H2020 funded
GA no. 732287

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# ROS-I Academy Training

## State Machine Based Programming

Ludovic DELVAL

Fraunhofer IPA

2018

FH AACHEN
UNIVERSITY OF APPLIED SCIENCES

# Overview

- State Machine Generalities
- SMACH
- SCXML State Machine framework

# Before Starting



Go into your catkin workspace.

```
$ cd src
$ git clone https://github.com/ipa-led/
    state_machine_tutorial.git
$ cd ..
$ catkin_make
$ source devel/setup.bash
$ roslaunch state_machine_tutorial exo_basicstates.
    launch exercise:=0
```

The slides and the tutorial can be found in the docs folder.

# Learning Objectives



You will:

- get to know the basic of state machine functionment to protype a sequence of action
- learn how to program using SMACH to build a state machine
- see other way to create your state machine or behavior tree.

# Outline

- State Machine Generalities
- SMACH
- Others State Machine / Behavior Tree Frameworks

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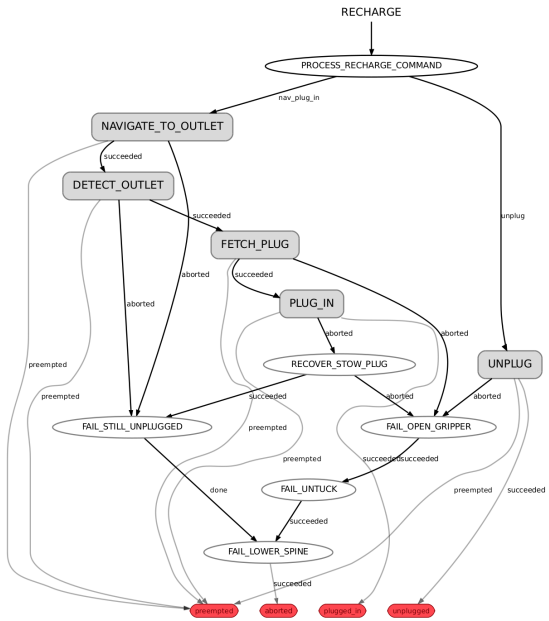
# State Machine

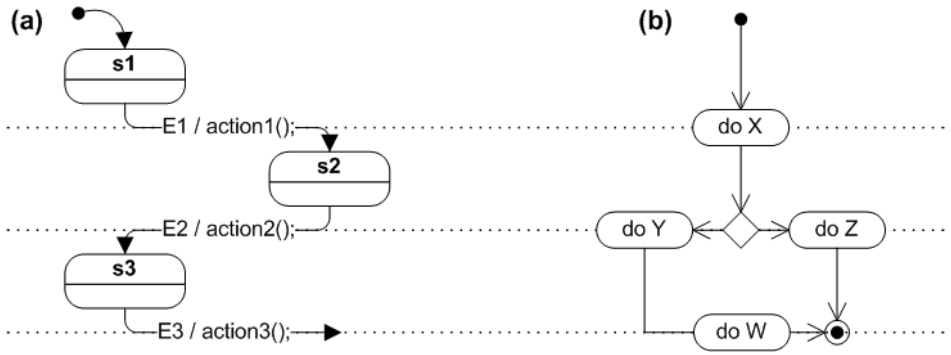





A Finite State Machine is a list of a finite number of states. The Finite State Machine change from a state to another state by a transition. The Finite State Machine is defined by its states, its initial state and its transitions.

# State diagrams vs flowcharts






A State Diagram (State Machine) perform an action in response of an event then it may change its state.

A Flowcharts don’t need event to transition from state to state. It transitions upon completion of the action.

# State Machine Application



## Airbus Floor Screwing

https://drive.google.com/file/d/0B3PdNHHyyoTFY3pPemdJMkxOdXM/view?usp=sharing

## Denso Cell Pick and Place

https://drive.google.com/file/d/0B3PdNHHyyoTFelFFenJkcEQxbWM/view?usp=sharing

## TiaGo Pick and Place

https://drive.google.com/file/d/0B3PdNHHyyoTFc1dBWm5ibzFsU28/view?usp=sharing

# State Machine



## When use a State Machine ?

- You can describe your task as a sequence of actions and transitions.
- You want to synchronize different high/middle level modules.
- You need to have a clear view of what your robot is currently doing.

## When not use a State Machine ?

- You want to do low-level efficient tasks (Low cycle time).
- You need to create a very complex behavior sequence. (Use a behaviour tree)

# Glossary



**State**

An unreductible action.

**State machine**

A container of a finite number of states or state machines.

**Transition**

A link between states or state machines

# Outline



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# SMACH



## What is SMACH ?

SMACH is a Python State Machine Framework. SMACH core libraries are ROS-independent but it also provides some ROS interaction. The SMACH programation is oriented to be like a flow chart. Meaning the states are ACTION and not CONFIGURATION.

## What SMACH provides ?

- Fast prototyping: The straightforward Python-based SMACH syntax makes it easy to quickly prototype a state machine and start running it.
- Complex state machines: SMACH allows you to design, maintain and debug large, complex hierarchical state machines.
- Userdata: SMACH provides an easy way to manage data between the differents elements of your state machines.
- Introspection: SMACH gives you full introspection in your state machines, state transitions, data flow, etc.

SMACH ROS Wiki : `http://wiki.ros.org/smach`

# SMACH basic structures



## smach.State

This is the core class of SMACH. It's the basic building bricks to setup your state machine. You have to make your classes inherit this one.

### Important functions :

```
__init__(outcomes=[], input_keys=[], output_keys=[], io_keys=[])
```

**outcomes** List of strings that describes the possible results of the execution function

**input_keys** List of strings that give you read access on the userdata

**ouput_keys** List of strings that give you write access on the userdata

**io_keys** List of strings that give you read and write access on the userdata

```
execute(self, ud)
```

**Function to reimplement in your class**. It's the code that is executed when the state become active.

**ud** Userdata for the scope in which this state is executing

# SMACH basic structures



**Simple State class example :**

```
class Publish_msg(smach.State):
#This class publish the message then reset the message and return "ok".
#If the message is not set, it fails.
  def __init__(self):
    #Init of the smach class with the outcomes and the io_keys
    smach.State.__init__(self,outcomes=["ok","fail"],io_keys=["msg"])
    #init of the publisher
    self.msg_publisher = rospy.Publisher('/msg_topic',String)

  def execute(self, ud): #Execute function reimplemted
    if ud.msg is not None:
      self.msg_publisher.publish(ud.msg)
      return "ok"
    else:
      return "fail"
```

# SMACH basic structures



## smach.StateMachine

A container which can include other states or containers and execute them one at a time. It has the same *init* function than the State class and should be opened to add states or containers in it then closed (or use the keyword "**with**"). The first state added will be the initial (or you can specify it by using the **set_initial_state** function).

### Important function :

```
add(label, state, transitions=None, remapping=None)
```

This function add a state to the state machine.

| | |
|---|---|
| **label** | The name to reference the state that you add. |
| **state** | The class instance you want to add. |
| **transitions** | A dictionary mapping state outcomes to other state labels or container outcomes. |
| **remapping** | A dictionary mapping local userdata keys to userdata keys in the container. |

Other functions can be found here : `http://docs.ros.org/groovy/api/smach/html/python/smach.state_machine.StateMachine-class.html`

# SMACH basic structures



## Simple State Machine class example :

```
class Message_set_and_publish(smach.StateMachine):
#This class setup a string message and publish it.
  def __init__(self):
    smach.StateMachine.__init__(self, outcomes=["ok","fail"],
                                      input_keys=["message"],
                                      output_keys=["message"])
    self.userdata.message = None #initialisation of the message userdata

    with self: #We use the keyword with to open and close the container
      #add the setup message state
      self.add('Setup', #label
               SetupMsg(), #class instance
               {"ok":'Publish',"fail":"fail"}, #transitions mapping
               {"msg":"message"}) #userdata remapping
      #add the Publish message state
      self.add('Publish',Publish_msg(),
               {"ok" : "ok",
               "fail": 'Setup'}
               {"msg":"message"})
```

# SMACH basic structures



## smach.Concurrence

A container which can include other states or containers and execute them in parallel (using threads). It works as a State Machine but you need to define the outcome maps (Which combinations of states outcomes will trigger which concurrence outcome) and a default outcome (in case none of the combination are met).

**Example :**

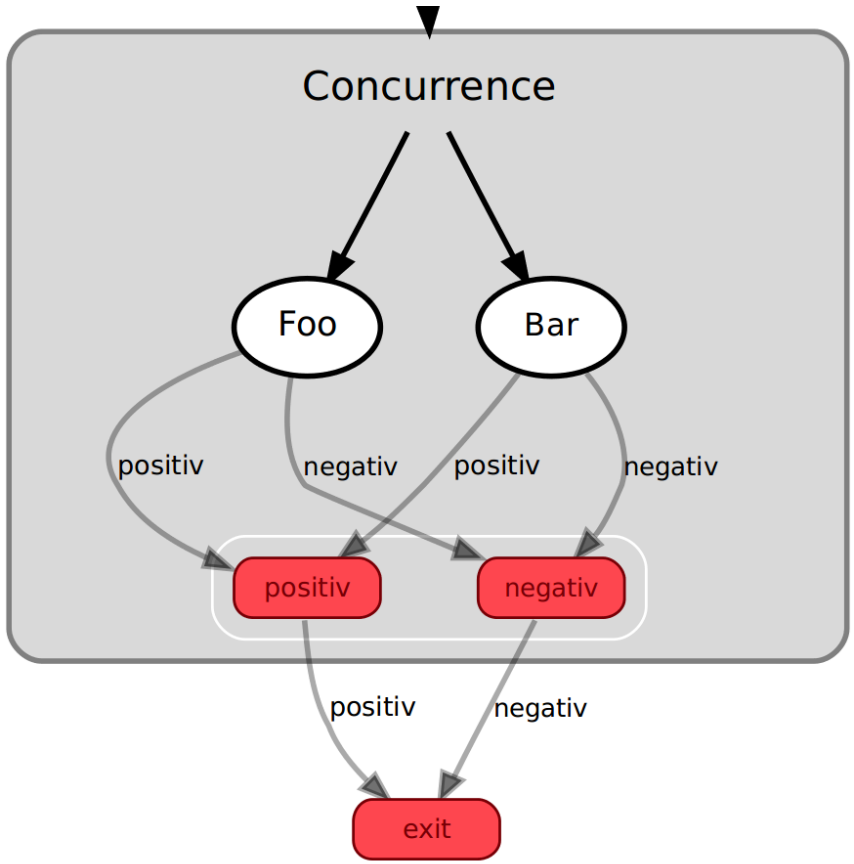
```
sm_con = smach.Concurrence(outcomes=['outcome4','outcome5'],
                           default_outcome='outcome4',
                           outcome_map={'outcome5':
                              { 'FOO':'outcome2',
                                'BAR':'outcome1'}})

# Open the container
with sm_con:
   # Add states to the container
   smach.Concurrence.add('FOO', Foo())
   smach.Concurrence.add('BAR', Bar())
```

# SMACH basic structures



**Example :**



# SMACH usefull tools



## Preemption

There is a built-in preemption propragation system in SMACH. You can check for preemption signal or either trigger it. It will be propagated to the whole state machine (e.g. in a concurrence, all the state running will trigger the preempt signal if one is triggered. You have to manually code the behavior of states in case a preempt signal is received but for containers, it will trigger the termination of the whole State Machine.

**Functions :**

```
self.request_preempt() #trigger the preempt signal

self.preempt_requested() #Return True if a preempt has been requested

self.recall_preempt() #set the preempt signal to False
```

# SMACH usefull tools



## Introspection

SMACH containers can provide a debugging interface (over ROS topics) which allows a developer to get a full introspection into a state machine. Using the smach_viewer package, you can visualize the flow of your state machine and the user data during runtime.

### Functions :

```
sis = smach_ros.IntrospectionServer('server_name', sm, 'SM_ROOT')
sis.start() #start the server
sm.execute() #start the state machine
rospy.spin()
sis.stop() #stop the server
```

This create an instance of the SMACH Introspection server. The parameters are :

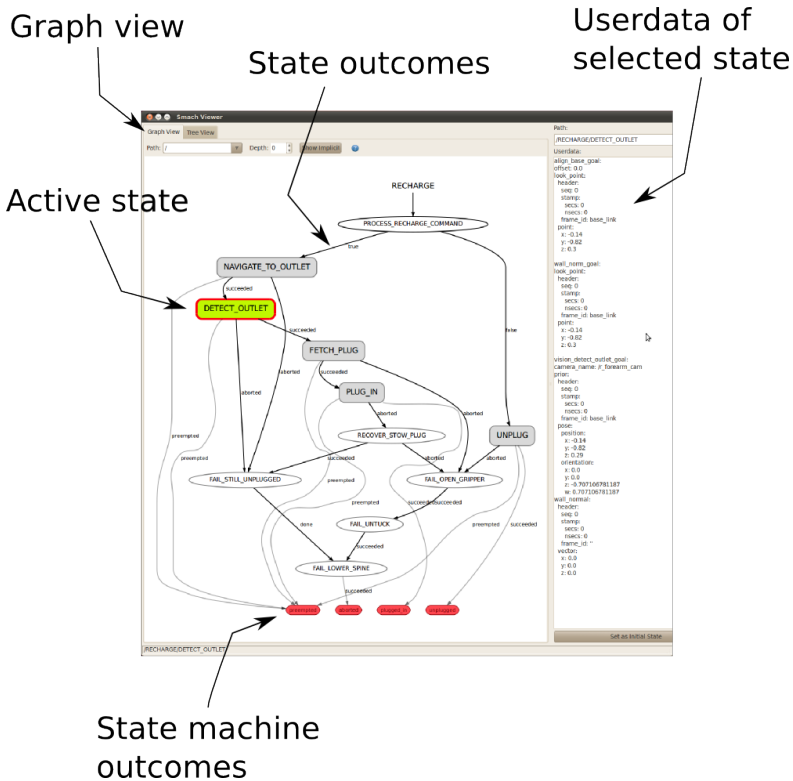
**'server_name'** A name that you give as a namespace for introspection topics.

**sm** The state machine you want to inspect To have access to your whole state machine, give your hightest state machine instance.

**'SM_ROOT'** The name that you give at your top level state machine.

# SMACH Viewer

SMACH Viewer is a released ROS Package that provides a GUI to monitor your State Machine while running.




ROS Wiki Page: `http://wiki.ros.org/smach_viewer`

To run SMACH Viewer : ***rosrun smach_viewer smach_viewer.py***

# SMACH ROS template



## CBState

Wrap a function into a SMACH state.
`http://wiki.ros.org/smach/Tutorials/CBState`

## ServiceState

Convert a service client into a SMACH state.
`http://wiki.ros.org/smach/Tutorials/ServiceState`

## SimpleActionState

Convert an action client into a SMACH state.
`http://wiki.ros.org/smach/Tutorials/SimpleActionState`

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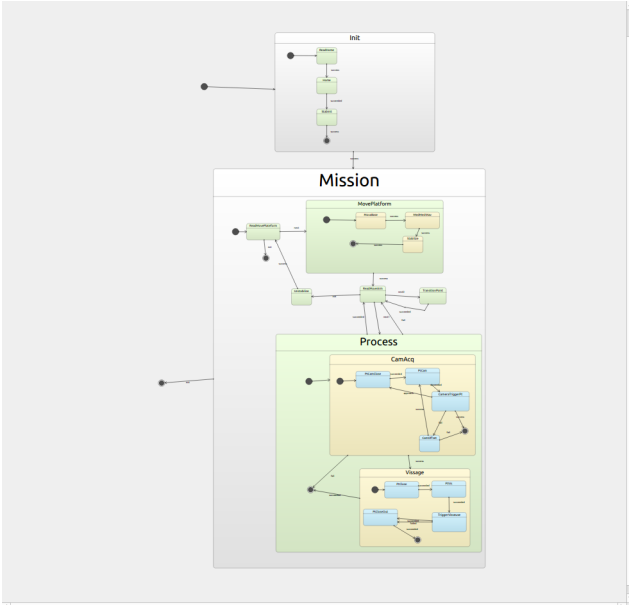
# SCXML State Machine (SSM)






The goal of SCXML State Machine called SSM is to ease the management of medium sized state machine by using graphical interface and markup language to ease modifications, extensions and "plumbing" of SMACH State Machine.

# State Chart XML Standard



SCXML is a XML-based markup language use to describe state-machine. Is possible to describe nested states or state machines, parallel executions and data model.

**Example :**

```
<?xml version="1.0" encoding="UTF-8"?>
<scxml xmlns="http://www.w3.org/2005/07/scxml" version="1.0" initial="Foo">
   <datamodel>
      <data id="skill_file" expr="${airbus_ssm_core}/resources/empty_register.xml"/>
   </datamodel>
   <state id="Foo">
      <transition type="external" target="Bar" event="next">
      </transition>
   </state>
   <state id="Bar">
      <transition type="external" event="next" target="final"/>
   </state>
   <final id="final">
   </final>
</scxml>
```

**The SCXML standard web site :** https://www.w3.org/TR/scxml/

# SCXML State Machine Framework



In order to make an SCXML file working as a SMACH state machine, there is a SCXML interpreter. This framework also extends SMACH at different levels.

**Mapping between SCXML and SMACH**

| SCXML | SMACH |
|---|---|
| <SCXML /> Root | Main State Machine |
| <State /> Atomic State | State |
| <State / State /> Coumpound State | State Machine |
| <Parallel /> Parallel | Concurrence |
| <State / Transition /> State Transition<br>• Event<br>• Target | Transitions<br>• Outcome<br>• Outcome's target |
| <Parallel / Transition /> Parallel Transition<br>• Cond | Outcomes_map<br>• Logic combination of outcomes |
| <Datamodel / Data /> | Userdata |
| <Initial /> | Initial |
| <Final /> | State Machine (self outcomes) |

# SSM Framework



SSM extend the SMACH framework with new functionalities or ease the access to some. To have access to most of them you have to use the SSM derivate classes (like ssmState or ssmStateMachine).

- "/preempt" topic that trigger the preempt flag in every states.
- "/pause" topic that pause the state machine at the next transition (still finishing the current running atomic state).
- "onEntry and onExit" to save logs and execute python script before or after executing a state.

- Release Source Code : `https://github.com/ipa320/airbus_coop`
- Devel Source Code : `https://github.com/ipa-led/airbus_coop`
- ROS Wiki Page : `http://wiki.ros.org/airbus_coop`

# From SMACH to SSM



You can use SMACH inside the SSM Framework, but you will lose most of the extension provided. Here are the steps to convert from SMACH to SSM:

1. Convert smach.State (the class you inherited and the initialisation of the interface) to ssm_state.ssmState. This will provide all the SSM interfaces on top of SMACH.
2. Change the input_keys and output_keys into io_keys (be sure to check your execute function if you change some names)
3. Change the execute(self,ud) function to execution(self,ud)

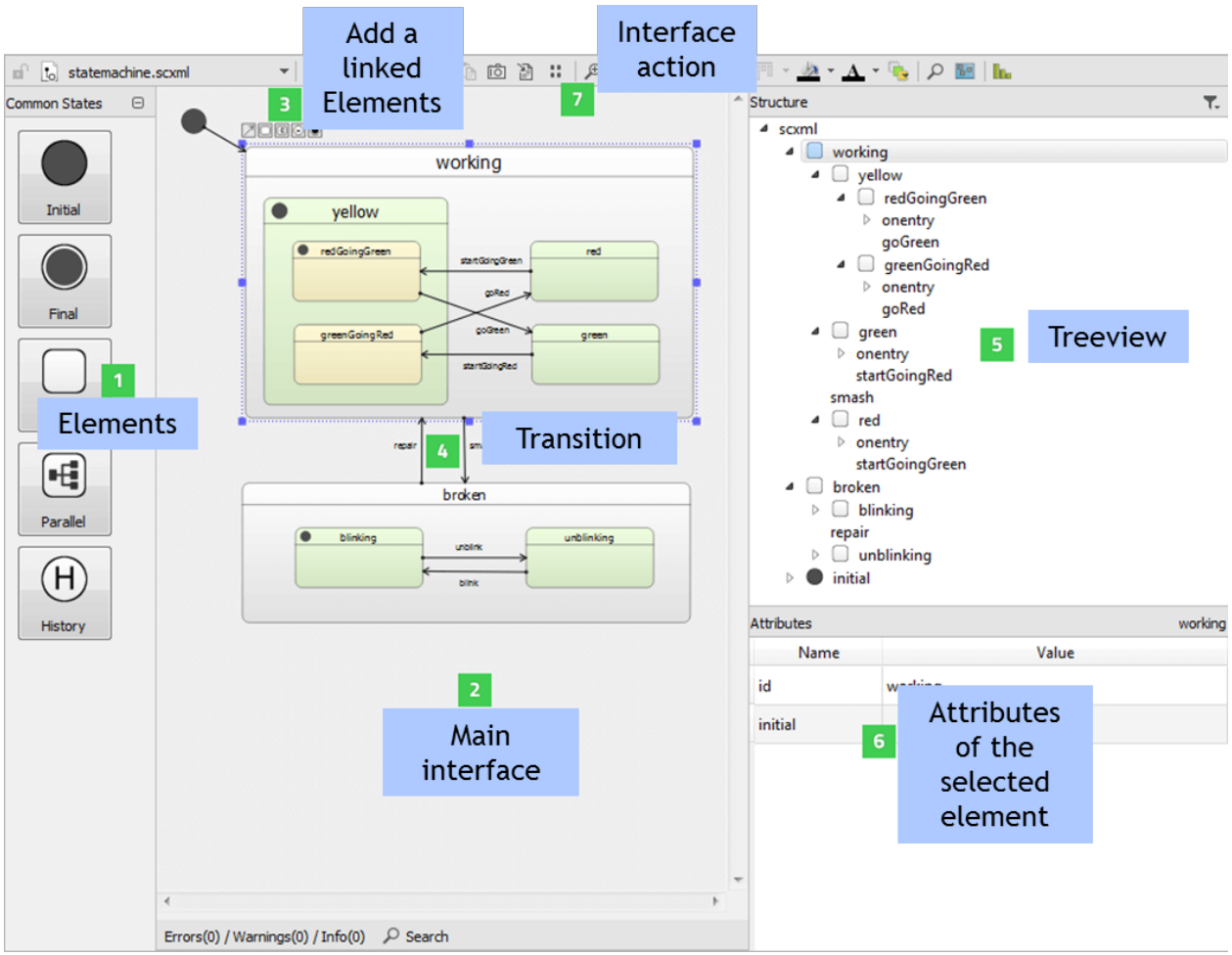
SMACH

```
class WaitState(smach.State):
    def __init__(self):
        smach.State.__init__(self, outcomes=["continue"],
                             input_keys=["sleep_time"])

    def execute(self, ud):
        rospy.sleep(ud.sleep_time)
        return "continue"
```

SSM

```
class WaitState(ssm_state.ssmState):
    def __init__(self):
        ssm_state.ssmState.__init__(self, outcomes=["continue"],
                                    io_keys=["sleep_time"])

    def execution(self, ud):
        rospy.sleep(ud.sleep_time)
        return "continue"
```

# Usefull tools for SSM: Qt SCXML editor

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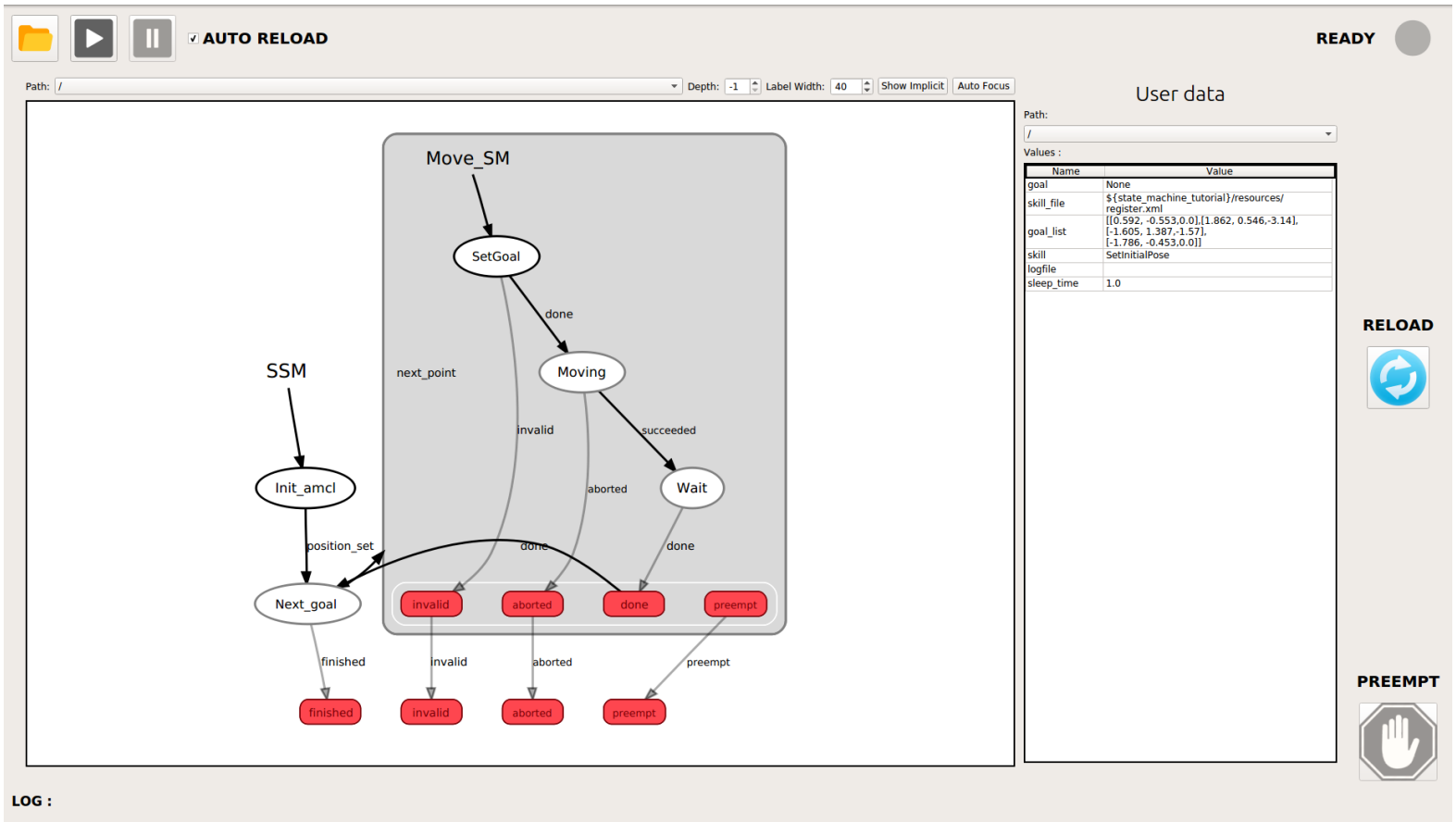
# Usefull tools for SSM: SSM GUI



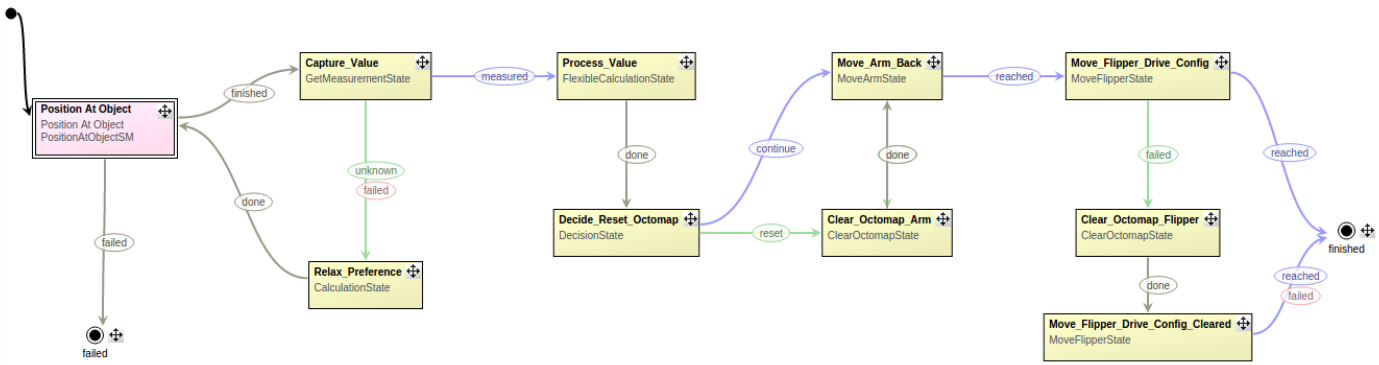
Included in the Airbus Core package.



# FlexBE: The flexible behavior engine



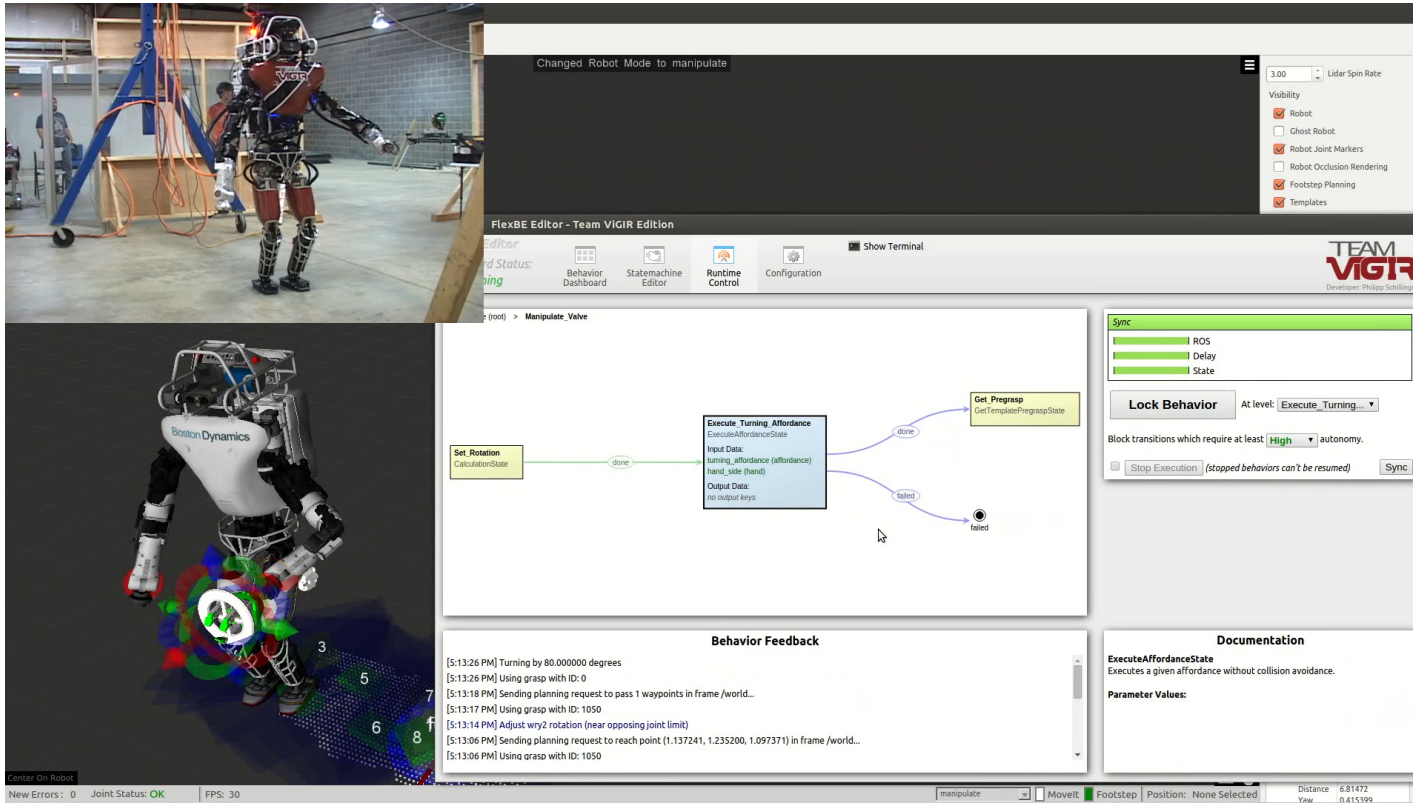
FlexBE is a powerful high-level behavior engine, flexibly applicable to numerous systems and scenarios. It provides numerous features: GUI based editor, monitoring, tutorial and documentation.




FlexBE Homepage: `http://philserver.bplaced.net/fbe/`

# FlexBE: Aplication on ATLAS v5

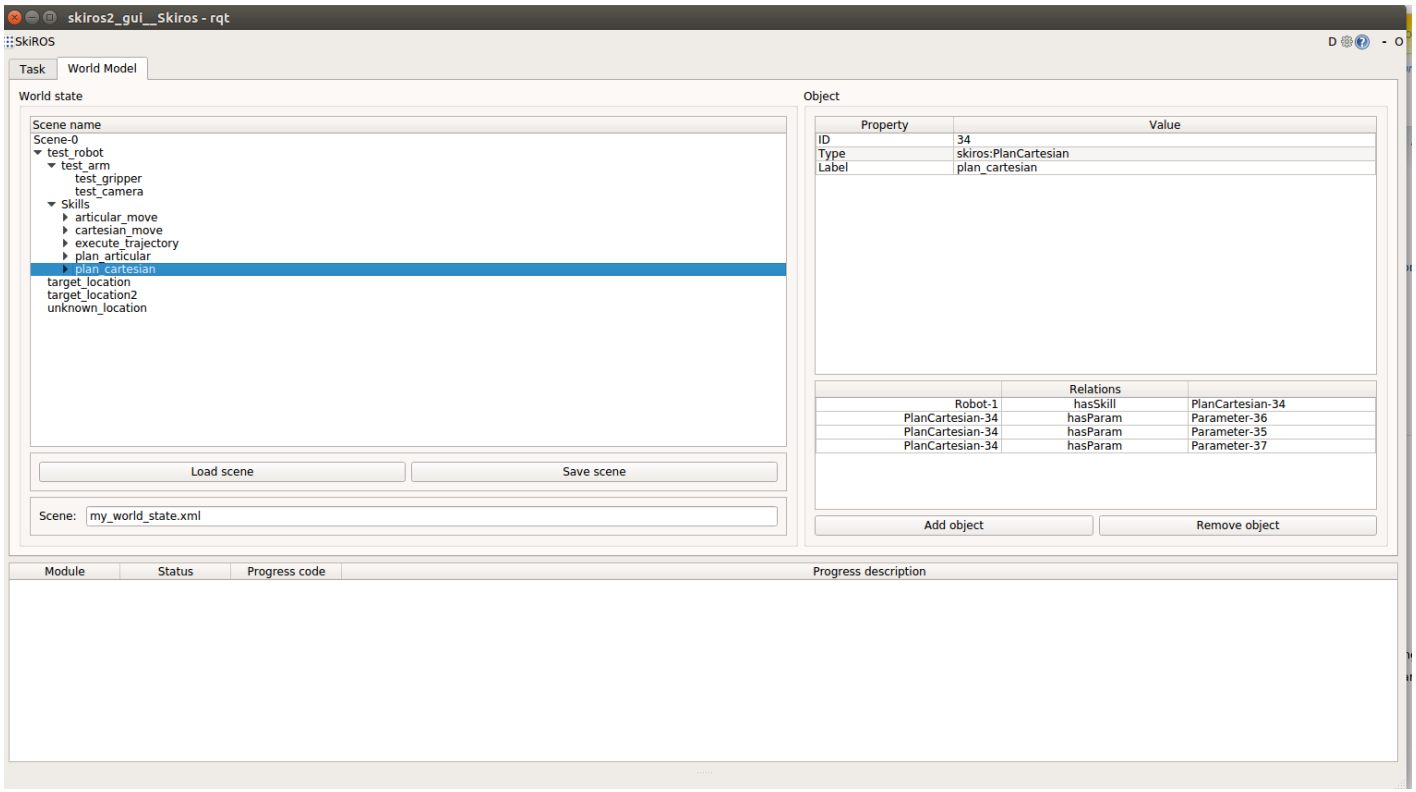





Video: `https://www.youtube.com/watch?time_continue=90&v=lu2b4qQmjgA`

# SkiROS: Task Planner

SkiROS composed automatically skills at run-time in order to do a complex tasks.




SkiROS sources: `https://github.com/frovida/skiros`

# SMACH tutorial



Start the SMACH Tutorial !