Verification of system-wide safety properties of ROS applications

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InfoBlender 2020

Verifying system-wide safety properties

A toy example

How to guarantee that a *bumper* event eventually triggers a stop *velocity*?

Verifying system-wide safety properties

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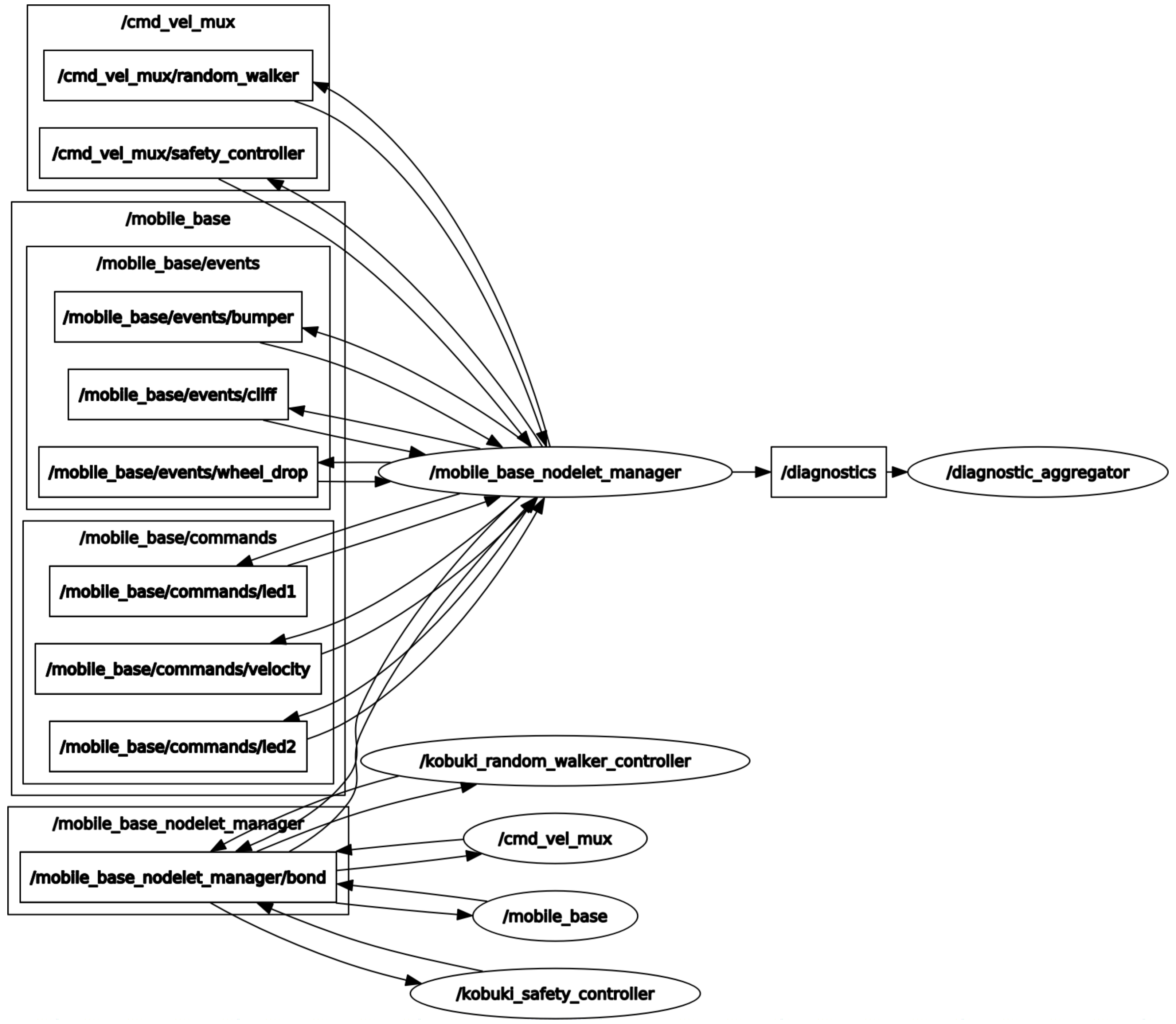

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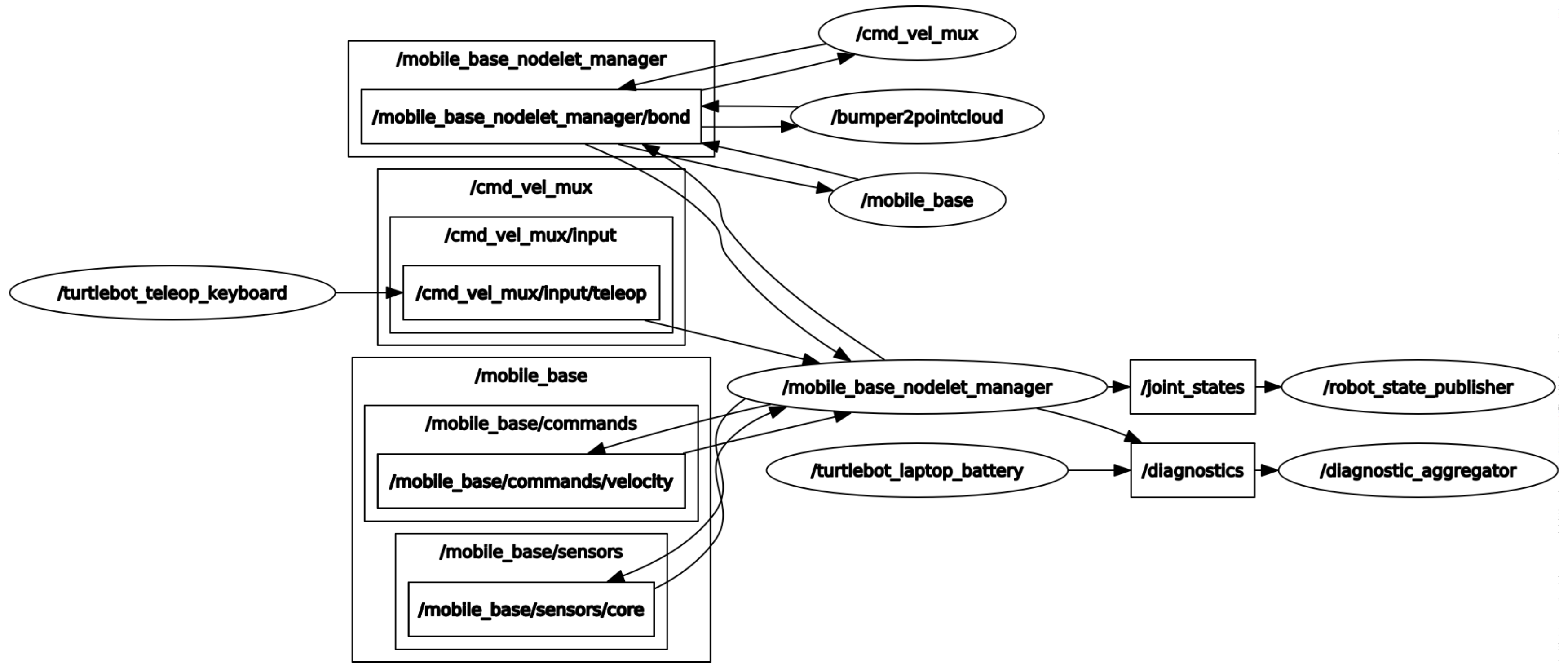

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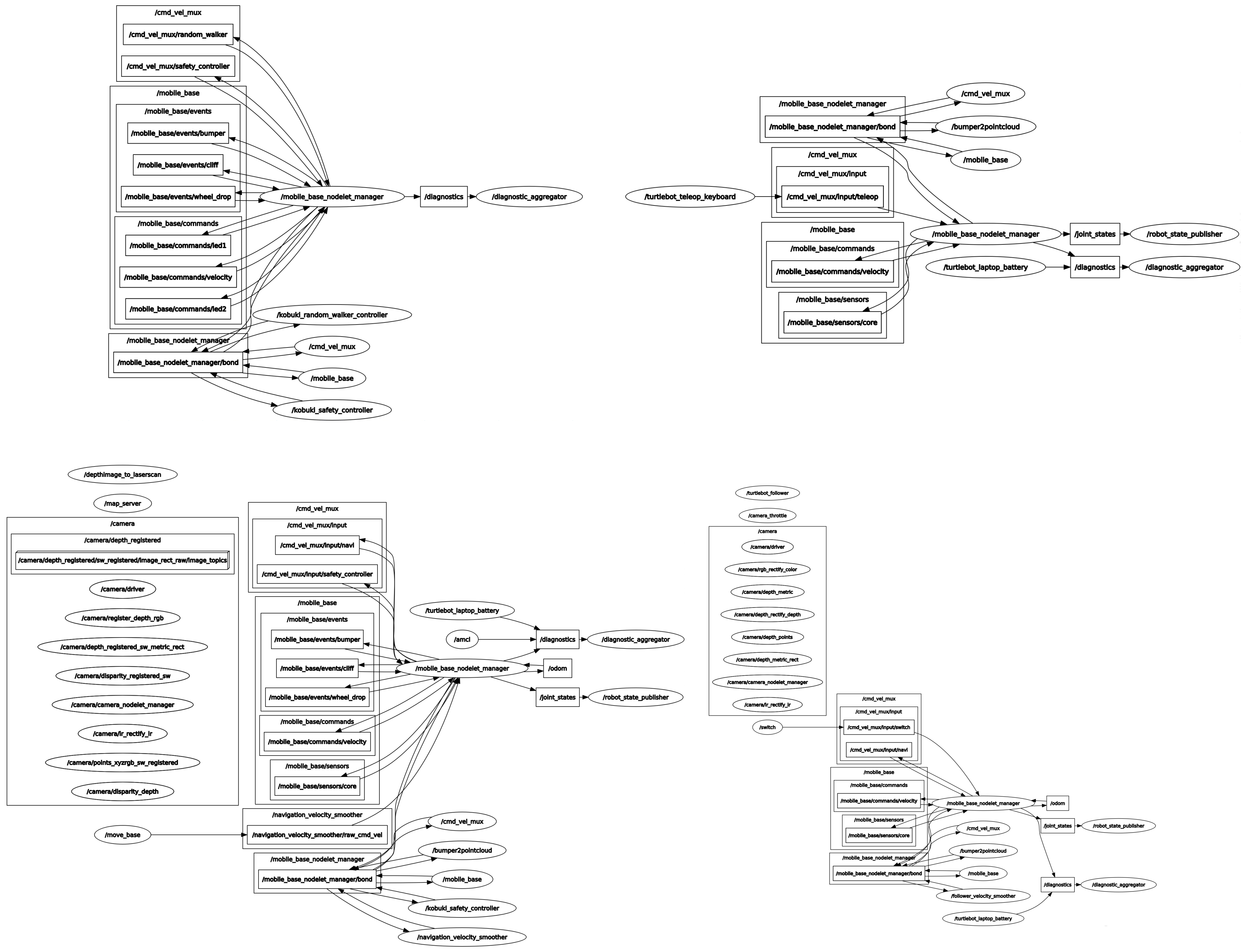

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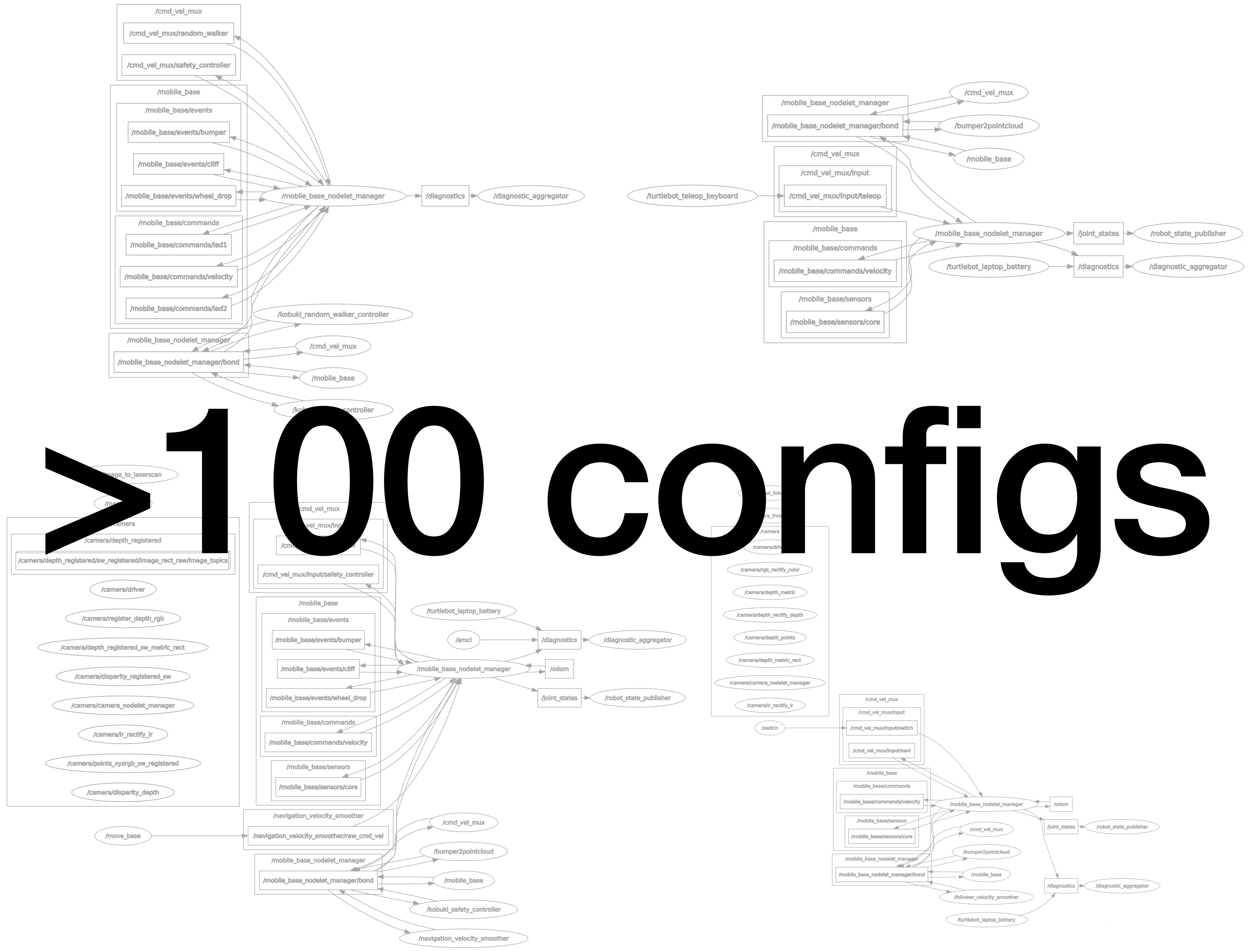

>100 configs

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Verifying system-wide safety properties

The challenges for ROS static verification

- How to automatically extract architectures from ROS code?
- How to enable roboticists to specify node and system behaviour?
- Which formal languages support rich architectures with loose behaviour?
- Which formal analysis support the automatic verification of safety properties?

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HAROS

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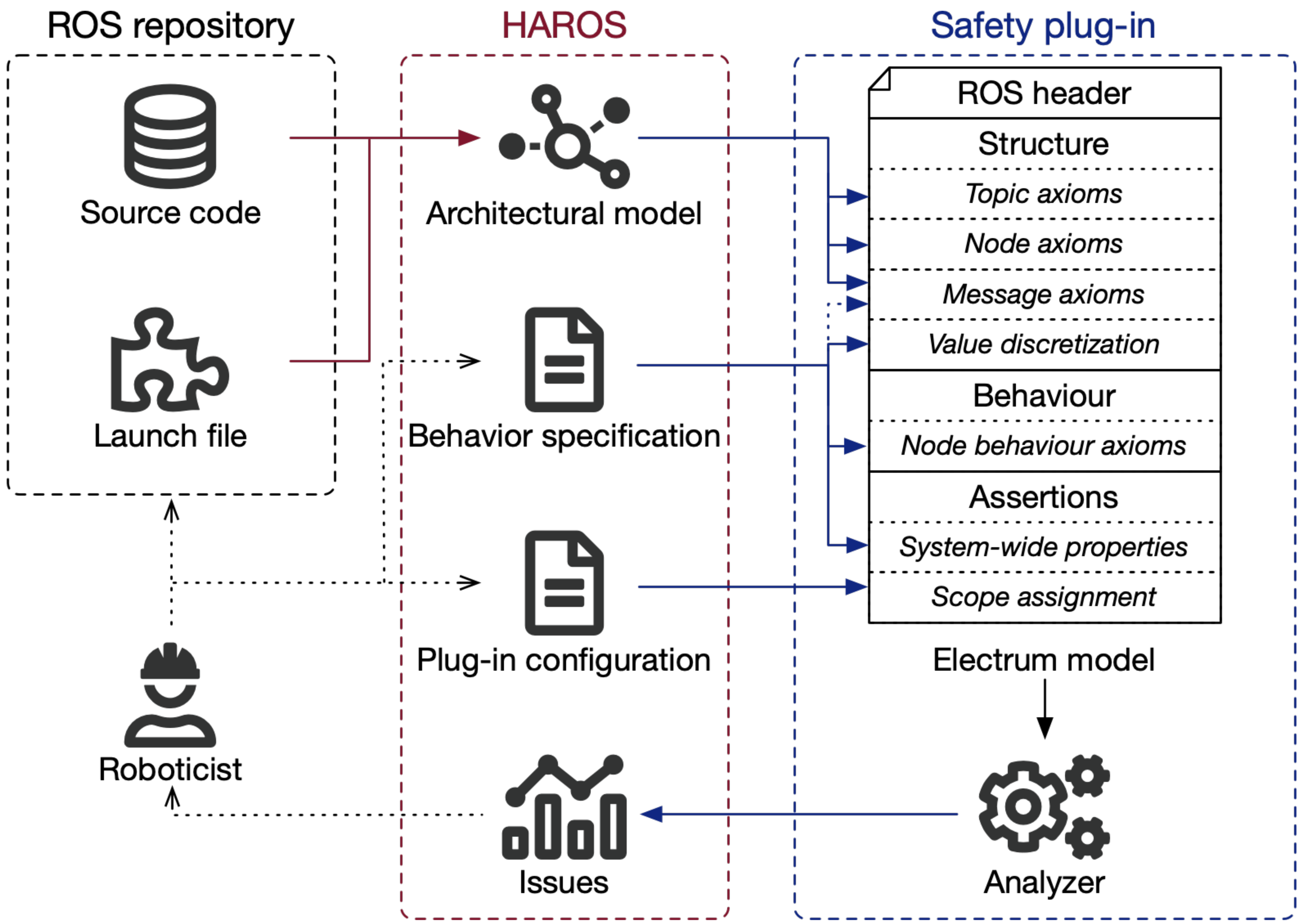
Our proposal

A model checking plug-in for HAROS

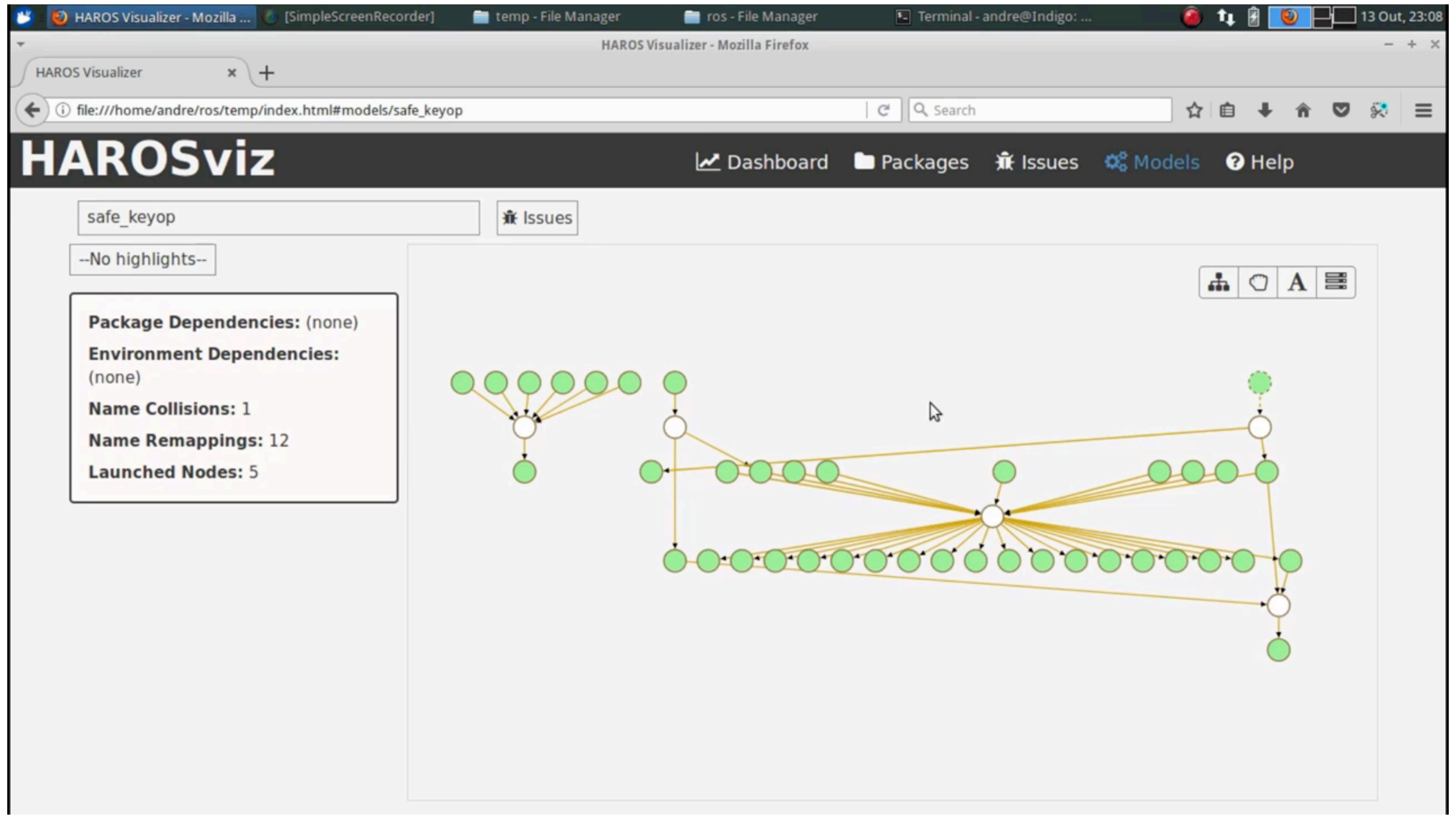
- User only required to loosely specify node behaviour and desired properties
- Automatically reports counter-examples in a ROS-friendly interface



HAROS

The quality assurance platform

- Plug-in based platform for ROS quality assessment in continuous integration
- Automatically extracts arquitectural models from ROS code
- Detected issues are presented in a unified interface, with traceability to code



github.com/git-afsantos/haros

HAROS

The specification language

- HAROS provides a DSL to specify behaviours as well-known patterns
- A specification has an activation scope and a property on message events
- Can be used to specify the behaviour of individual nodes and of the whole system
- Semantics in (metric) linear temporal logic

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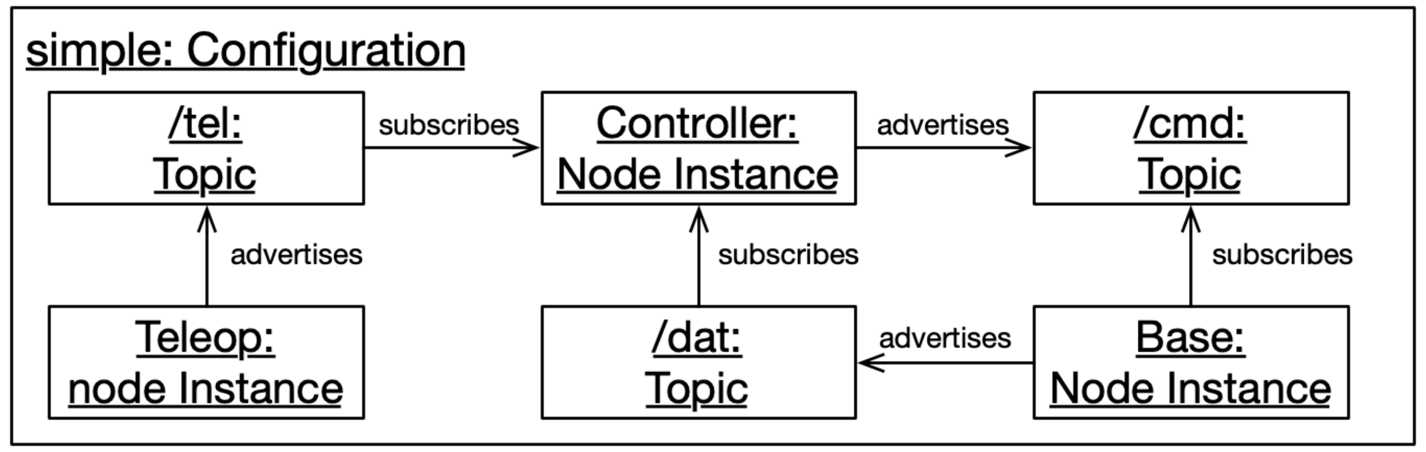

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Teleop:
  globally: no /tel{val not in 0 to 100}


Controller:
  after /dat{val=0} until /dat{val!=0}:
    no /cmd{val!=0}
  …
  globally: /cmd{val!=0} as m requires /tel{val=$m.val}
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simple:
  globally: /cmd{msg="stop"} requires /dat{val=0}
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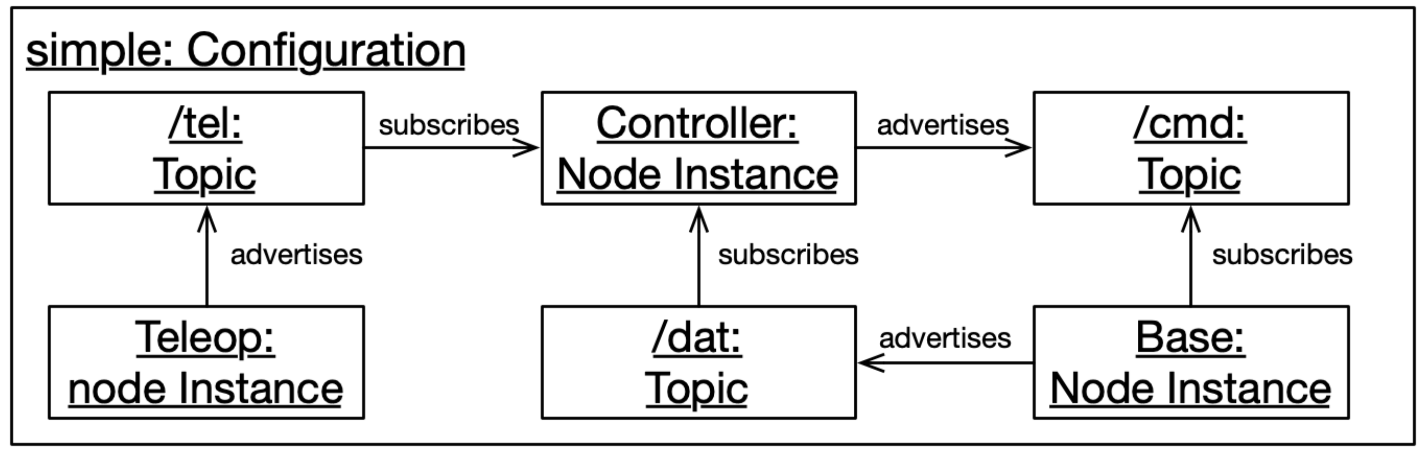


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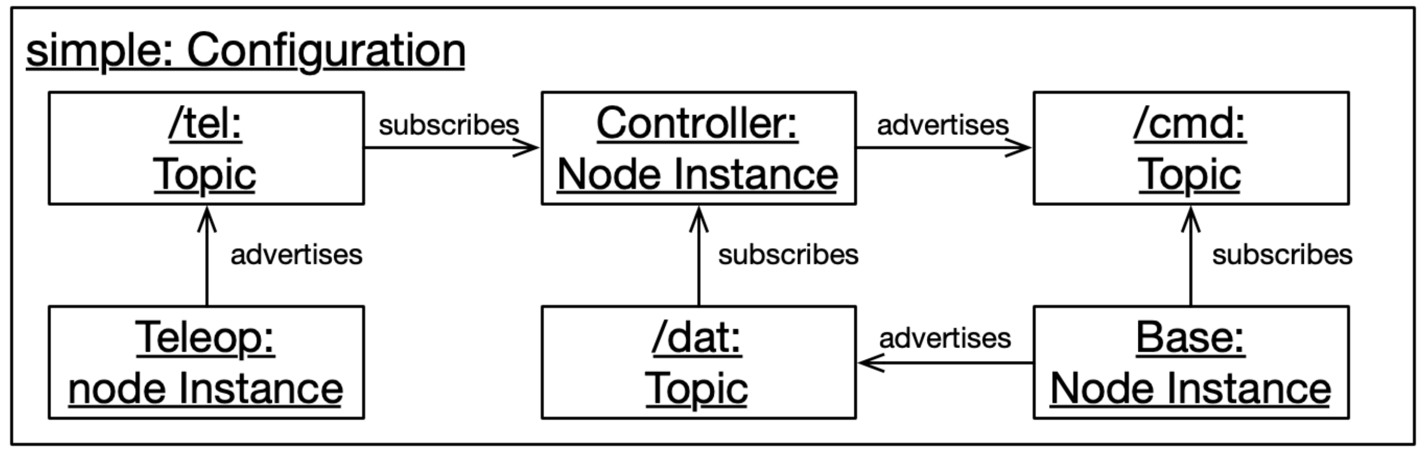


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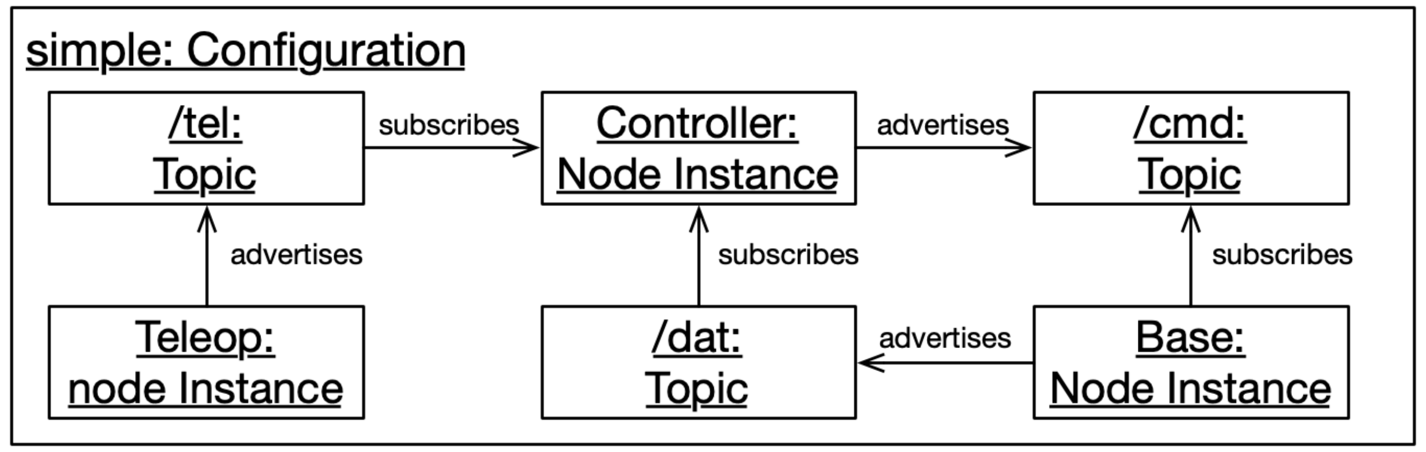


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The model checking plug-in

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- Reports back counter-examples at the ROS-level, either textually or graphically at the architecture

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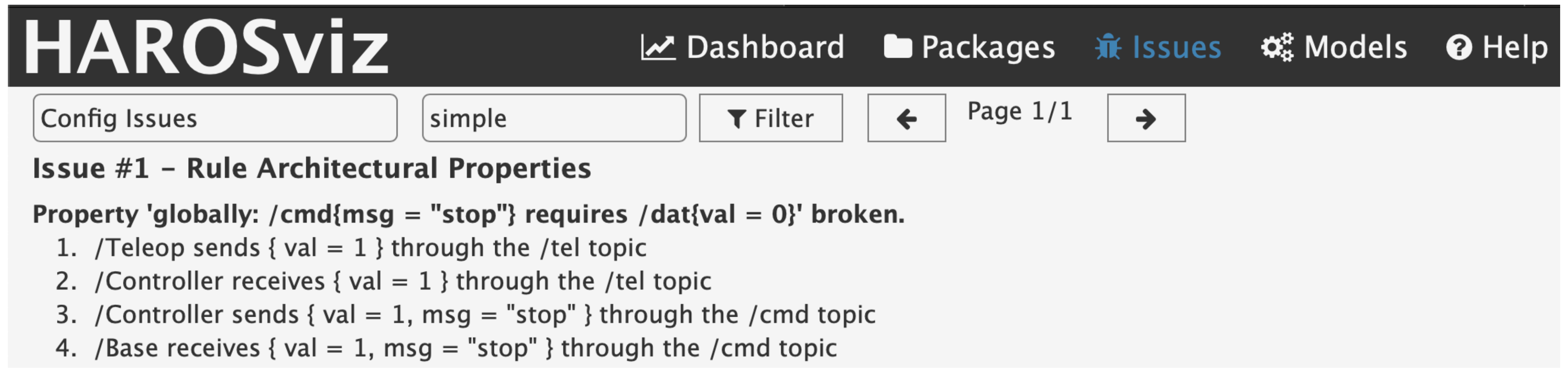
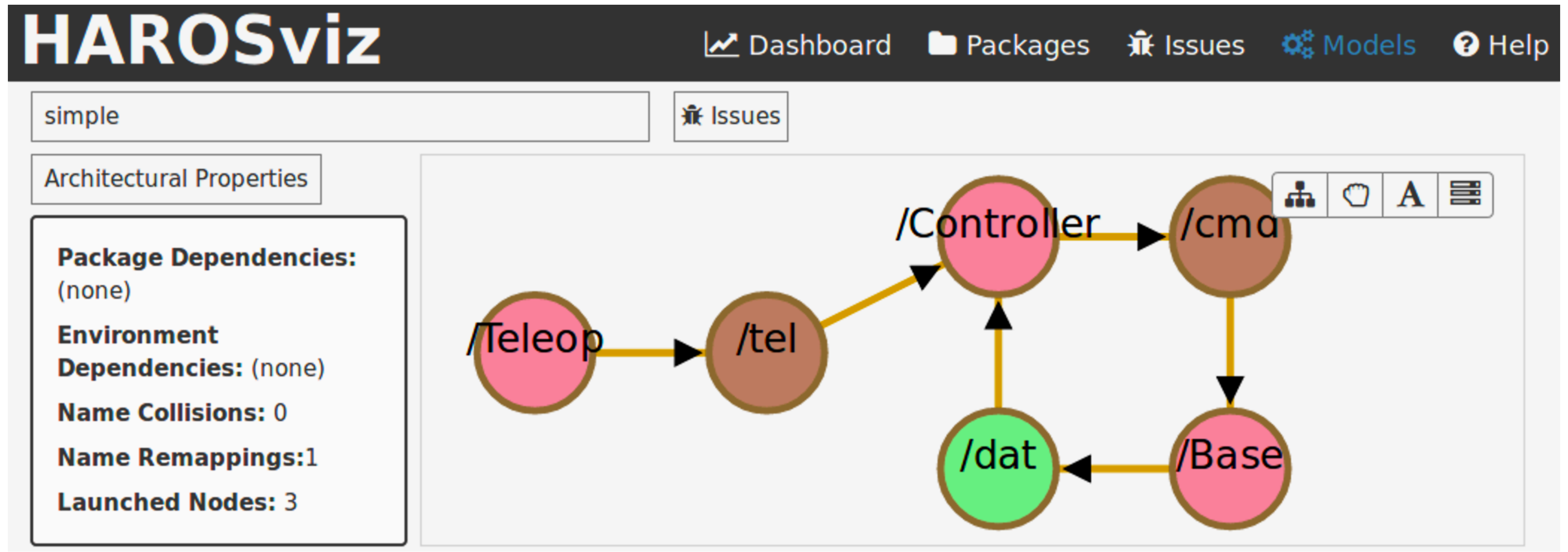
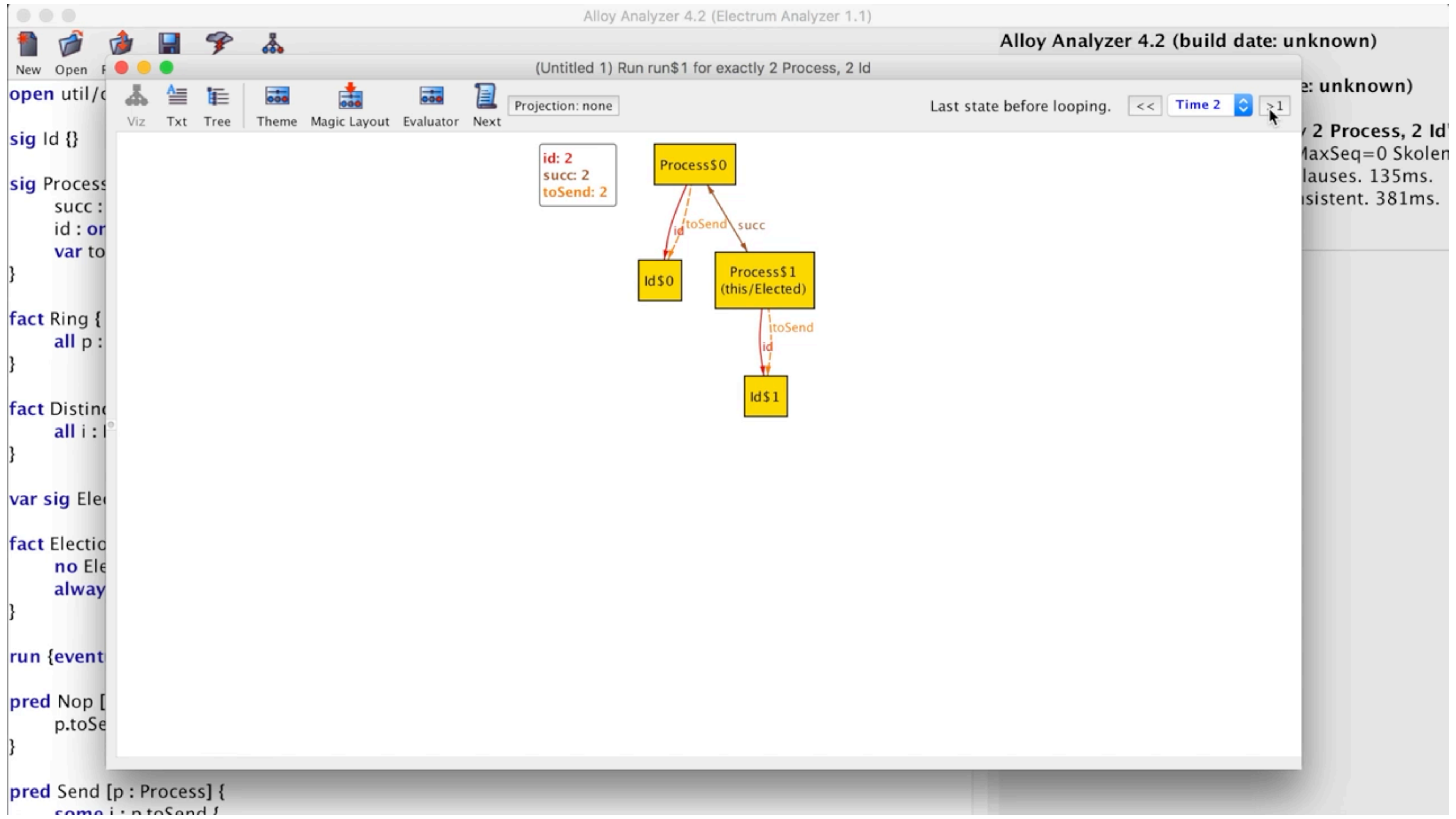




Alloy6 (Electrum)

A model checker for relational linear temporal logic

- Formal specification language with structural and dynamic constructs
- Declarative specifications, behaviour can be under-specified
- Automatic verification through solving, returns counter-example traces
- Varying universe size provides increasing confidence



haslab.github.io/Electrum/

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Encoding ROS architectures

- Architectures encoded in a straight-forward way as fixed signatures
- Messages (and their values) are left unrestricted
  - An arbitrary number will be considered (within scopes)
- Large types (eg, integers) would overwhelm analysis
  - Relevant ranges inferred from the specs, only those classes are encoded

```
abstract sig Topic, Field, Value {}
sig IntVal, StrVal extends Value {}
abstract sig Node { subs, advs        : set Topic,
                    var inbox, outbox: set Message }

one sig tel, dat, cmd extends Topic {}
one sig Teleop, Base, Controller extends Node {}
fact Links {
  advs = Teleop->tel + Base->dat + Controller->cmd
  subs = Controller->(tel+dat) + Base->cmd }

sig Message { topic: one Topic,
              val  : Field->lone Value }

one sig tel_val, …, cmd_val, cmd_msg extends Field {}
fact Fields {
  all m: topic.cmd {
    m.val in cmd_val->IntVal + cmd_msg->StrVal
    m.val in (cmd_val+cmd_msg)->one (IntVal+StrVal) }
  … }

lone sig Int_0,Int_1 in IntVal {}
sig Int_0_10,Int_0_100 in IntVal {}
fact Values {
  Int_0+Int_1 in Int_0_10 and Int_0_10 in Int_0_100
  no Int_0&Int_1 }
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- The message-passing behaviour is loosely specified
  - Messages in the outbox will eventually reach the inboxes of subscribers
- Specifications translated to linear temporal logic
- Node behaviour imposed as a fact, desirable system properties as assertions to be checked

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fact Messages { always {
  all m: Node.outbox {
    all n: subs.(m.topic) | eventually m in n.inbox
    eventually m not in Node.outbox }
  all m: Node.inbox |
    before once m in advs.(m.topic).outbox }
  … }
```

```
fact NodeBehavior { always {
  no m: Teleop.outbox&topic.tel |
    tel_val.(m.val) not in Int_0_100
  …
  all m: Controller.inbox&topic.dat |
    dat_val.(m.val) = Int_0 implies after eventually
      some m0: Controller.outbox&topic.cmd {
        cmd_val.(m0.val) = Int_0
        cmd_msg.(m0.val) = Str_stop } } }
```

```
assert simple1 { always {
  all m: Node.outbox&topic.cmd |
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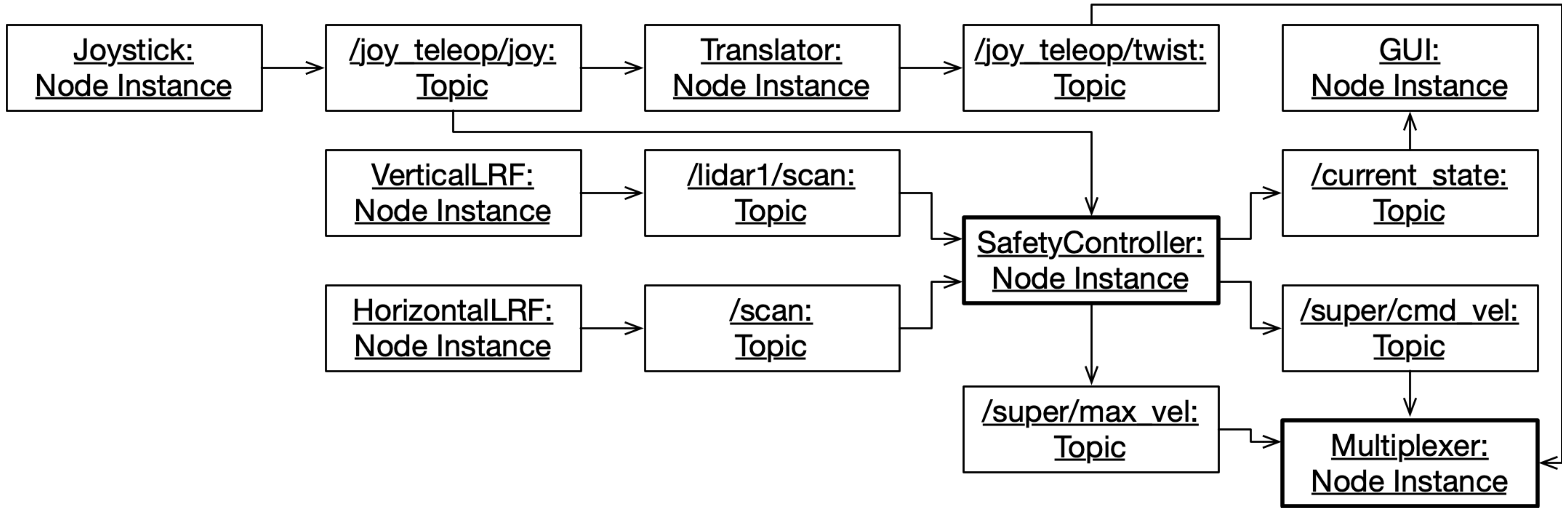
Evaluation

Case study: AgRob V16



Modular robot, alternative configurations for navigation

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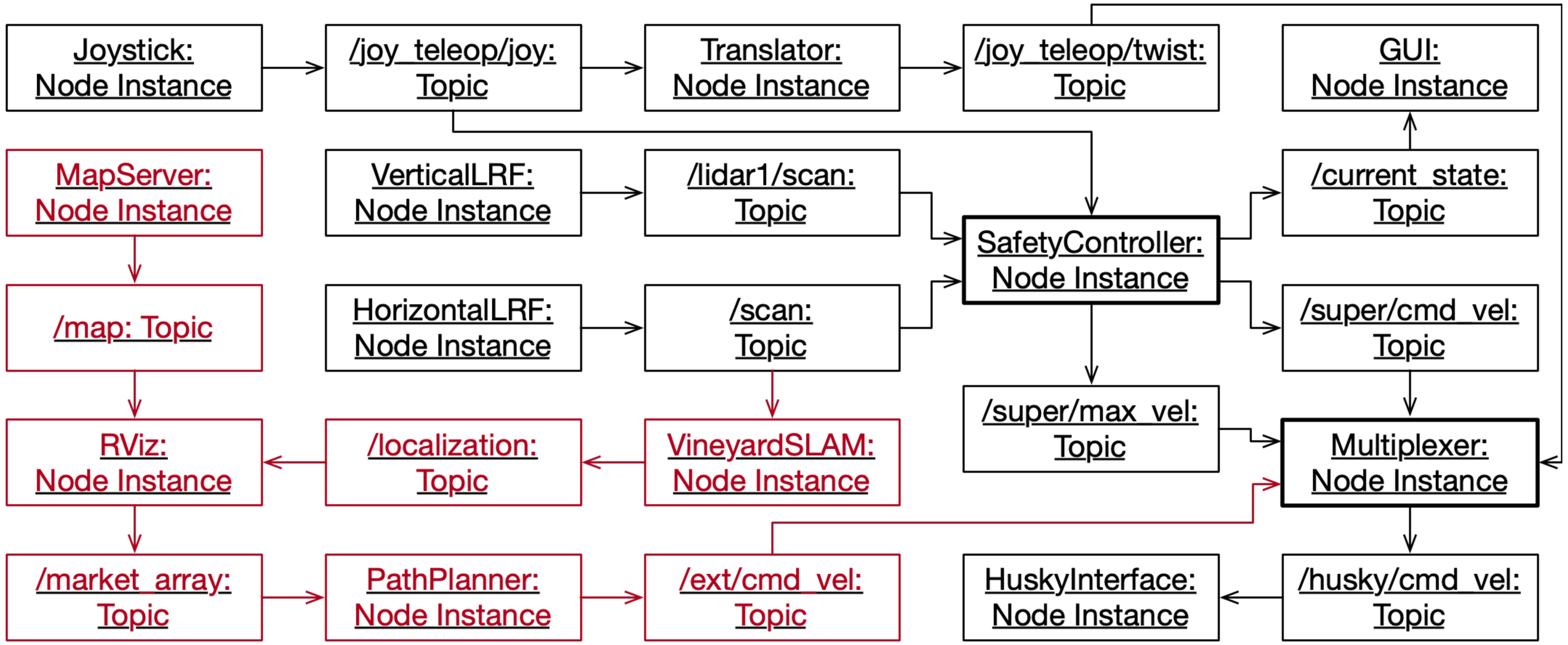

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              /joy_teleop/joy{button[0]=0, button[1]=1} ||
              /joy_teleop/joy{button[4]=1, button[5]=0}


map:
  globally: /agrobv16/current_state{data[0]=3} requires
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  globally: /husky/cmd_vel{linear.x=0, angular.x in -100 to 100} requires
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Counter-example in 1 min for 10 Messages

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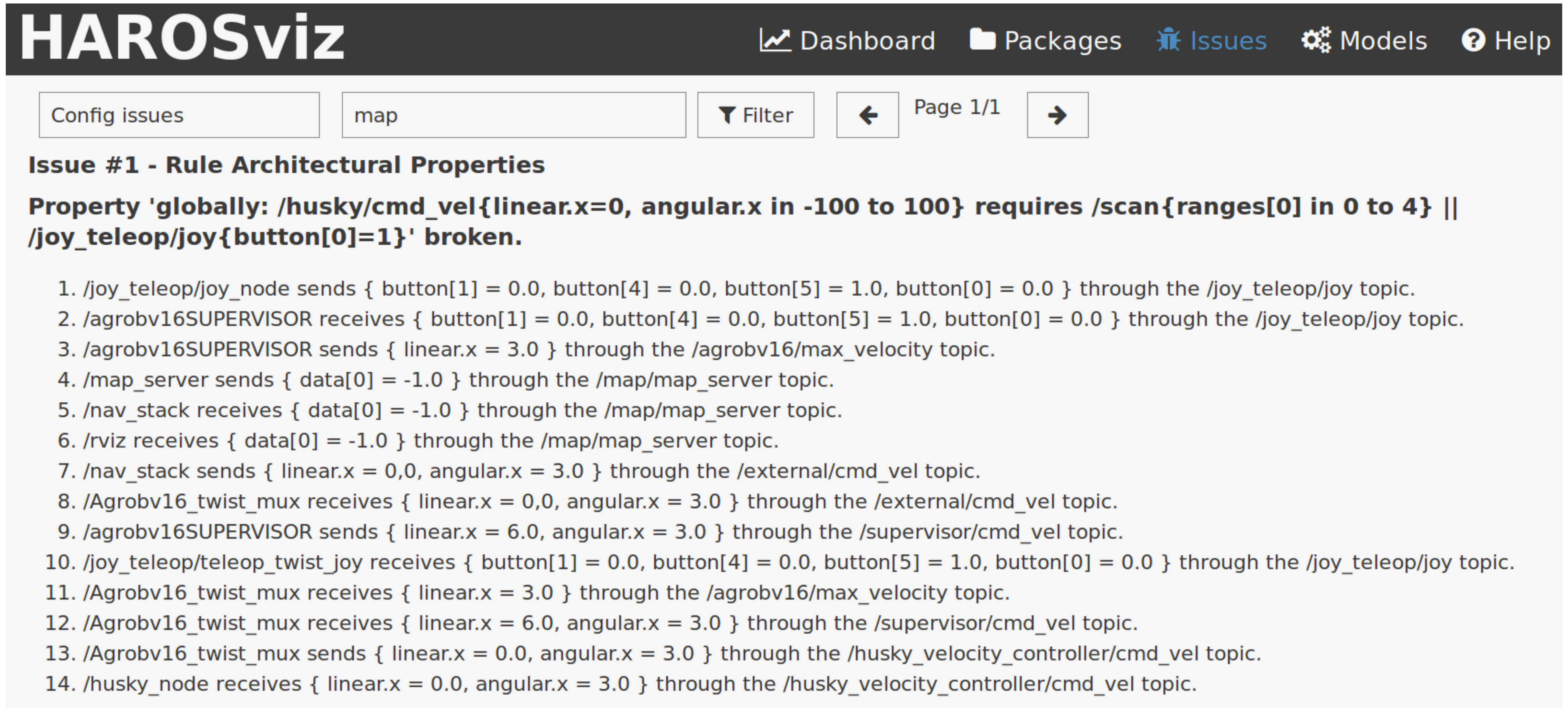

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Limitations and future work

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    - Mechanisms to infer sensible scopes and support the user

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Verification of system-wide safety properties of ROS applications

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COMPETE 2020

PORTUGAL 2020

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