SARL Agent Programming Language

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Outline

1 Reminders on Multiagent Systems

2 Programming Multiagent Systems with SARL

3 Overview of a MABS Architecture

4 Simulation with a Physic Environment

Agent (Wooldridge, 2001)

An agent is an entity with (at least) the following attributes / characteristics:

- Autonomy
- Reactivity
- Pro-activity
- Social Skills - Sociability

No commonly/universally accepted definition.

Autonomy

Agents encapsulate their internal state (that is not accessible to other agents), and make decisions about what to do based on this state, without the direct intervention of humans or others;

- Able to act without any direct intervention of human users or other agents.
- Has control over his own internal state.
- Has control over his own actions (no master/slave relationship)
- Can, if necessary/required, modify his behavior according to his personal or social experience (adaptation-learning).

Reactivity

Agents are situated in an environment, (physical world, a user via a GUI, a collection of other agents, Internet, or perhaps many of these combined), are able to perceive this environment (through the use of potentially imperfect sensors), and are able to respond in a timely fashion to changes that occur in it;

- Environment static $\Rightarrow$ the program can execute itself blindly.
- Real world as a lot of systems are highly dynamic: constantly changing, partial/incomplete information
- Design software in dynamic environment is difficult: failures, changes, etc.
- A reactive system perceives its environment and responds in a timely appropriate fashion to the changes that occur in this environment (Event-directed).

Pro-activity of an Agent

Pro-activity

Agent do not simply act in response to their environment, they are able to exhibit goal-directed behavior by taking the initiative; They pursue their own personal or collective goals.

- Reactivity is limited (e.g. Stimulus $\Rightarrow$ Response).
- A proactive system generates and attempts to capture objectives, it is not directed only by events, take the initiative.
- Recognize/Identify opportunities to act/trigger something.

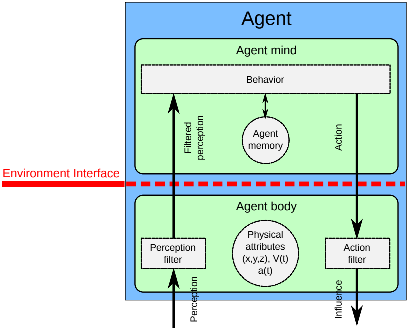
Sociability - Social Ability

Agents interact with other agents (and possibly humans), and typically have the ability to engage in social activities (such as cooperative problem solving or negotiation) in order to achieve their goals. Unity is strength.

- Many tasks can only be done by cooperating with others
- An agent must be able to interact with virtual or/and real entities
- Require a mechanism to exchange information either directly (Agent-to-Agent) or indirectly (through the environment).
- May require a specific (agent-communication) language.

An agent:

- is located in an environment (situatedness)
- perceives the environment through its sensors.
- acts upon that environment through its effectors.
- tends to maximize progress towards its goals by acting in the environment.



More details are given in Chapter #??

Mono-agent approach

- The system is composed of a single agent.
- Example: Personal Assistant

Multi-agent approach

- The system is composed of multiple agents.
- The realization of global/collective task relies on a set of agents, on the composition of their actions.
- The solution emerges from the interactions of agents in an environment.

Multiagent systems

An MultiAgent Systems (MAS) is a system composed of agents that interact together and through their environment.

Interactions:
$\rightarrow$ Direct, agent to agent
$\rightarrow$ Indirect, Stigmergy, through the Environment

Micro perspective (local): Agent

Individual level

- Reactivity - Pro-activity
- Autonomy
- Delegation

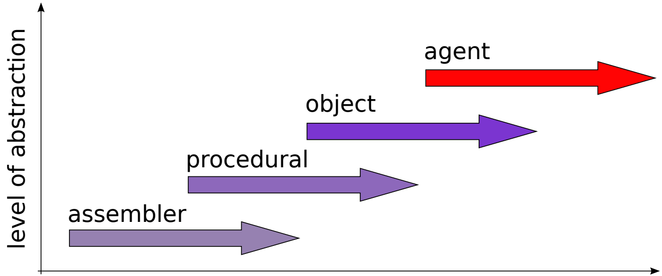
Macro perspective (global): Multiagent systems

Society/Community level

- Distribution
- Decentralization (control and/or authority)
- Hierarchy
- Agreement technologies (coordination)
- Emergence, social order/pattern, norms

Agent: a new paradigm ?

- Agent-Oriented Programming (AOP) reuses concepts and language artifacts from Object-Oriented Programming (OOP).
- It also provides an higher-level abstraction than the other paradigms.



Language

- **All agents are holonic (recursive agents).**
- There is not only one way of interacting but infinite.
- Event-driven interactions as the default interaction mode.
- Agent/environment architecture-independent.
- Massively parallel.
- Coding should be simple and fun.

Execution Platform

- Clear separation between Language and Platform related aspects.
- Everything is distributed, and it should be transparent.
- Platform-independent.

Name	Domain	Hierar.[a]	Simu.[b]	C.Phys.[c]	Lang.	Beginners[d]	Free
GAMA	Spatial simulations		✓		GAML, Java	**[*]	✓
Jade	General		✓	✓	Java	*	✓
Jason	General		✓	✓	Agent-Speaks	*	✓
Madkit	General		✓		Java	**	✓
NetLogo	Social/ natural sciences		✓		Logo	***	✓
Repast	Social/ natural sciences		✓		Java, Python, .Net	**	
SARL	General	✓	✓[e]	✓	SARL, Java, Xtend, Python	**[*]	✓

a Native support of hierarchies of agents.

b Could be used for agent-based simulation.

c Could be used for cyber-physical systems, or ambient systems.

d *: experienced developers; **: for Computer Science Students; ***: for others beginners.

e Ready-to-use Library: ▸ Jaak Simulation Library

This table was done according to experiments with my students.

```java
public class ExampleOfClass
    extends SuperClass
    implements SuperInterface {
  // Field
  private int a;
  // Single-initialization field
  private final String b
                = "example";
  // Constructor
  public ExampleOfClass(int p) {
    this.a = p;
  }
  // Function with return value
  public int getA() {
    return this.a;
  }
  // Simulation of default
  // parameter value
  public void increment(int a) {
    this.a += a;
  }
  public void increment() {
    increment(1);
  }
  // Variadic parameter
  public void add(int... v) {
    for(value : v) {
      this.a += value;
    }
  }
}
```

```sarl
class ExampleOfClass
    extends SuperClass
    implements SuperInterface {
  // Field
  var a : int
  // Single-initialization field
  // automatic detection of the
  // field type
  val b = "example"
  // Constructor
  new(p : int) {
    this.a = p
  }
  // Function with return value
  def getA : int {
    this.a
  }
  // Real default parameter value
  def increment(a : int = 1) {
    this.a += a
  }
  // Variadic parameter
  def add(v : int*) {
    for(value : v) {
      this.a += value
    }
  }
}
```

Implicit Calls to Getter and Setter Functions

- Calling getter and setter functions is verbose and annoying.
- Syntax for field getting and setting is better.
- SARL compiler implicitly calls the getter/setter functions when field syntax is used.

```
class Example {
  private var a : int

  def getA : int {
    this.a
  }
  def setA(a : int) {
    this.a = a
  }
}

class Caller {
  def function(in : Example) {
    // Annoying calls
    in.setA(in.getA + 1)
    // Implicit calls by SARL
    in.a = in.a + 1
  }
}
```

- With call: `variable.field`; SARL seach for:
  1. the function `getField` defined in the variable's type,
  2. the accessible field `field`.
- If the previous syntax is left operand of assignment operator, SARL seach for:
  1. the function `setField` defined in the variable's type,
  2. the accessible field `field`.

- Goal: Extension of existing types with new methods.
- Tool: Extension methods.
- Principe: The first argument could be externalized prior to the function name.

- Standard notation: `function(value1, value2, value3)`

- Extension method notation: `value1.function(value2, value3)`

```
class Example {

  // Compute the Leivenstein
  // distance between two
  // strings of characters
  def distance(s1 : String,
               s2 : String)
               : int {
    // Code
  }

  def standardNotation {
    var d = distance("abc", "abz")
  }

  def extensionMethodNotation {
    var d = "abc".distance("abz")
  }
}
```

- Lambda expression: a piece of code, which is wrapped in an object to pass it around.
- Notation:
  [paramName : paramType, ... | code]
- Parameters' names may be not typed. If single parameter, it is used as name.
- Parameters' types may be not typed. They are infered by the SARL compiler.

```
class Example {
  def example1 {
    var lambda1 = [
          a : int , b : String |
          a + b.length ]
  }

  def example2 {
    var lambda2 = [ it.length ]
  }
}
```

Type for a Lambda Expression

- Type for a lambda expression may be written with a SARL approach, or a Java approach.
- Let the example of a lambda expression with:
  - two parameters, one int, one String, and
  - a returned value of type int.

```
class Example {
  def example1 :
    (int, String) => String {
    return [
          a : int, b : String |
          a + b.length ]
  }

  def example2 :
      Function2<Integer, String,
                Integer> {
    return [
          a : int, b : String |
          a + b.length ]
  }
}
```

- SARL notation: `(int, String) => int`
- Java notation: `Function2<Integer, String, Integer>`

- Problem: Giving a lambda expression as function's argument is not friendly (see `example1`).
- Goal: Allow a nicer syntax.

- Principle: If the last parameter is a lambda expression, it may be externalized after the function's arguments (see `example2`).

```
class Example {

  def myfct(a : int, b : String,
            c : (int) => int) {
    // Code
  }

  def example1 {
    myfct(1, "abc", [ it * 2 ])
  }

  def example2 {
    myfct(1, "abc") [ it * 2 ]
  }
}
```

Special instance variables

- Usually, the OO languages provide special instance variables.
- SARL provides:
  - this: the instance of current type declaration (class, agent, behavior...)
  - super: the instance of the inherited type declaration.
  - it: an object that depends on the code context.

```
class Example extends SuperType {

  var field : int

  def thisExample {
    this.field = 1
  }

  def superExample {
    super.myfct
  }

  def itExample_failure {
    // it is unknown in this
    // context
    it.field
  }

  def itExample_inLambda {
    // it means: current parameter
    lambdaConsumer [ it + 1 ]
  }

  def lambdaConsumer((int) => int)
  {}
}
```

- Type: Explicit naming a type may be done with the optional operator:
  typeof(TYPE).
- Casting: Dynamic change of the type of a variable is done with operator:
  VARIABLE as TYPE.
- Instance of: Dynamic type testing is supported by the operator:
  VARIABLE instanceof TYPE.

  If the test is done in a if-statement, it is not neccessary to cast the variable inside the inner blocks.

```
class Example {

  def typeofExample {
    var t : Class<?>
    t = typeof(String)
    t = String
  }

  def castExample {
    var t : int
    t = 123.456 as int
  }

  def instanceExample(t:Object) {
    var x : int
    if (t instanceof Number) {
      x = t.intValue
    }
  }

}
```

Other Special Operators

- SARL provides special operators in addition to the classic operators from Java or C++:

Operator	Semantic	Java equivalent
a == b	Object equality test	`a.equals(b)`
a != b	Object inequality test	`!a.equals(b)`
a === b	Reference equality test	`a == b`
a !== b	Reference inequality test	`a != b`
a <=> b	Compare a and b	`Comparable` interface
a .. b	Range of values $[a, b]$	n/a
a ..< b	Range of values $[a, b)$	n/a
a >.. b	Range of values $(a, b]$	n/a
a ** b	Compute a^b	n/a
a -> b	Create a pair (a, b)	n/a
a ?: b	If a is not null then a else b	`a == null ? b : a`
a?.b	If a is not null then a.b is called else a default value is used	`a == null ? defaultValue : a.b`
if (a) b else c	Inline condition	`a ? b : c`

Operator Definition and Overriding

- SARL allows overriding or definition operators.
- Each operator is associated to a specific function name that enables the developper to redefine the operator's code.
- Examples of operators in SARL:

Operator	Function name	Semantic
`col += value`	operator_add(Collection, Object)	Add an value into a collection.
`a ** b`	operator_power(Number, Number)	Compute the power b of a.

```
class Vector {
  var x : float
  var y : float
  new (x : float, y : float) {
    this.x = x ; this.y = y
  }
  def operator_plus(v: Vector)
      : Vector {
    new Vector(this.x + v.x,
               this.y + v.y)
  }
}
```

```
class X {
  def fct {
    var v1 = new Vector(1, 2)
    var v2 = new Vector(3, 4)

    var v3 = v1 + v2
  }
}
```

Multiagent System in SARL

A collection of agents interacting together in a collection of shared distributed spaces.

4 main concepts

- Agent
- Capacity
- Skill
- Space

3 main dimensions

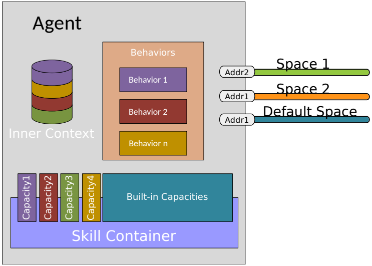
- Individual:: the Agent abstraction (Agent, Capacity, Skill)
- Collective:: the Interaction abstraction (Space, Event, etc.)
- Hierarchical:: the Holon abstraction (Context)

SARL: a general-purpose agent-oriented programming language. Rodriguez, S., Gaud, N., Galland, S. (2014) Presented at the The 2014 IEEE/WIC/ACM International Conference on Intelligent Agent Technology, IEEE Computer Society Press, Warsaw, Poland. (Rodriguez, 2014)

`http://www.sarl.io`

Agent

- An agent is an autonomous entity having some intrinsic skills to implement the capacities it exhibits.
- An agent initially owns native capacities called Built-in Capacities.
- An agent defines a Context.




```
agent HelloAgent {
  on Initialize {
    println("Hello World!")
  }
  on Destroy {
    println("Goodbye World!")
  }
}
```

```
package org.multiagent.example

agent HelloAgent {

  var myvariable : int
  val myconstant = "abc"

  on Initialize {
    println("Hello World!")
  }

  on Destroy {
    println("Goodbye World!")
  }

}
```

The content of the file will be assumed to be in the given package.

```
package org.multiagent.example

agent HelloAgent {

  var myvariable : int
  val myconstant = "abc"

  on Initialize {
    println("Hello World!")
  }

  on Destroy {
    println("Goodbye World!")
  }

}
```

Define the code of all the agents of type HelloAgent

```
package org.multiagent.example

agent HelloAgent {

  var myvariable : int
  val myconstant = "abc"

  on Initialize {
    println("Hello World!")
  }

  on Destroy {
    println("Goodbye World!")
  }

}
```

This block of code contains all the elements related to the agent.

```
package org.multiagent.example

agent HelloAgent {

  var myvariable : int
  val myconstant = "abc"

  on Initialize {
    println("Hello World!")
  }

  on Destroy {
    println("Goodbye World!")
  }

}
```

Define a variable with name "myvariable" and of type integer

```
package org.multiagent.example

agent HelloAgent {

  var myvariable : int
  val myconstant = "abc"

  on Initialize {
    println("Hello World!")
  }

  on Destroy {
    println("Goodbye World!")
  }

}
```

Define a constant with name "myconstant" and the given value.

```
package org.multiagent.example

agent HelloAgent {

  var myvariable : int
  val myconstant = "abc"

  on Initialize {
    println("Hello World!")
  }

  on Destroy {
    println("Goodbye World!")
  }

}
```

Execute the block of code when an event of type "Initialize" is received by the agent.

```
package org.multiagent.example

agent HelloAgent {

  var myvariable : int
  val myconstant = "abc"

  on Initialize {
    println("Hello World!")
  }

  on Destroy {
    println("Goodbye World!")
  }

}
```

Events predefined in the SARL language:
- When initializing the agent
- When destroying the agent

Action

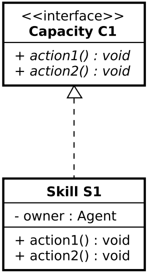
- A specification of a transformation of a part of the designed system or its environment.
- Guarantees resulting properties if the system before the transformation satisfies a set of constraints.
- Defined in terms of pre- and post-conditions.

Capacity

Specification of a collection of actions.

Skill

A possible implementation of a capacity fulfilling all the constraints of its specification, the capacity.



Enable the separation between a generic behavior and agent-specific capabilities.

Example of Capacity and Skill

```
capacity Logging {

  def debug(s : String)

  def info(s : String)

}
```

```
skill BasicConsoleLogging
implements Logging {

  def debug(s : String) {
    println("DEBUG:" + s)
  }

  def info(s : String) {
    println("INFO:" + s)
  }

}
```

```
agent HelloAgent {

  uses Logging

  on Initialize {
    setSkill(new
     BasicConsoleLogging)
    info("Hello World!")
  }

                    d!")

}
```

Definition of a capacity that permits to an agent to print messages into the log system.

Example of Capacity and Skill


```
capacity Logging {

  def debug(s : String)

  def info(s : String)

}


skill BasicConsoleLogging
implements Logging {

  def debug(s : String) {
    println("DEBUG:" + s)
  }

  def info(s : String) {
    println("INFO:" + s)
  }

}
```

```
agent HelloAgent {

  uses Logging

  on Initialize {
    setSkill(new
     BasicConsoleLogging)
    info("Hello World!")
  }

                     World!")

}
```

Define a function that could be invoked by the agent.

Example of Capacity and Skill

```
capacity Logging {

  def debug(s : String)

  def info(s : String)

}

skill BasicConsoleLogging
implements Logging {

  def debug(s : String) {
    println("DEBUG:" + s)
  }

  def info(s : String) {
    println("INFO:" + s)
  }

}
```

Define the skill that implements the Logging capacity.

```
    uses Logging

    on Initialize {
      setSkill(new
       BasicConsoleLogging)
      info("Hello World!")
    }

    on Destroy {
      info("Goodbye World!")
    }

}
```

Example of Capacity and Skill

```
capacity Logging {

  def debug(s : String)

  def info(s : String)

}


skill BasicConsoleLogging
implements Logging {

  def debug(s : String) {
    println("DEBUG:" + s)
  }

  def info(s : String) {
    println("INFO:" + s)
  }

}
```

Every function declared into the implemented capacity must be implemented in the skill. The current implementations output the message onto the standard output stream.

```
                   g)
      info("Hello World!")
    }

    on Destroy {
      info("Goodbye World!")
    }

}
```

```
capac
  def
  def info(s : String)
}

skill BasicConsoleLogging
implements Logging {
  def debug(s : String) {
    println("DEBUG:" + s)
  }
  def info(s : String) {
    println("INFO:" + s)
  }
}
```

The use of a capacity into the agent code is enabled by the "uses" keyword.

```
agent HelloAgent {
  uses Logging
  on Initialize {
    setSkill(new
     BasicConsoleLogging)
    info("Hello World!")
  }
  on Destroy {
    info("Goodbye World!")
  }
}
```

Example of Capacity and Skill

```
capacity Logging {
  def debug(s : String)
  def info(s : String)
}

sk
im

    println("DEBUG:" + s)
  }

  def info(s : String) {
    println("INFO:" + s)
  }

}
```

All functions defined into the used capacities are directly callable from the source code.

```
agent HelloAgent {

  uses Logging

  on Initialize {
    setSkill(new
     BasicConsoleLogging)
    info("Hello World!")
  }

  on Destroy {
    info("Goodbye World!")
  }

}
```

```
capacity Logging {

  def debug(s : String)

  def info(s : String)

}


ski
imp

  d

  }

  def info(s : String) {
    println("INFO:" + s)
  }

}
```

An agent MUST specify the skill to use for a capacity (except for the buildin skills that are provided by the execution framework)

```
agent HelloAgent {

  uses Logging

  on Initialize {
    setSkill(new
     BasicConsoleLogging)
    info("Hello World!")
  }

  on Destroy {
    info("Goodbye World!")
  }

}
```

Space

Support of interaction between agents respecting the rules defined in various Space Specifications.

Space Specification

- Defines the rules (including action and perception) for interacting within a given set of Spaces respecting this specification.
- Defines the way agents are addressed and perceived by other agents in the same space.
- A way for implementing new interaction means.

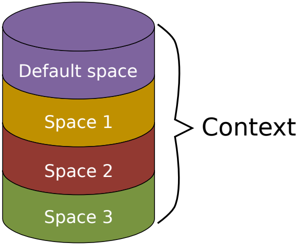
.

The spaces and space specifications must be written with the Java programming language

Context and Spaces

Context

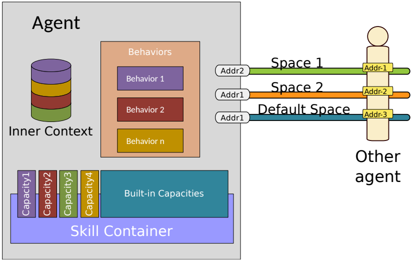
- Defines the boundary of a sub-system.
- Collection of Spaces.
- Every Context has a Default Space.
- Every Agent has a Default Context, the context where it was spawned.



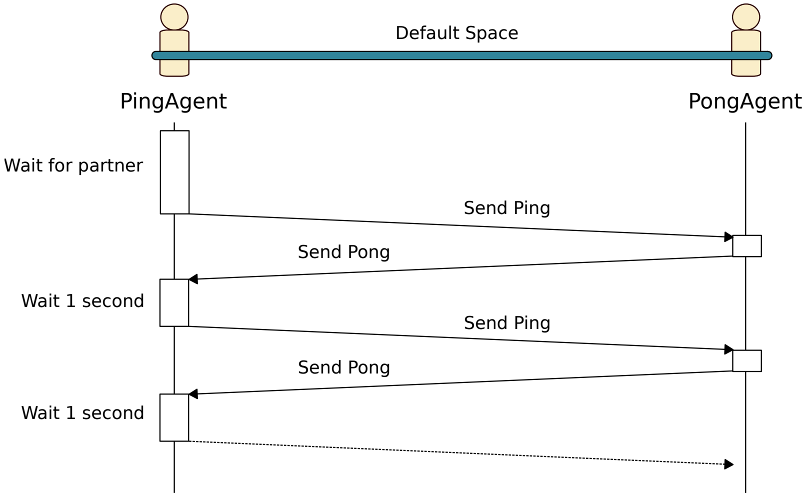
Default Space in Every Contexts

Default Space: an Event Space

- Event-driven interaction space.
- Default Space of a context, contains all agents of the considered context.
- Event: the specification of some occurrence in a Space that may potentially trigger effects by a participant.



Example of Interactions: Ping - Pong



```
event Ping {
  var value : Integer
  new (v : Integer) {
    value = v
  }
}

event Pong {
  var value : Integer
  new (v : Integer) {
    value = v
  }
}

agent PongAgent {
  uses DefaultContextInteractions
  on Initialize {
    println("Waiting for ping")
  }
  on Ping {
    println("Recv Ping: "
       + occurrence.value)
    println("Send Pong: "
       + occurrence.value)
    emit(new Pong(
             occurrence.value))
  }
}
```

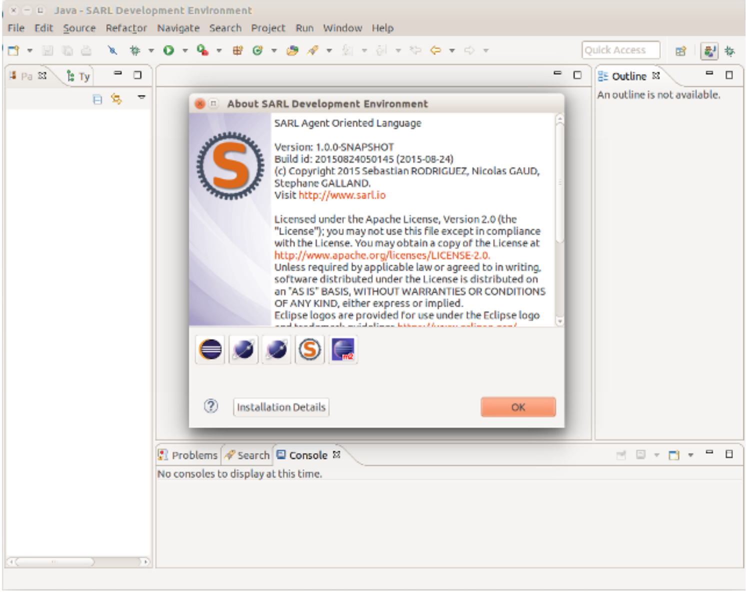
```
agent PingAgent {
  uses Schedules
  uses DefaultContextInteractions
  var count : Integer
  on Initialize {
    println("Starting PingAgent")
    count = 0
    in(2000) [ sendPing ]
  }
  def sendPing {
    if (defaultSpace.
          participants.size > 1) {
      emit(new Ping(count))
      count = count + 1
    } else {
      in(2000) [ sendPing ]
    }
  }
  on Pong {
    in(1000) [
      println("Send Ping: "+count)
      emit(new Ping(count))
      count = count + 1
    ]
  }
}
```

Documentation of SARL

The SARL syntax is explained into the “General Syntax Reference” on the SARL website.

`http://www.sarl.io/docs/`

`http://www.sarl.io/docs/suite/io/sarl/docs/reference/GeneralSyntaxReferenceSpec.html`



Java - SARL Development Environment
File Edit Source Refactor Navigate Search Project Run Window Help
Quick Access
Outline
An outline is not available.
About SARL Development Environment
SARL Agent Oriented Language
Version: 1.0.0-SNAPSHOT
Build id: 20150824050145 (2015-08-24)
(c) Copyright 2015 Sebastian RODRIGUEZ, Nicolas GAUD, Stephane GALLAND.
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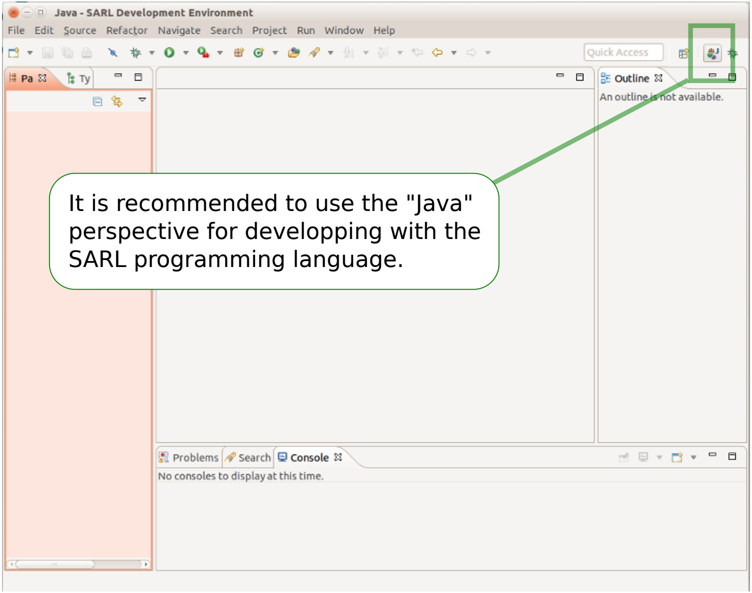
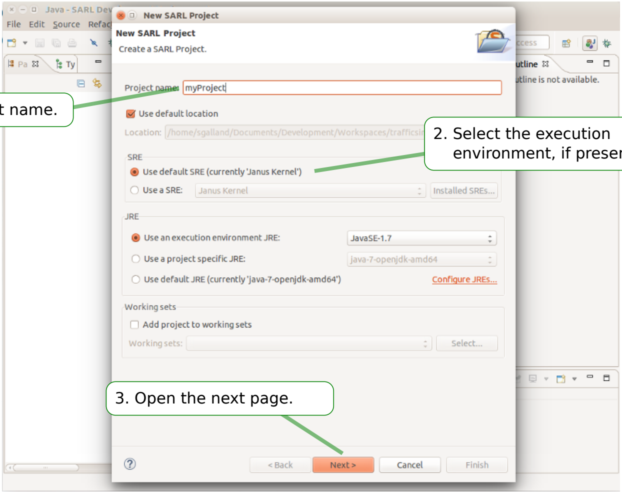
Eclipse logos are provided for use under the Eclipse logo
Installation Details
OK
Problems
Search
Console
No consoles to display at this time.

Use the Java Perspective



It is recommended to use the "Java" perspective for developping with the SARL programming language.

Create a SARL Project

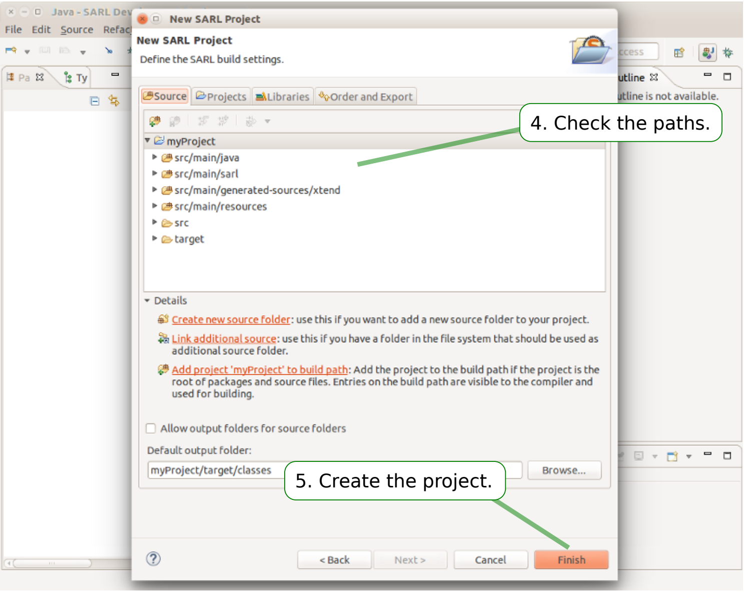


1. Enter the project name.

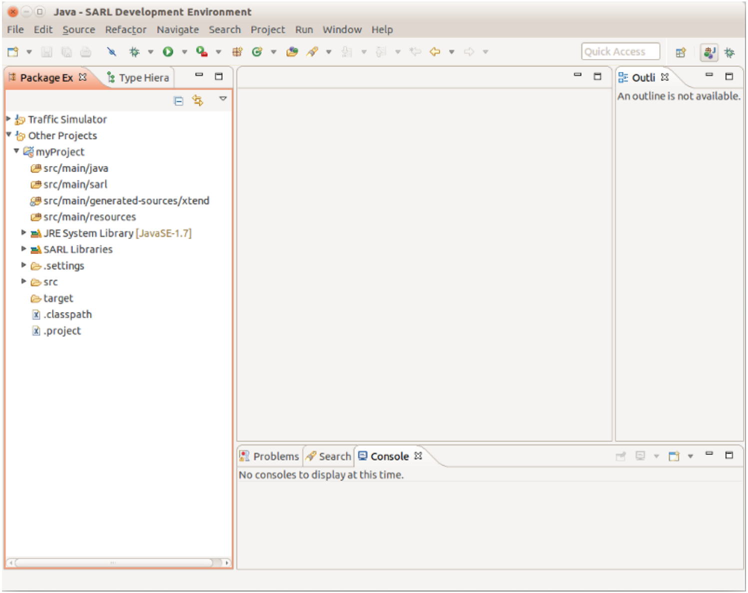
2. Select the execution environment, if present.

3. Open the next page.

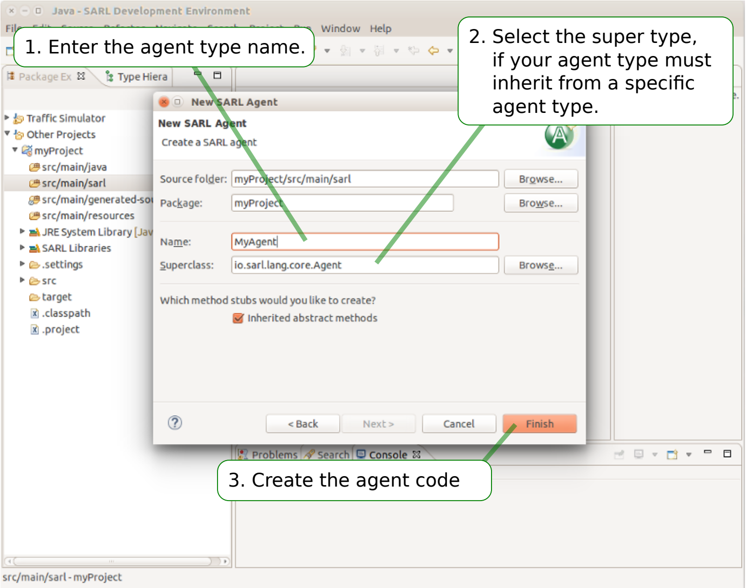
Create a SARL Project (cont.)



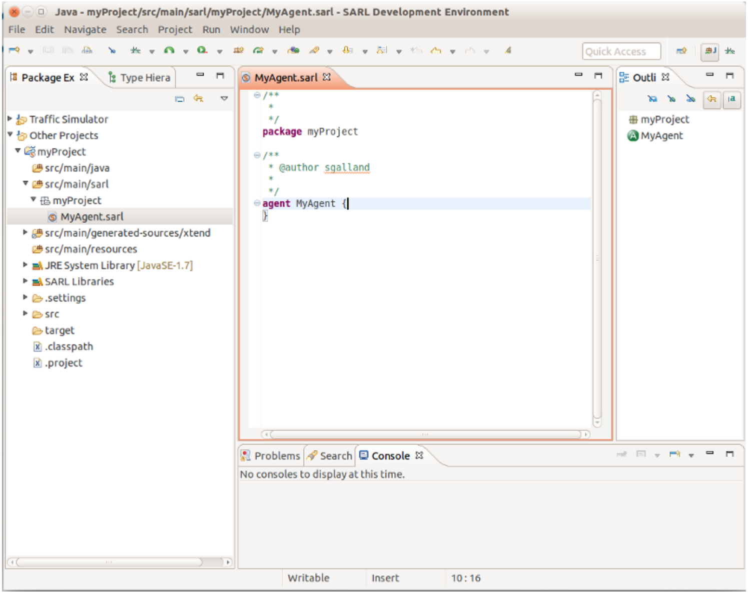
Create a SARL Project (cont.)



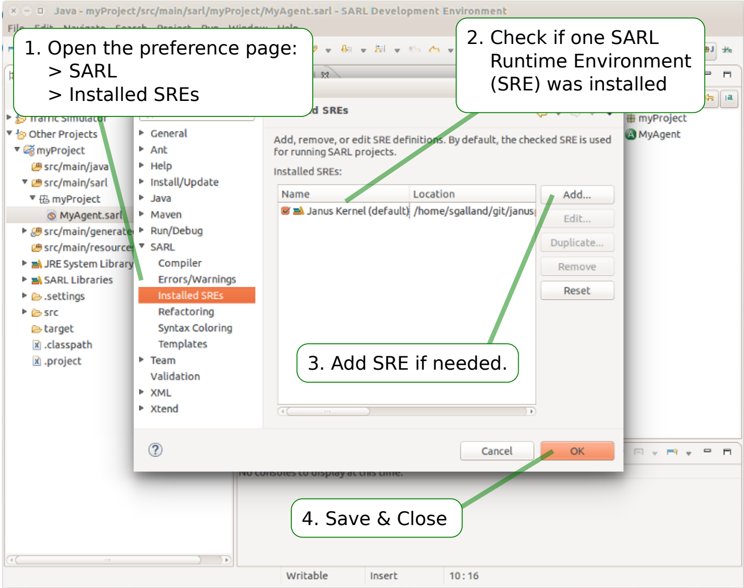
Create Your First Agent



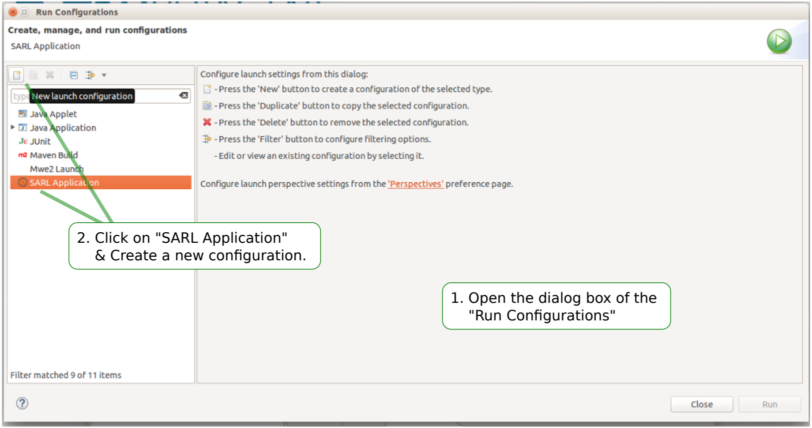
Create Your First Agent (cont.)



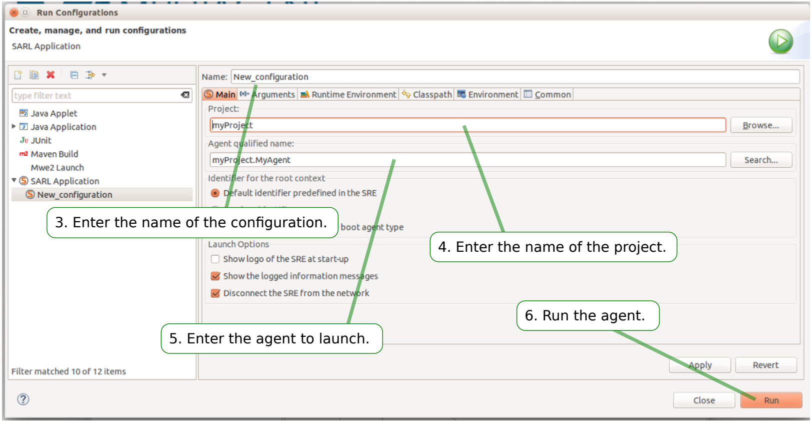
Define the Execution Environment



Executing the Agent with Janus

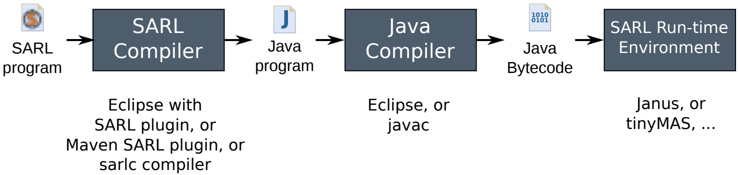


Executing the Agent with Janus (cont.)



Compatibility between SARL and Java

SARL is 100% compatible with Java



- Any Java feature or library could be included and called from SARL.
- A Java application could call any public feature from the SARL API.

Runtime Environment for SARL

Runtime Environment Requirements

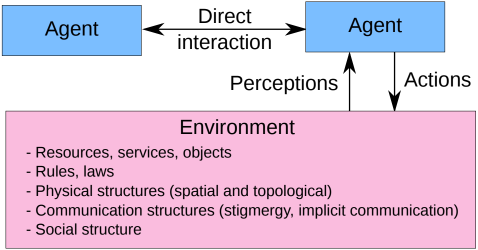
- Implements SARL concepts.
- Provides Built-in Capacities.
- Handles Agent's Lifecycle.
- Handles resources.

Janus as a SARL Runtime Environment

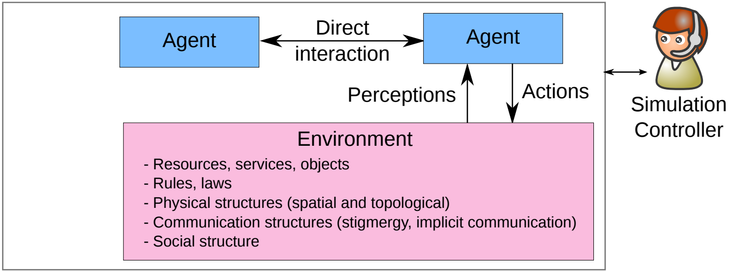
- Fully distributed.
- Dynamic discovery of Kernels.
- Automatic synchronization of kernels' data (easy recovery).
- Micro-Kernel implementation.
- Official website: `http://www.janusproject.io`

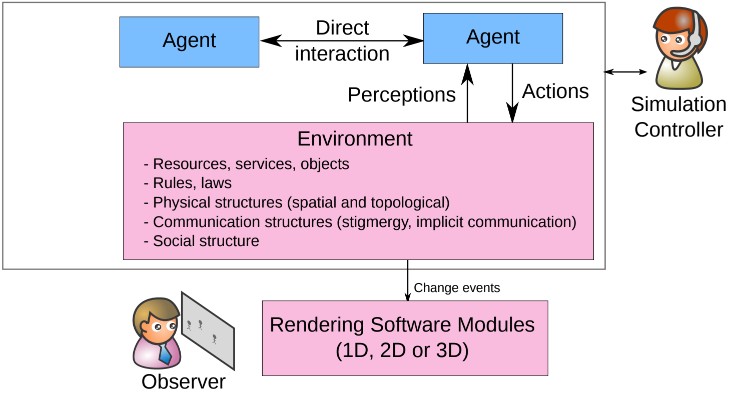
Other SREs may be defined.

General Architecture



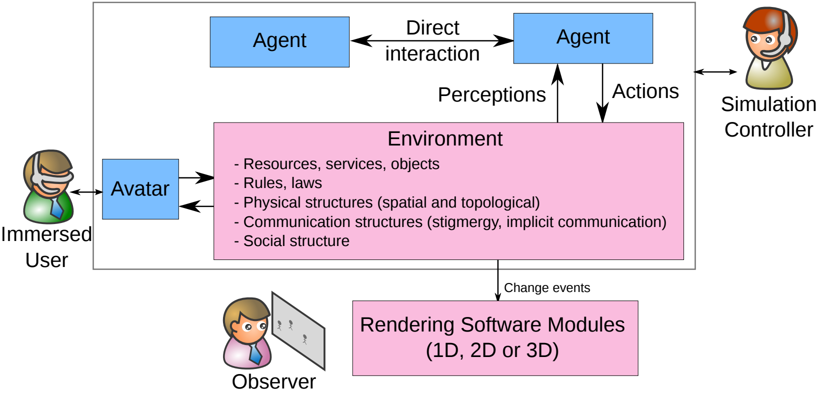
General Architecture

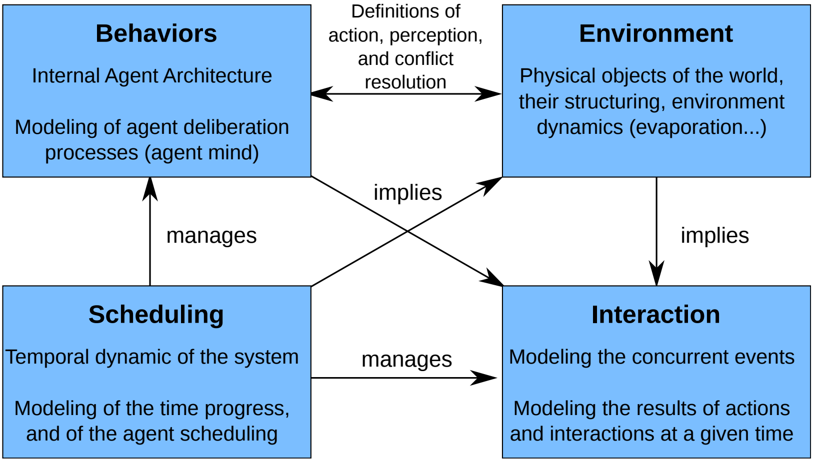




Agent
Direct interaction
Agent
Perceptions
Actions
Simulation Controller
Environment
- Resources, services, objects
- Rules, laws
- Physical structures (spatial and topological)
- Communication structures (stigmergy, implicit communication)
- Social structure
Change events
Rendering Software Modules (1D, 2D or 3D)
Observer

General Architecture

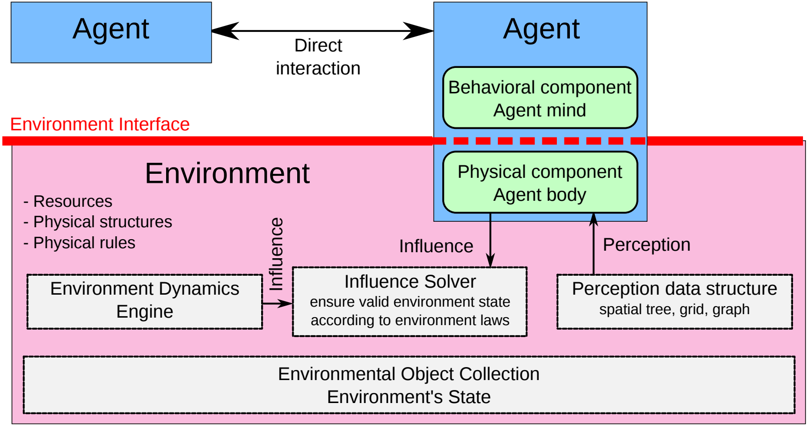




Behaviors
Internal Agent Architecture
Modeling of agent deliberation processes (agent mind)
Definitions of action, perception, and conflict resolution
Environment
Physical objects of the world, their structuring, environment dynamics (evaporation...)
implies
manages
implies
Scheduling
Temporal dynamic of the system
Modeling of the time progress, and of the agent scheduling
manages
Interaction
Modeling the concurrent events
Modeling the results of actions and interactions at a given time

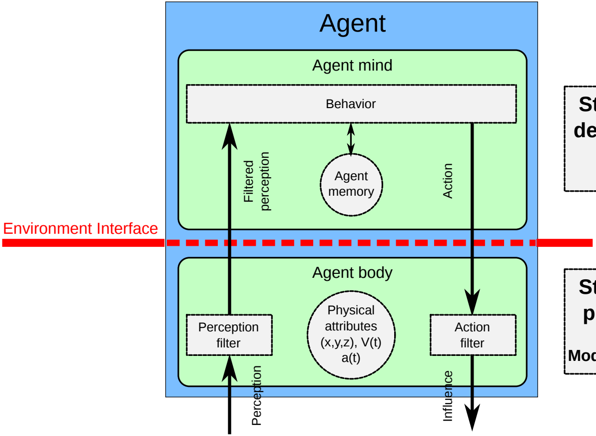
Michel (2004)

Situated Environment Model



Galland (2009)

Body-Mind Distinction



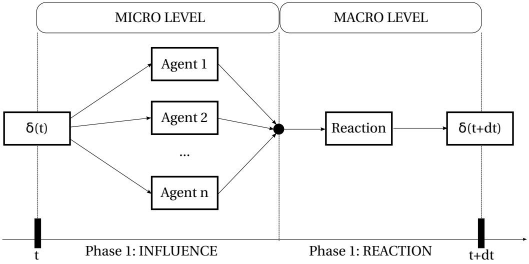
State variables of the decisional component
Readable/modifiable only by the agent

State variables of the physical component
Readable by the agent
Modifiable by the environment

Galland (2009)

How to support simultaneous actions from agents?

1. An agent does not change the state of the environment directly.
2. Agent gives a state-change expectation to the environment: the influence.
3. Environment gathers influences, and solves conflicts among them for obtaining its reaction.
4. Environment applies reaction for changing its state.



Michel (2007)

Physic Environment in SARL

- The agent has the capacity to use its body.
- The body supports the interactions with the environment.

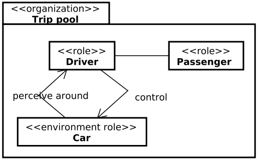
```
event Perception {
  val object : Object
  val relativePosition : Vector
}

capacity EnvironmentInteraction {
  moveTheBody(motion : Vector)
  move(object : Object,
       motion : Vector)
  executeActionOn(object : Object,
       actionName : String,
       parameters : Object*)
}


space PhysicEnvironment {
  def move(object : Object,
           motion : Vector) {
    //...
  }
}
```

```
skill PhysicBody implements
      EnvironmentInteraction {

  val env : PhysicEnvironment

  val body : Object

  def moveTheBody(motion:Vector) {
    move(this.body, motion)
  }

  def move(object : Object,
           motion : Vector) {
    env.move(object, motion)
  }
}
```

Galland (2015)

- Each vehicle is simulated but road signs are skipped $\Rightarrow$ mesoscopic simulation.
- The roads are extracted from a Geographical Information Database.

- The simulation model is composed of two parts (Galland, 2009):
  1. the environment: the model of the road network, and the vehicles.
  2. the driver model: the behavior of the driver linked to a single vehicle.



Road Network

- Road polylines: $S = \left\{ \langle path, objects \rangle \middle| path = \langle (x_0, y_0) \cdots \rangle \right\}$
- Graph: $G = \{S, S \mapsto S, S \mapsto S\} = \{\text{segments}, \text{entering}, \text{exiting}\}$

Operations

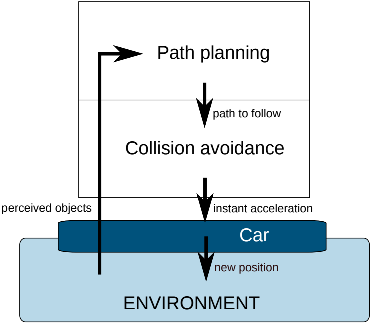
- Compute the set of objects perceived by a driver (vehicles, roads...):

$$P = \left\{ o \middle| \begin{array}{c} distance(d, o) \leq \Delta \wedge \\ o \in O \wedge \\ \forall (s_1, s_2), path = s_1.\langle p, O \rangle.s_2 \end{array} \right\}$$

  where *path* is the roads followed by a driver d.
- Move the vehicles, and avoid physical collisions.

Galland (2009)

Architecture of the Driver Agent



Jasim model (Galland, 2009)

Path Planning

- Based on the A* algorithm (Dechter, 1985; Delling, 2009):
  - extension of the Dijkstra's algorithm: search shortest paths between the nodes of a graph.
  - introduce the heuristic function *h* to explore first the nodes that permits to converge to the target node.
- Inspired by the D*-Lite algorithm (Koenig, 2005):
  - A* family.
  - supports dynamic changes in the graph topology and the values of the edges.

Collision Avoidance

- Principle: compute the acceleration of the vehicle to avoid collisions with the other vehicles.
- Intelligent Driver Model (Treiber, 2000)

$$\texttt{followerDriving} = \begin{cases} -\dfrac{(v\Delta v)^2}{4b\Delta p^2} & \text{if the ahead object is far} \\ -a\dfrac{(s+vw)^2}{\Delta p^2} & \text{if the ahead object is near} \end{cases}$$

- Free driving:

$$\texttt{freeDriving} = a\left(1 - \left(\frac{v}{v_c}\right)^4\right)$$

```
agent StandardDriver {
  uses DrivingCapacity

  var path : Path

  on Initialize {
    setSkill(DrivingCapacity, IDM_Dstart_DrivingSkill)
  }

  on Perception {
    var stopVehicleInStandardCondition = isVehicleStop(occurrence)
    var siren = occurrence.body.getFirstPerceptionAtCurrentPosition(Siren)
    var stopVehicleForEmergencyVehicle = isStopWhenEmergencyVehicle(siren)

    if (!stopVehicleForEmergencyVehicle&&!stopVehicleInStandardCondition){
      var motion : Vector2i = null
      path = updatePathWithDstart(path, occurrence)

      if (!path.empty) {
        motion = followPathWithIDM(path, occurrence)
      }

      if (motion !== null && motion.lengthSquared > 0) {
        move(motion, true)
        this.previousOrientation = direction
      }

    }
  }
}
```

Several Perspectives for SARL

- Language:
  - Statements for Space and Space specification.
  - Statements for organizational concepts.
  - Design by contract with SARL.
  - Ontology support.
- Development Environment:
  - UI tools for creating (simulated) universes.
  - IntelliJ support.
- Run-time Environments:
  - Real-time implementation of Janus for embedded systems.
  - Addition of modules to Janus for agent-based simulation (drones, traffic, pedestrians)
  - Extension of GAMA for being a SARL Runtime Environment.
  - Extension of MATSIM for being a SARL Runtime Environment.

Thank you for your attention...

Appendix

Sources

The LaTeX code of this document is available at `https://bitbucket.org/sgalland/ia51-lessons`.

Generation

This document is generated the March 15, 2017 with the following tools:

- pdfLaTeX.
- Beamer.
- LE2I-UTBM style for beamer [2016/02/27] (`http://www.multiagent.fr/SlideStyle`).
- AutoLaTeX (`http://www.arakhne.org/autolatex`).

Professor

Université de Bourgogne Franche-Comté

Université de Technologie de Belfort-Montbéliard, France

Topics: Multiagent systems, Agent-based simulation, Agent-oriented software engineering, Mobility and traffic modeling

Web page: `http://www.multiagent.fr/People:Galland_stephane`
Email: stephane.galland@utbm.fr

Open-source contributions:

- `http://www.sarl.io`
- `http://www.janusproject.io`
- `http://www.aspecs.org`
- `http://www.arakhne.org`
- `https://github.com/gallandarakhneorg/`

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