity
- Task and environments get more complex
- Human help may be difficult or impossible (underwater, military, space…)



Dangerous job for South African wildlife rangers despite new technology (Michael Strang/UN Environment-GEF rhino project, Aug 2016)

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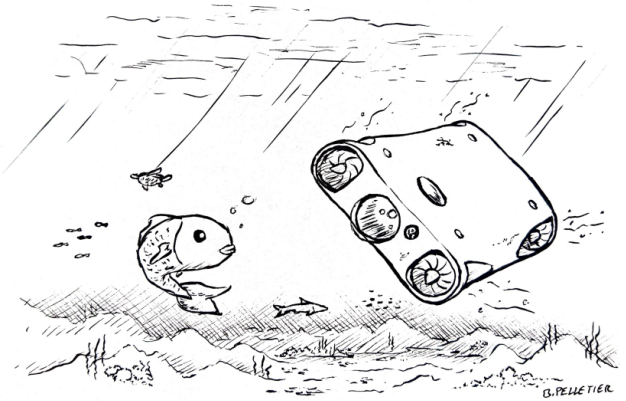


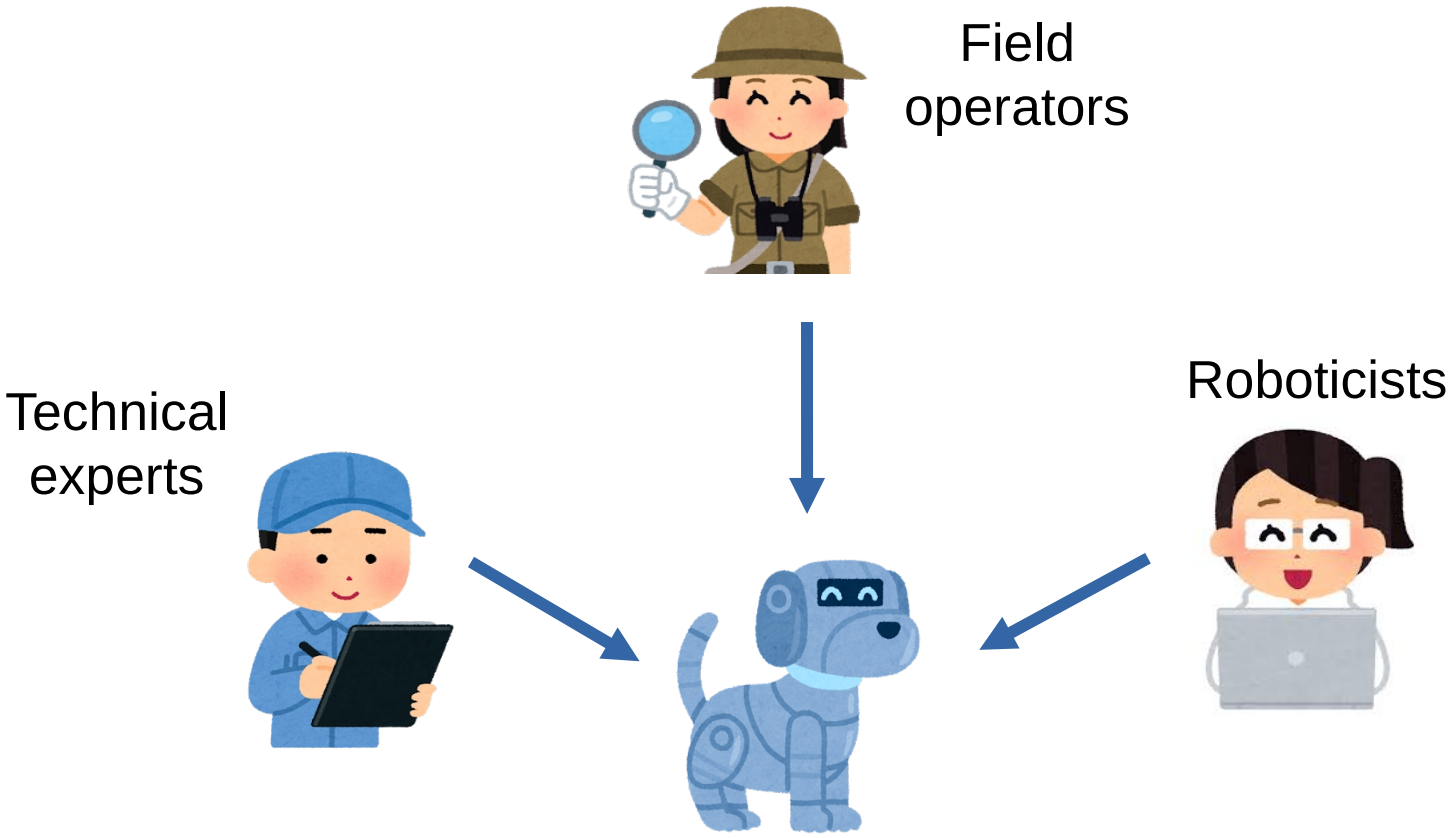
Apply formal methods to bring trust to the system

- Prove the feasability of a mission
- Improve fault-tolerance
- Anticipate runtime problems

Dangerous job for South African wildlife rangers despite new technology (Michael Strang/UN Environment-GEF rhino project, Aug 2016)

Context : FMs in robotics

Problem: actors have heterogenous backgrounds…



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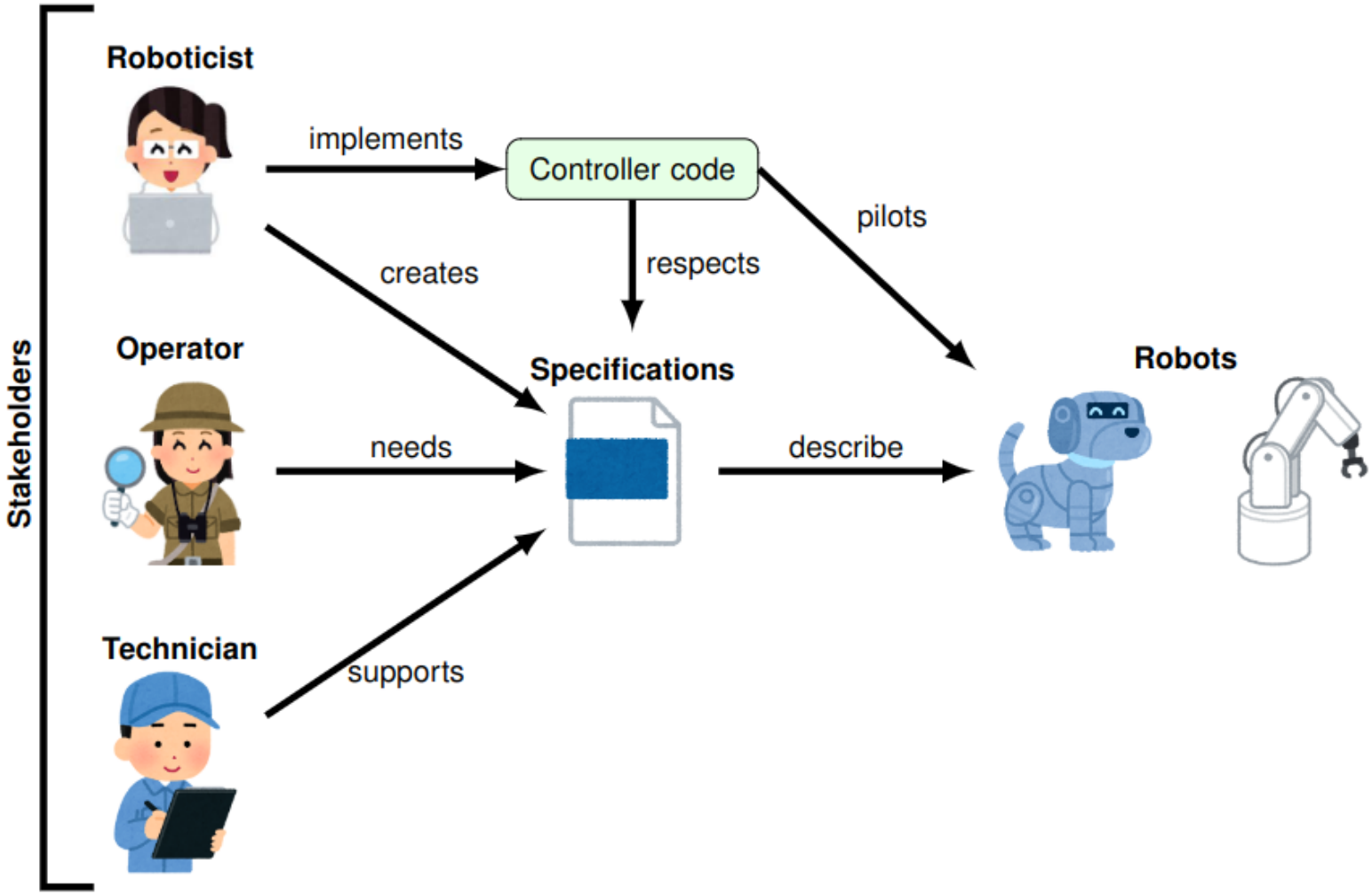

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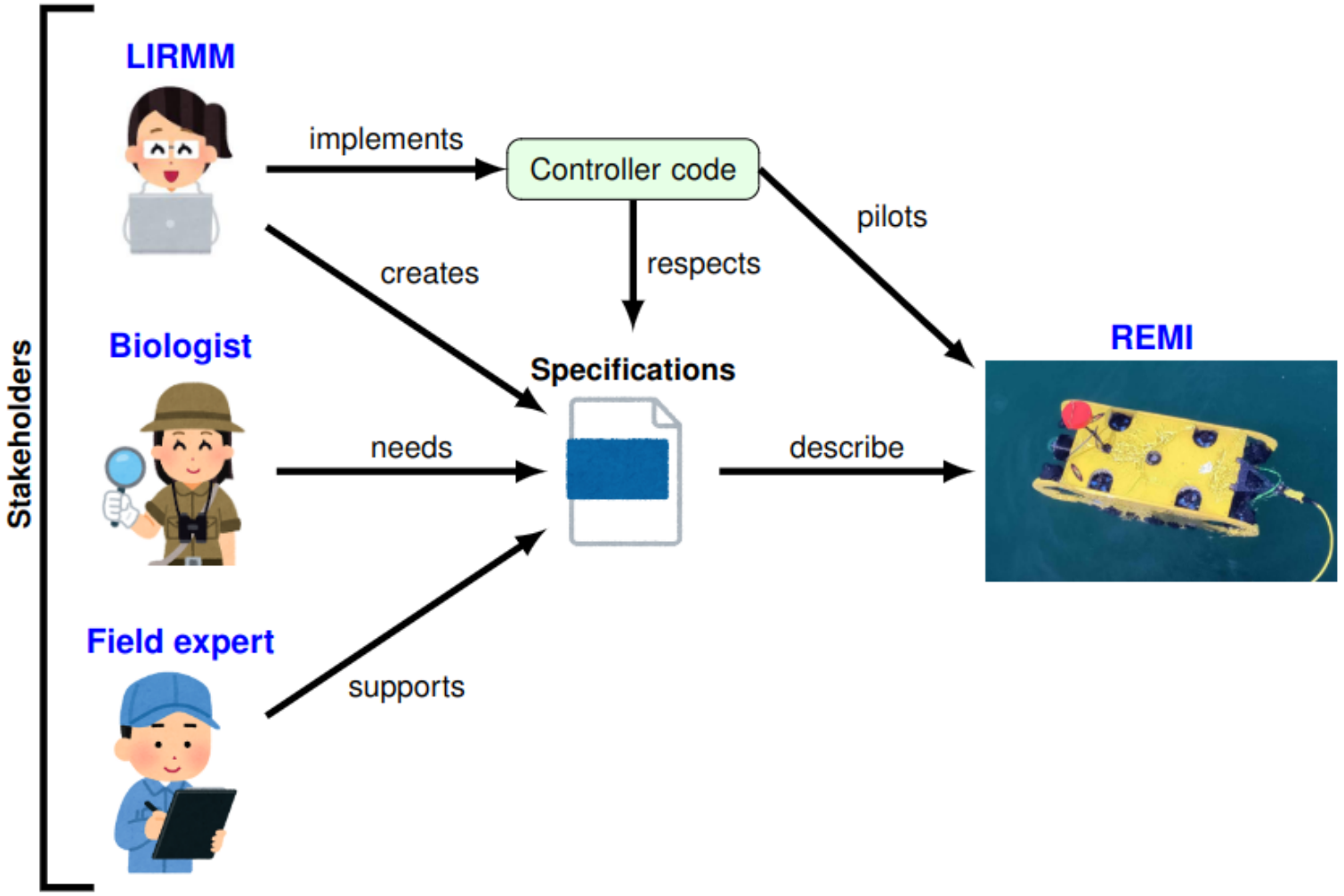

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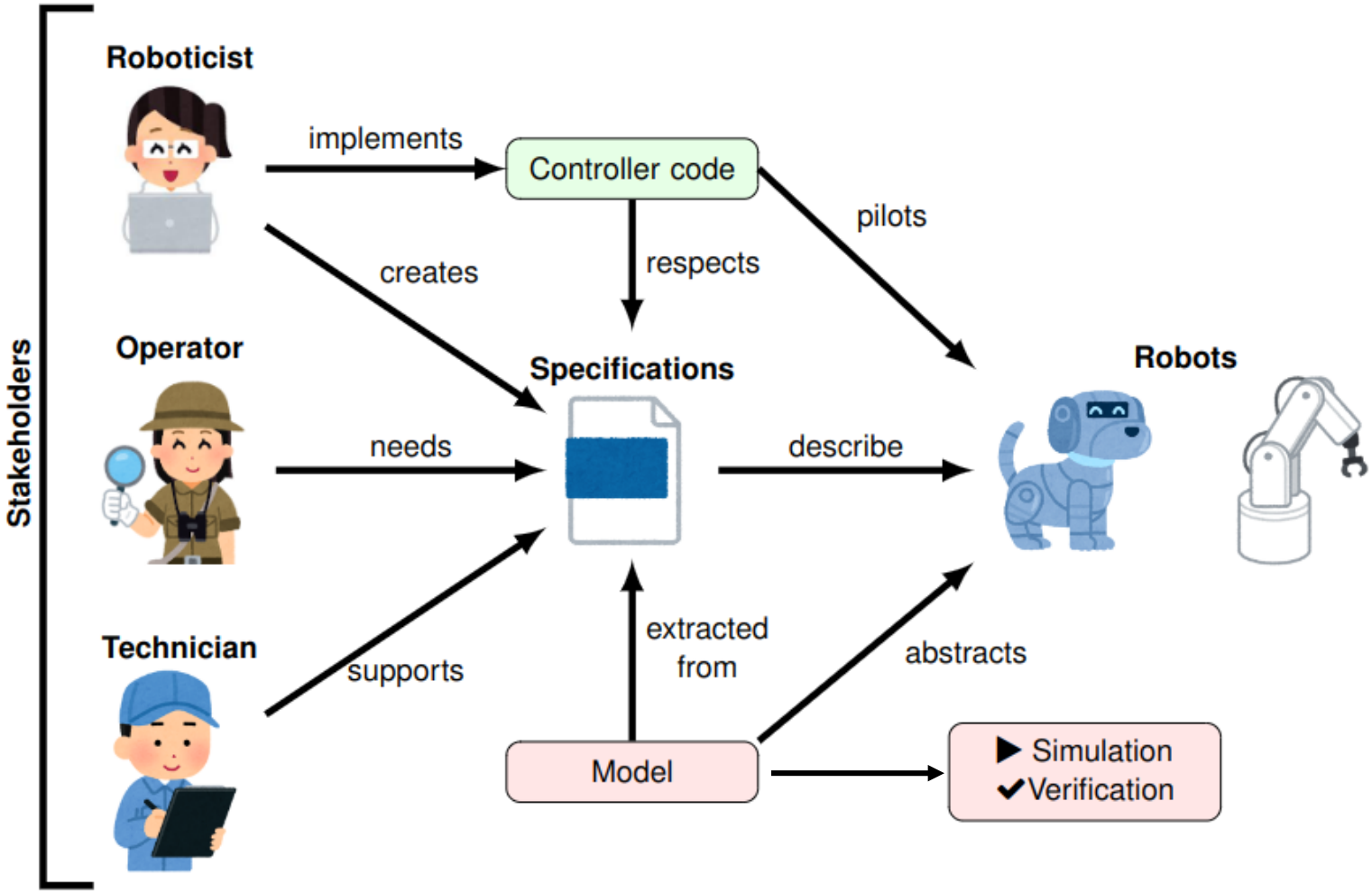

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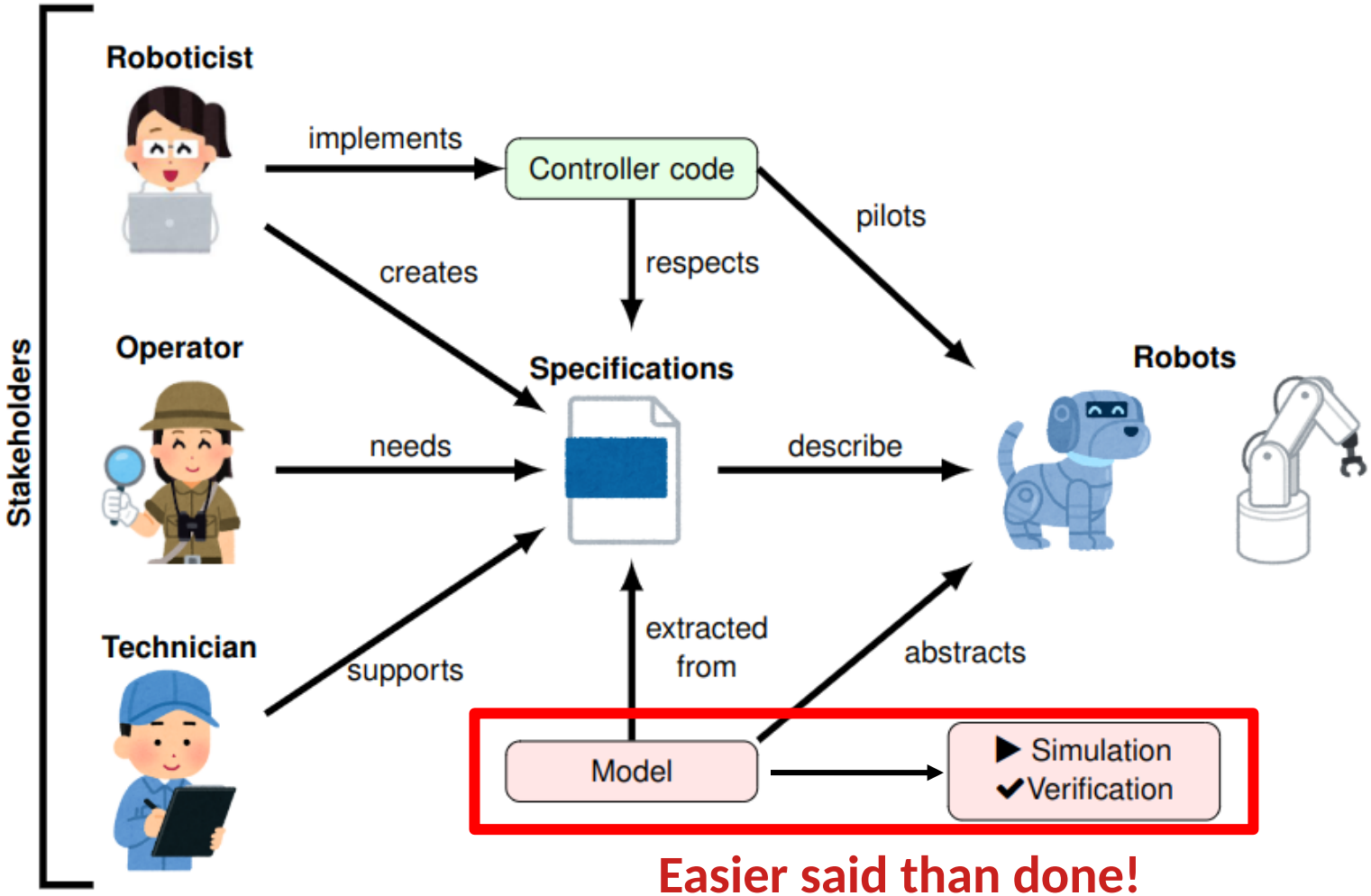

Easier said than done!

Context : FMs in robotics

Problem: actors have heterogenous backgrounds… But who will get their hands dirty?

What's a robot?

AF (x=5 => y>2)

I can't keep up!

What's a Petri net?

Context : FMs in robotics

Problem: actors have heterogenous backgrounds… But who will get their hands dirty?

The perfect specimen

- Has never heard of FMs
- 3 hours of experience in robotics
- Full of hope and optimism

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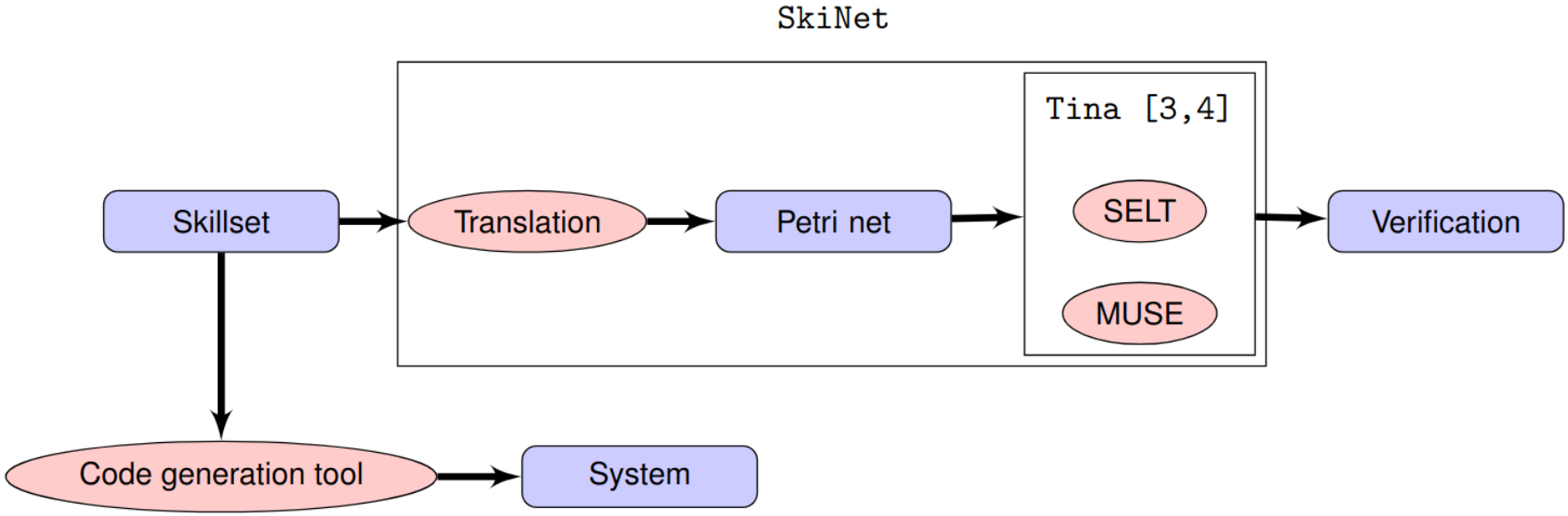
SkiNet Overview

A transformer from Robotic Skills Language specifications [Albore et al., 2023] to PNs

Pelletier et al., FMAS (formal methods for autonomous systems), 2022



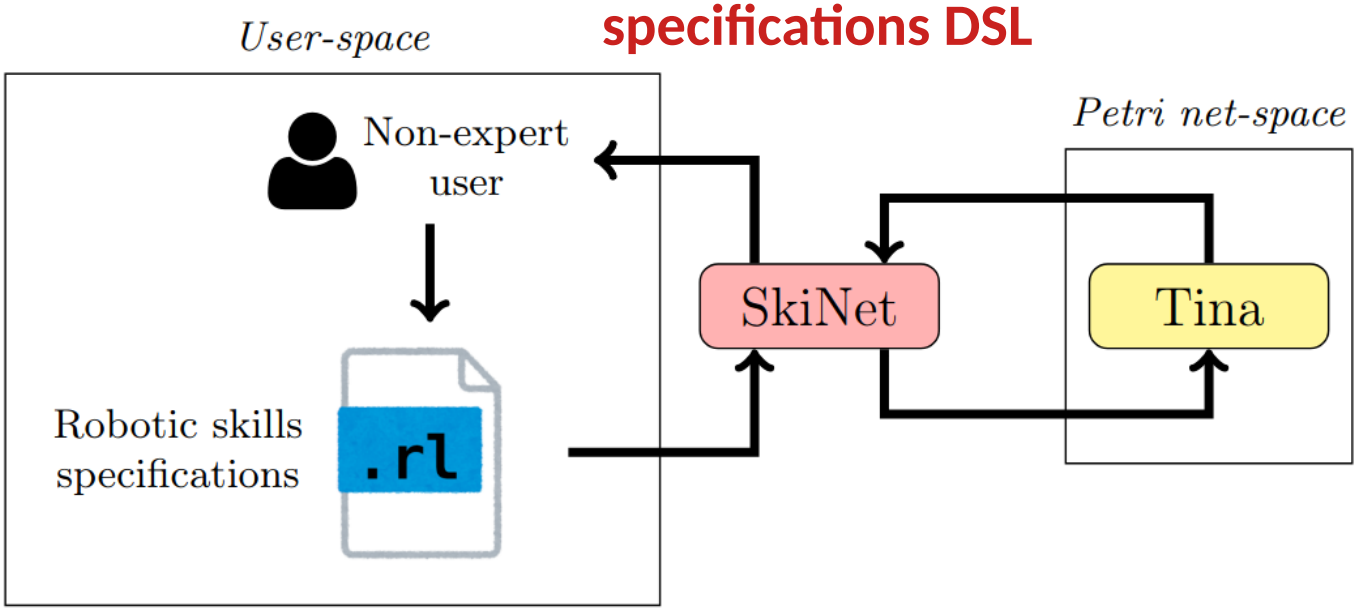
[3] B. Berthomieu, P.-O. Ribet and F. Vernadat (2004): The tool TINA – Construction of abstract state spaces for petri nets and time petri nets. International Journal of Production Research 42, pp. 2741–2756, doi:10.1080/00207540412331312688.
[4] Bernard Berthomieu, François Vernadat and Silvano dal Zilio (2004): The TINA toolbox Home Page - Time Petri Net Analyzer - by LAAS/CNRS. Available at https://projects.laas.fr/tina/home.php

SkiNet Overview

Now a back-and-forth transformer!

Pelletier et al., 2025 (this paper)

The user evolves the specifications DSL



The tool serves as an interface to use FMs

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User-space: Robotic Skills Language

```
skillset spot_fmas {

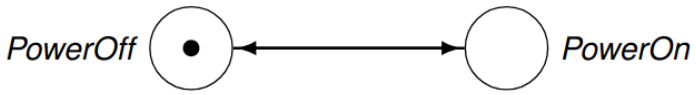
    resource {
        power_status {
            initial PowerOff
            PowerOff -> PowerOn
            PowerOn -> PowerOff
        }
        lease_status {
            initial AutoMode
            AutoMode -> ManualMode
            ManualMode -> AutoMode
        }
        control_mode {
            initial Idle
            Idle -> Busy
            Busy -> Idle
        }
    }
```

Albore et al., 2023

Resources $\mathcal{R}$ = **finite-state machines** (FMSs)

- **Internal elements**: battery level, stance, power status, control mode, mutex, sensor data...
- **External elements**: operator control, environment objects, mission elements...

Ex. `power_status`:



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            AutoMode -> ManualMode
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        }
        control_mode {
            initial Idle
            Idle -> Busy
            Busy -> Idle
        }
    }

        event {
            toauto_frommanual {
                guard lease_status == ManualMode
                lease_status -> AutoMode
            }
            tomanual_fromauto {
                guard lease_status == AutoMode
                lease_status -> ManualMode
            }
            power_switchoff {
                guard power_status == PowerOn
                power_status -> PowerOff
            }
            power_switchon {
                guard power_status == PowerOff
                power_status -> PowerOn
            }
        }
```

Albore et al., 2023

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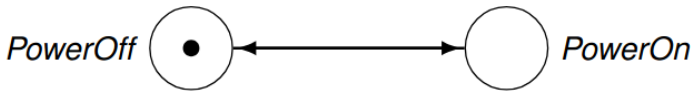
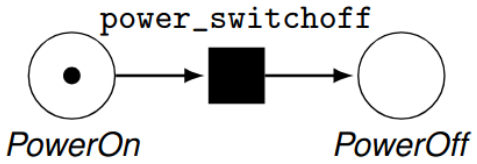


Events $\mathcal{V}$ = **uncontrollable elements** that can affect the state of resources.

- **Resource guard** = **logical formula** $\phi : \{S^r, r \in \mathcal{R}\} \rightarrow \{True, False\}$
- **Effect** $\epsilon = (r, S_i^r)$ of a resource and its **next state**.



User-space: Robotic Skills Language

Albore et al., 2023

```
skill go_to_graphnav {
    input {
        waypoint : GeoPoint
    }
    precondition {
        is_free : control_mode == Idle
    }
    start { control_mode -> Busy }
    invariant {
        is_busy {
            guard control_mode == Busy
        }
    }
    interrupt { effect control_mode -> Idle }
    success reached { effect control_mode -> Idle }
    failure failed { effect control_mode -> Idle }
}
```

PN-space: PN model & Tina

Albore et al., 2023

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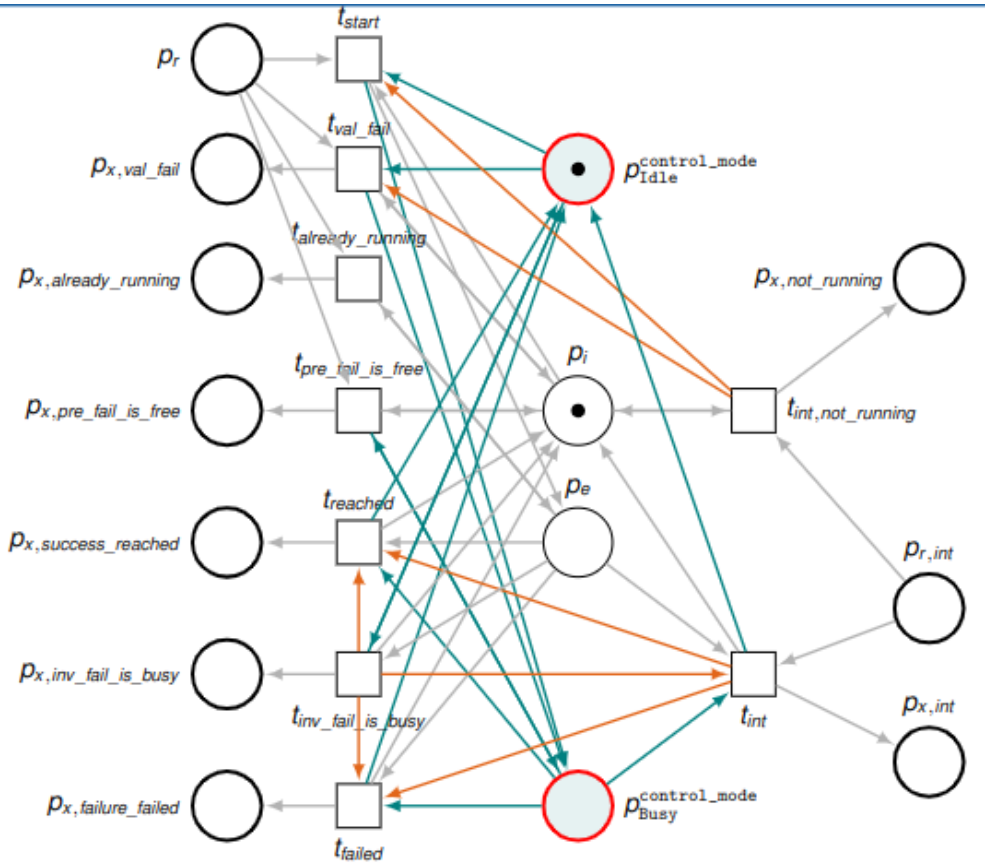

PN-space: PN model & Tina

But models are rarely simple…

- Resources to model hardware/software
- Skills for autonomous actions and user-operated
- Events for each uncontrollable action that could hit the robot (increases when modelling fault tolerance)

Skillset	Res	Sk	Pl	Tr	States
UGV	3	5	24	60	37
Spot	6	10	48	164	400
UAV	6	10	54	297	1512
Jaco	4	6	49	266	**51340**
Jaco (6DOF)	6	1	63	16089	**16265**

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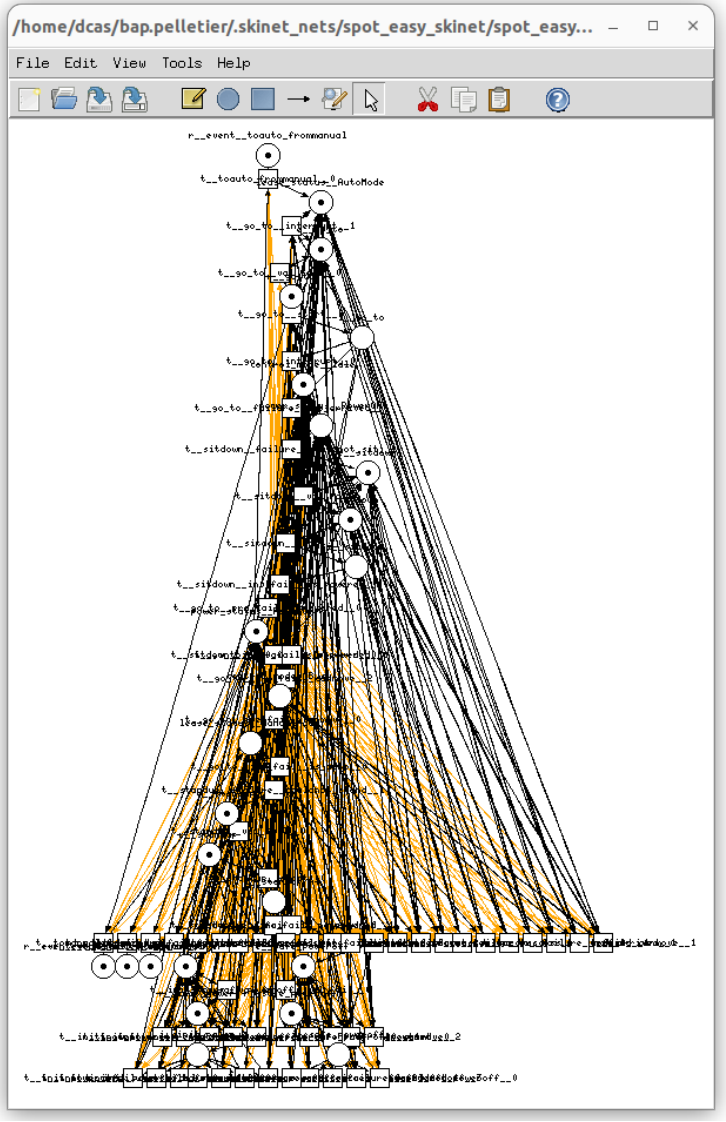

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Graphical simulation/debugging is impossible

PN-space: PN model & Tina

```
Play version 3.7.5 -- 03/29/23 -- LAAS/CNRS
parsed net spot_easy
0.004s

initial
state 0: control_mode__Idle e__go_to e__init_power e__safe_poweroff e__sitdown e__
standup lease_status__AutoMode power_status__PowerOff r__event__power_switchoff r_
_event__power_switchon r__event__toauto_frommanual r__event__tomanual_fromauto r__
go_to r__init_power r__safe_poweroff r__sitdown r__standup
enabled: t__go_to__pre_fail__ispowered__0 t__go_to__val_fail__0 t__init_power__sta
rt__0 t__init_power__val_fail__0 t__power_switchon__0 t__safe_poweroff__pre_fail__
ispowered__0 t__safe_poweroff__val_fail__0 t__sitdown__pre_fail__ispowered__0 t__s
itdown__val_fail__0 t__standup__pre_fail__ispowered__0 t__standup__val_fail__0 t__
tomanual_fromauto__0
firable: t__go_to__pre_fail__ispowered__0 t__go_to__val_fail__0 t__init_power__sta
rt__0 t__init_power__val_fail__0 t__power_switchon__0 t__safe_poweroff__pre_fail__
ispowered__0 t__safe_poweroff__val_fail__0 t__sitdown__pre_fail__ispowered__0 t__s
itdown__val_fail__0 t__standup__pre_fail__ispowered__0 t__standup__val_fail__0 t__
tomanual_fromauto__0

?
```

Marking

Firable transitions

Enabled transitions

Hum...

PN-space: PN model & Tina

Present the simulation as the user expects!

```
RESOURCES                    | SKILLS                 | EVENTS
                             |                        |
power_status        PowerOff | init_power       IDLE  | toauto_frommanual   -----
lease_status        AutoMode | safe_poweroff    PRE!  | tomanual_fromauto   READY
control_mode            Idle | standup          PRE!  | power_switchoff     -----
                             | sitdown          PRE!  | power_switchon      READY
                             | go_to            PRE!  |

 nb enabled: 12
 firable:
   0 - trigger tomanual_fromauto
   1 - trigger power_switchon
   2 - start init_power

- safe_poweroff  : precondition ispowered not met.
- standup        : precondition ispowered not met.
- sitdown        : precondition ispowered not met.
- go_to          : precondition ispowered not met.

?
```

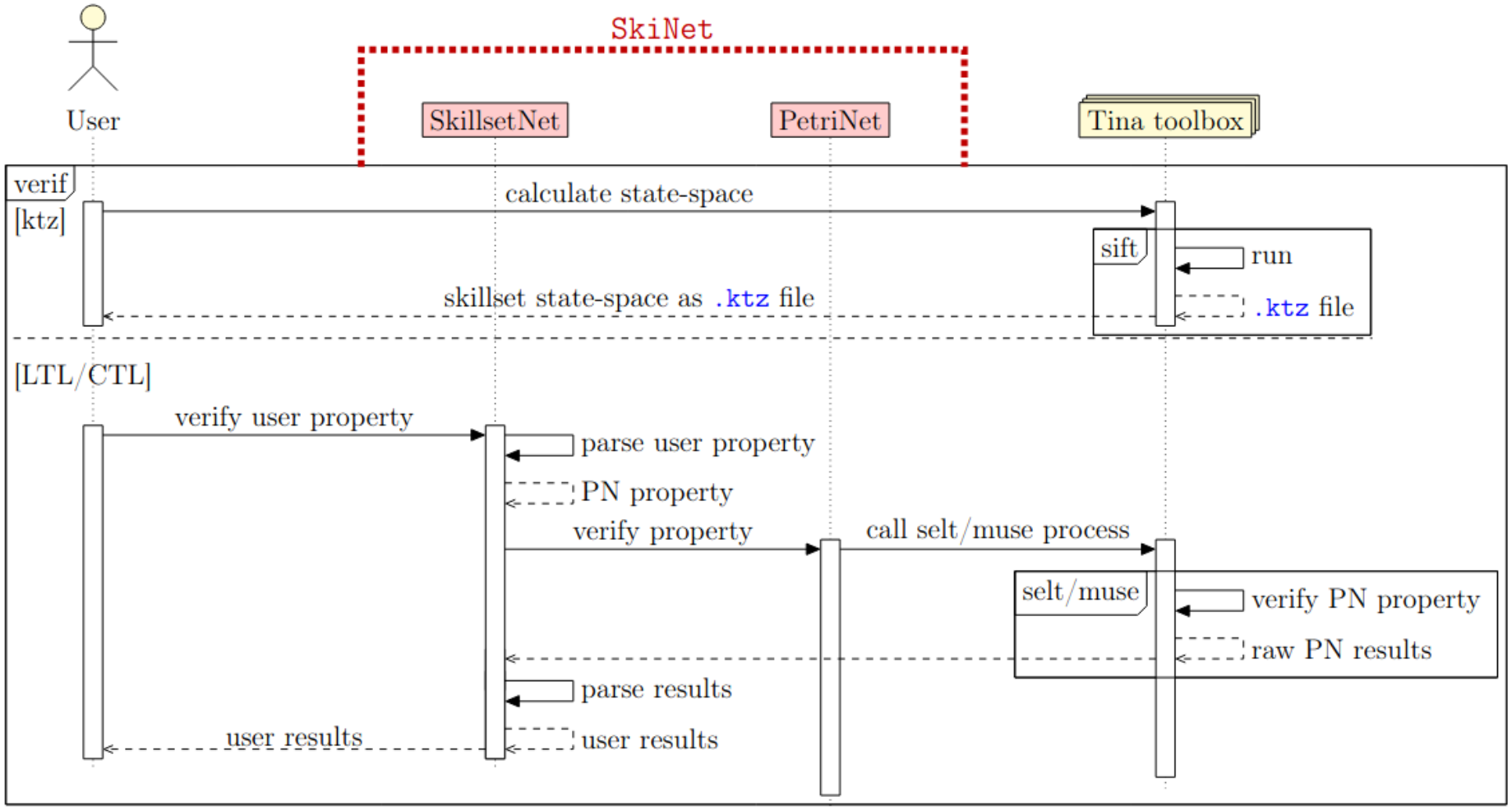
Skillset state

Firable transitions

Additional information

PN-space: PN model & Tina

What about model-checking?



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Conclusion & future works

Goals achieved

- SkiNet turned into a **two-way transformer** and we hope it inspires others to do so!
- Currently **used by students** as part of the embedded software and autonomous systems master courses at ISAE Supaero (Toulouse, FR)

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Perspectives

- Conduct a **small user-experience survey** on the whole Robotic Skills toolchain (skills DSL, SkiNet, controller code implementation…)
- **Improve the formal models** of skills by adding data to the models
- Improve **modularity** with other formal frameworks (Fiacre, Automata/UPPAAL, BPMN, SMT, …)

Thank you for your attention !

Gitlab : gitlab.com/onera-robot-skills/skinet-release

Pelletier et al., 2022: arxiv.org/pdf/2209.14039