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Ensemble-oriented programming of self-adaptive systems with SCEL and jRESP

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  - representing Knowledge, Behaviors and Aggregations according to specific Policies
  - programming interaction, adaptation and self- and context- awareness
- linguistic primitives with solid semantic grounds
  - To develop logics, tools and methodologies for formal reasoning on systems behavior
  - To establish qualitative and quantitative properties of both the individual components and the ensembles

Key Notions

We need to enable programmers to model and describe the behavior of service components and their ensembles, their interactions, and their sensitivity and adaptivity to the environment they are working in.

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4. The global knowledge of the systems and that of its components
5. The tasks to be accomplished, the properties to guarantee and the constraints to respect.

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4. Policies: to model and enforce the wanted evolutions of computations.

1. Knowledge

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Knowledge representation

- Tuples, Records
- Horn Clause Clauses,
- Concurrent Constraints,
- ...

1. Knowledge

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Knowledge handling mechanisms

- Pattern-matching, Reactive Tuple Spaces
- Data Bases Querying
- Resolution
- Constraint Solving
- ...

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1. Knowledge (and Adaptation)

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- Application data: Used for the progress of the computation.
- Control data: Providing information about the environment (e.g. data from sensors) and about the current status (e.g. its position or its battery level).
- Knowledge handling mechanisms
  - Add information to a knowledge repository
  - Retrieve information from a knowledge repository
  - Withdraw information from a knowledge repository

2. Behaviors

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Processes

$$\textbf{nil} \;\mid\; a.P \;\mid\; P_1 + P_2 \;\mid\; P_1[\,P_2\,] \;\mid\; X \;\mid\; A(\bar{p}) \quad (A(\bar{f}) \triangleq P)$$

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The operators have the expected semantics. $P_1[\,P_2\,]$ (Controlled Composition) can be seen as a generalization of the many "parallel compositions" of process calculi. For the meaning of $a.-$, see next.

Actions

$\textbf{get}(T)@c \mid \textbf{qry}(T)@c \mid \textbf{put}(t)@c \mid \textbf{fresh}(n) \mid \textbf{new}(\mathcal{I}, \mathcal{K}, \Pi, P)$

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Action Targets

$c ::= n \mid x \mid \mathsf{self} \mid \mathsf{P}$

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Actions manage knowledge repositories by

- withdrawing information - $\textbf{get}(T)@c$,
- retrieving information - $\textbf{qry}(T)@c$
- adding information - $\textbf{put}(t)@c$

Actions operate on knowledge repository c and use T as a pattern to select knowledge items.

Aggregations

describe how different entities are brought together

- Model resource *allocation* and *distribution*
- Reflect the idea of *administrative domains*, i.e. the authority controlling a given set of resources and computing agents.
- are modelled by resorting to the notions of system, component and ensemble.

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Systems

$$S \quad ::= \quad C \quad | \quad S_1 \parallel S_2 \quad | \quad ((\nu n))S$$

Components

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  - *id*: the name of the component C

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- A knowledge manager $\mathcal{K}$ providing control data (i.e. the local and (part of the) global knowledge) and application data; together with a specific knowledge handling mechanism

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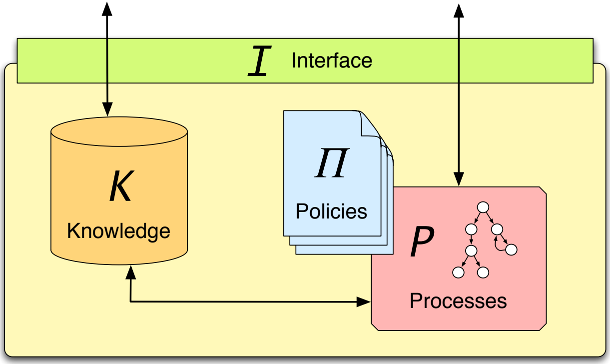
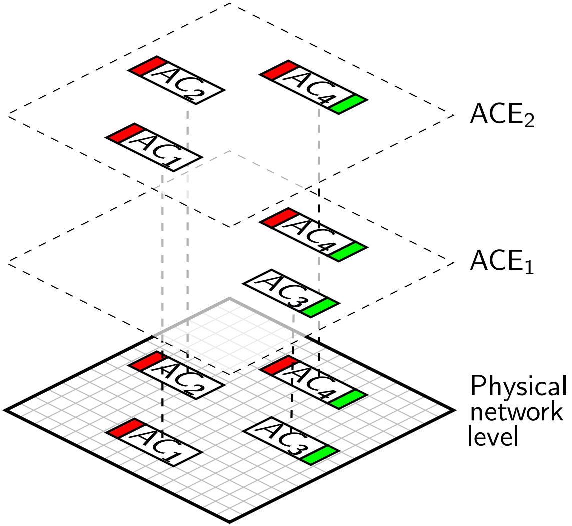
- A set of policies Π regulating inter-component and intra-component interactions
- A process term P that performs the local computation, coordinates their interaction with the knowledge repository and deals with adaptation and reconfiguration

A SCEL component



Programming Abstractions

Important for improving code productivity


AC2
AC4
AC1
ACE2
AC4
AC3
ACE1
AC2
AC4
AC1
AC3
Physical
network
level

4. Policies

Policies deal with the way properties of computations are represented and enforced

- Interaction: interaction predicates, . . .
- Resource usage: accounting, leasing, . . .
- Security: access control, trust, reputation, . . .

- SCEL is *parametric* wrt the actual language used to express policies.
- Currently we (Pugliese, Tiezzi) are defining a specific language based on XACML.
- When considering the operational semantics, we will see how policies are exploited to control components actions, their evolutions and their interactions.

SCEL: Syntax (in one slide)

SYSTEMS:	S	$::=$	$C \quad \mid \quad S_1 \parallel S_2 \quad \mid \quad ((\nu n))S$
COMPONENTS:	C	$::=$	$\mathcal{I}[\mathcal{K}, \Pi, P]$
KNOWLEDGE:	K	$::=$	$\ldots$
PROCESSES:	P	$::=$	$\mathbf{nil} \mid a.P \mid P_1 + P_2 \mid P_1[\,P_2\,] \mid X \mid A(\bar{p}) \;\; (A(\bar{f})$
ACTIONS:	a	$::=$	$\mathbf{get}(T)@c \mid \mathbf{qry}(T)@c \mid \mathbf{put}(t)@c \mid \mathbf{fresh}(n) \mid \mathbf{new}(\mathcal{I}, \mathcal{K},$
TARGETS:	c	$::=$	$n \mid x \mid \mathrm{self}$
ITEMS:	t	$::=$	$\ldots$ – for the moment just tuples
TEMPLATES:	T	$::=$	$\ldots$ – for the moment tuples with variables

Basic design principles. . .

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1. no centralized control

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2. heavy use of *recurrent patterns* to simply the development of specific
   - policies
   - knowledge
   - ...

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Basic design principles...

1. no centralized control
2. heavy use of *recurrent patterns* to simply the development of specific
   - policies
   - knowledge
   - ...
3. use of *open technologies* to support the integration with other tools/frameworks
   - Argos
   - DEECo
   - ...

SCEL Syntax...

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ACTIONS:

$$a \quad ::= \quad \textbf{get}(T)@c \quad | \quad \textbf{qry}(T)@c \quad | \quad \textbf{put}(t)@c \quad | \quad \textbf{exec}(P) \quad | \quad \textbf{new}(\mathcal{I}, \mathcal{K}, \Gamma$$

TARGETS:

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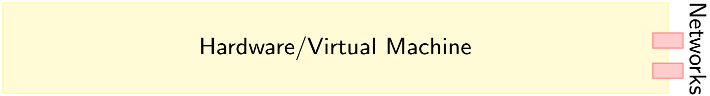
SCEL component

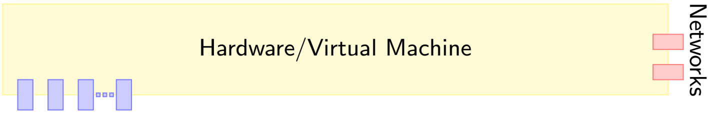
SCEL component

Hardware/Virtual Machine

SCEL component

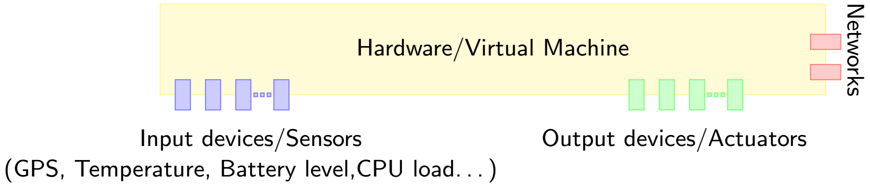


SCEL component



Input devices/Sensors
(GPS, Temperature, Battery level,CPU load. . .)

SCEL component



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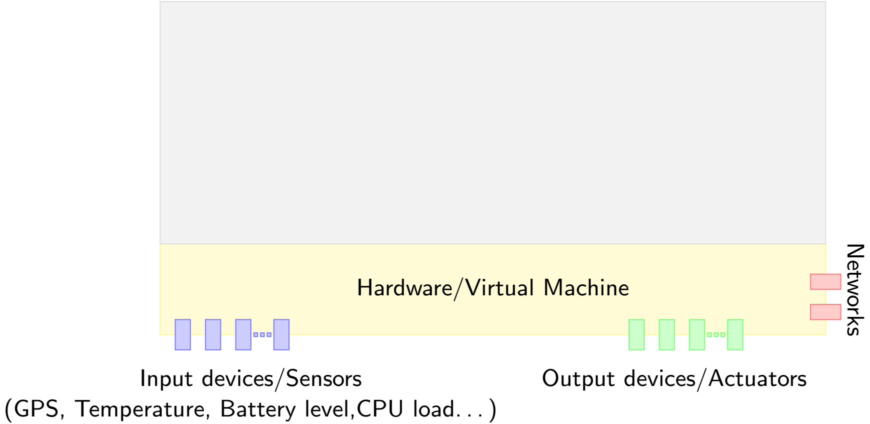

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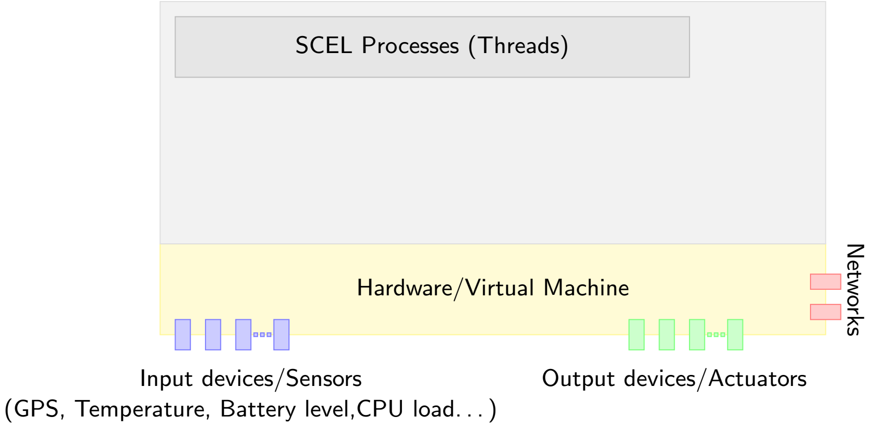

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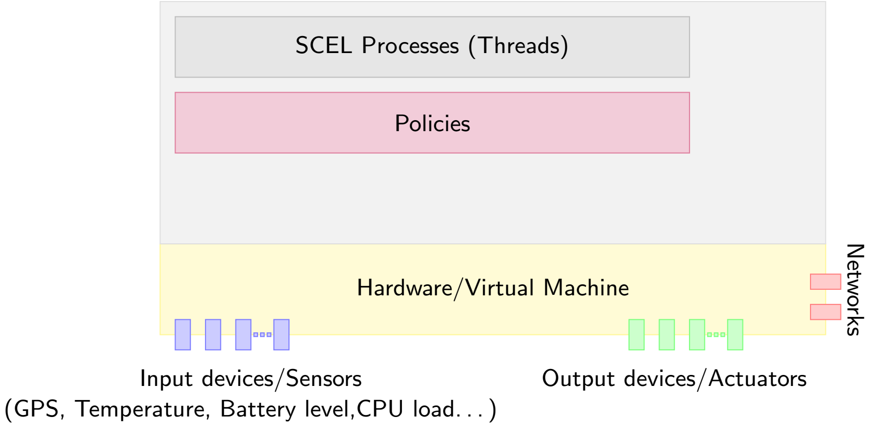

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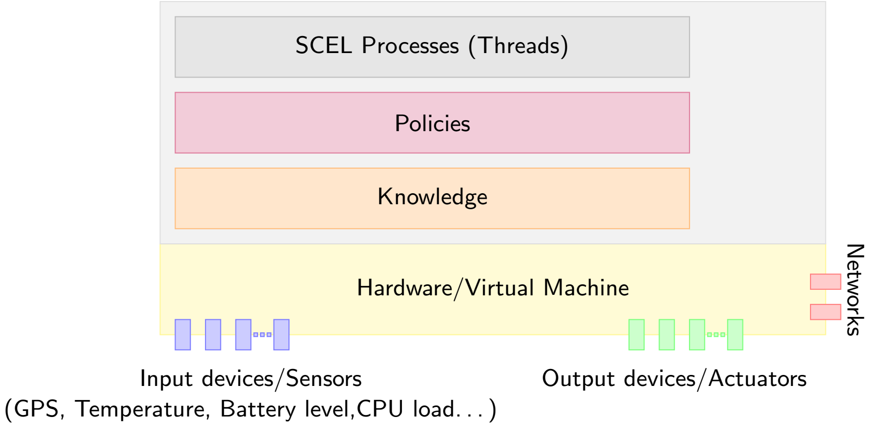
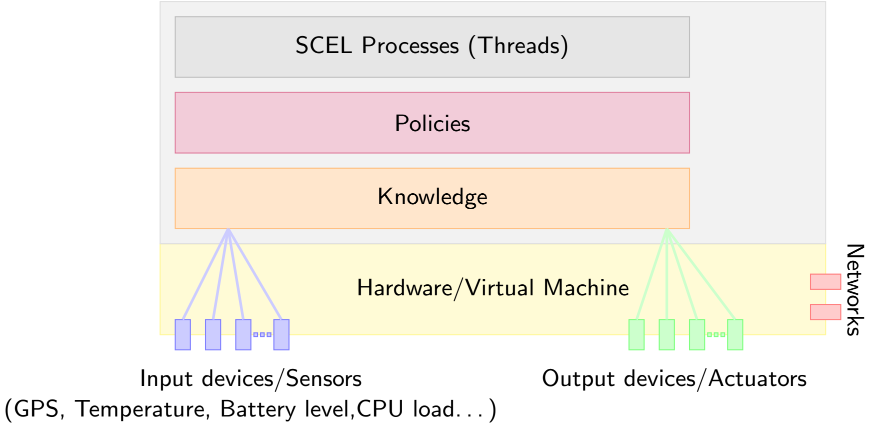
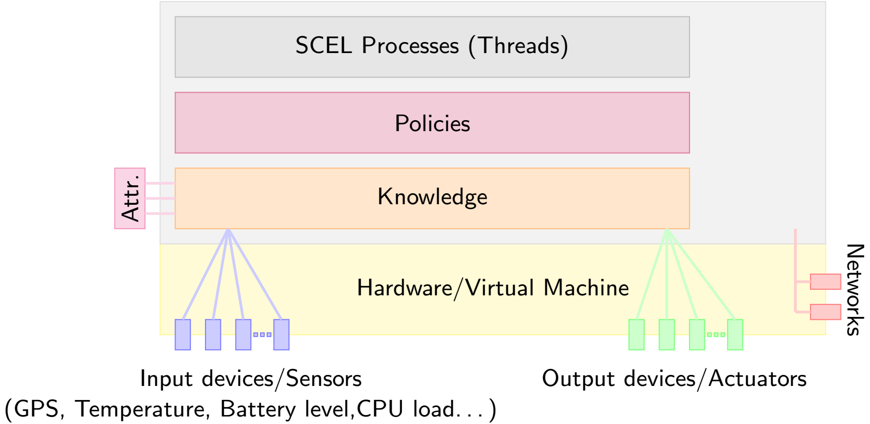
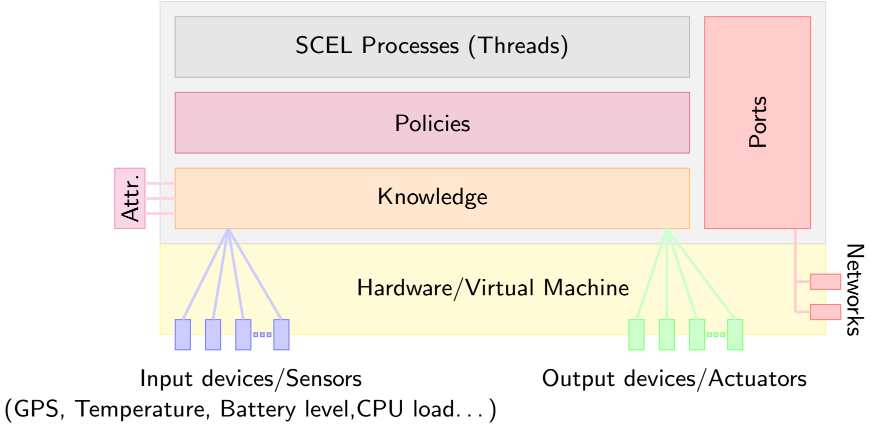



SCEL Processes (Threads)
Policies
Knowledge
Hardware/Virtual Machine
Networks
Input devices/Sensors
(GPS, Temperature, Battery level,CPU load...)
Output devices/Actuators

SCEL component



SCEL component



Knowledge

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Indeed, *Knowledge* is a Java interface with the following methods:

- put(Tuple t): boolean
- get(Template t): Tuple
- query(Template t): Tuple

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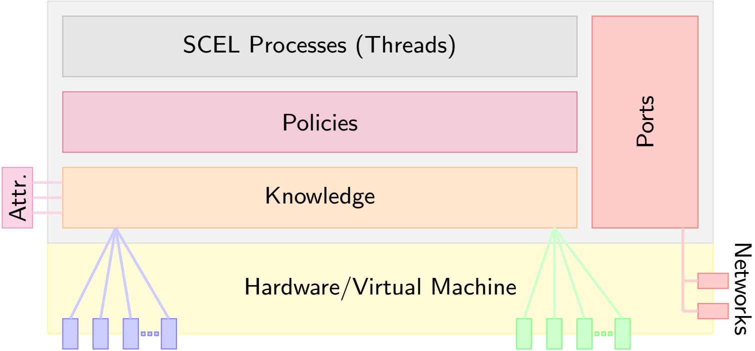
A single implementation of this interface is currently provided:

- class TupleSpace implements a *tuple space* (*á la klaim*)



Input devices/Sensors
(GPS, Temperature, Battery level,CPU load. . .)

Output devices/Actuators

Sensors. . .

Sensors. . .

Abstract class Sensor is used to identify a generic source of information:

- it can be associated to a logical/physical sensor
- values are exported as a *tuple*, each implementation has to define the structure of the tuple containing
  - (“GPS” , 45.8 , 37.2)
  - (“BATTERY” , %87)
- query actions are used to *retrieve* data from sensor

. . . and Actuators

. . . and Actuators

Abstract class Actuator is used to identify an external device that can be controlled by SCEL processes:

- it can be associated to a logical/physical actuator
- values are passed as a *tuple*, each implementation has to define the structure of the tuple containing
  - (“DIRECTION”, $\pi/3$)
- values are passed to a actuator via put actions

Component Knowledge in jRESP

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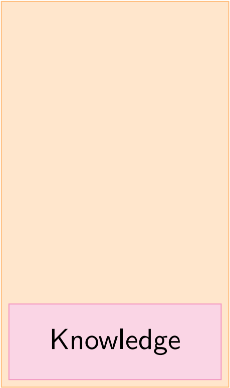
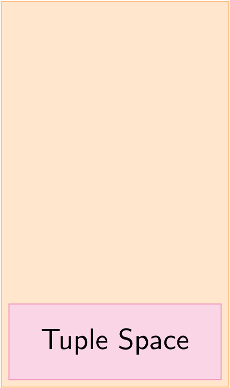
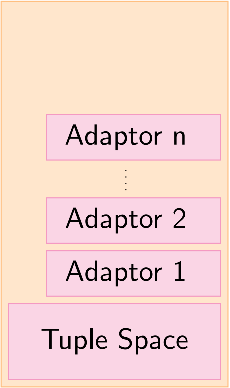


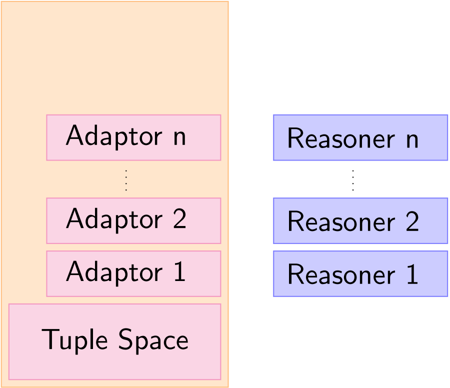
Component Knowledge in jRESP



Component Knowledge in jRESP



Component Knowledge in jRESP



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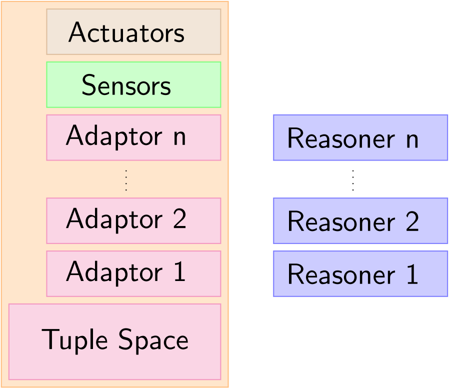
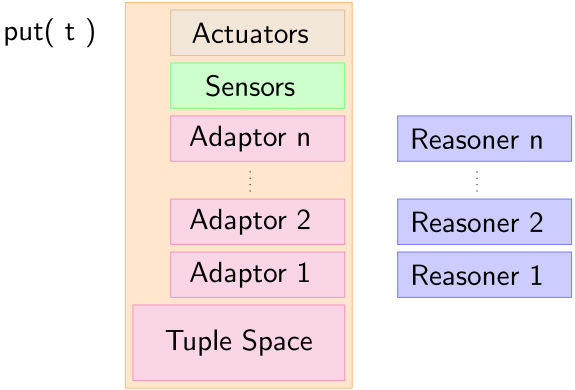
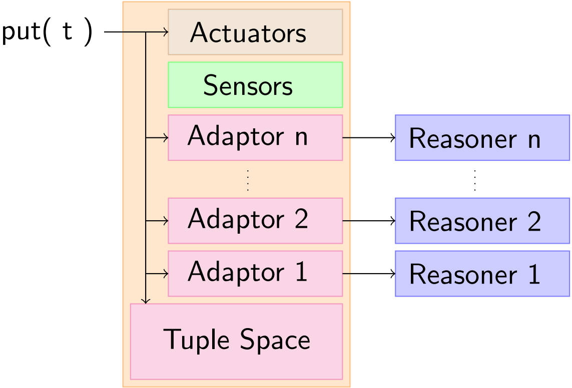

Actuators
Sensors
Adaptor n
Adaptor 2
Adaptor 1
Tuple Space
Reasoner n
Reasoner 2
Reasoner 1

Component Knowledge in jRESP



Component Knowledge in jRESP



When a put(t) is invoked, according to the structure of t, the *right* element is selected.

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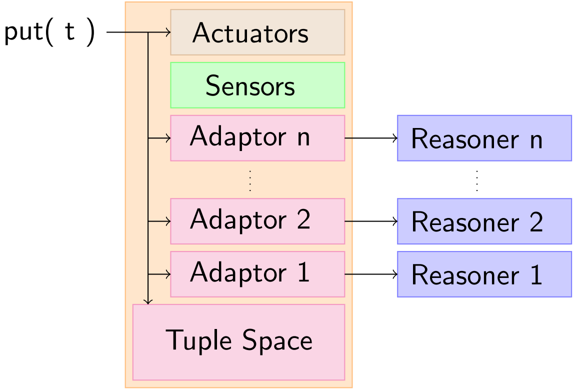

Adapters will use a *put* to add a knowledge item (e.g. a fact) represented by *t* in the corresponding reasoner.

Component Knowledge in jRESP

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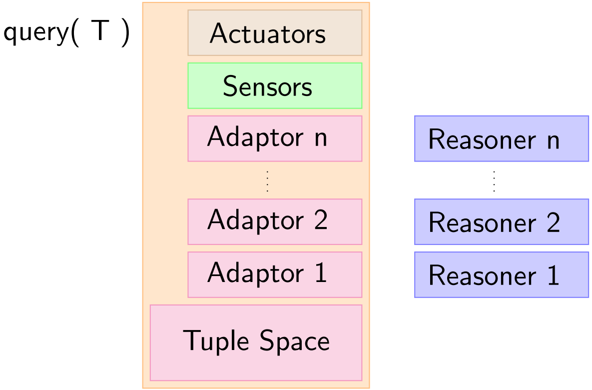
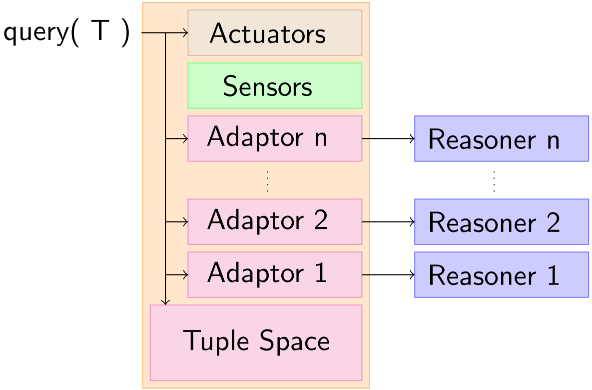
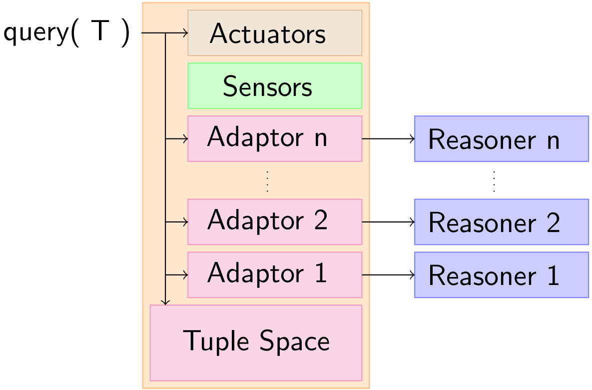




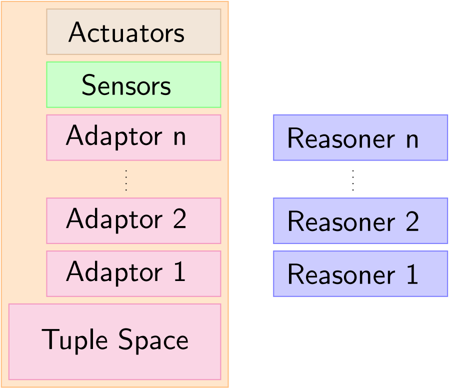
Similarly, a *get* will be *dispatched* according to template T.

Component Knowledge in jRESP



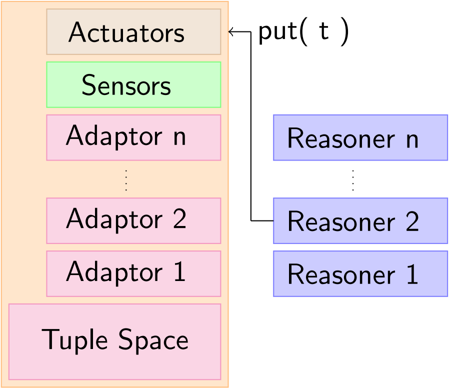
Adapters will use a *query* to ask to the corresponding reasoner about a *query* described via T.

Component Knowledge in jRESP



Reasoners can *autonomously* interact with the knowledge!

Component Knowledge in jRESP



Reasoners can *autonomously* interact with the knowledge!

Policies

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Action execution on each component is regulated by a *policy*.

Policies

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Policies are organized in a *stack*:

- the policy at one level relies on the one at the level below to actually execute SCEL actions
- the policy at the lower level is the one that allows any operation

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To simplify interactions with other framework/tools, even developed in languages that are different from Java, JSon format is used.

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2. All the components that receives the message reply with:
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   - a list of requested attributes
3. If the node originating the requests receives attributes that *satisfies* predicate P, action is executed. Otherwise, the request is sent again.

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- A *special* topic is used to coordinate activities.

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  - robots with the same *task* can get aware about position of target area.
- robots stop moving when the level of their batteries goes under a given threshold.

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By relying on *group-oriented* queries robots in the same ensemble can get aware about the position of the zone and then can move directly towards the target.

Robotics scenario in SCEL. . .

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Each robot is a SCEL component with two main behaviours:

- *managed element* (*ME*), that executes the next *control step* retrieved from local knowledge;
- *autonomic manager* (*AM*), that depending on info received from the environment puts in the knowledge the next *control step*.

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- messages collected/received from other robots.

Self-adaptation is realised by exploiting SCEL higher-order features:

- autonomic manager *AM* implements the adaptation logic by replacing the control step code in knowledge repository.

A component is created when an object of class Node is instantiated:

```
Node<TupleSpace> n =
          new Node<TupleSpace>(
                    "Robot"+i,
                    new TupleSpace()
          );
n.addPort(vp);
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New *knowledge managers*, **for instance the one based on KnowLang**, can be easily integrated!

Knowledge...

The interface Knowledge identifies a generic knowledge repository and indicates the high-level primitives to manage pieces of relevant information coming from different sources.

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Sensors and Actuators:

- external data can be collected into a knowledge repository via *sensors*;
- *actuators* can be used to forward data to external components.

Robotics scenario in SCEL...

Step 2: Adding sensors and actuators

```
n.addActuator(scenario.getDirectionActuator(i));
n.addSensor(scenario.getLocationSensor(i));
n.addActuator(scenario.getStopActuator(i));
n.addSensor(scenario.getBatterySensor(i));
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Remark:

In the code above, *scenario* is the Java classes modelling the *physical environment* where robots work.

Attribute collectors...

Attribute values are published on component interfaces via *attribute collectors*:

- when a request for an attribute is received, the corresponding collector is selected.
- node's knowledge is used to compute the actual attribute value.

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Each attribute collector is associated with a *name* and a *template*:

- when the attribute is evaluated a tuple matching the template is retrieved (via a predicative query action);
- the retrieved tuple is used to compute the actual attribute value.

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```
n.addAttributeCollector(
     new AttributeCollector(
          "task",
          new Template(
               new ActualTemplateField( "task"),
               new FormalTemplateField(Integer.class)
          )
     ) {
          @Override
          protected Attribute doEval(Tuple t) {
               return new Attribute(
                    "task",
                    t.getElementAt(Integer.class, 1));
          }
     }
);
```

Behaviours. . .

SCEL processes are implemented as threads via the abstract class Agent which provides the methods for:

- executing another agent,
- for generating fresh names,
- for instantiating a new component
- and for withdrawing/retrieving/adding information items from/to shared knowledge repositories.

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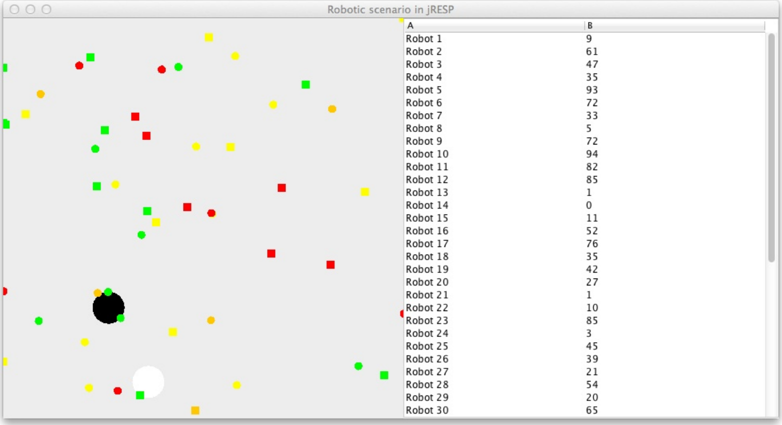
```
public class ManagedElement extends Agent {
   public ManagedElement() {
      super("ManagedElement");
   }
   @Override
   protected void doRun() throws Exception {
      while (true) {
         Tuple t = query(new Template(
                     new ActualTemplateField("controlStep")
                        ,
                     new FormalTemplateField(Agent.class)) ,
                  Self.SELF );
         Agent X = t.getElementAt(Agent.class, 1);
         call(X);
      }
   }
}
```

Autonomic manager (a fragment):

```
t = query( new Template(
        new ActualTemplateField("informed") ,
        new FormalTemplateField(Boolean.class)) ,
    Self.SELF );
boolean informed = t.getElementAt(Boolean.class, 1);
if (informed) {
    put( new Tuple( "controlStep" , new Informed() ) ,
        Self.SELF );
    get( new Template( new ActualTemplateField("seek") ) ,
        Self.SELF );
} else {
    put( new Tuple( "controlStep" , new RandomWalk() ) ,
        Self.SELF );
    get( new Template( new ActualTemplateField("seek") ) ,
        Self.SELF );
}
```

Running the scenario...



A	B
Robot 1	9
Robot 2	61
Robot 3	47
Robot 4	35
Robot 5	93
Robot 6	72
Robot 7	33
Robot 8	5
Robot 9	72
Robot 10	94
Robot 11	82
Robot 12	85
Robot 13	1
Robot 14	0
Robot 15	11
Robot 16	52
Robot 17	76
Robot 18	35
Robot 19	42
Robot 20	27
Robot 21	1
Robot 22	10
Robot 23	85
Robot 24	3
Robot 25	45
Robot 26	39
Robot 27	21
Robot 28	54
Robot 29	20
Robot 30	65

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- significative examples that can also help assessing/improving the performance of runtime framework.

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Considered framework should be now *populated* with...

- specific implementations for *policies*, *knowledge* the proposed solutions;
- significative examples that can also help assessing/improving the performance of runtime framework.

We are now working on a *top-level* programming language that, enriching SCEL with standard programming primitives, permits simplifying development of SCEL programs.

Good work!