some research topics in software engineering

Wardah Mahmood, Mukelabai Mukelabai, Patrick Franz, Daniel Strüber, Thorsten Berger

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EASElab (Empirical and Automated Software Eng. Lab)

We automate **software engineering** for the next generation of **intelligent, autonomous, and variant-rich** software systems. We explore new ways of **software creation, analysis, and evolution**. Our application domains are **automotive systems, systems software (e.g., Linux kernel), software ecosystems (e.g. Android apps), and mobile robots**.

http://www.easelab.org

Focus areas

- **Model-Driven Software Engineering (MDSE)**
- Software Analytics (SWA)
- AI Engineering (SE4AI/AI4SE)
- Software Product Line Engineering (SPLE)

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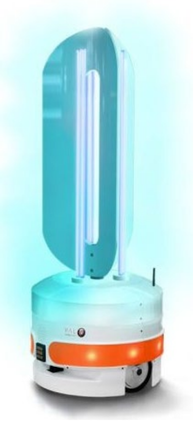
ANDROID

ABB

TIAGO
TIAGO@HOME

TIAGo++



SCANIA
SCANIA
SCANIA
HIGHLINE

agenda

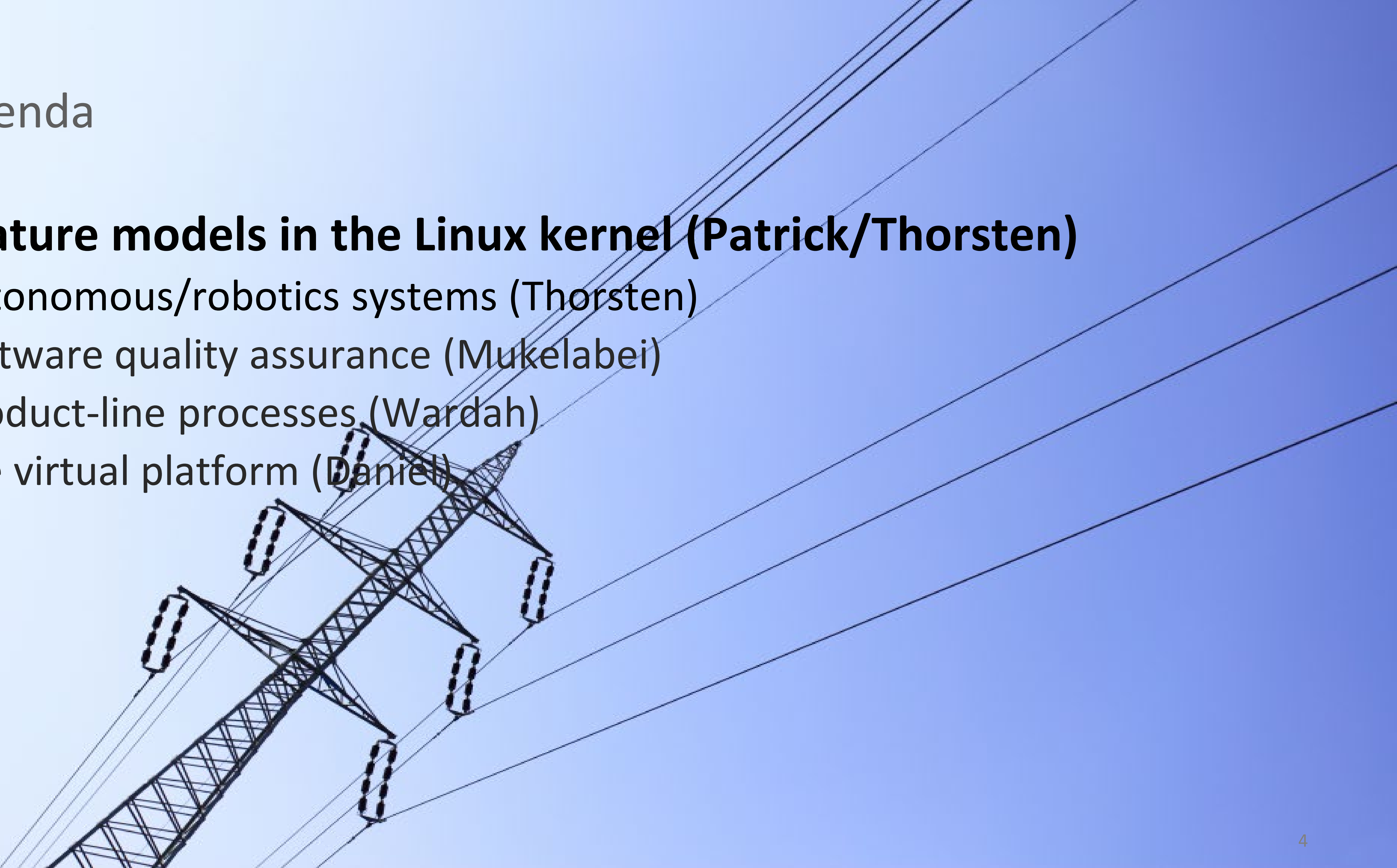
feature models in the Linux kernel (Patrick/Thorsten)

autonomous/robotics systems (Thorsten)

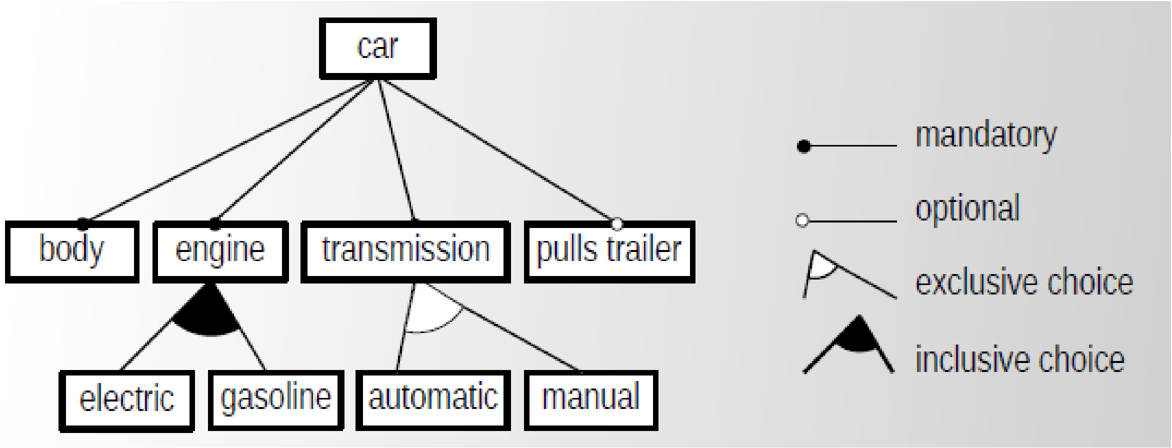
software quality assurance (Mukelabei)

product-line processes (Wardah)

the virtual platform (Daniel)



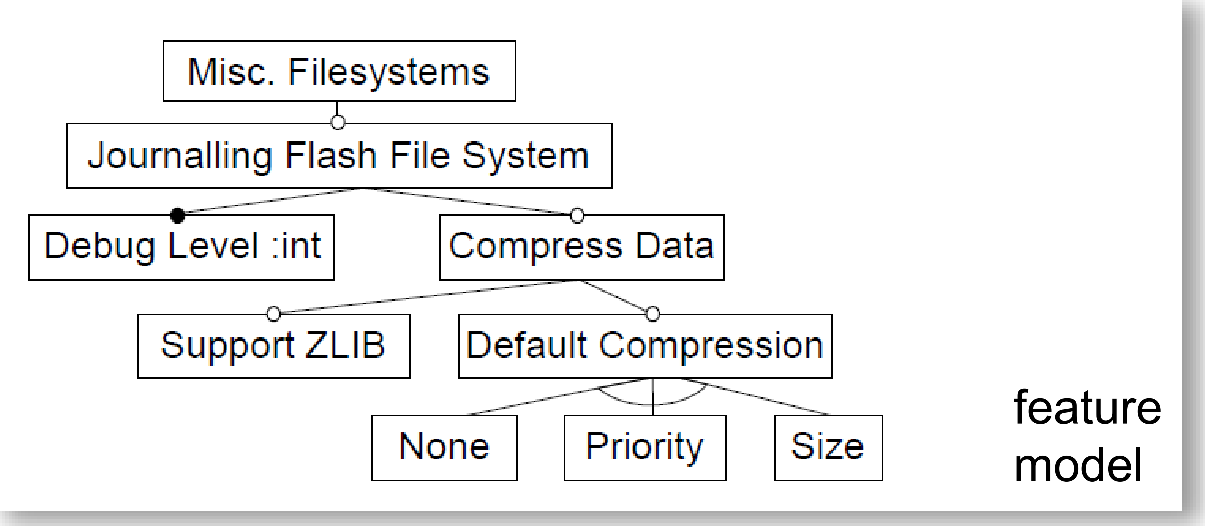
feature modeling

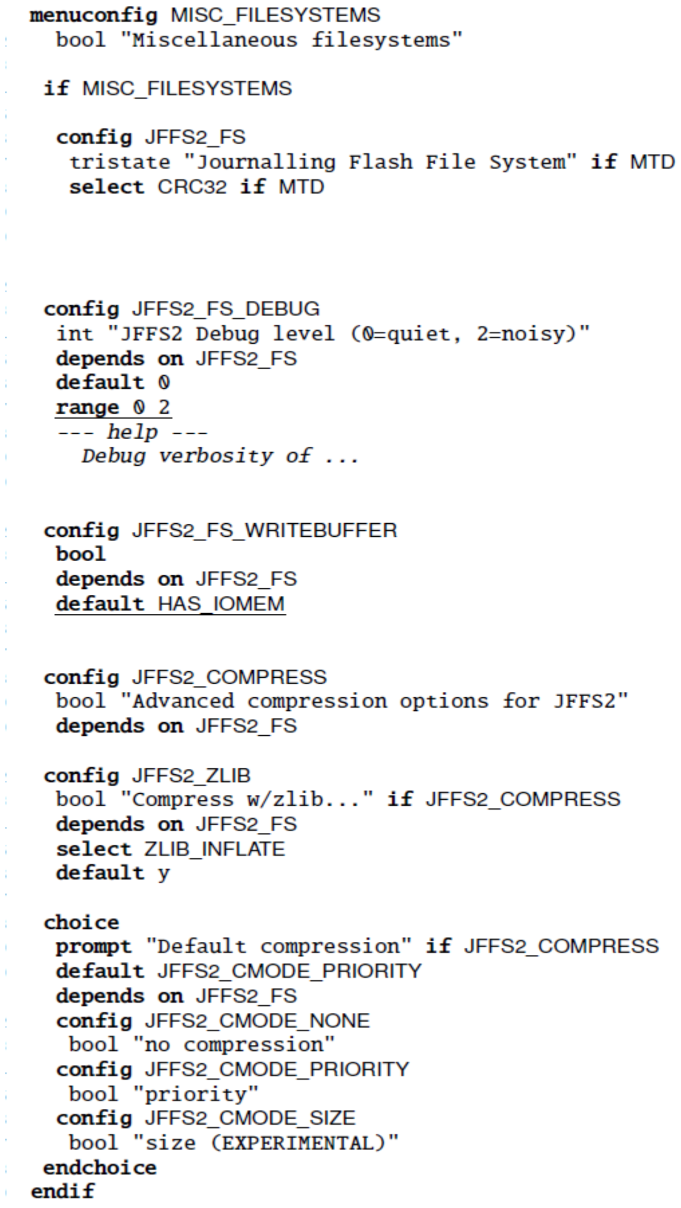


electric *requires* automatic

avoid illegal variants

feature models in the Linux kernel



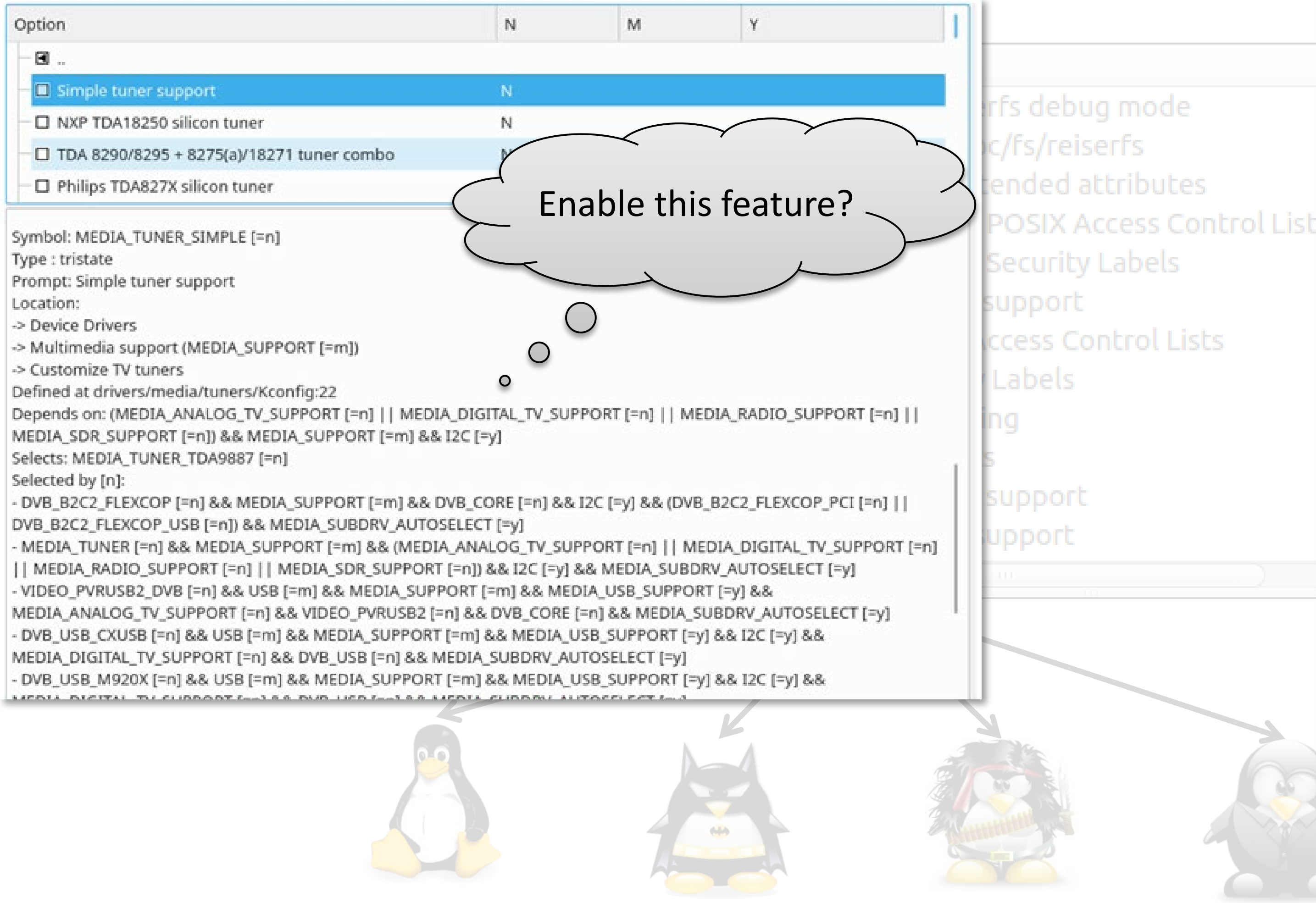


```
menuconfig MISC_FILESYSTEMS
  bool "Miscellaneous filesystems"

 if MISC_FILESYSTEMS

  config JFFS2_FS
   tristate "Journalling Flash File System" if MTD
   select CRC32 if MTD



 config JFFS2_FS_DEBUG
  int "JFFS2 Debug level (0=quiet, 2=noisy)"
  depends on JFFS2_FS
  default 0
  range 0 2
  --- help ---
    Debug verbosity of ...


 config JFFS2_FS_WRITEBUFFER
  bool
  depends on JFFS2_FS
  default HAS_IOMEM


 config JFFS2_COMPRESS
  bool "Advanced compression options for JFFS2"
  depends on JFFS2_FS

 config JFFS2_ZLIB
  bool "Compress w/zlib..." if JFFS2_COMPRESS
  depends on JFFS2_FS
  select ZLIB_INFLATE
  default y

 choice
  prompt "Default compression" if JFFS2_COMPRESS
  default JFFS2_CMODE_PRIORITY
  depends on JFFS2_FS
  config JFFS2_CMODE_NONE
   bool "no compression"
  config JFFS2_CMODE_PRIORITY
   bool "priority"
  config JFFS2_CMODE_SIZE
   bool "size (EXPERIMENTAL)"
 endchoice
endif
```

Berger, She, Lotufo, Wasowski, Czarnecki. A study of variability models and languages in the systems software domain. *IEEE Transactions on Software Engineering*, 2013

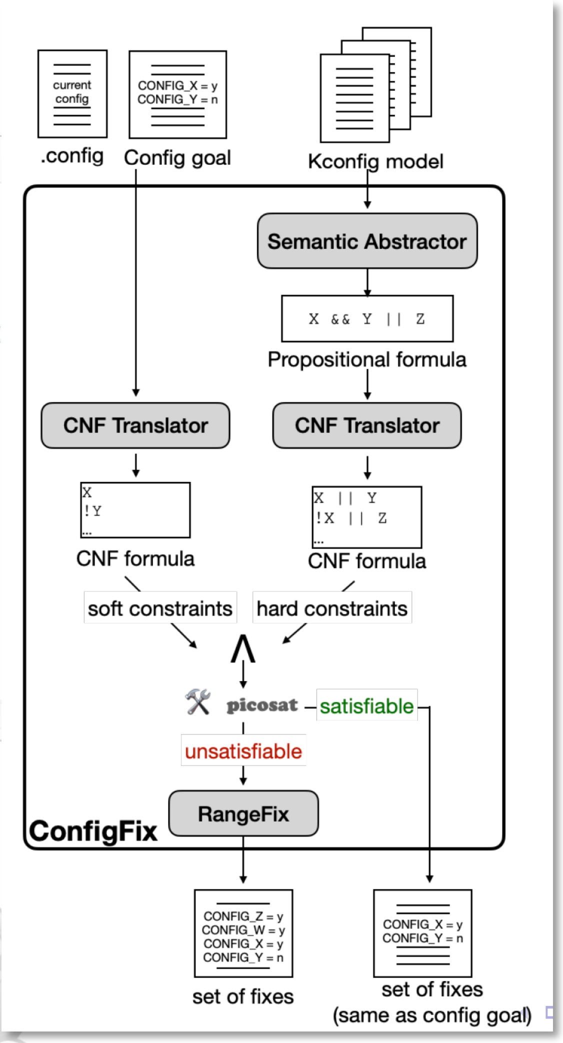
Franz, Berger, Fayaz, Nadi, Groshev. ConfigFix: Interactive Configuration Conflict Resolution for the Linux Kernel,” *43rd International Conference on Software Engineering.* 2021.

Linux kernel configurator (xconfig)



Option	N	M	Y
..			
□ Simple tuner support	N		
□ NXP TDA18250 silicon tuner	N		
□ TDA 8290/8295 + 8275(a)/18271 tuner combo	N		
□ Philips TDA827X silicon tuner			

```
Symbol: MEDIA_TUNER_SIMPLE [=n]
Type : tristate
Prompt: Simple tuner support
Location:
-> Device Drivers
-> Multimedia support (MEDIA_SUPPORT [=m])
-> Customize TV tuners
Defined at drivers/media/tuners/Kconfig:22
Depends on: (MEDIA_ANALOG_TV_SUPPORT [=n] || MEDIA_DIGITAL_TV_SUPPORT [=n] || MEDIA_RADIO_SUPPORT [=n] ||
MEDIA_SDR_SUPPORT [=n]) && MEDIA_SUPPORT [=m] && I2C [=y]
Selects: MEDIA_TUNER_TDA9887 [=n]
Selected by [n]:
- DVB_B2C2_FLEXCOP [=n] && MEDIA_SUPPORT [=m] && DVB_CORE [=n] && I2C [=y] && (DVB_B2C2_FLEXCOP_PCI [=n] ||
DVB_B2C2_FLEXCOP_USB [=n]) && MEDIA_SUBDRV_AUTOSELECT [=y]
- MEDIA_TUNER [=n] && MEDIA_SUPPORT [=m] && (MEDIA_ANALOG_TV_SUPPORT [=n] || MEDIA_DIGITAL_TV_SUPPORT [=n]
|| MEDIA_RADIO_SUPPORT [=n] || MEDIA_SDR_SUPPORT [=n]) && I2C [=y] && MEDIA_SUBDRV_AUTOSELECT [=y]
- VIDEO_PVRUSB2_DVB [=n] && USB [=m] && MEDIA_SUPPORT [=m] && MEDIA_USB_SUPPORT [=y] &&
MEDIA_ANALOG_TV_SUPPORT [=n] && VIDEO_PVRUSB2 [=n] && DVB_CORE [=n] && MEDIA_SUBDRV_AUTOSELECT [=y]
- DVB_USB_CXUSB [=n] && USB [=m] && MEDIA_SUPPORT [=m] && MEDIA_USB_SUPPORT [=y] && I2C [=y] &&
MEDIA_DIGITAL_TV_SUPPORT [=n] && DVB_USB [=n] && MEDIA_SUBDRV_AUTOSELECT [=y]
- DVB_USB_M920X [=n] && USB [=m] && MEDIA_SUPPORT [=m] && MEDIA_USB_SUPPORT [=y] && I2C [=y] &&
```



Berger, She, Lotufo, Wasowski, Czarnecki. A study of variability models and languages in the systems software domain. *IEEE Transactions on Software Engineering*, 2013

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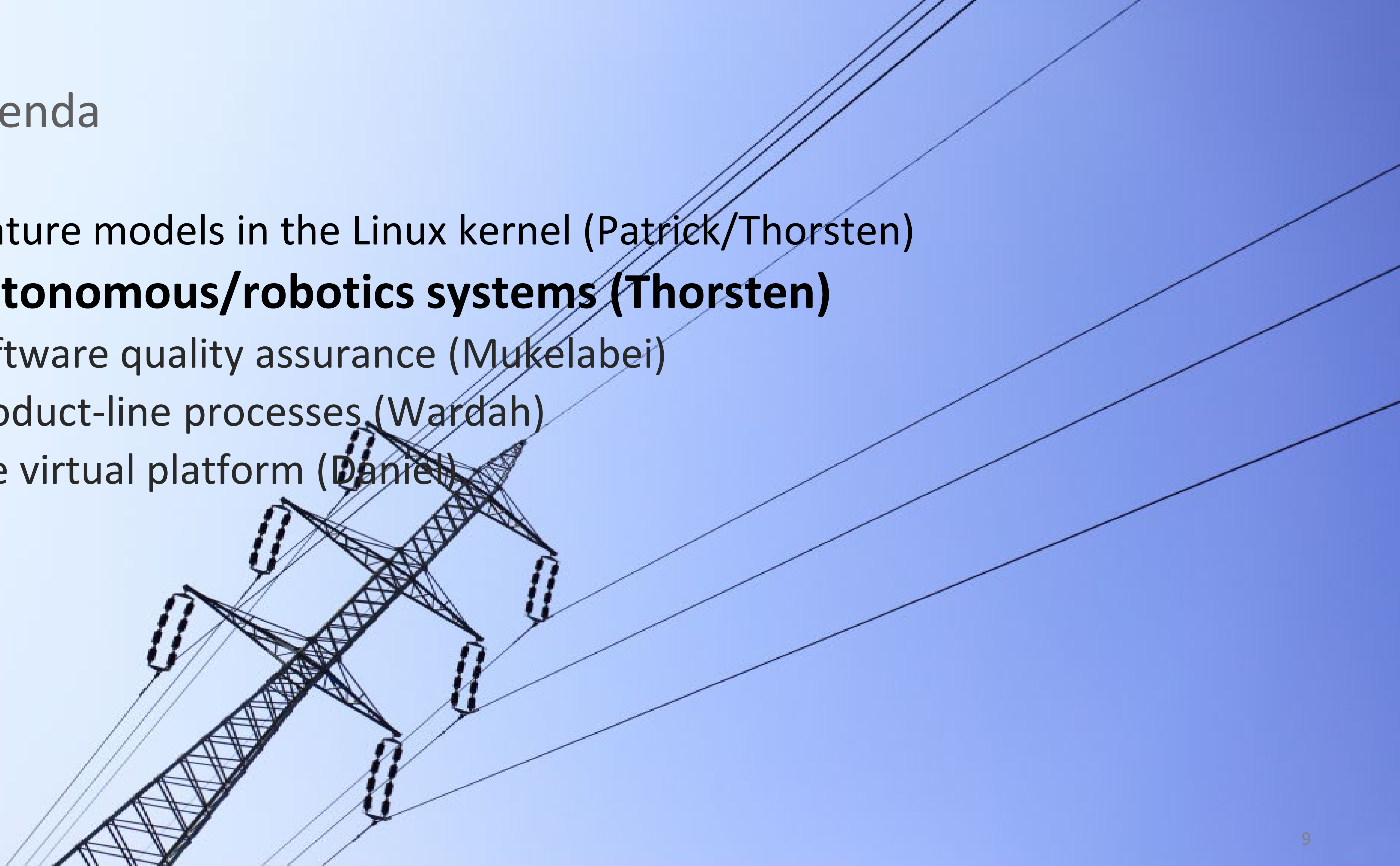
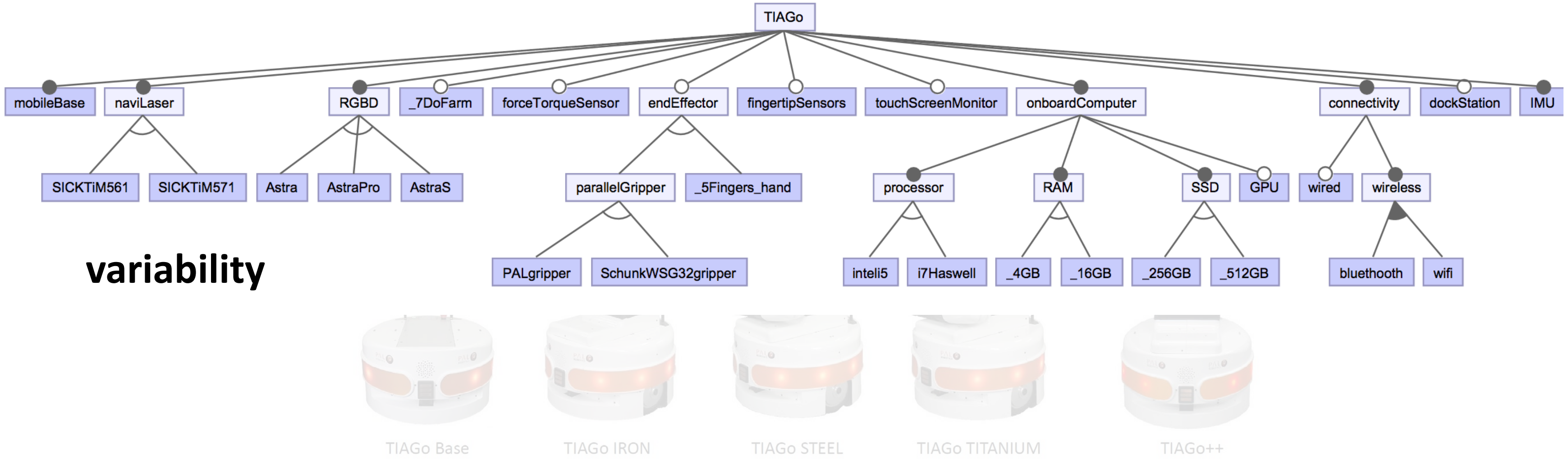
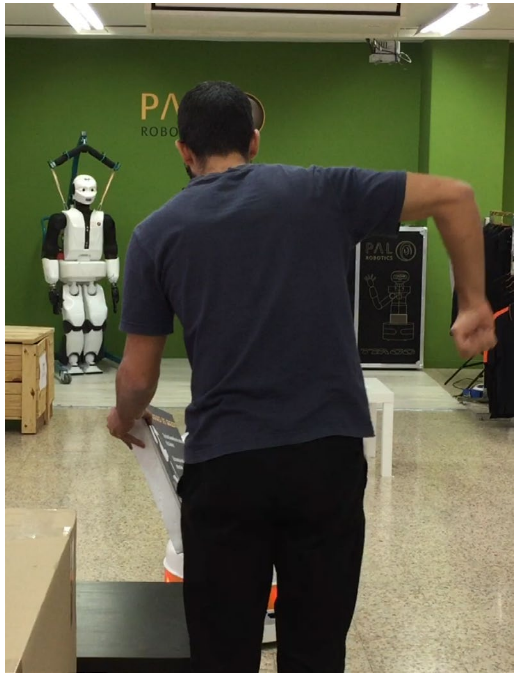


autonomous robots

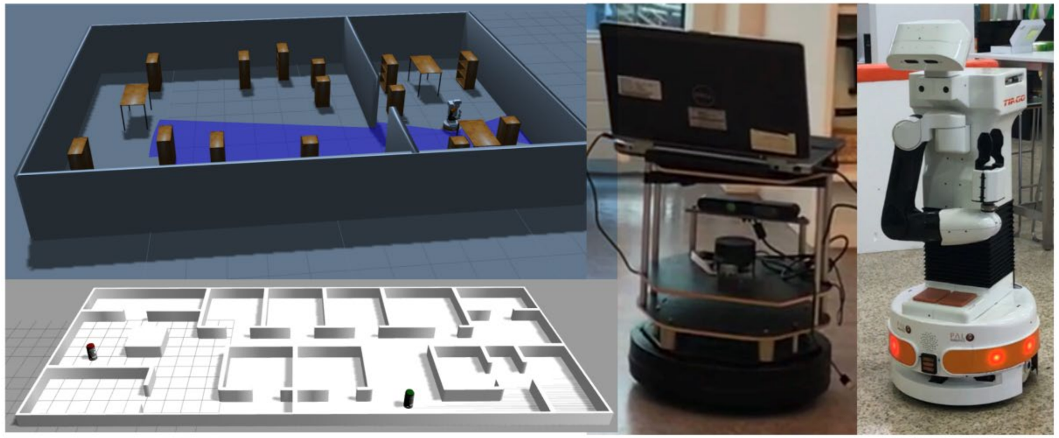
variability



gesture recognition



RoboCup tasks



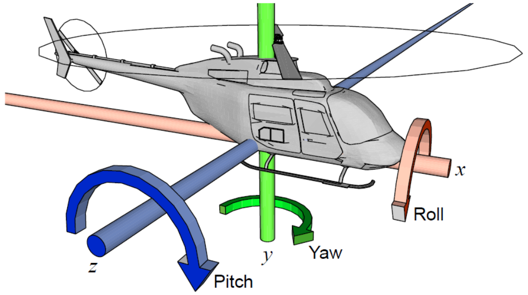
perception

human-robot interaction

behavior of autonomous systems

continuous dynamics

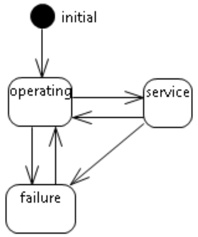
- Newton‘s mechanics
- ordinary differential equations
- actor models
- control properties (e.g., stability)



control theory

discrete dynamics

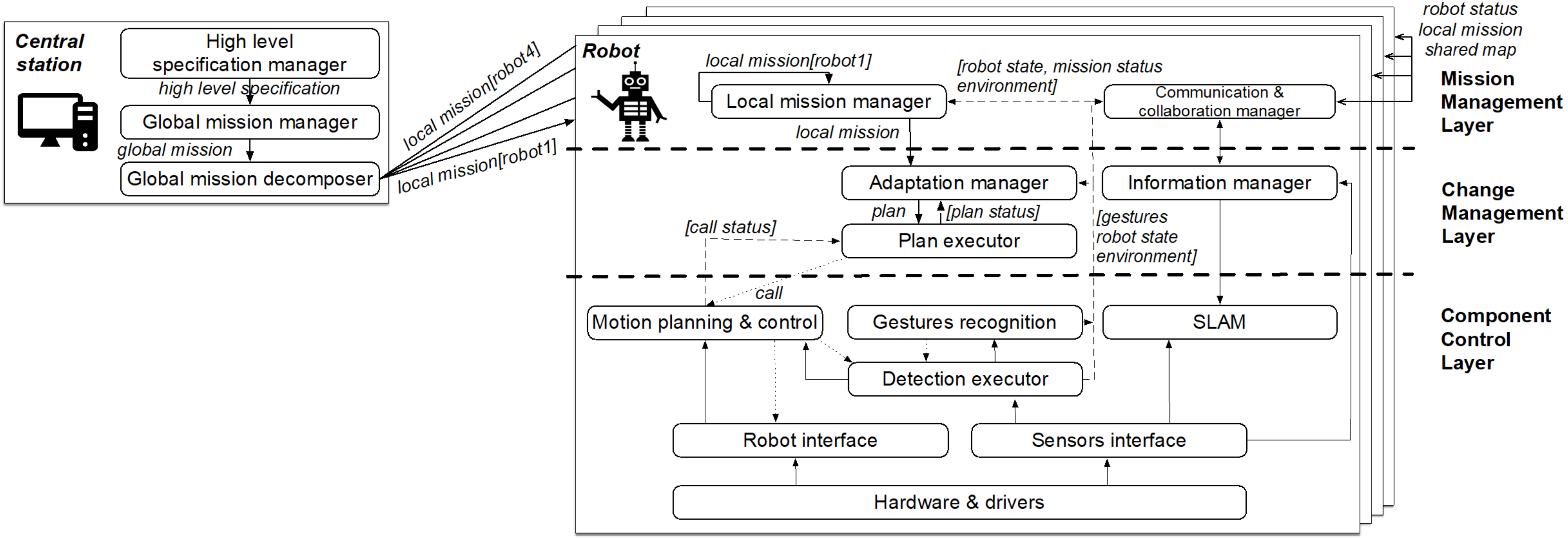
- states and state transitions
  - abrupt changes
  - operation modes
  - fail-safe states
- temporal properties



software engineering

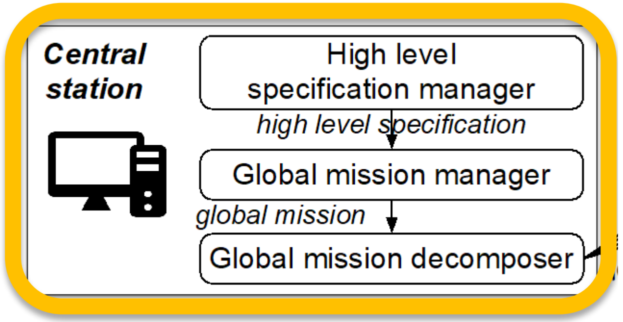
ROBOTICS ARCHITECTURE

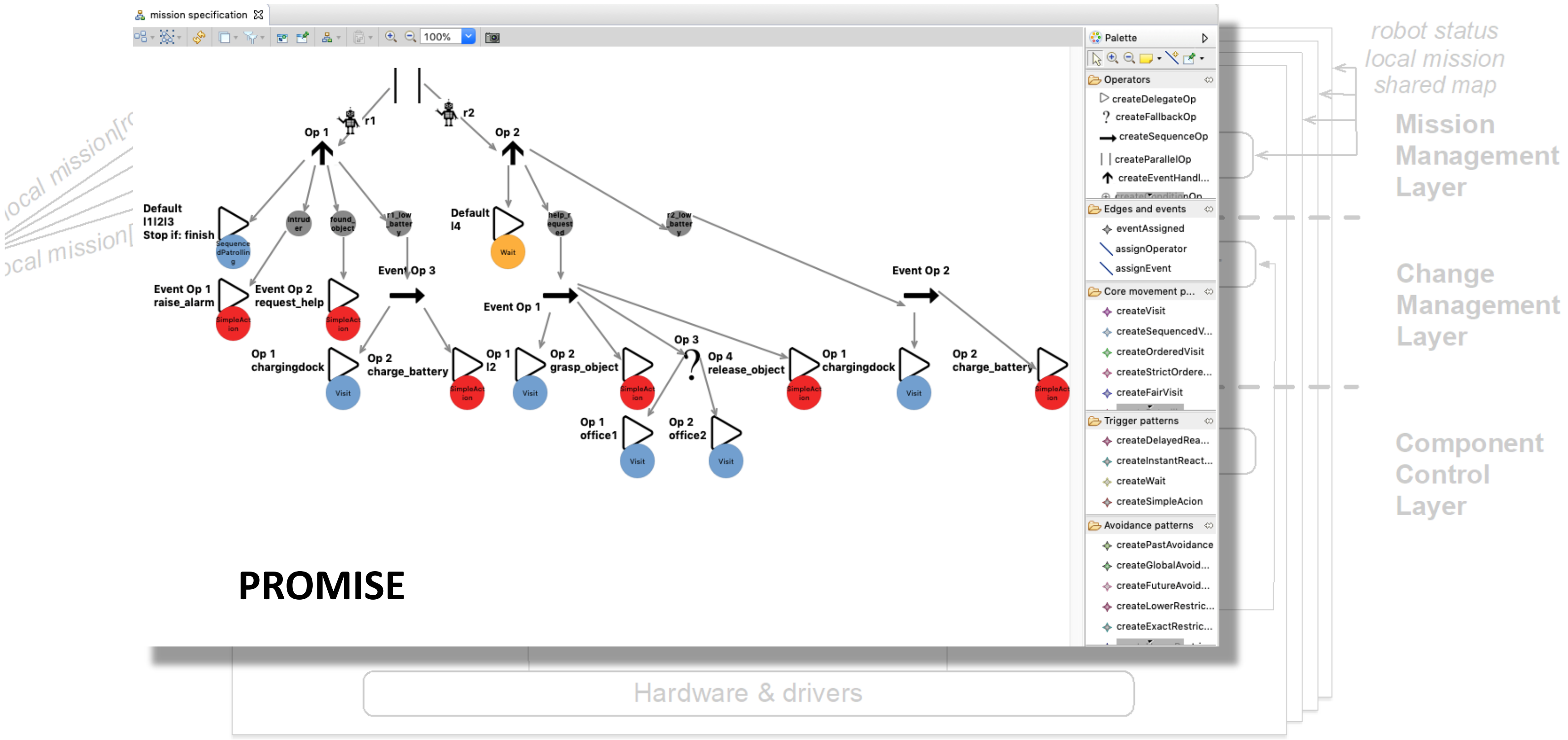
SERA (Self- adaptive dEcentralized Robotic Architecture)



Garcia, Pelliccione, Menghi, Berger, Wohlrab, “An Architecture for Decentralized, Collaborative, and Autonomous Robots,” in *International Conference on Software Architecture (ICSA)*, 2018

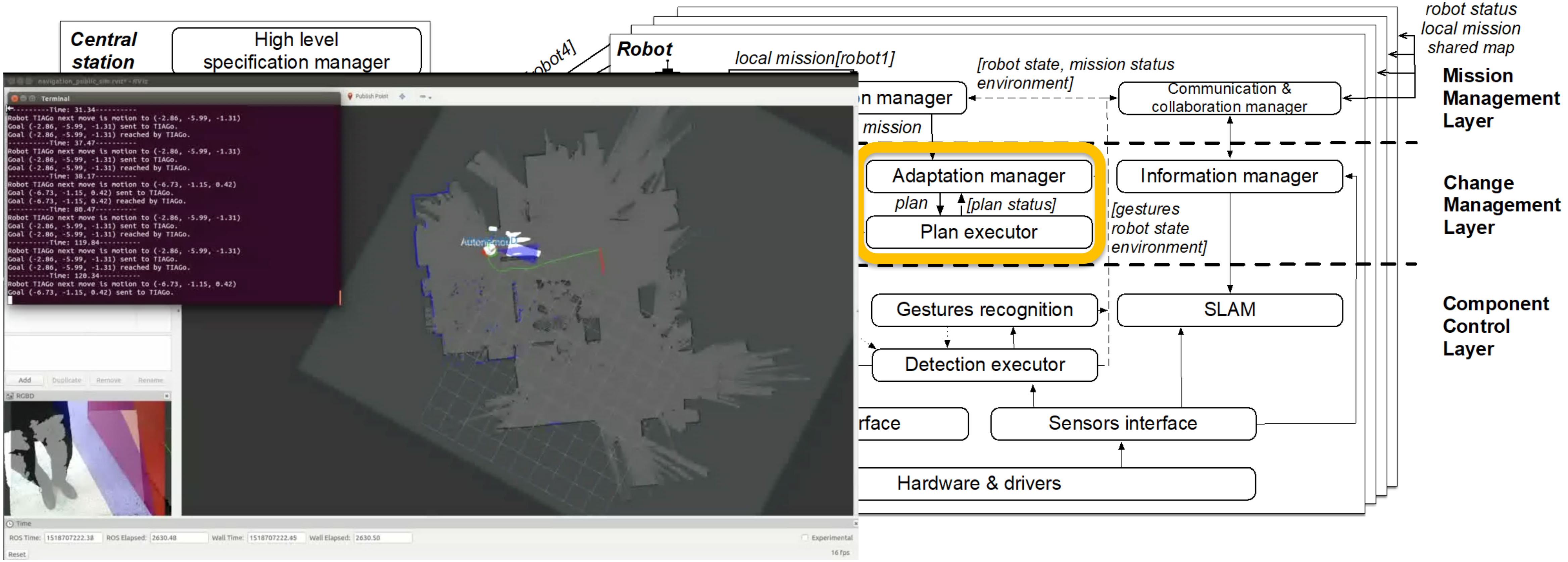
SERA: multi-robot mission control





PROMISE

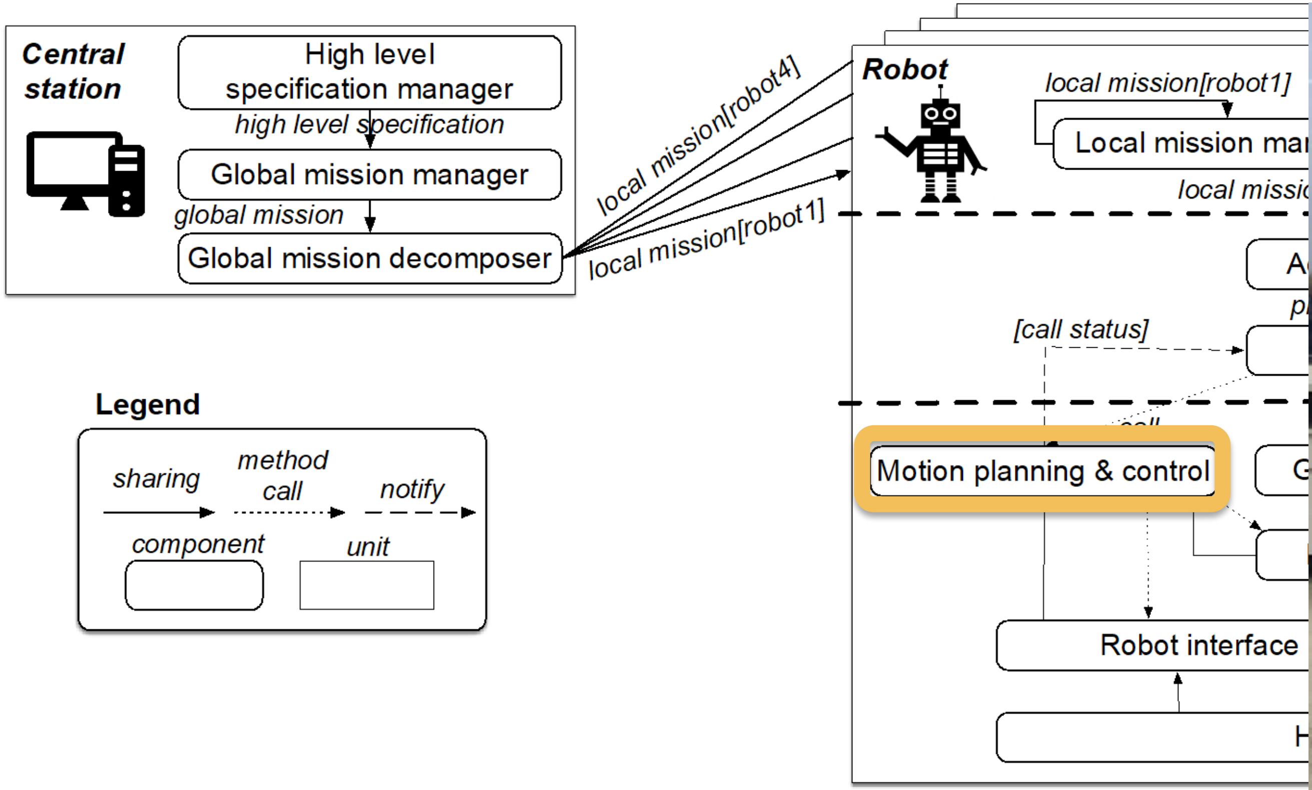
SERA: planning and adaptation



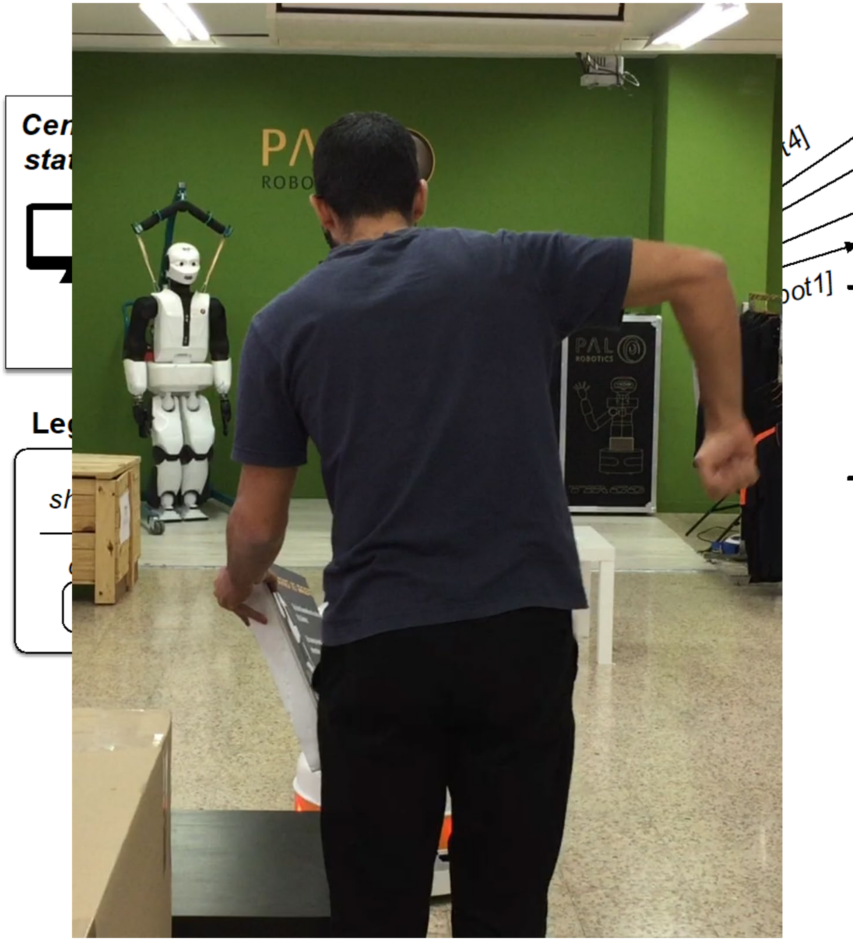
```
----------Time: 31.34----------
Robot TIAGo next move is motion to (-2.86, -5.99, -1.31)
Goal (-2.86, -5.99, -1.31) sent to TIAGo.
Goal (-2.86, -5.99, -1.31) reached by TIAGo.
----------Time: 37.47----------
Robot TIAGo next move is motion to (-2.86, -5.99, -1.31)
Goal (-2.86, -5.99, -1.31) sent to TIAGo.
Goal (-2.86, -5.99, -1.31) reached by TIAGo.
----------Time: 38.17----------
Robot TIAGo next move is motion to (-6.73, -1.15, 0.42)
Goal (-6.73, -1.15, 0.42) sent to TIAGo.
Goal (-6.73, -1.15, 0.42) reached by TIAGo.
----------Time: 80.47----------
Robot TIAGo next move is motion to (-2.86, -5.99, -1.31)
Goal (-2.86, -5.99, -1.31) sent to TIAGo.
Goal (-2.86, -5.99, -1.31) reached by TIAGo.
----------Time: 119.84---------
Robot TIAGo next move is motion to (-2.86, -5.99, -1.31)
Goal (-2.86, -5.99, -1.31) sent to TIAGo.
Goal (-2.86, -5.99, -1.31) reached by TIAGo.
----------Time: 120.34---------
Robot TIAGo next move is motion to (-6.73, -1.15, 0.42)
Goal (-6.73, -1.15, 0.42) sent to TIAGo.
```

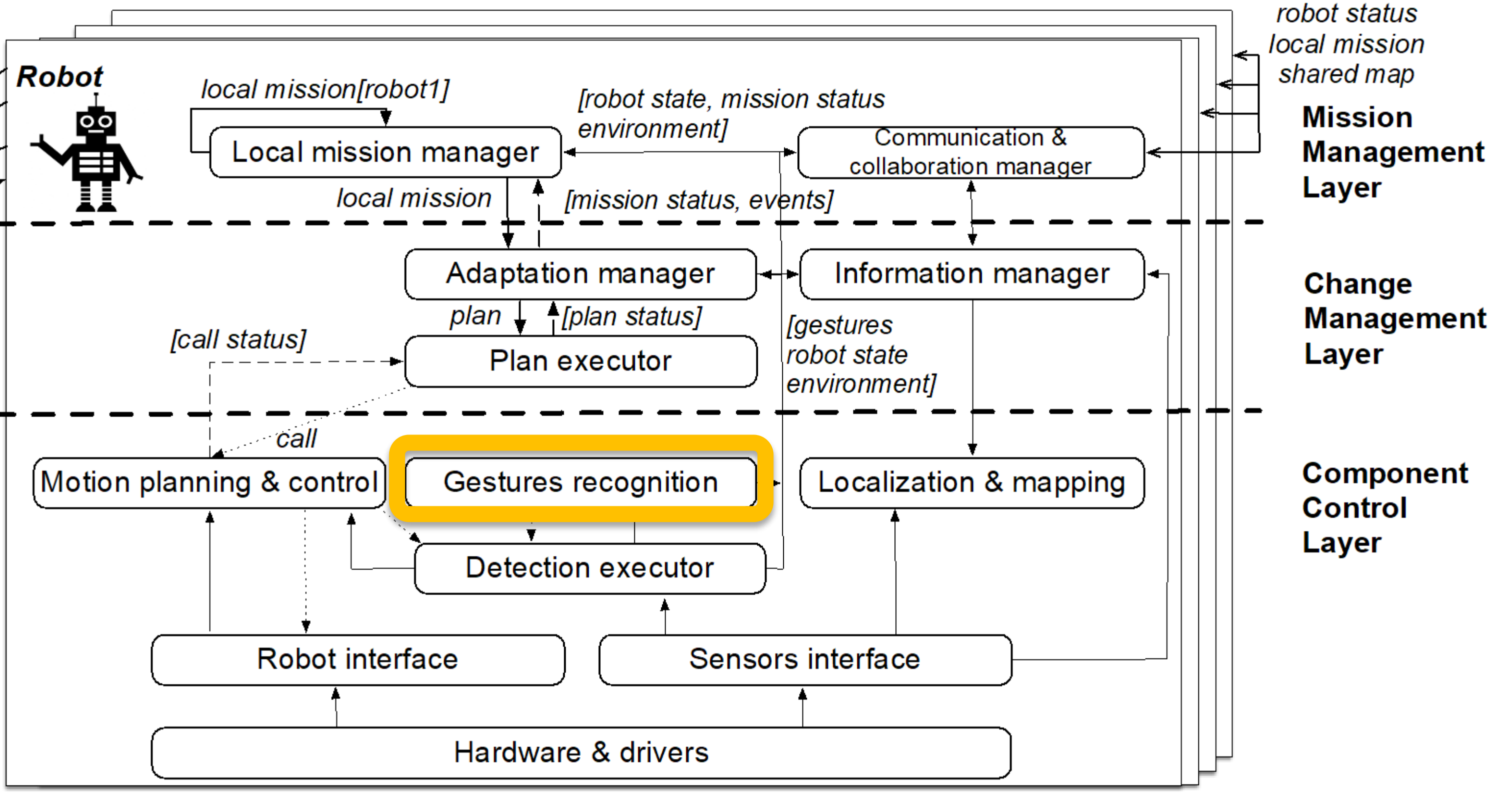
ROS Time: 1518707222.38 ROS Elapsed: 2630.48 Wall Time: 1518707222.45 Wall Elapsed: 2630.50

SERA: motion planning and control



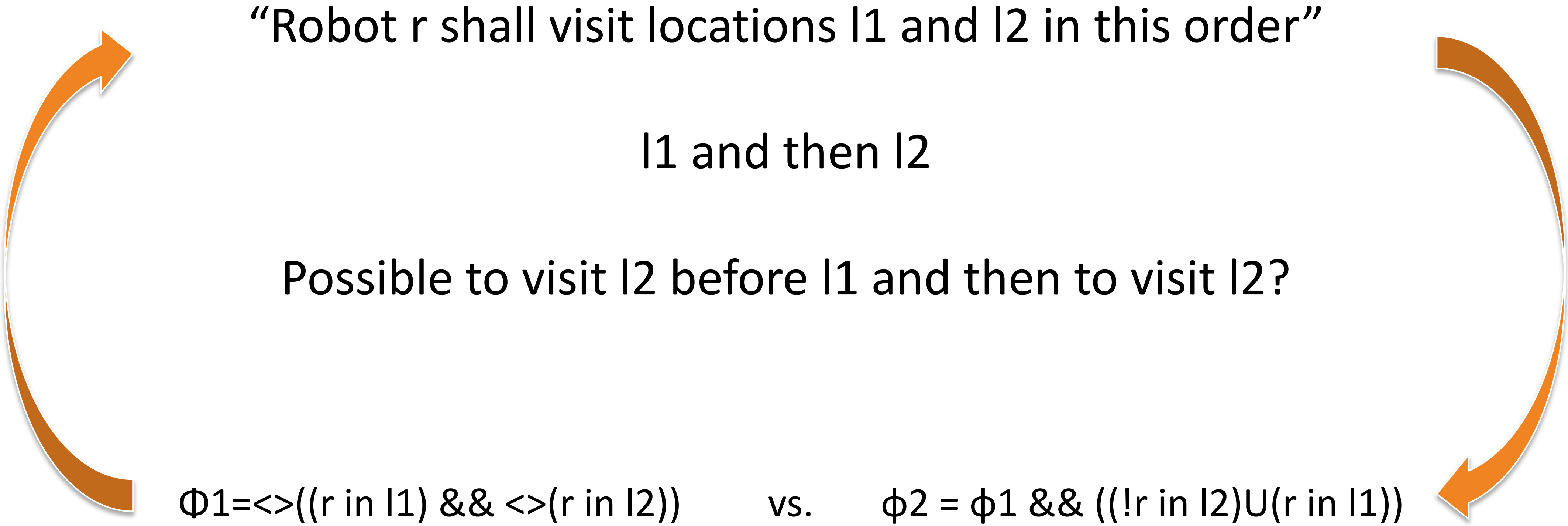
SERA: gesture recognition





ROBOTICS MISSION SPECIFICATION

user-friendly mission specification



“Robot r shall visit locations l1 and l2 in this order”

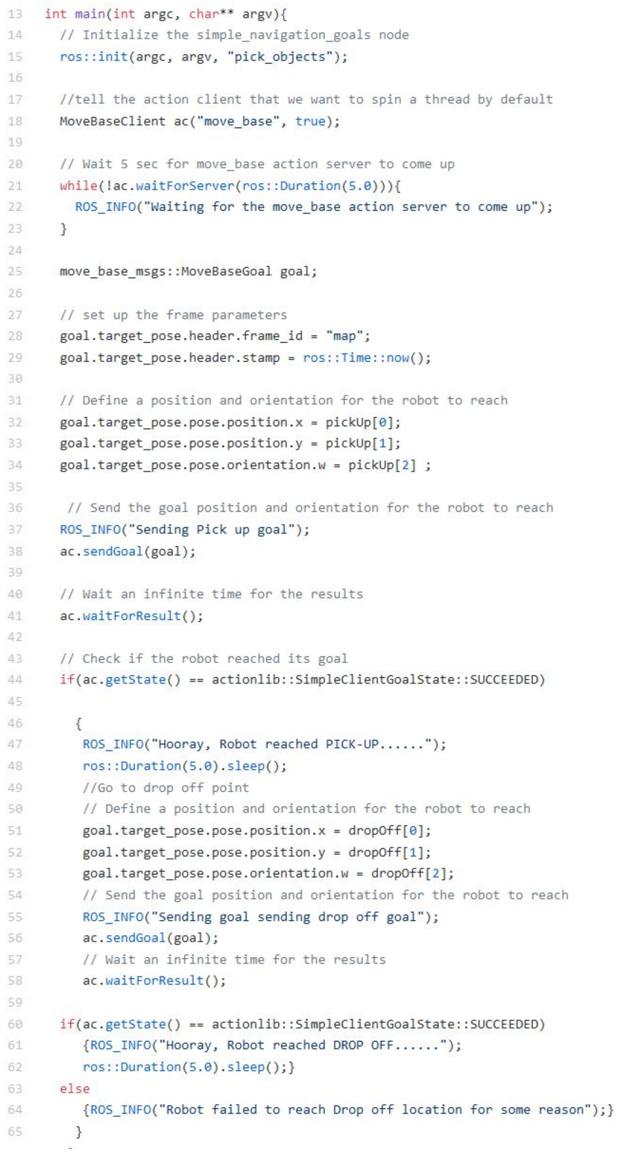
l1 and then l2

Possible to visit l2 before l1 and then to visit l2?

Φ1=<>((r in l1) && <>(r in l2)) vs. ϕ2 = ϕ1 && ((!r in l2)U(r in l1))

discrete dynamics: code and models

plain code



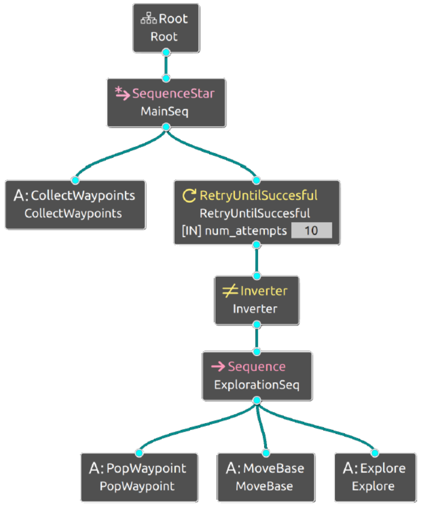
```
int main(int argc, char** argv){
  // Initialize the simple_navigation_goals node
  ros::init(argc, argv, "pick_objects");

  //tell the action client that we want to spin a thread by default
  MoveBaseClient ac("move_base", true);

  // Wait 5 sec for move_base action server to come up
  while(!ac.waitForServer(ros::Duration(5.0))){
    ROS_INFO("Waiting for the move_base action server to come up");
  }

  move_base_msgs::MoveBaseGoal goal;

  // set up the frame parameters
  goal.target_pose.header.frame_id = "map";
  goal.target_pose.header.stamp = ros::Time::now();

  // Define a position and orientation for the robot to reach
  goal.target_pose.pose.position.x = pickUp[0];
  goal.target_pose.pose.position.y = pickUp[1];
  goal.target_pose.pose.orientation.w = pickUp[2] ;

   // Send the goal position and orientation for the robot to reach
  ROS_INFO("Sending Pick up goal");
  ac.sendGoal(goal);

  // Wait an infinite time for the results
  ac.waitForResult();

  // Check if the robot reached its goal
  if(ac.getState() == actionlib::SimpleClientGoalState::SUCCEEDED)

    {
     ROS_INFO("Hooray, Robot reached PICK-UP......");
     ros::Duration(5.0).sleep();
     //Go to drop off point
     // Define a position and orientation for the robot to reach
     goal.target_pose.pose.position.x = dropOff[0];
     goal.target_pose.pose.position.y = dropOff[1];
     goal.target_pose.pose.orientation.w = dropOff[2];
     // Send the goal position and orientation for the robot to reach
     ROS_INFO("Sending goal sending drop off goal");
     ac.sendGoal(goal);
     // Wait an infinite time for the results
     ac.waitForResult();

  if(ac.getState() == actionlib::SimpleClientGoalState::SUCCEEDED)
     {ROS_INFO("Hooray, Robot reached DROP OFF......");
     ros::Duration(5.0).sleep();}
  else
     {ROS_INFO("Robot failed to reach Drop off location for some reason");}
    }
```

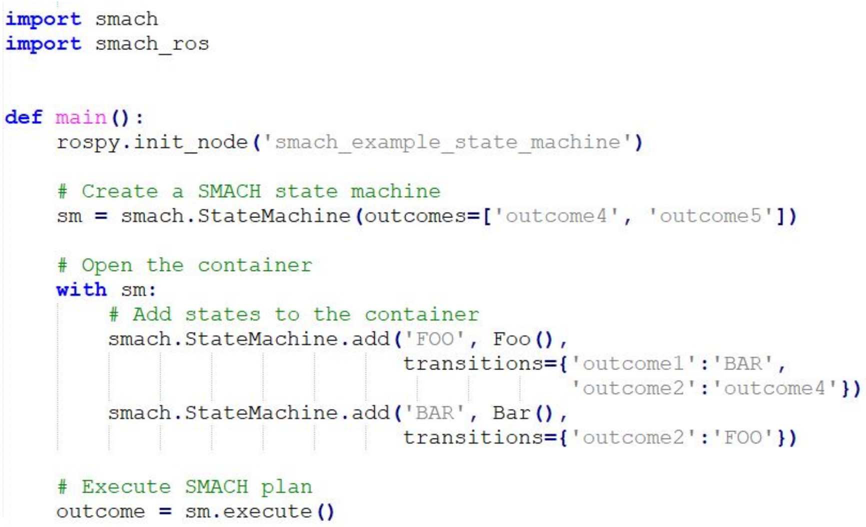
temporal logics

Φ1=<>((r in l1) && <>(r in l2))

```
<root main_tree_to_execute="BehaviorTree">

    <BehaviorTree ID="BehaviorTree">

        <Fallback name="ReachTable">

            <Sequence name="SelfFollowing">
                <Condition ID="TableKnown"/>
                <Action ID="GoToTable"/>
            </Sequence>

            <Sequence name="ShouldFollow">
                <Action ID="AskForHelp"/>
                <Action ID="FollowHuman"/>
            </Sequence>

        </Fallback>

    </BehaviorTree>

</root>
```

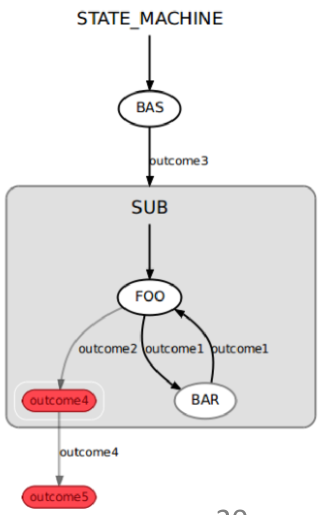
behavior trees





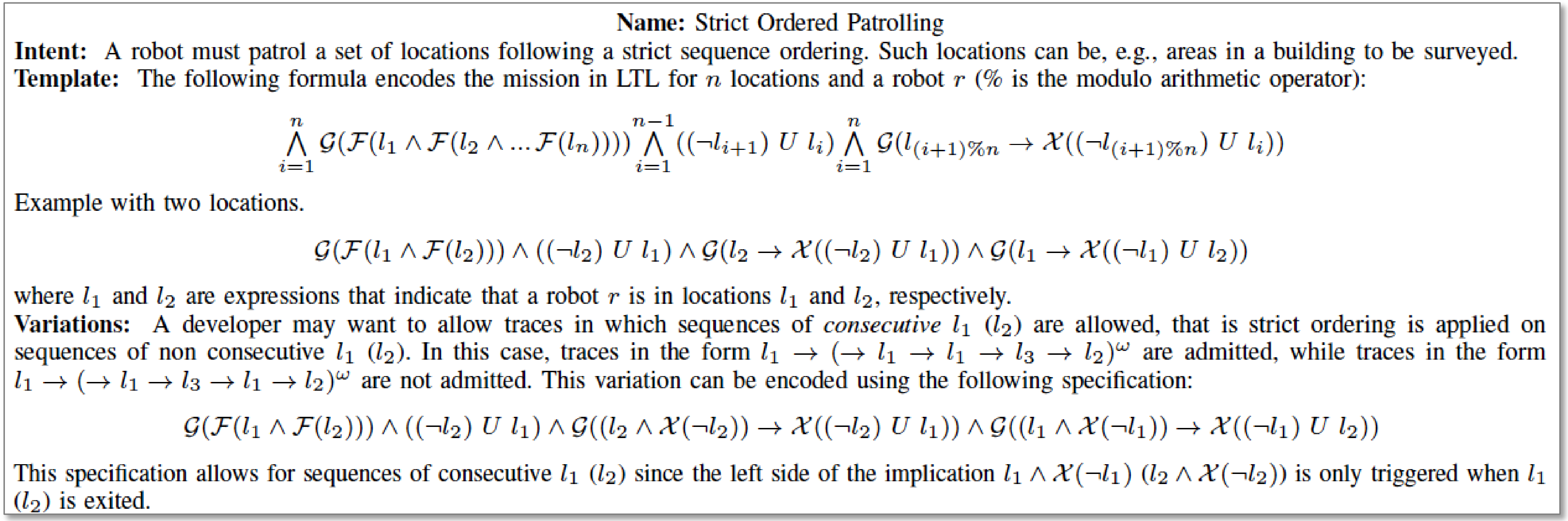
```
import smach
import smach_ros

def main():
    rospy.init_node('smach_example_state_machine')

    # Create a SMACH state machine
    sm = smach.StateMachine(outcomes=['outcome4', 'outcome5'])

    # Open the container
    with sm:
        # Add states to the container
        smach.StateMachine.add('FOO', Foo(),
                               transitions={'outcome1':'BAR',
                                            'outcome2':'outcome4'})
        smach.StateMachine.add('BAR', Bar(),
                               transitions={'outcome2':'FOO'})

    # Execute SMACH plan
    outcome = sm.execute()
```

state machines



Ghzouli, Berger, Broch Johnsen, Dragule, Wasowski, “Behavior Trees in Action: A Study of Robotics Applications,” *13th ACM SIGPLAN International Conference on Software Language Engineering (SLE)*, 2020

mission specification patterns



Name: Strict Ordered Patrolling

Intent: A robot must patrol a set of locations following a strict sequence ordering. Such locations can be, e.g., areas in a building to be surveyed.

Template: The following formula encodes the mission in LTL for n locations and a robot r (% is the modulo arithmetic operator):

$$\bigwedge_{i=1}^{n} \mathcal{G}(\mathcal{F}(l_1 \wedge \mathcal{F}(l_2 \wedge \ldots \mathcal{F}(l_n)))) \bigwedge_{i=1}^{n-1} ((\neg l_{i+1})\ U\ l_i) \bigwedge_{i=1}^{n} \mathcal{G}(l_{(i+1)\%n} \rightarrow \mathcal{X}((\neg l_{(i+1)\%n})\ U\ l_i))$$

Example with two locations.

$$\mathcal{G}(\mathcal{F}(l_1 \wedge \mathcal{F}(l_2))) \wedge ((\neg l_2)\ U\ l_1) \wedge \mathcal{G}(l_2 \rightarrow \mathcal{X}((\neg l_2)\ U\ l_1)) \wedge \mathcal{G}(l_1 \rightarrow \mathcal{X}((\neg l_1)\ U\ l_2))$$

where l_1 and l_2 are expressions that indicate that a robot r is in locations l_1 and l_2, respectively.

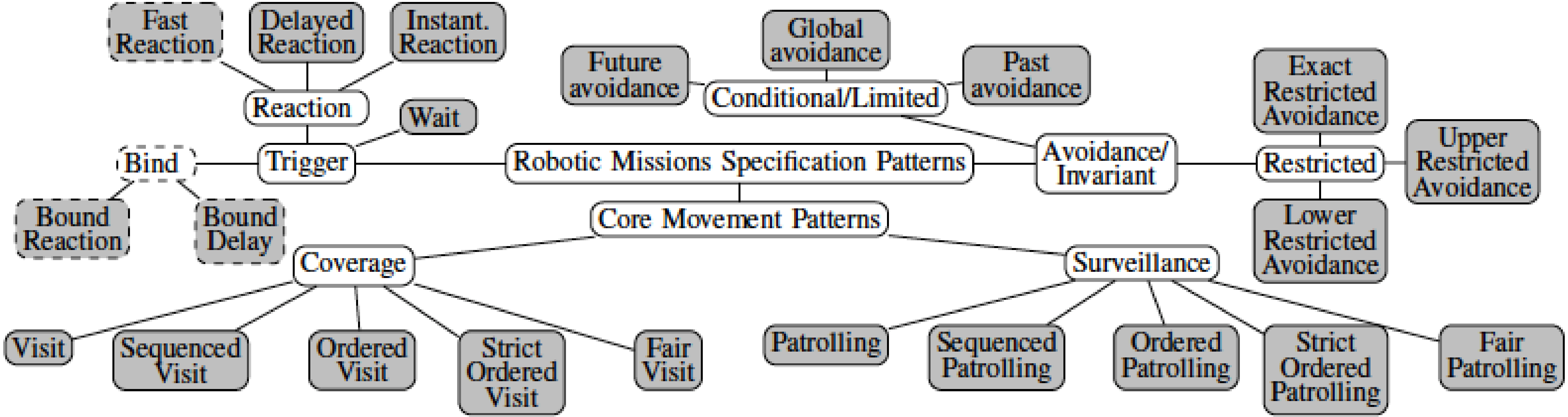
Variations: A developer may want to allow traces in which sequences of *consecutive* l_1 (l_2) are allowed, that is strict ordering is applied on sequences of non consecutive l_1 (l_2). In this case, traces in the form $l_1 \rightarrow (\rightarrow l_1 \rightarrow l_1 \rightarrow l_3 \rightarrow l_2)^{\omega}$ are admitted, while traces in the form $l_1 \rightarrow (\rightarrow l_1 \rightarrow l_3 \rightarrow l_1 \rightarrow l_2)^{\omega}$ are not admitted. This variation can be encoded using the following specification:

$$\mathcal{G}(\mathcal{F}(l_1 \wedge \mathcal{F}(l_2))) \wedge ((\neg l_2)\ U\ l_1) \wedge \mathcal{G}((l_2 \wedge \mathcal{X}(\neg l_2)) \rightarrow \mathcal{X}((\neg l_2)\ U\ l_1)) \wedge \mathcal{G}((l_1 \wedge \mathcal{X}(\neg l_1)) \rightarrow \mathcal{X}((\neg l_1)\ U\ l_2))$$

This specification allows for sequences of consecutive l_1 (l_2) since the left side of the implication $l_1 \wedge \mathcal{X}(\neg l_1)$ ($l_2 \wedge \mathcal{X}(\neg l_2)$) is only triggered when l_1 (l_2) is exited.

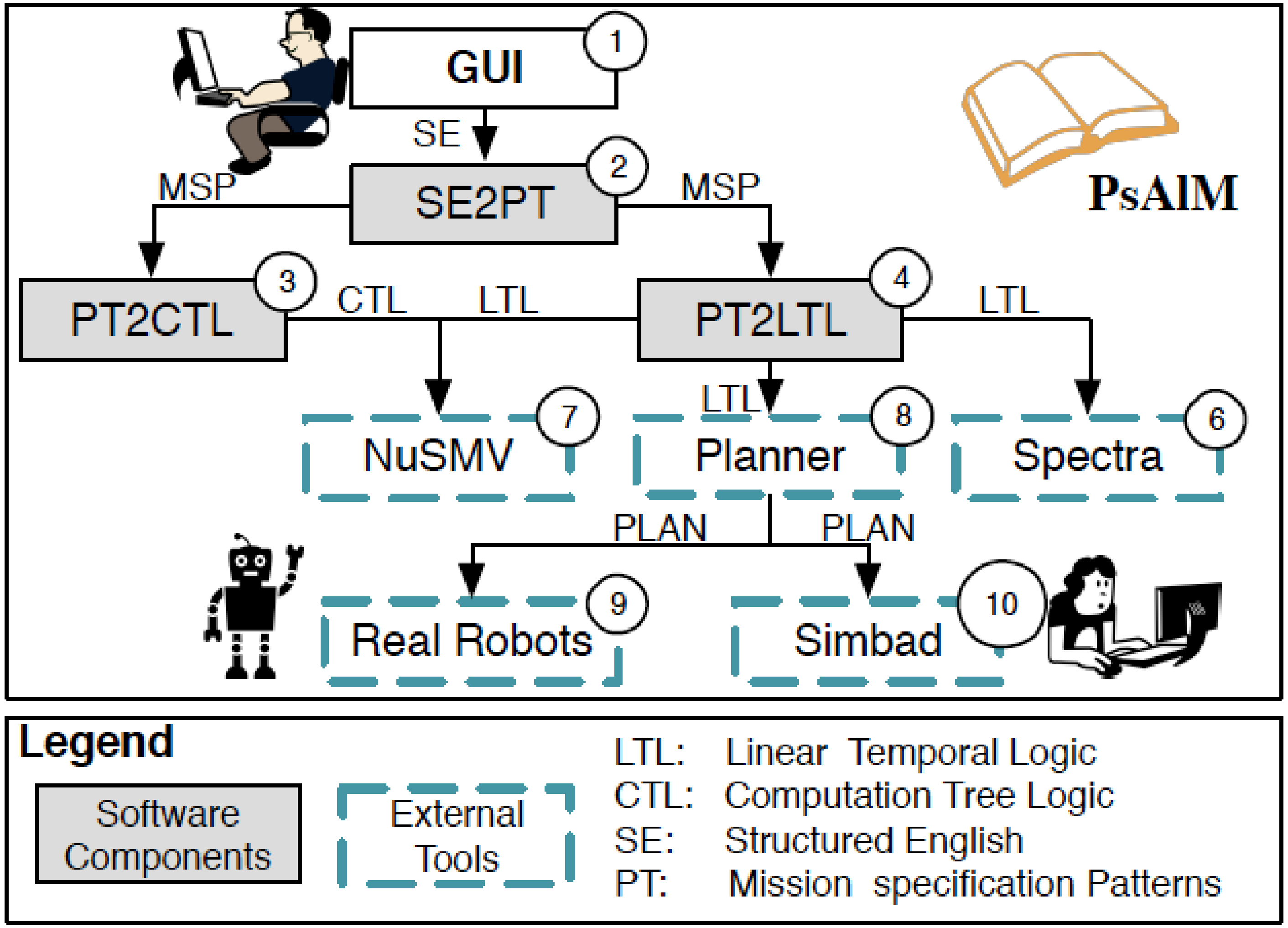
C. Menghi, C. Tsigkanos, P. Pelliccione, C. Ghezzi and T. Berger. "Specification Patterns for Robotic Missions,"
in *IEEE Transactions on Software Engineering (TSE)*, 2019

mission specification patterns

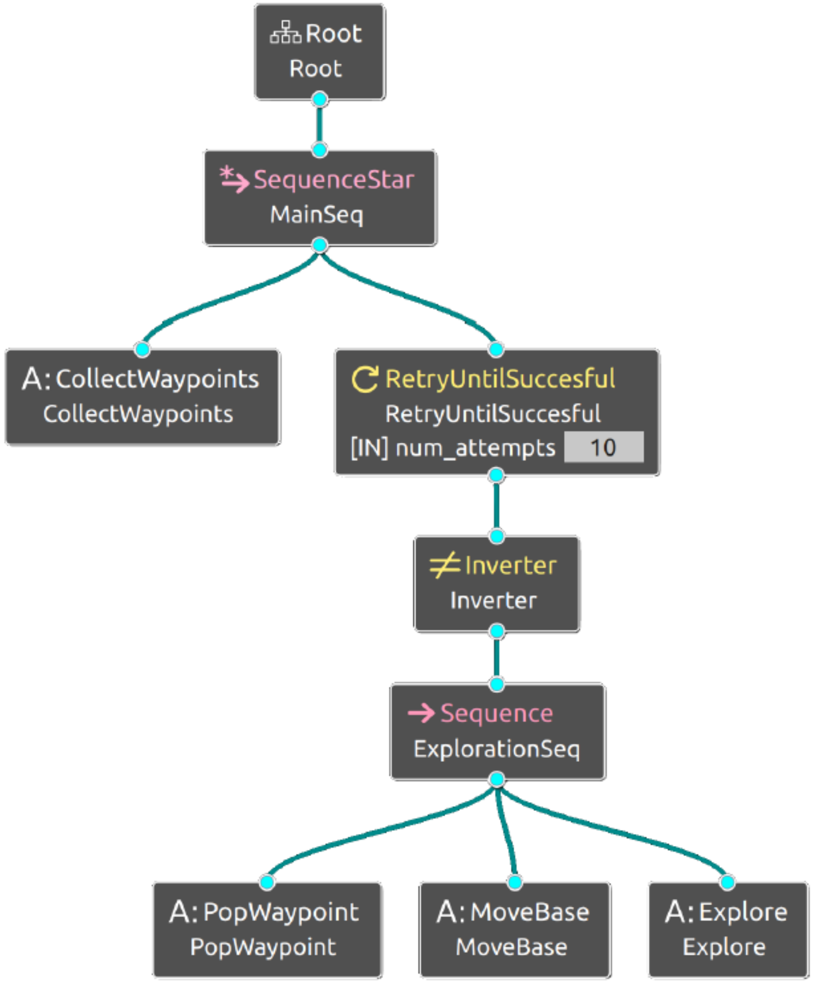


C. Menghi, C. Tsigkanos, P. Pelliccione, C. Ghezzi and T. Berger. "Specification Patterns for Robotic Missions,"
in *IEEE Transactions on Software Engineering (TSE)*, 2019

model checking, planning, and modeling

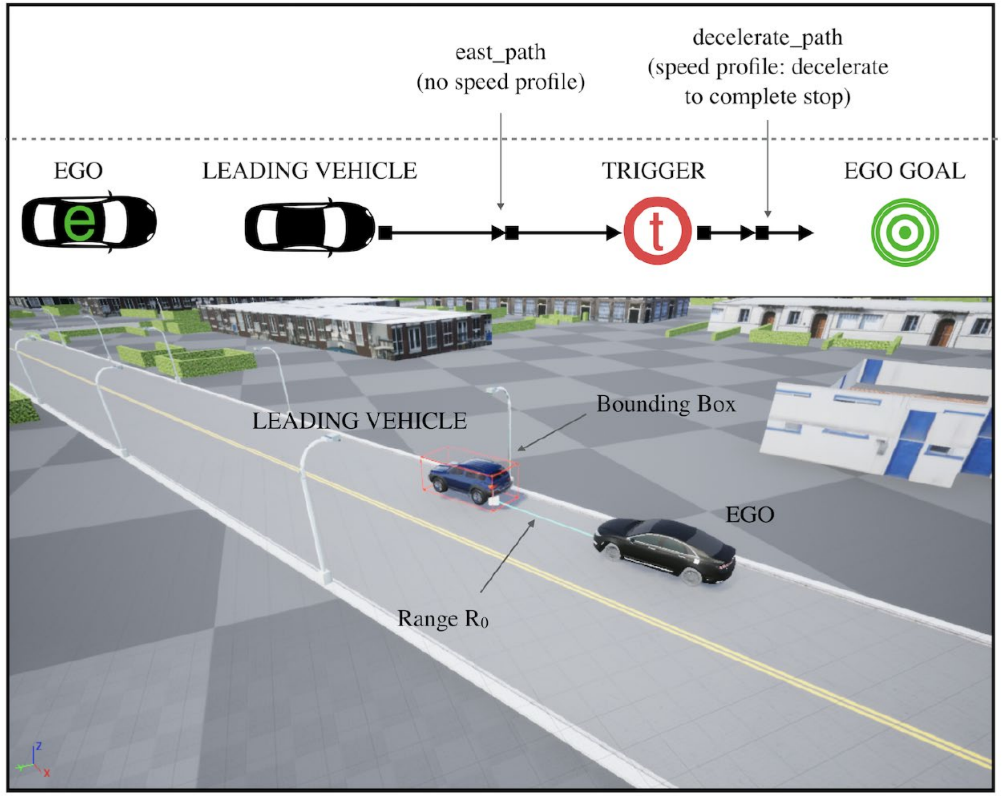


LTL: Linear Temporal Logic
CTL: Computation Tree Logic
SE: Structured English
PT: Mission specification Patterns



PROMISE
(behavior tree language)

autonomous driving



Rodrigo Queiroz, Thorsten Berger, Krzysztof Czarnecki, “Geoscenario: An Open DSL for Autonomous Driving Scenario Representation,” in *30th IEEE Intelligent Vehicles Symposium (IV)*, 2019.

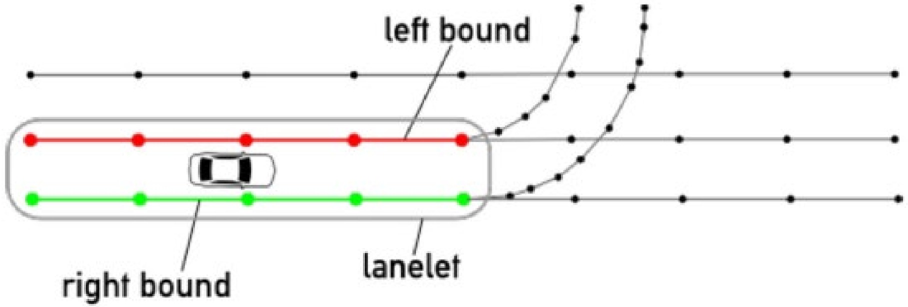
UWaterloo, CA

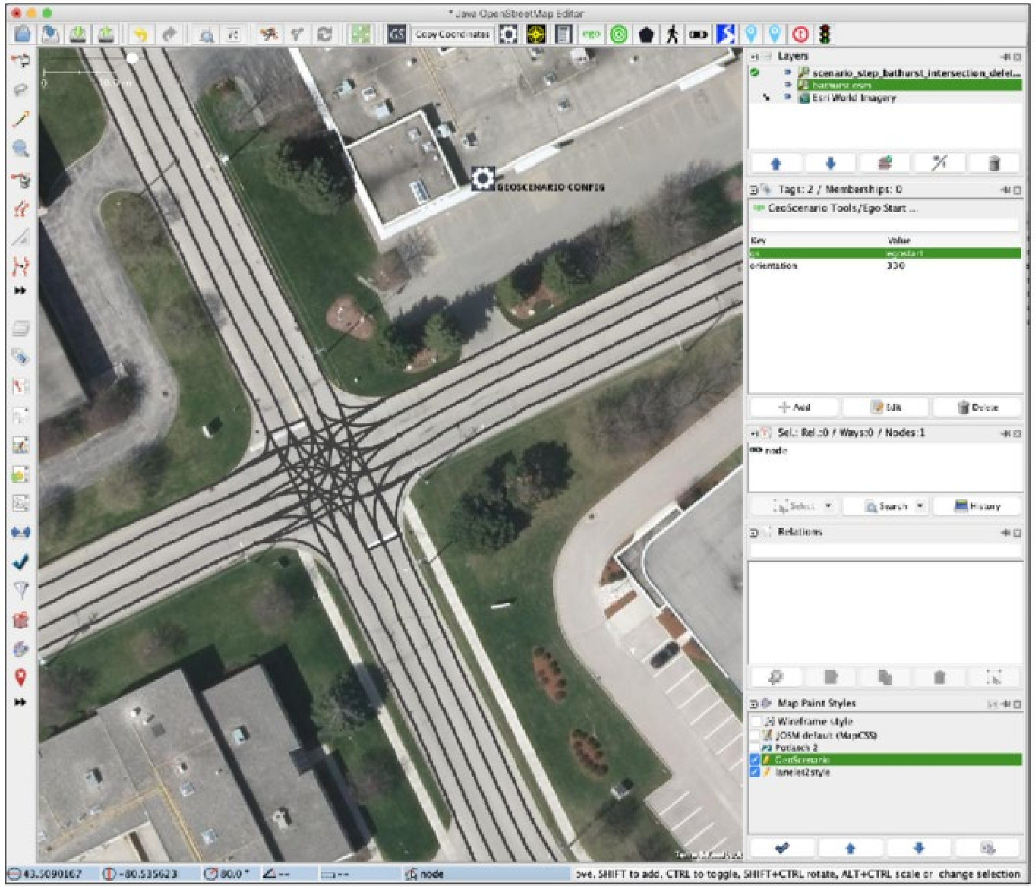
Autonomoose Self-Driving Research Platform
Lincoln MKZ Hybrid

CHALMERS, SE

REVERE Lab, Volvo XC90

road network models





* Java OpenStreetMap Editor

Layers
- scenario_step_bathurst_intersection_delet...
- bathurst.osm
- Esri World Imagery

Tags: 2 / Memberships: 0

GeoScenario Tools/Ego Start ...

Key	Value
gs	egostart
orientation	330

Sel.: Rel.:0 / Ways:0 / Nodes:1

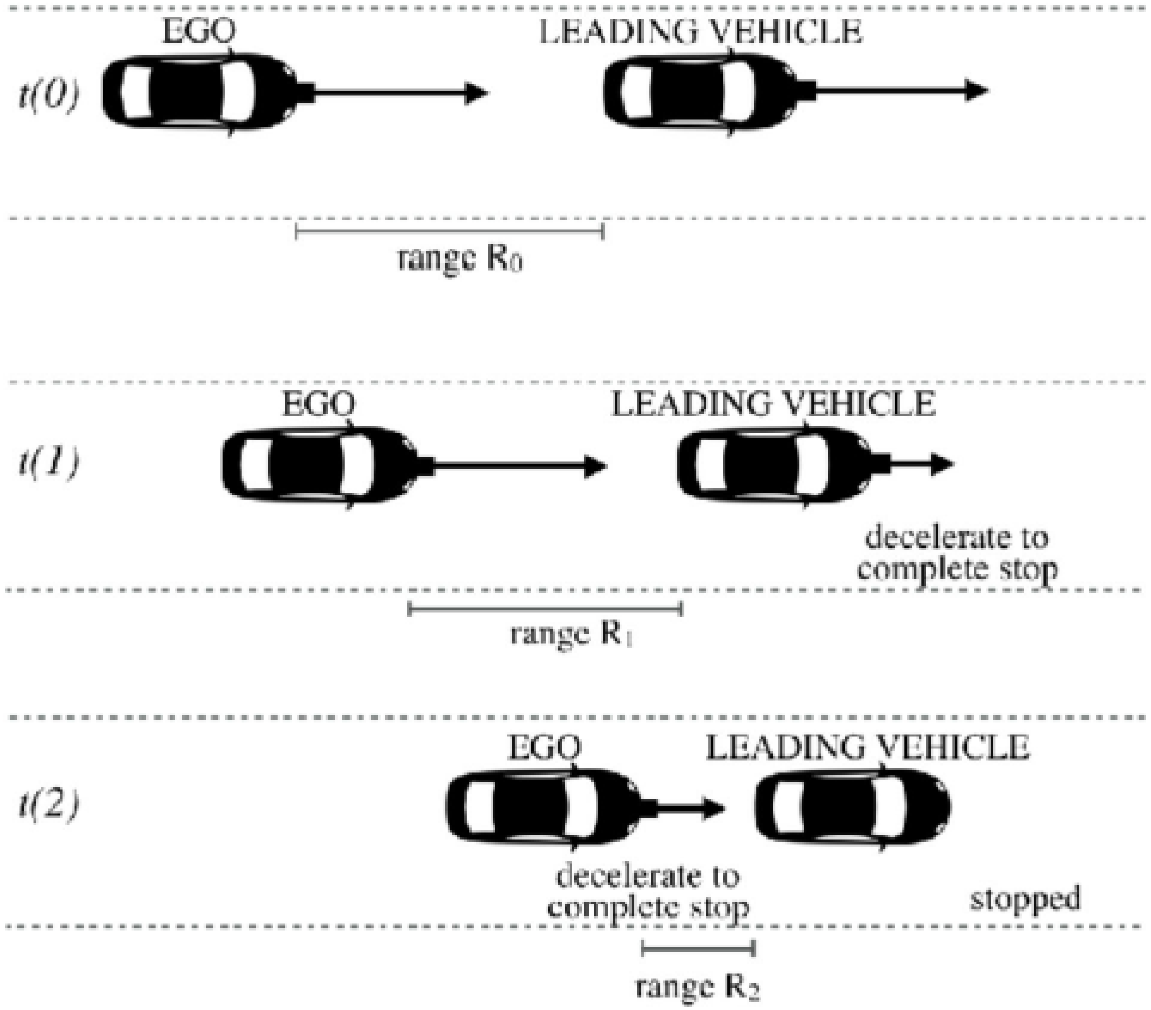
node

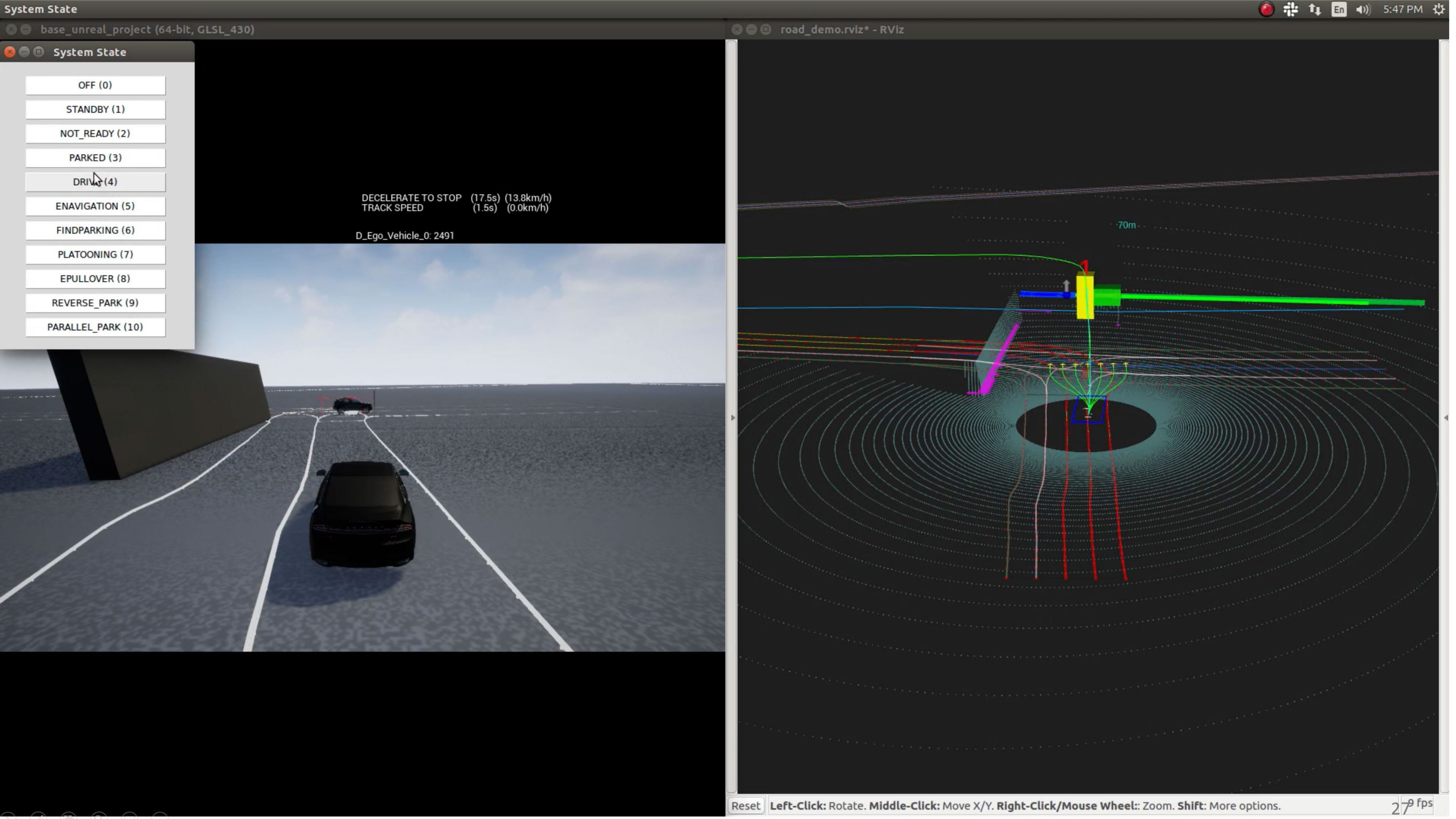
Relations

Map Paint Styles
- □ Wireframe style
- □ JOSM default (MapCSS)
- □ Potlatch 2
- ☑ GeoScenario
- ☑ lanelet2style

43.5090167 | -80.535623 | 80.0 ° | node | ove, SHIFT to add, CTRL to toggle, SHIFT+CTRL rotate, ALT+CTRL scale or change selection

behavior and maneuver models

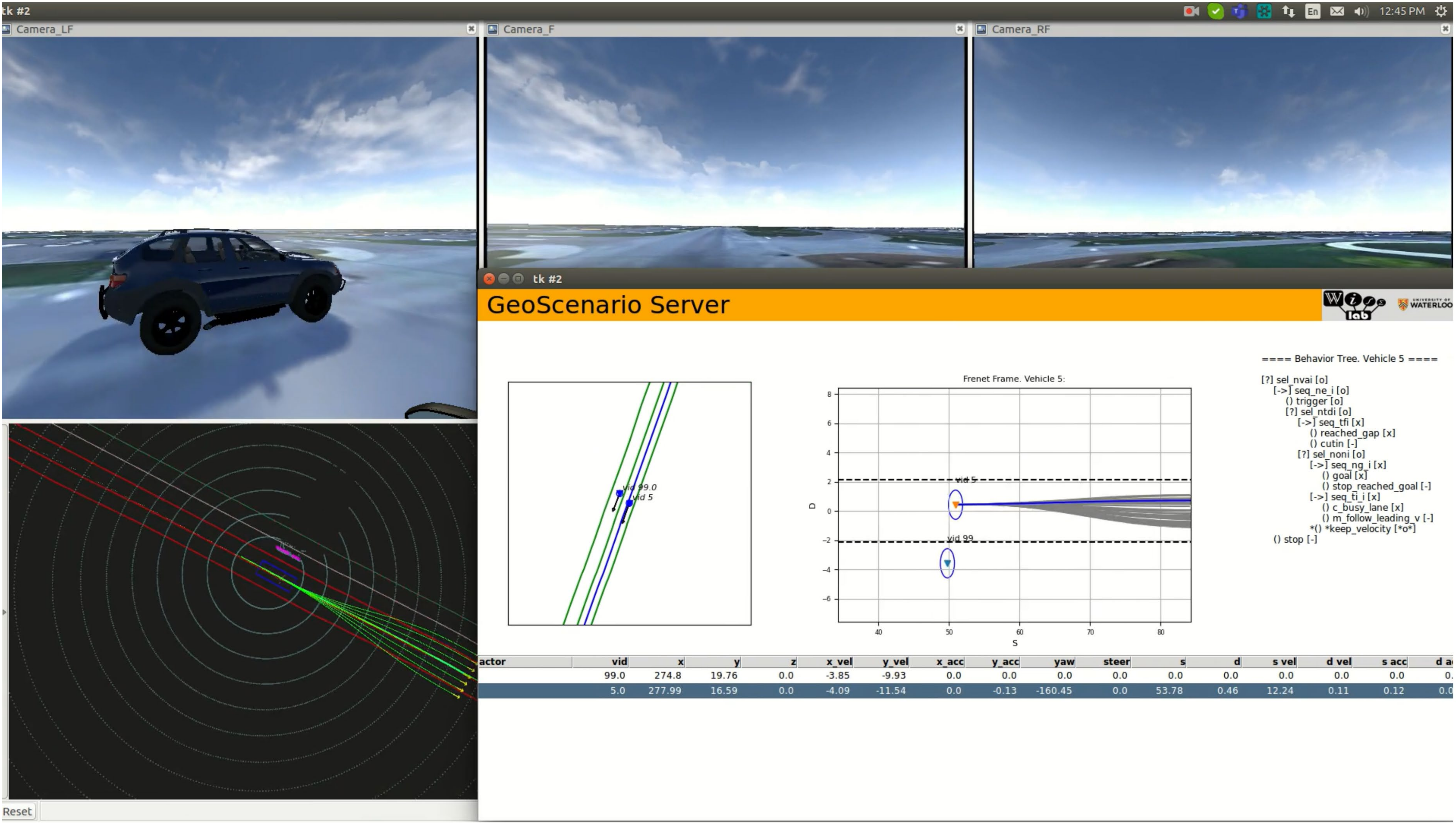




```
DECELERATE TO STOP   (17.5s)  (13.8km/h)
TRACK SPEED           (1.5s)   (0.0km/h)

D_Ego_Vehicle_0: 2491
```

Left-Click: Rotate. **Middle-Click:** Move X/Y. **Right-Click/Mouse Wheel:**: Zoom. **Shift:** More options.

9 fps



GeoScenario Server

```
==== Behavior Tree. Vehicle 5 ====

[?] sel_nvai [o]
    [->] seq_ne_i [o]
        () trigger [o]
        [?] sel_ntdi [o]
            [->] seq_tfi [x]
                () reached_gap [x]
                () cutin [-]
            [?] sel_noni [o]
                [->] seq_ng_i [x]
                    () goal [x]
                    () stop_reached_goal [-]
                [->] seq_ti_i [x]
                    () c_busy_lane [x]
                    () m_follow_leading_v [-]
                *() *keep_velocity [*o*]
    () stop [-]
```

actor	vid	x	y	z	x_vel	y_vel	x_acc	y_acc	yaw	steer	s	d	s vel	d vel	s acc	d a
	99.0	274.8	19.76	0.0	-3.85	-9.93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.
	5.0	277.99	16.59	0.0	-4.09	-11.54	0.0	-0.13	-160.45	0.0	53.78	0.46	12.24	0.11	0.12	0.0

research assistants and thesis topics

research assistants, deadline: Dec. 20!

https://web103.reachmee.com/ext/I005/1035/job?site=7&lang=UK&validator=9b89bead79bb7258ad55c8d75228e5b7&job_id=23034

thesis topics

- http://www.cse.chalmers.se/~bergert/teaching

agenda

feature models in the Linux kernel (Patrick/Thorsten)

autonomous/robotics systems (Thorsten)

software quality assurance (Mukelabei)

product-line processes (Wardah)

the virtual platform (Daniel)