Modeling and Analysis of Collective Adaptive Systems with CARMA and its Tools

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Outline

1. Introduction
   - Collective Adaptive Systems
   - Quantitative Analysis
2. Modelling CAS
3. CARMA
   - The CARMA Modelling Language
4. CARMA Operational semantics
5. CASL:CARMA Specification Language
6. CARMA Eclipse plug-in
7. CARMA and its tools in Action

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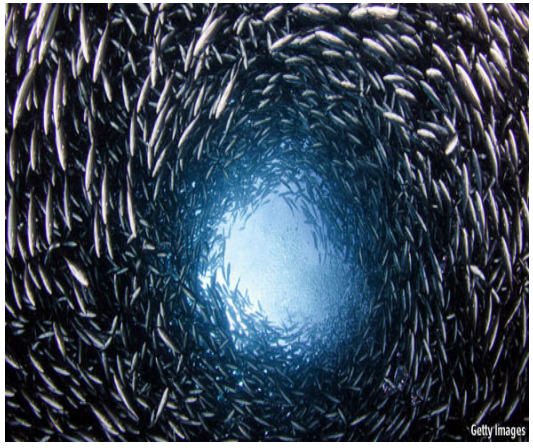

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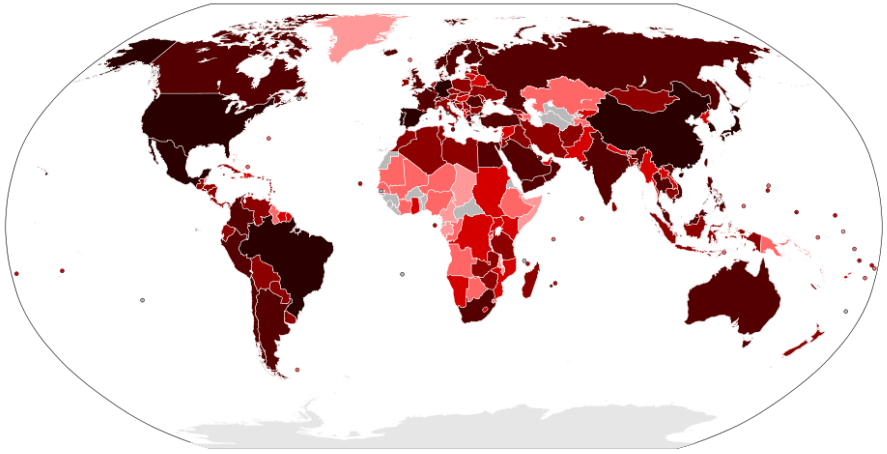

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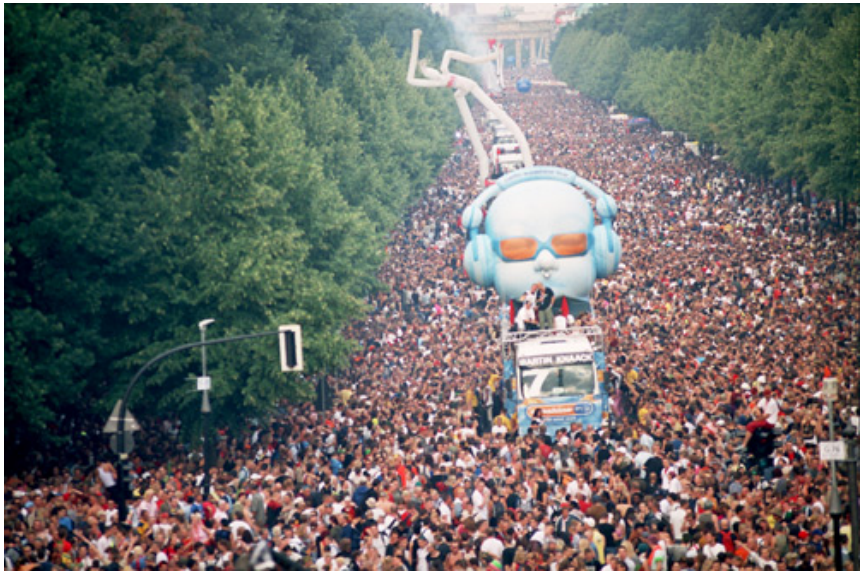

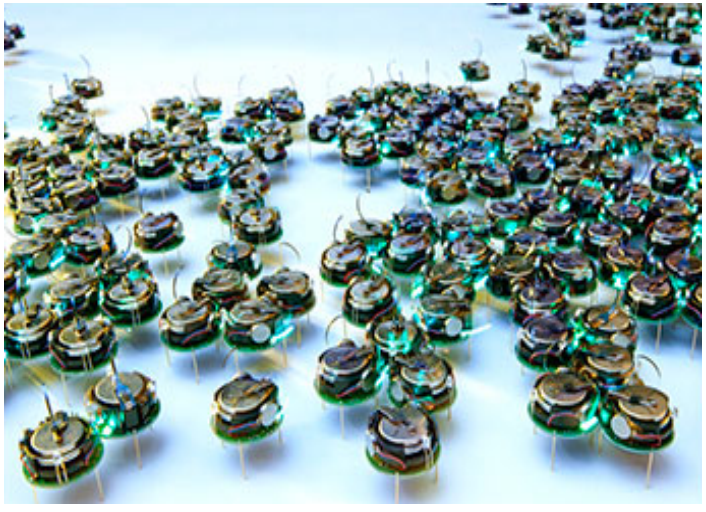

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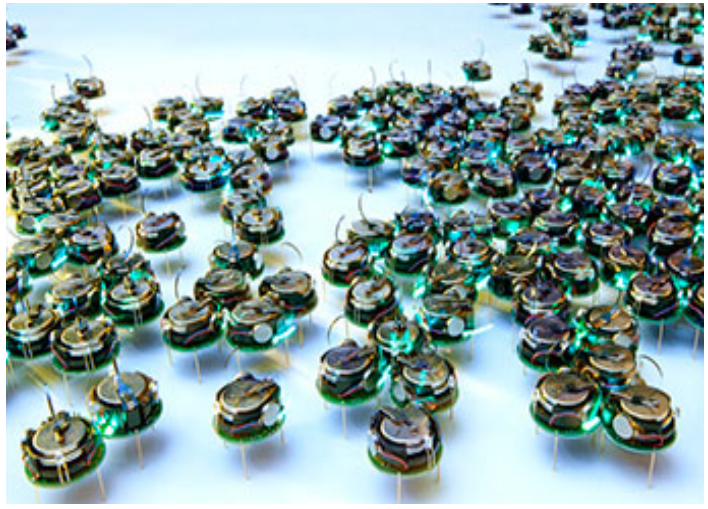
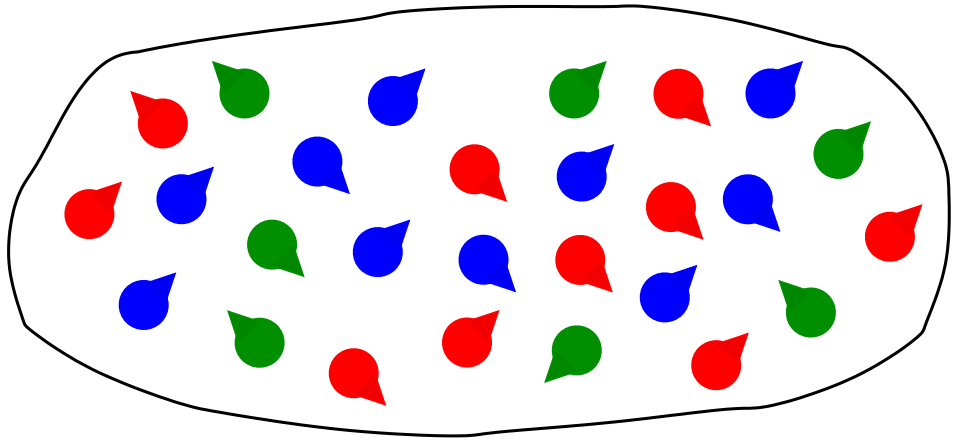


Most of these systems are also adaptive to their environment

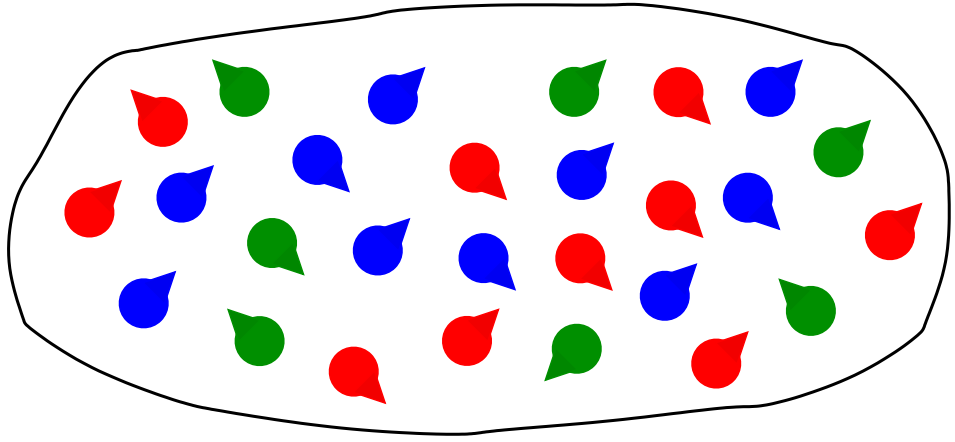
From a computer science perspective these systems can be viewed as being made up of a large number of interacting entities.



Each entity may have its own properties, objectives and actions.

At the system level these combine to create the collective behaviour.

The behaviour of the system is thus dependent on the behaviour of the individual entities.



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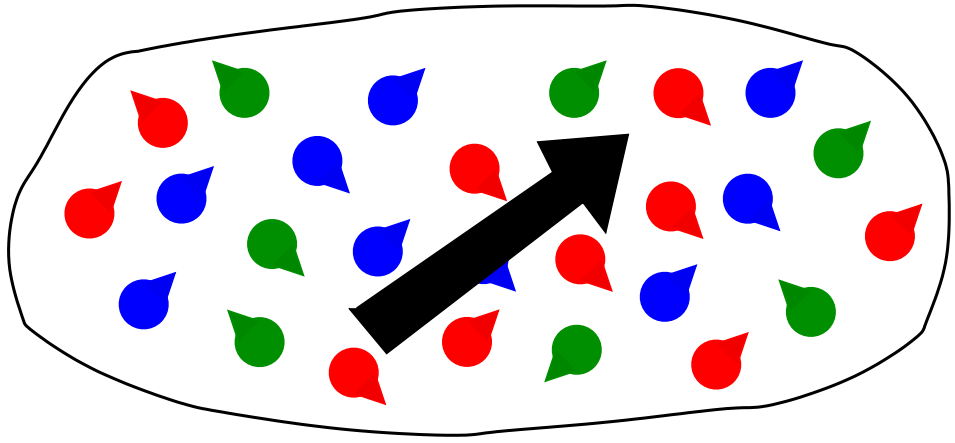

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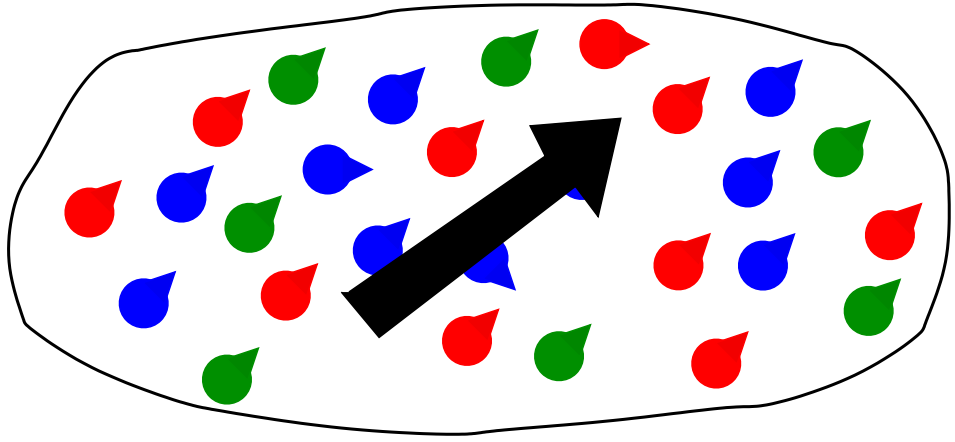
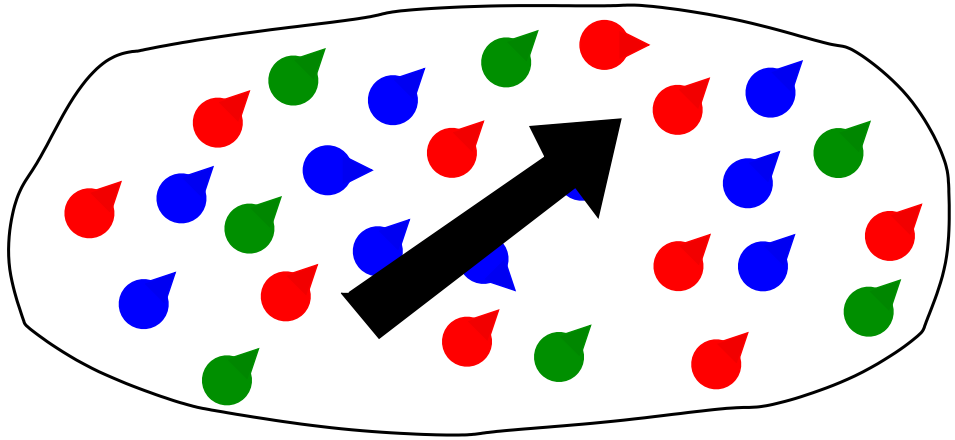


And the behaviour of the individuals will be influenced by the state of the overall system.

Such systems are often embedded in our environment and need to operate without centralised control or direction.



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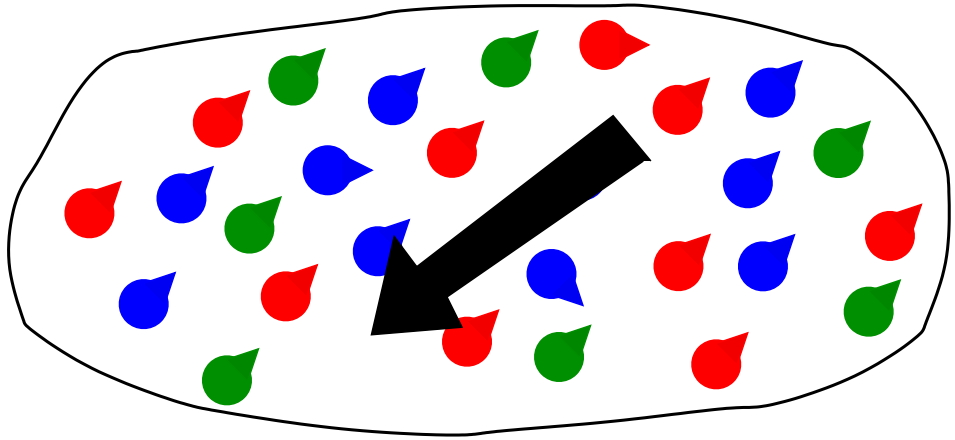

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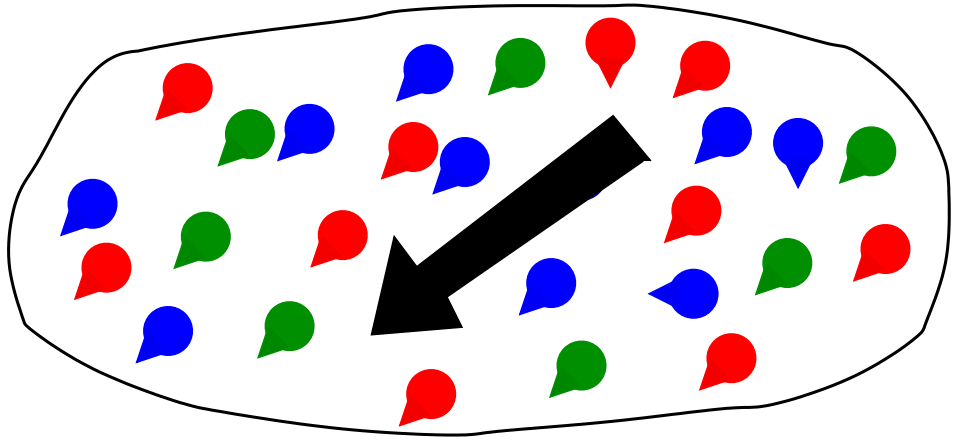

Moreover when conditions within the system change it may not be feasible to have human intervention to adjust behaviour appropriately.

Thus systems must be able to autonomously adapt.

The Informatic Environment

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Such systems are now becoming the reality, and many form collective adaptive systems, in which large numbers of computing elements collaborate to meet the human need.

For instance, may examples of such systems can be found in components of Smart Cities, such as smart urban transport and smart grid electricity generation and storage.

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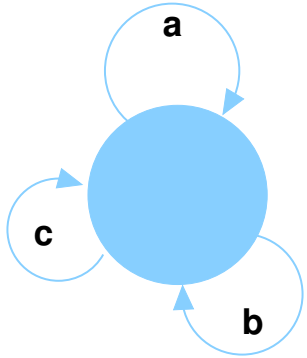

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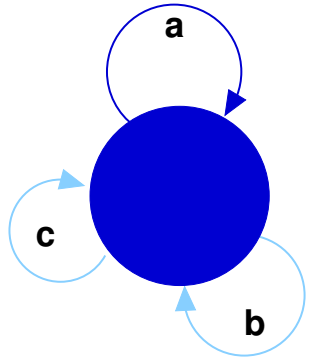

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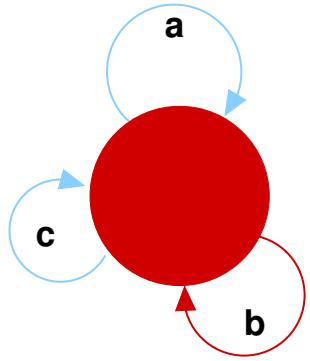

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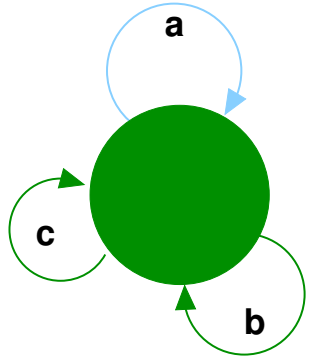

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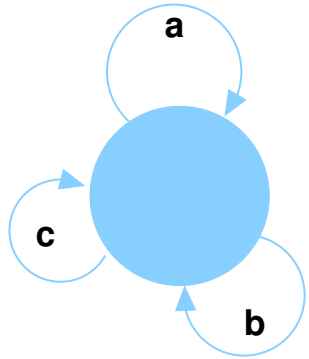
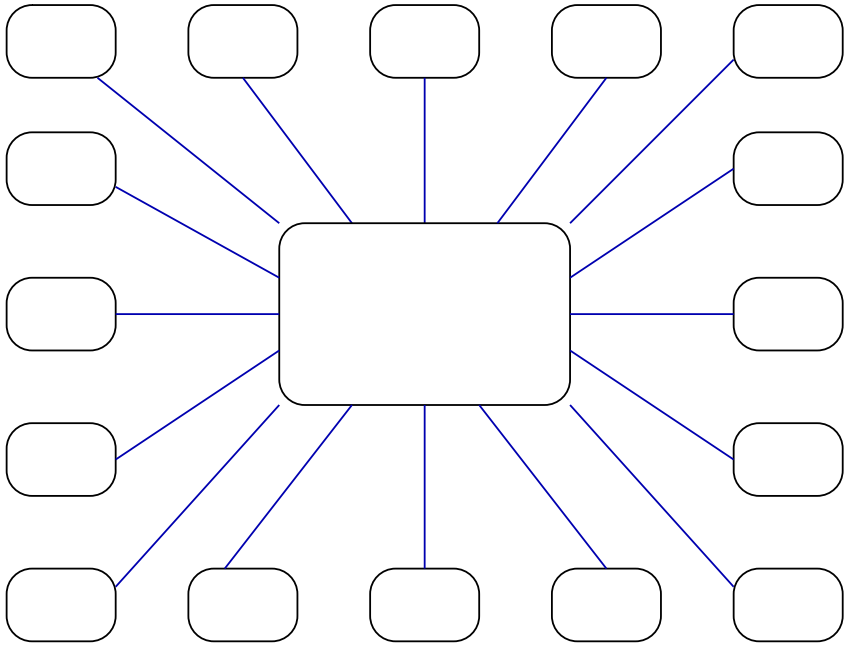


Various formalisms have been designed for capturing such behaviour.

Performance Modelling: Motivation



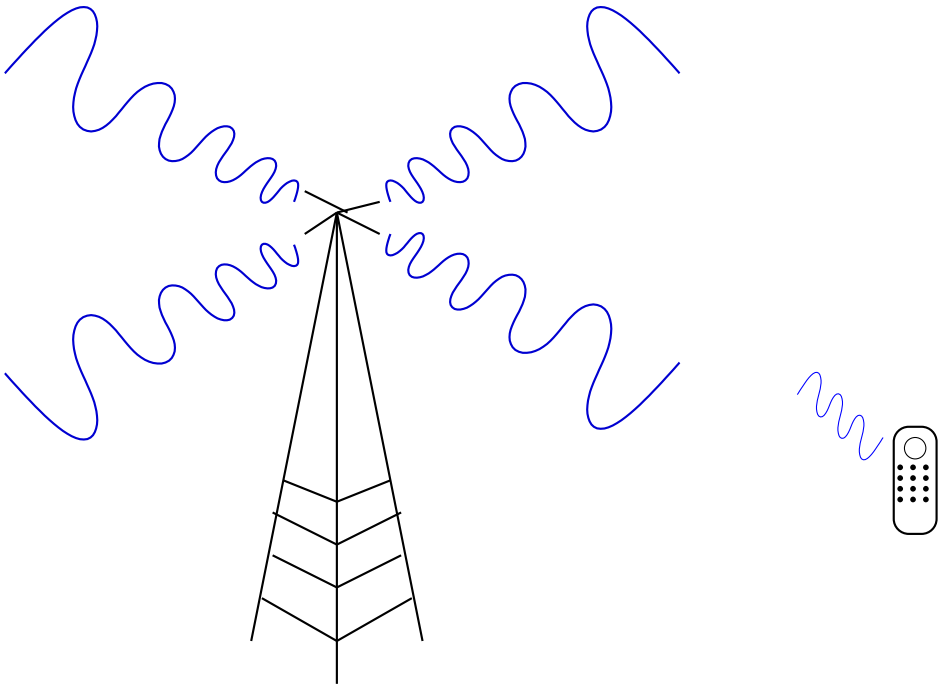
Capacity planning

- How many clients can the existing server support and maintain reasonable response times?

Performance Modelling: Motivation

Capacity planning

- How many buses do I need to maintain service at peak time in a smart urban transport system?



Mobile Telephone Antenna

System Configuration

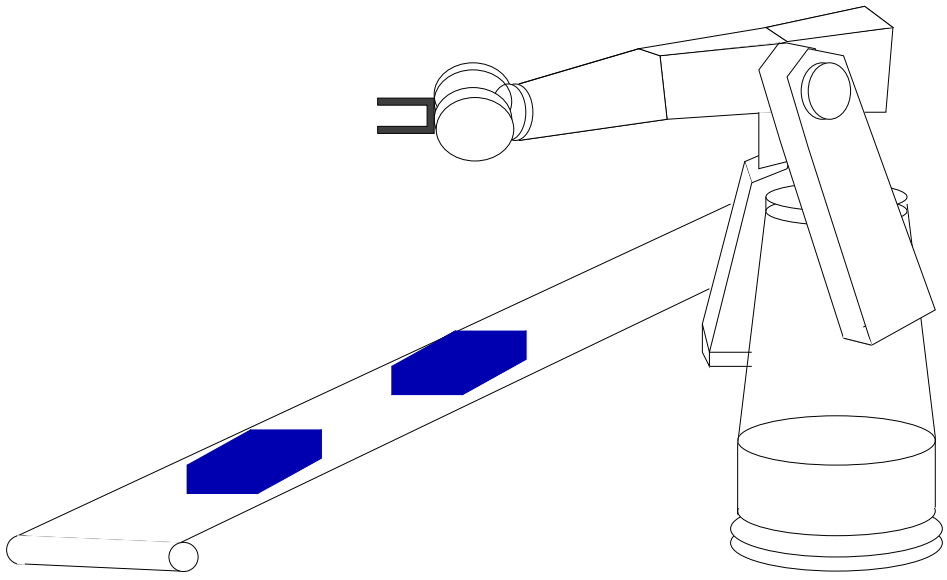
- How many frequencies do you need to keep blocking probabilities low?

Performance Modelling: Motivation

System Configuration

- What capacity do I need at bike stations to minimise the movement of bikes by truck?

Performance Modelling: Motivation



System Tuning

- What speed of conveyor belt will minimize robot idle time and maximize throughput whilst avoiding lost widgets?

Performance Modelling: Motivation

System Tuning

- What strategy can I use to maintain supply-demand balance within a smart electricity grid?

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Primary examples include:

- Stochastic Petri Nets and
- Stochastic Process Algebras.

Stochastic Process Algebra

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- The rate defines an exponential distribution which means that the duration of an activity is a random variable.
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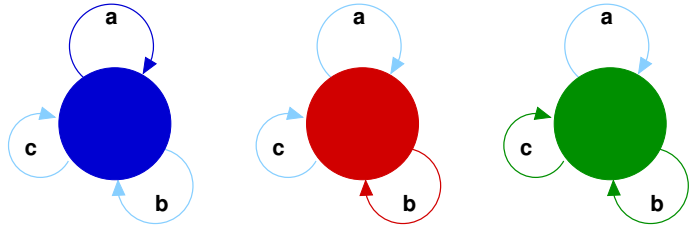
- The language is used to generate a CTMC for performance modelling (via the semantics).

Solving discrete state models



Using the semantics a SPA model is mapped to a CTMC with global states determined by the local states of all the participating components.

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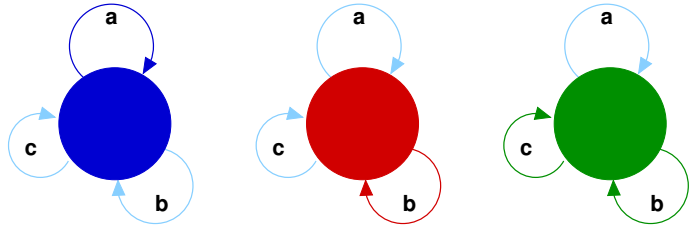

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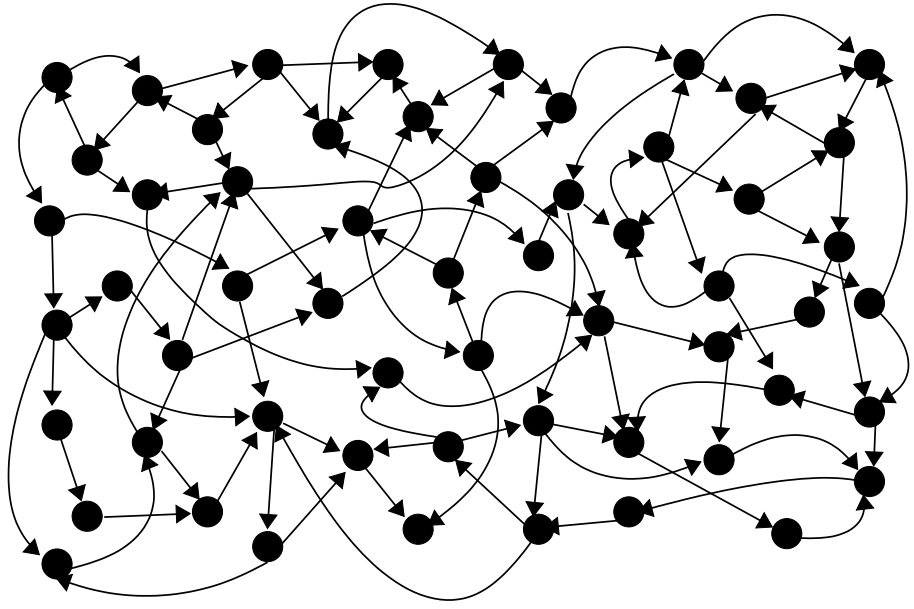

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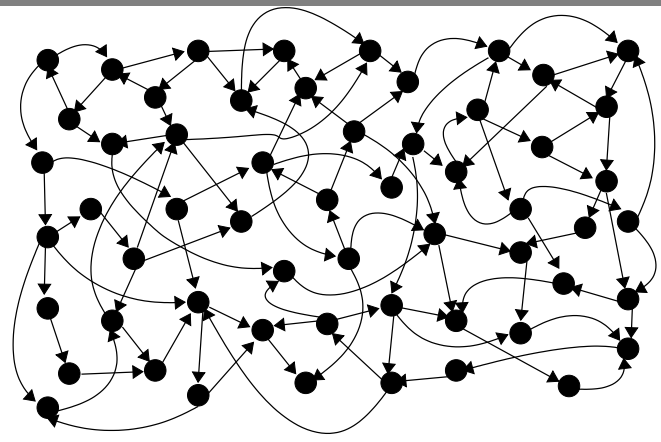

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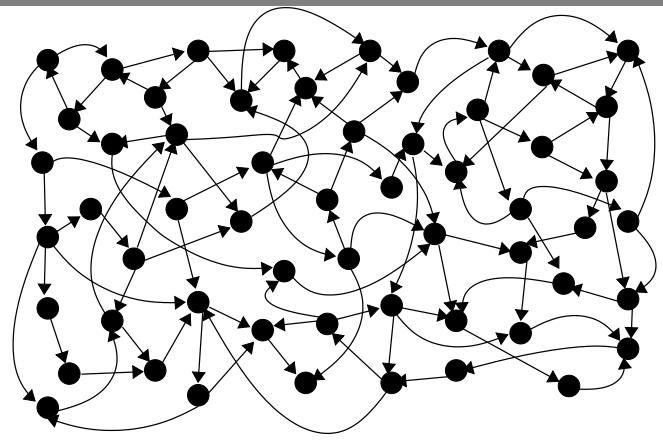

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$$Q = \begin{pmatrix} q_{1,1} & q_{1,2} & \cdots & q_{1,N} \\ q_{2,1} & q_{2,2} & \cdots & q_{2,N} \\ \vdots & \vdots & & \vdots \\ q_{N,1} & q_{N,2} & \cdots & q_{N,N} \end{pmatrix}$$

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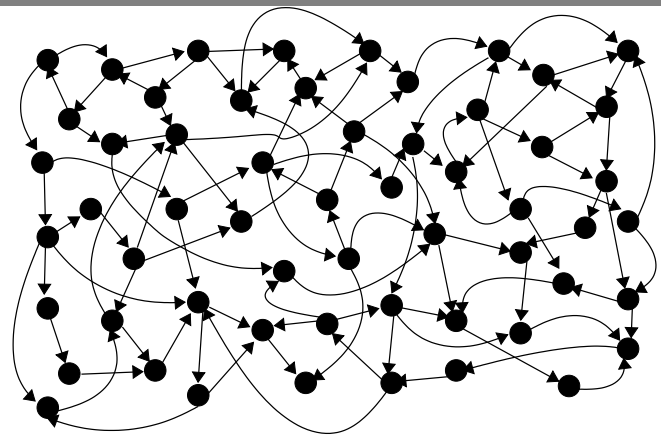

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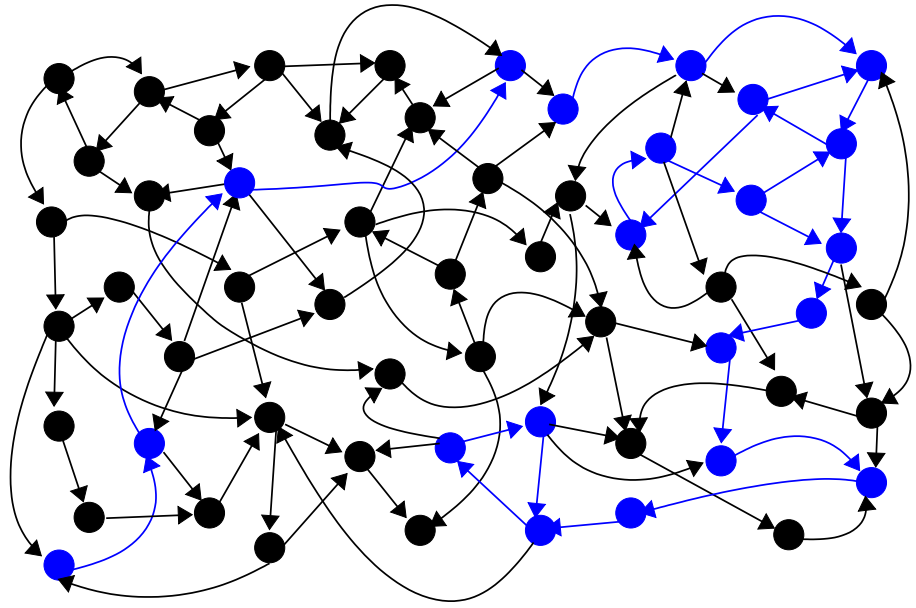
$$\pi(t) = (\pi_1(t), \pi_2(t), \ldots, \pi_N(t))$$

$$\pi(\infty)Q = 0$$

Solving discrete state models

Alternatively they may be studied using stochastic simulation. Each run generates a single trajectory through the state space. Many runs are needed in order to obtain average behaviours.



State space explosion

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As we have seen in a previous lecture, when the population sizes become large we can make a mean-field approximation, approximating the average trajectory of the CTMC by a set of ordinary differential equations.

M.Tribastone, S.Gilmore and J.Hillston. Scalable Differential Analysis of Process Algebra Models. IEEE TSE 2012.

The Fluid Approximation Alternative

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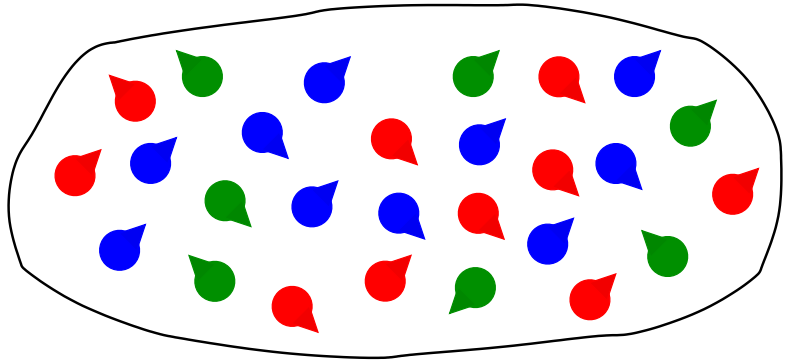

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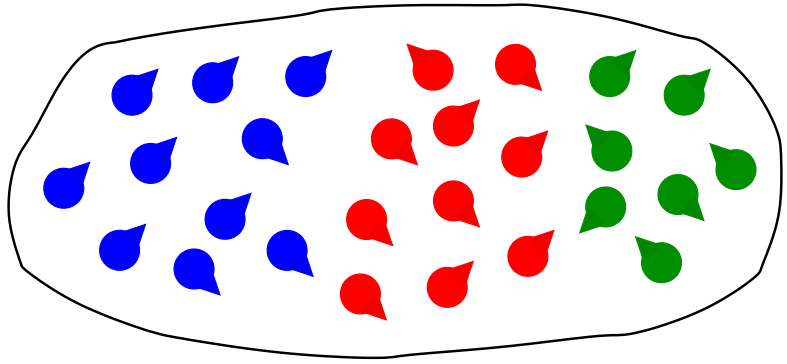

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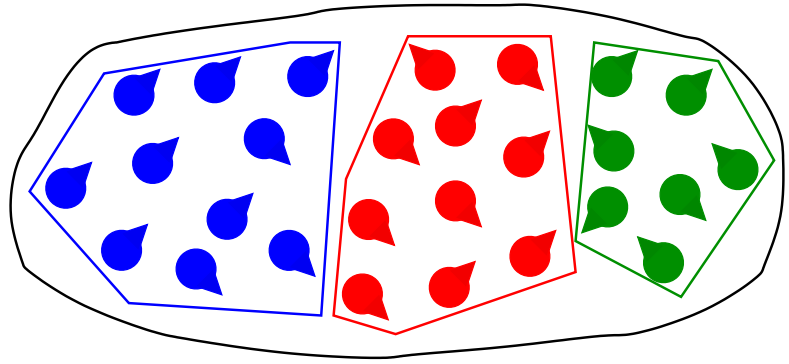

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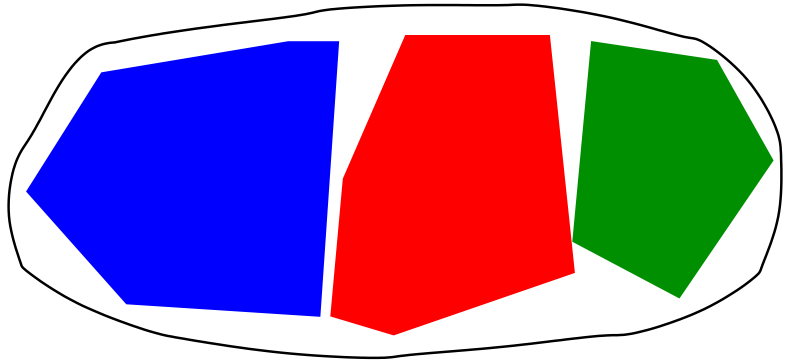

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Even better reductions can be achieved when we no longer regard the components as individuals.

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Challenges for modelling CAS

Work over the last twenty years on stochastic process algebra provides a solid basic framework for modelling CAS but there remain a number of challenges:

- Richer forms of interaction
- The influence of space on behaviour
- Capturing adaptivity

Richer forms of interaction

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Languages like SCEL offer these richer communication patterns, with components which include a knowledge store which can be manipulated by other components and attribute-based communication.

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But languages designed for other purposes typically contain too much detail to be used as the basis of quantitative modelling and analysis.

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There is a tension with scalable analysis which is often based on an implicit assumption that all components are co-located.

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But for truly adaptive systems there should also be some way to identify the goal or objective of an entity in addition to its behaviour.

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A new language for CAS

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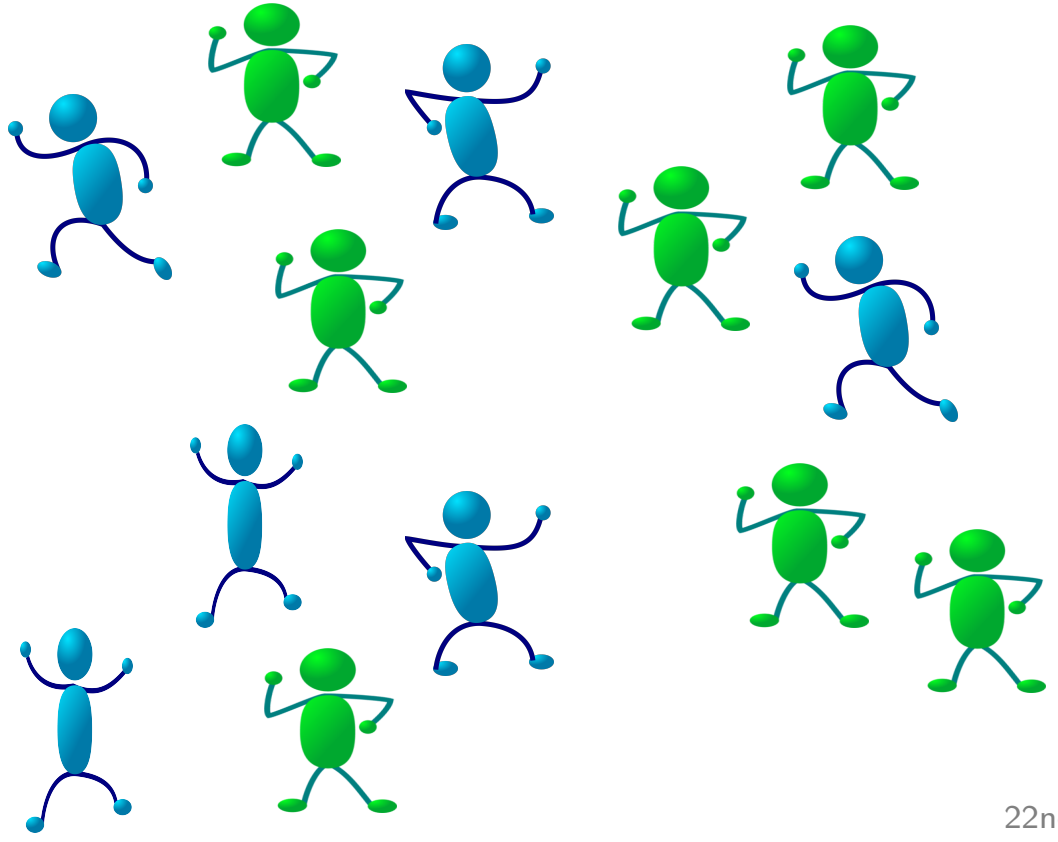

A new language for CAS

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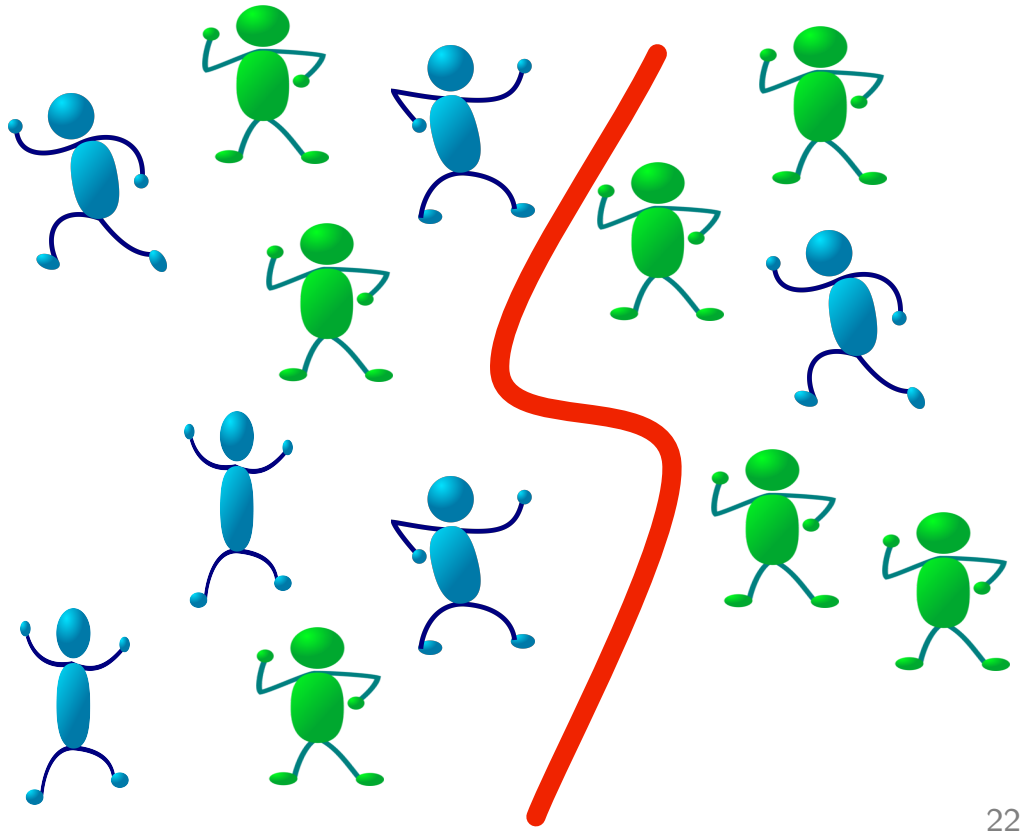

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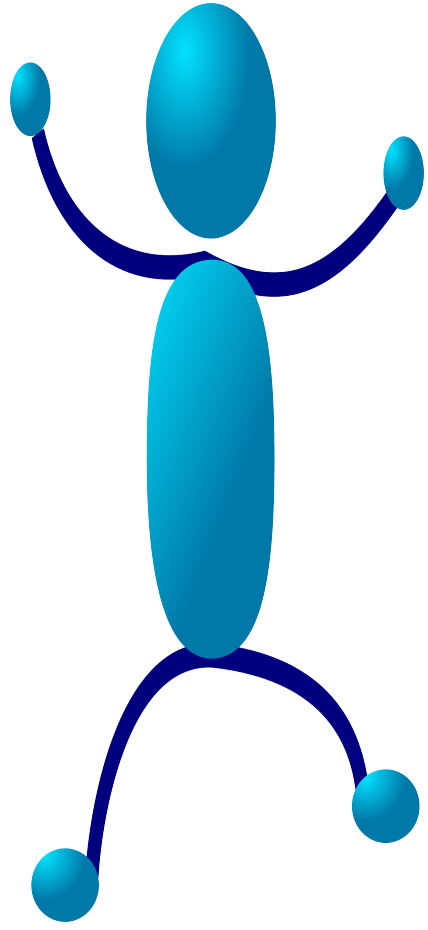
M.Loreti et al. CARMA: Collective Adaptive Resource-sharing Markovian Agents. QAPL 2015.

Agents in CARMA



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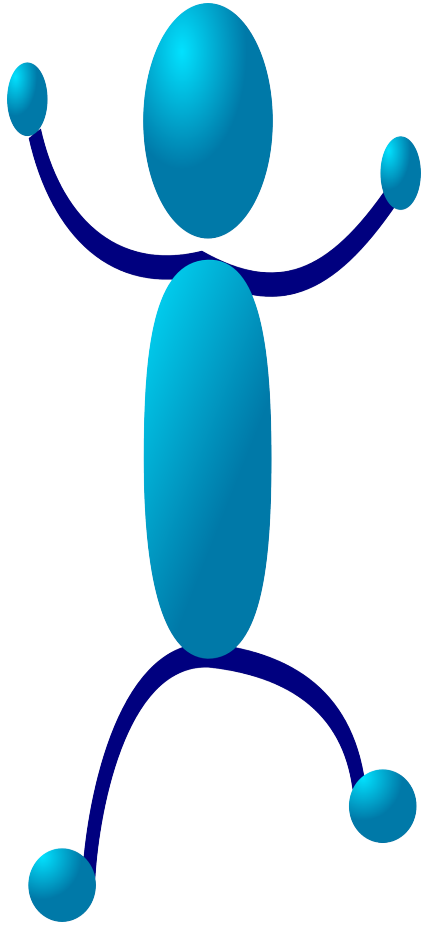

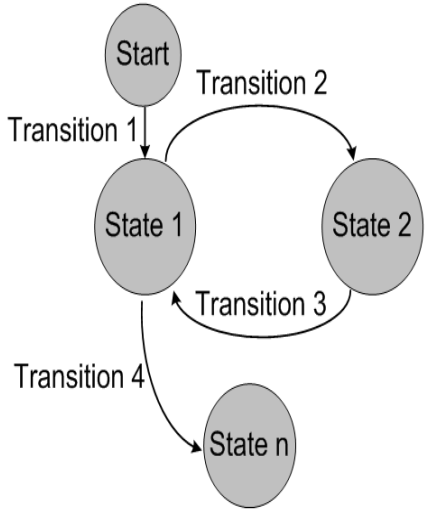

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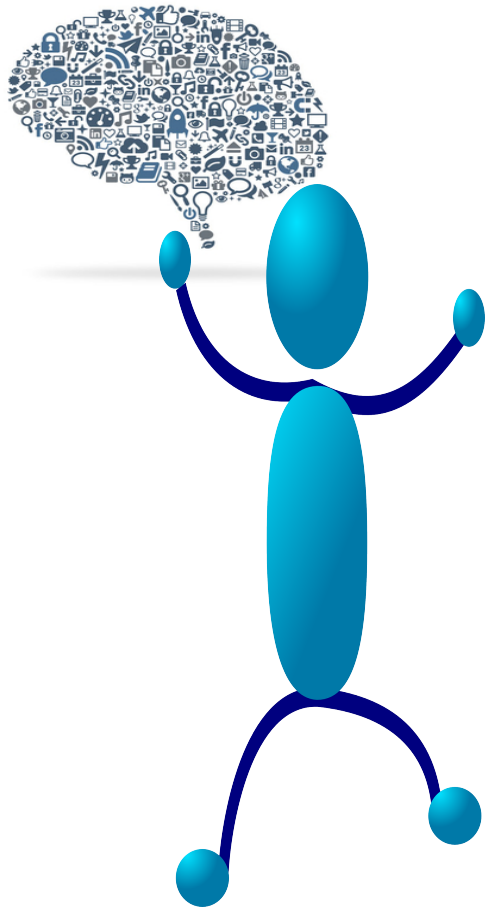

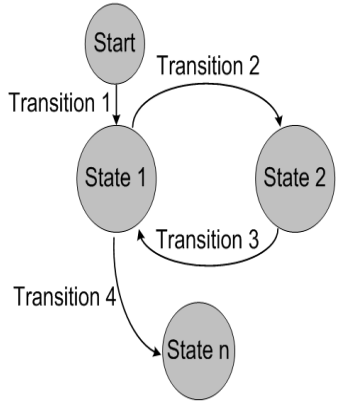

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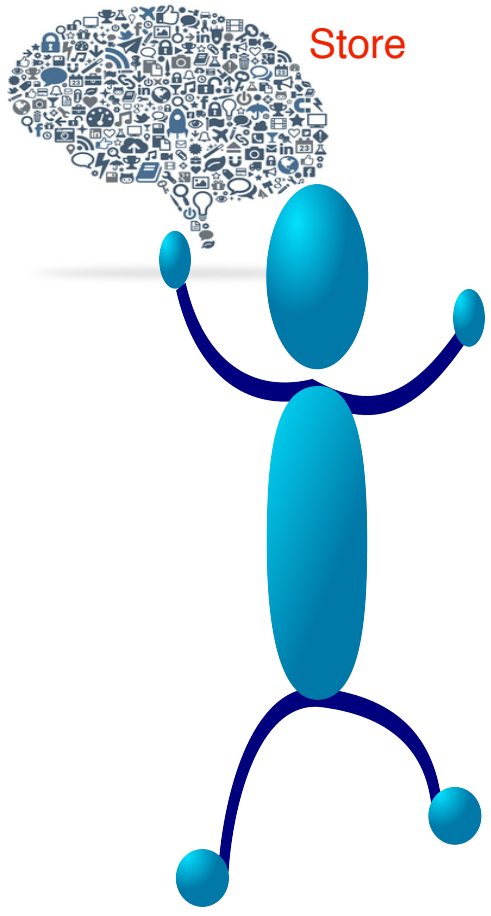
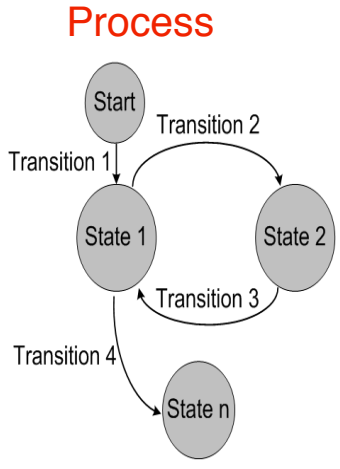
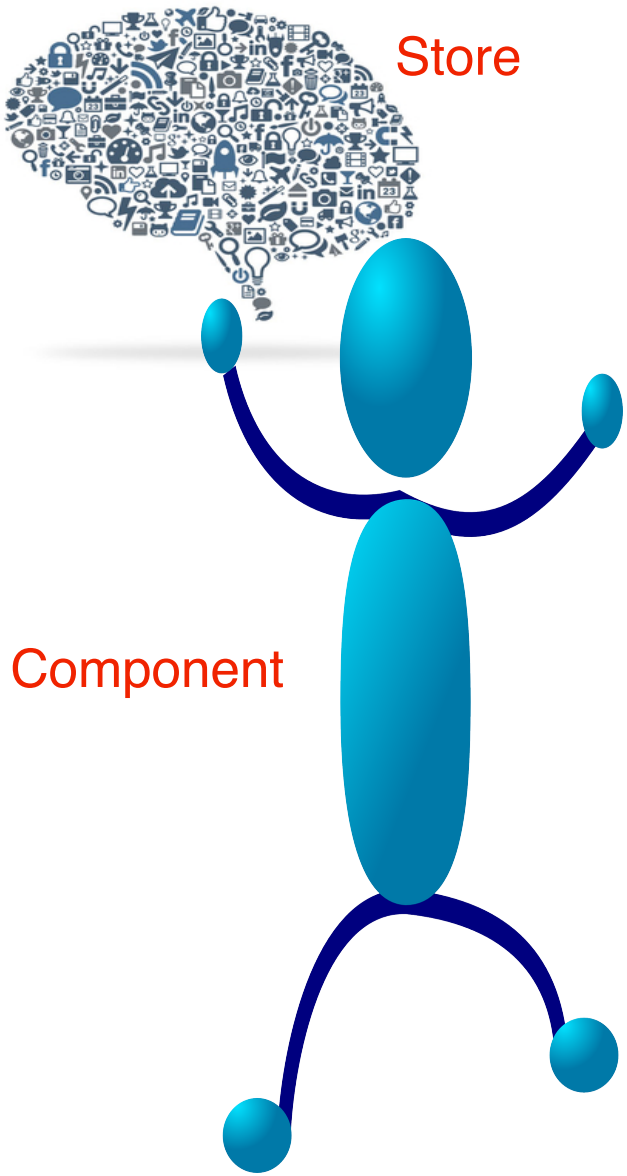




Components



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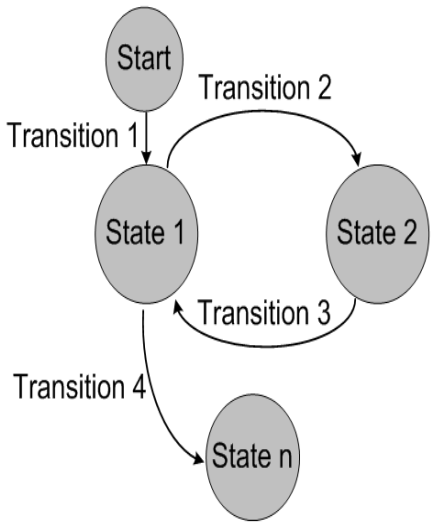

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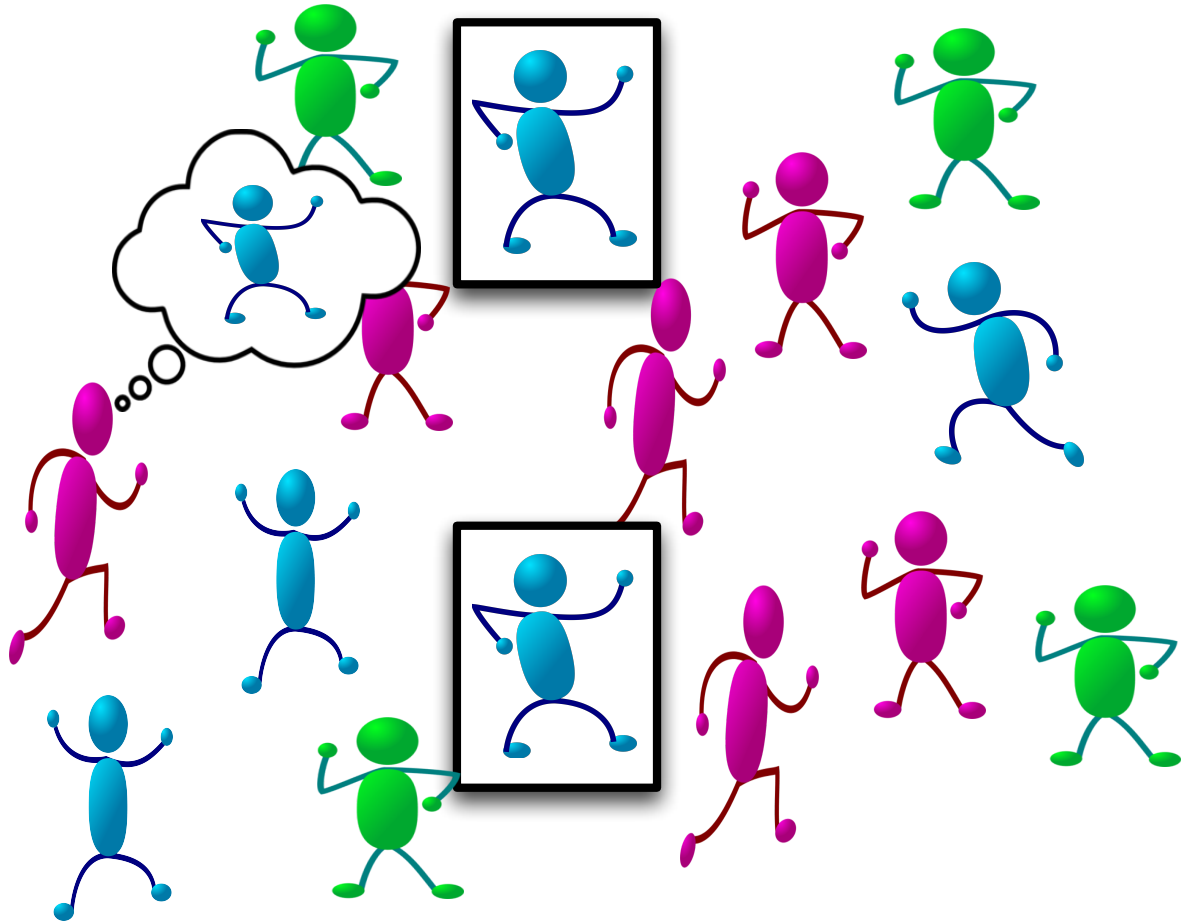

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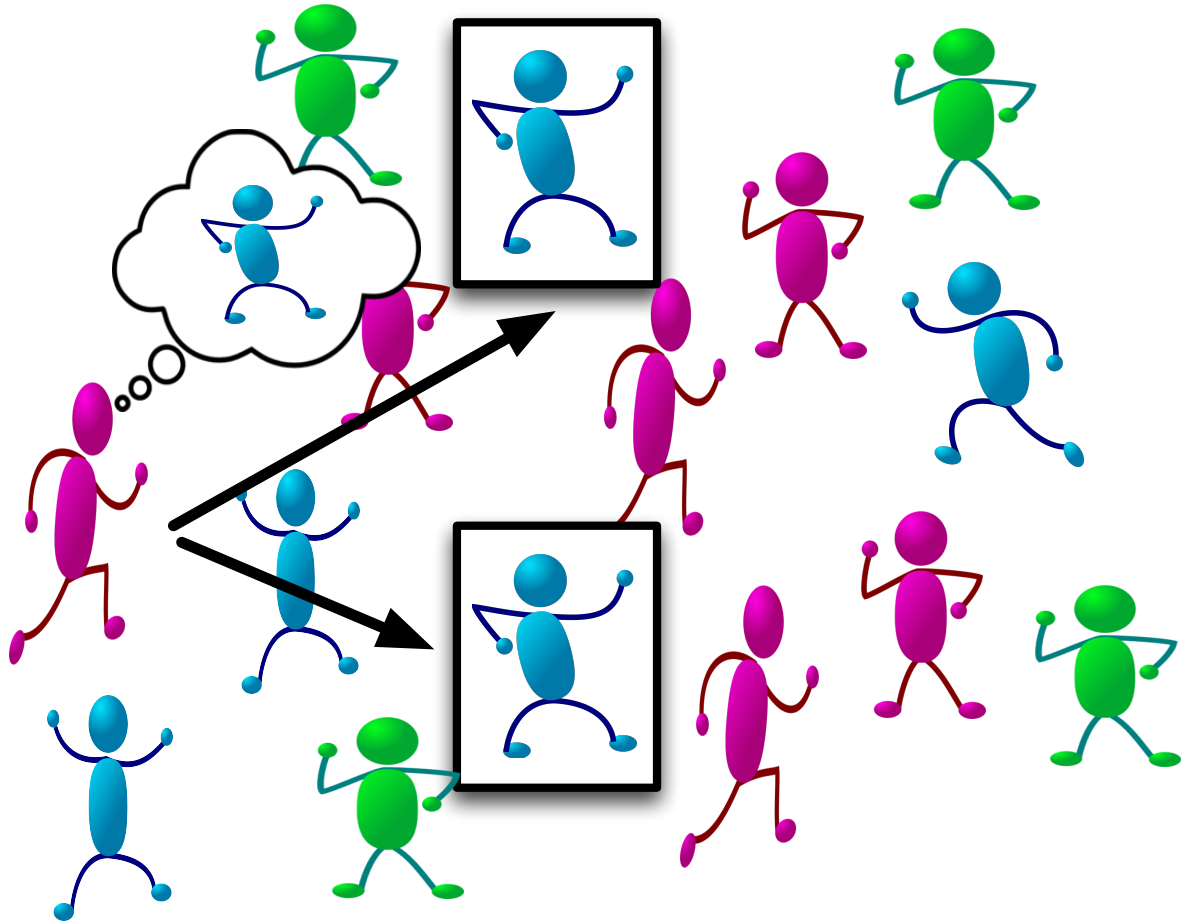

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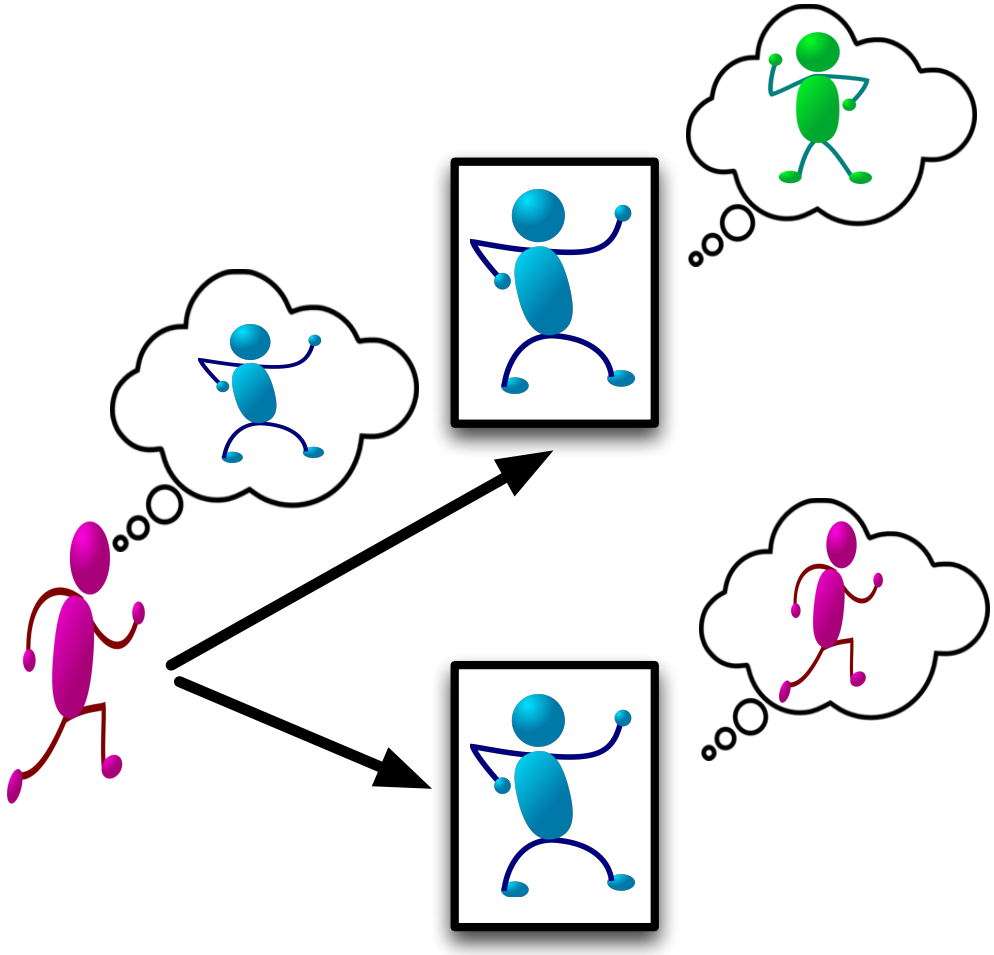

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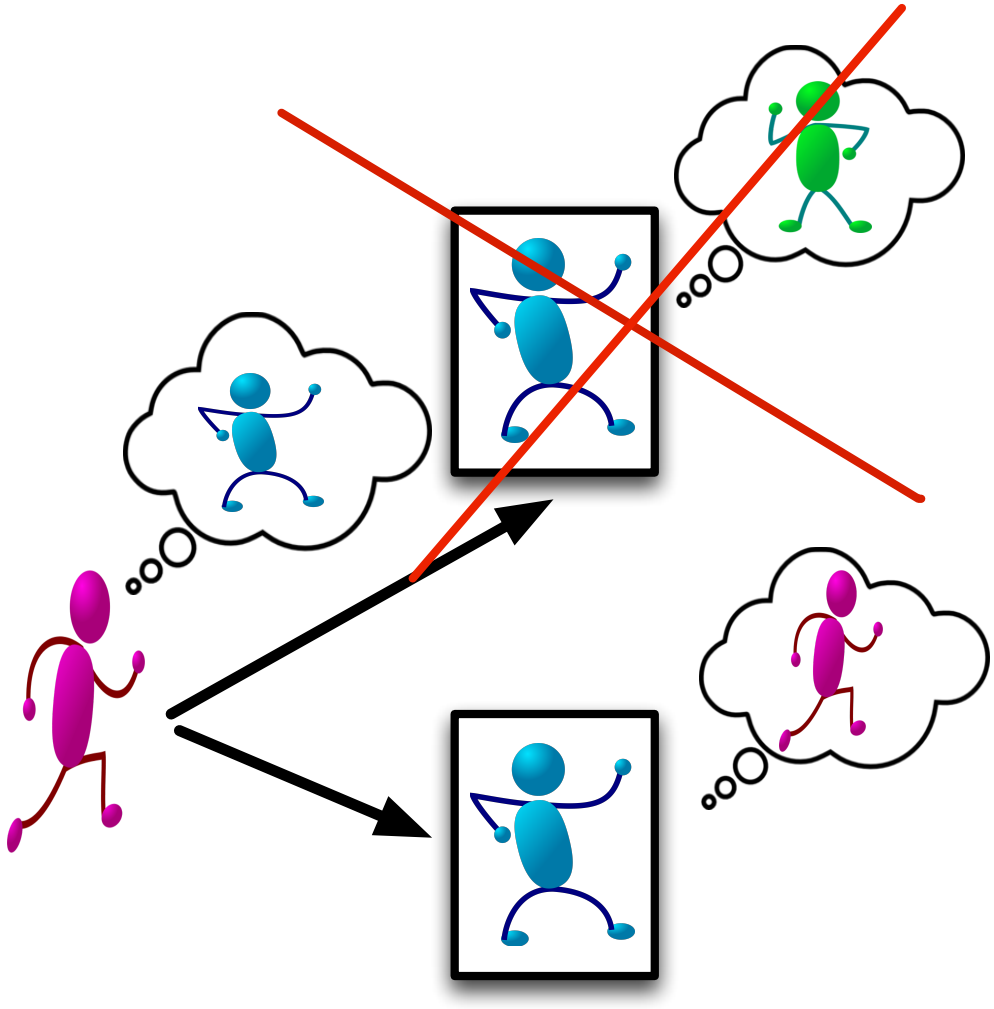

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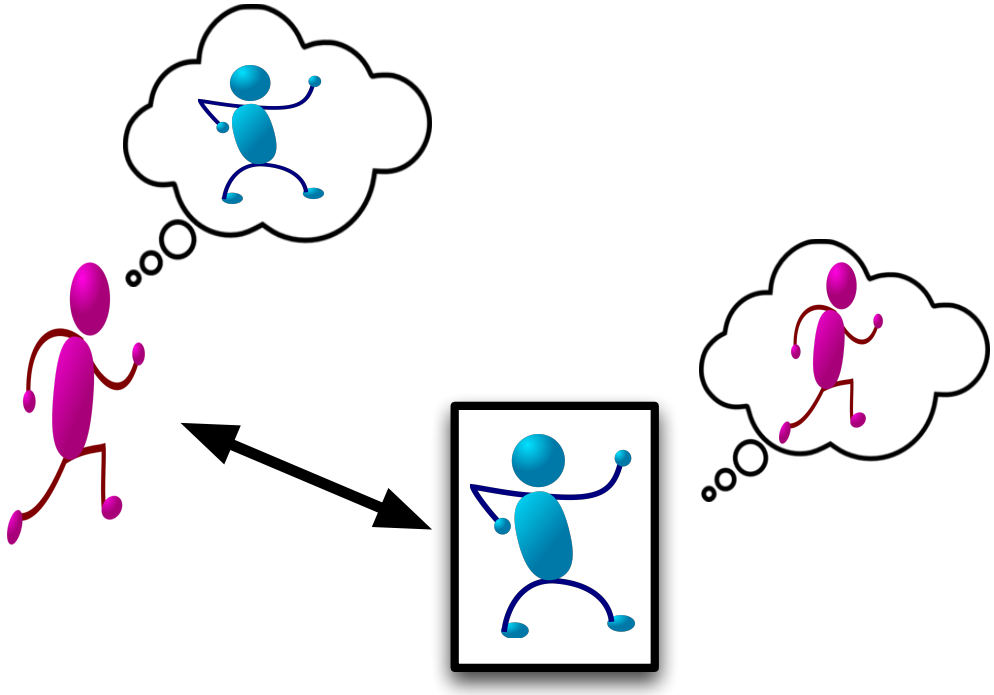

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The execution of an action takes an exponentially distributed time; the rate of each action is determined by the environment.

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\begin{array}{rcll}
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- π is a predicate;
- σ is the effect of the action on the store.

Simple example

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&+ \mathit{coffee}^{\star}[\mathit{true}]\langle \cdot \rangle \{\mathit{boring} := \mathit{false}\} \ldots
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Short (5 minute) Break!

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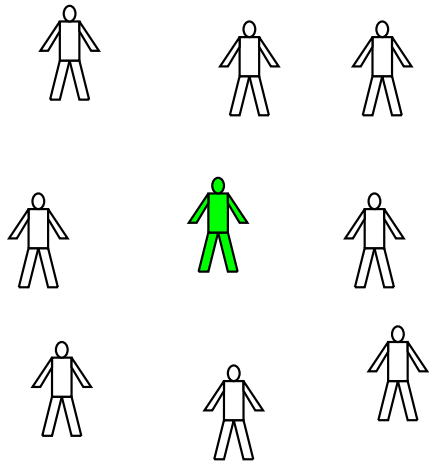

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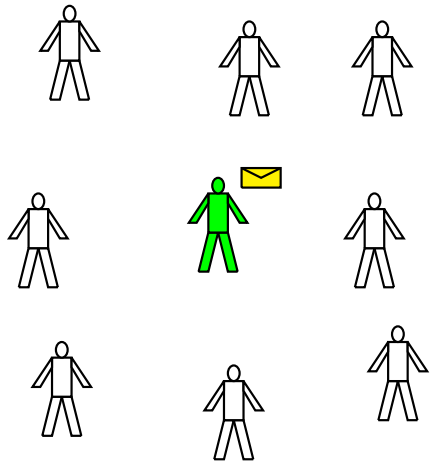

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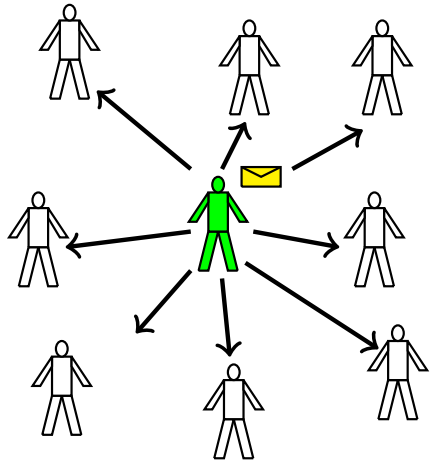

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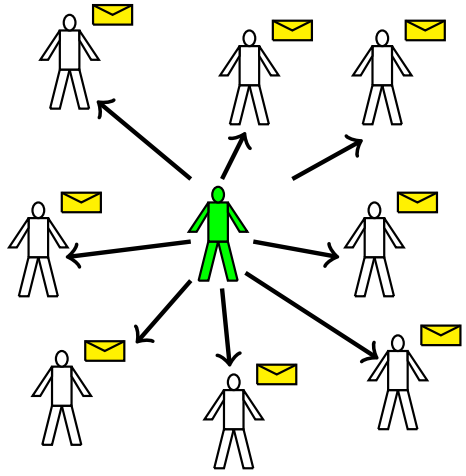

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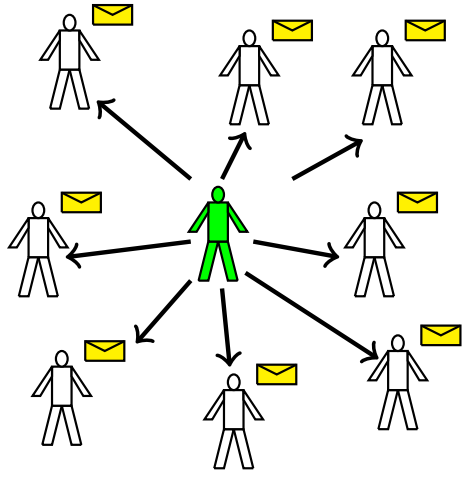

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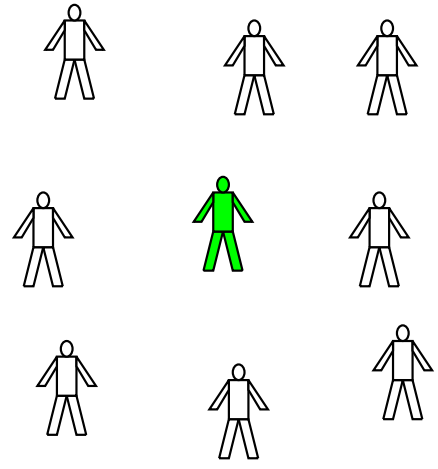

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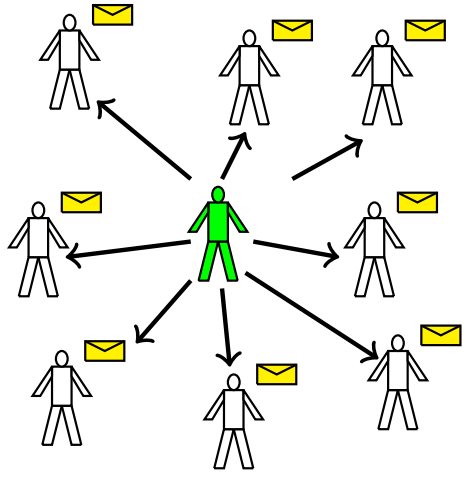

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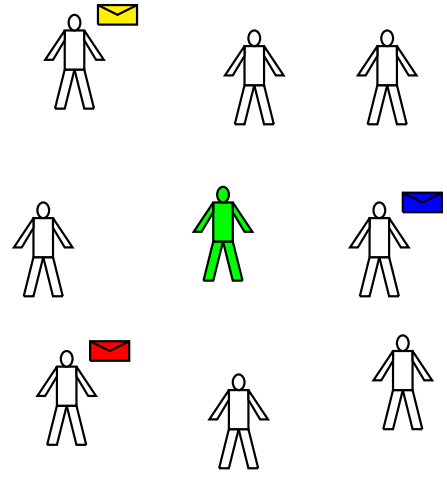

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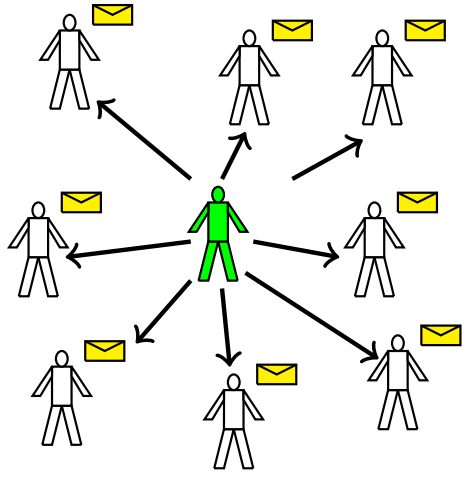

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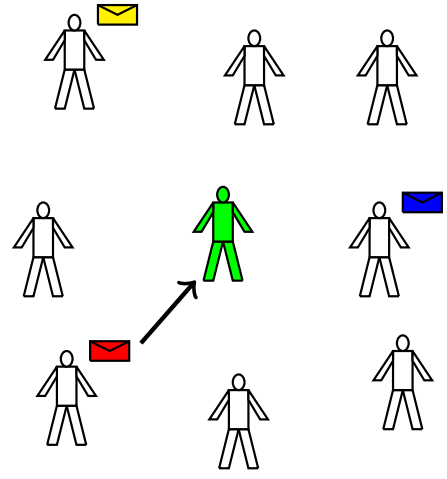

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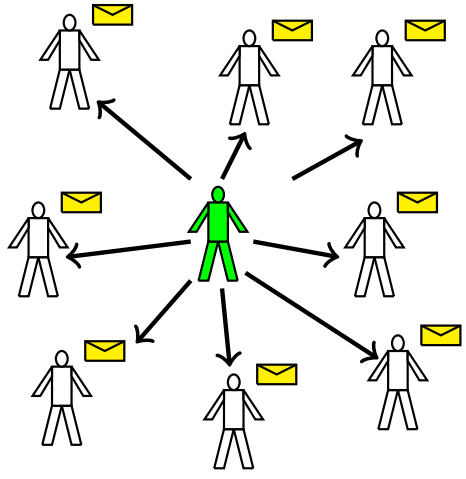

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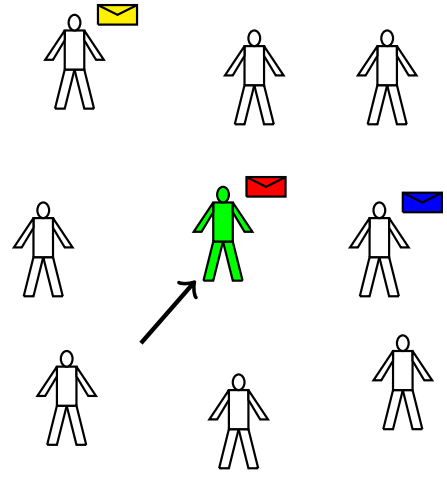

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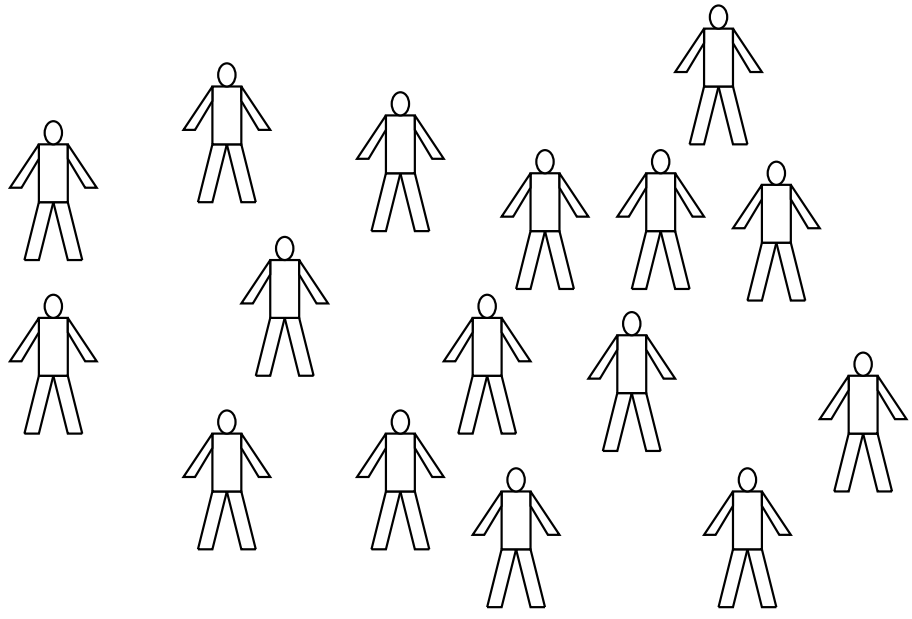
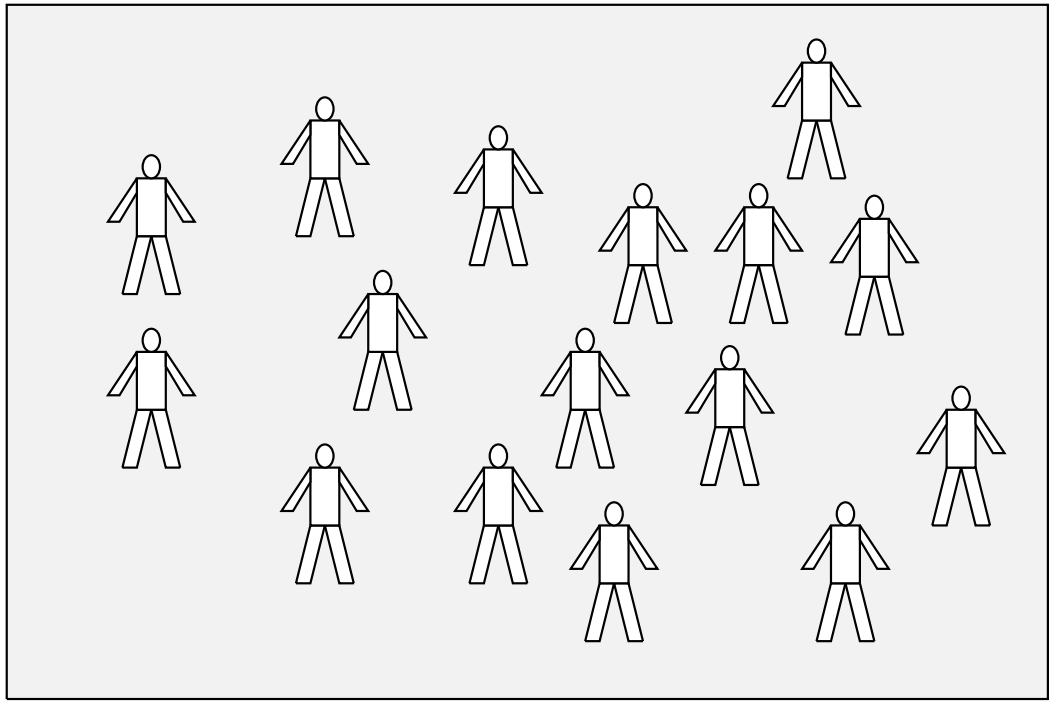
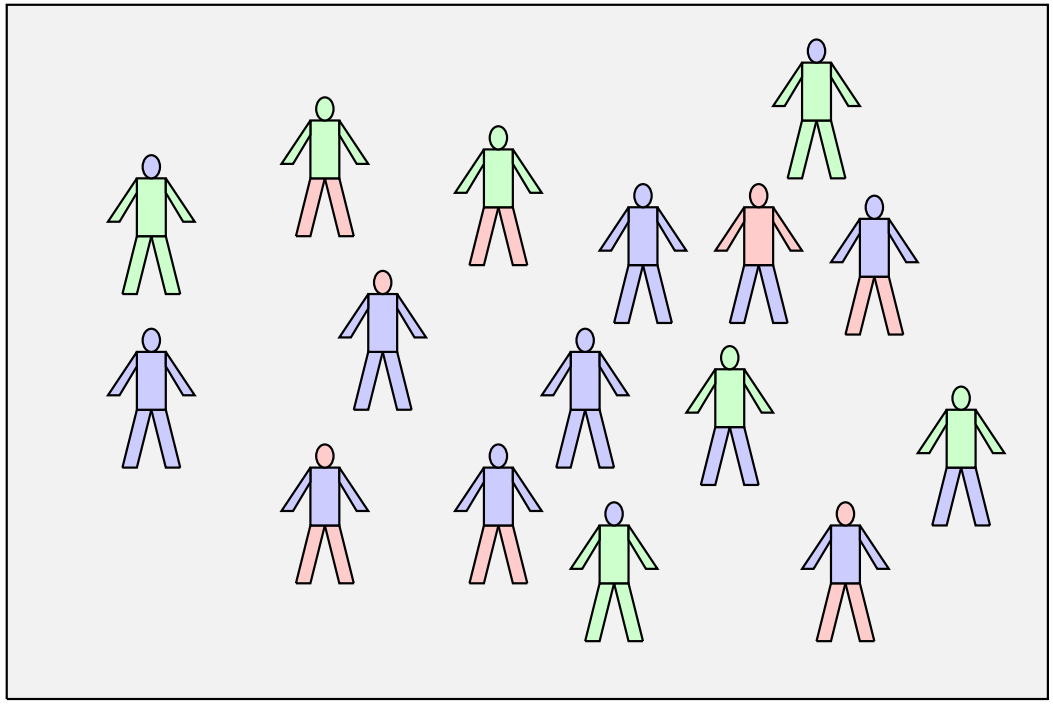


Collective **Environment**



CAS: CARMA perspective

Collective **Environment** **Attributes**



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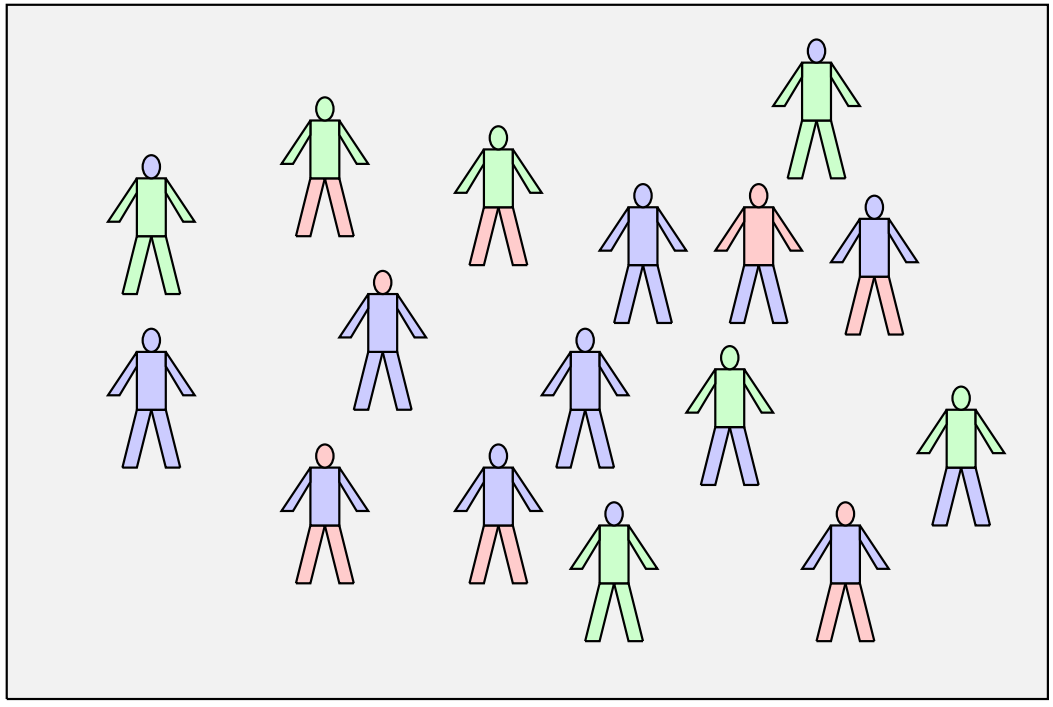

Processes are referenced via their attributes!

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Environment...

- models the rules intrinsic to the context where agents operate;
- mediates and regulates agent interactions.

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- α is an action type;
- π is a predicate;
- σ is the effect of the action on the store.

Updating the store

After the execution of an action, a process can update the component store:

- σ denotes a function mapping each γ to a probability distribution over possible stores.

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Remark:

- Processes running in the same component can implicitly interact via the local store;
- Updates are instantaneous.

More on synchronisation

Predicates regulating broadcast/unicast inputs can refer also to the received values.

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Example:

A value greater than 0 is expected from a component with a *trust_level* less than 3:

$$\alpha^{\star}[(x > 0) \wedge (\mathit{trust\_level} < 3)](x)\sigma.P$$

Examples of interactions...

Broadcast synchronisation:

$$
\begin{aligned}
&(\ \mathsf{stop}^{\star}[\mathsf{bl} < 5\%]\langle v\rangle\sigma_1.P\ ,\{\mathit{role} = \text{“}\mathit{master}\text{”}\}) \parallel \\
&\quad (\ \mathsf{stop}^{\star}[\mathsf{role} = \text{“}\mathit{master}\text{”}](x)\sigma_2\ .Q_1\ ,\{\mathsf{bl} = 4\%\}) \parallel \\
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$$\Downarrow$$

$$
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\quad\quad (\mathsf{stop}^{\star}[\mathsf{role} = \text{“}\mathit{super}\text{”}](x)\sigma_3.Q_2, \{\mathsf{bl} = 2\%\}) \parallel \\
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Interactions between components can be affected by the environment:

- a wall can inhibit wireless interactions;
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- consists of a pair (γ, ρ):
  - a global store γ, that models the overall state of the system;
  - an evolution rule ρ that regulates component interactions (receiving probabilities, action rates,...).

The evolution rule

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The environment manages these aspects of system behaviour, and others in the evolution rule.

The evolution rule γ

ρ is a function, dependent on current time, the global store and the current state of the collective, returns a tuple of functions $\varepsilon = \langle \mu_p, \mu_w, \mu_r, \mu_u \rangle$ known as the evaluation context

- $\mu_p(\gamma_s, \gamma_r, \alpha)$: the probability that a component with store γ_r can receive a broadcast message α from a component with store γ_s;
- $\mu_w(\gamma_s, \gamma_r, \alpha)$: the weight to be used to compute the probability that a component with store γ_r can receive a unicast message α from a component with store γ_s;
- $\mu_r(\gamma_s, \alpha)$ computes the execution rate of action α executed at a component with store γ_s;
- $\mu_u(\gamma_s, \alpha)$ determines the updates on the environment (global store and collective) induced by the execution of action α at a component with store γ_s.

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Note that, due to nondeterminism, starting from the same process, different evolutions can be inferred.

$$\frac{P \xrightarrow{\alpha} P'}{P + Q \xrightarrow{\alpha} P'}\ \textbf{Choice1} \qquad \frac{Q \xrightarrow{\alpha} Q'}{P + Q \xrightarrow{\alpha} Q'}\ \textbf{Choice2}$$

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Standard compositional approaches are cumbersome and may fail when rich SPA are considered (e.g., when the multiplicity of transitions is important).

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In FuTS the behaviour of a term is described using a function that, given a term and a transition label, yields a function associating each component, collective, or system with a non-negative number.

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- the rate of the exponential distribution characterising the time needed for the execution of an action;
- the probability of receiving a given broadcast message;
- the weight used to compute the probability that a given component is selected for the synchronisation.

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1. the function $\mathbb{C}$ that describes the behaviour of a single component;
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In all cases the value zero is associated with unreachable terms.

Component Semantics

The behaviour of a single component is defined by a function

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where $\textsc{Lab}$ denotes the set of transition labels ℓ:

$$\begin{array}{rcll} \ell & ::= & \alpha^\star[\pi_s]\langle\overrightarrow{v}\rangle, \gamma & \text{Broadcast Output} \\ & | & \alpha^\star[\pi_s](\overrightarrow{v}), \gamma & \text{Broadcast Input} \\ & | & \alpha[\pi_s]\langle\overrightarrow{v}\rangle, \gamma & \text{Unicast Output} \\ & | & \alpha[\pi_s](\overrightarrow{v}), \gamma & \text{Unicast Input} \end{array}$$

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If $\mathbb{C}[C, \ell] = \mathscr{C}$ and $\mathscr{C}(C') = p$ then C evolves to C' with a weight p when ℓ is executed.

$$\frac{}{\mathbb{C}[(\mathbf{nil},\gamma),\ell] = \emptyset}\ \textbf{Nil} \qquad \frac{}{\mathbb{C}[\mathbf{0},\ell] = \emptyset}\ \textbf{Zero}$$

$$\frac{[\![\pi_s]\!]_\gamma = \pi_s' \quad [\![\overrightarrow{e}]\!]_\gamma = \overrightarrow{v} \quad \mathbf{p} = \sigma(\gamma)}{\mathbb{C}[(\alpha^\star[\pi_s]\langle\overrightarrow{e}\rangle\sigma.P,\gamma),\alpha^\star[\pi_s']\langle\overrightarrow{v}\rangle,\gamma] = (P,\mathbf{p})}\ \textbf{B-Out}$$

$$\frac{\gamma_r \models \pi_s \quad \gamma_s \models \pi_r[\overrightarrow{v}/\overrightarrow{x}] \quad \mathbf{p} = \sigma[\overrightarrow{v}/\overrightarrow{x}](\gamma_2)}{\mathbb{C}[(\alpha^\star[\pi_r](\overrightarrow{x})\sigma.P,\gamma_r),\alpha^\star[\pi_s](\overrightarrow{v}),\gamma_s] = (P[\overrightarrow{v}/\overrightarrow{x}],\mathbf{p})}\ \textbf{B-In}$$

$$\frac{\mathbb{C}[(P,\gamma),\ell] = \mathscr{C}_1 \quad \mathbb{C}[(Q,\gamma),\ell] = \mathscr{C}_2}{\mathbb{C}[(P+Q,\gamma),\ell] = \mathscr{C}_1 \oplus \mathscr{C}_2}\ \textbf{Plus}$$

$$\frac{\mathbb{C}[(P,\gamma),\ell] = \mathscr{C}_1 \quad \mathbb{C}[(Q,\gamma),\ell] = \mathscr{C}_2}{\mathbb{C}[(P|Q,\gamma),\ell] = \mathscr{C}_1|Q \oplus P|\mathscr{C}_2}\ \textbf{Par}$$

Semantics of Collectives

The operational semantics of a collective is defined via the function

$$\mathbb{N}_{\varepsilon} : \textsc{Col} \times \textsc{Lab}_{I} \to [\textsc{Col} \to \mathbb{R}_{\geq 0}]$$

defining how a collective reacts when a broadcast/unicast message is received.

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defining how a collective reacts when a broadcast/unicast message is received.

$\textsc{Lab}_{I}$ denotes the subset of $\textsc{Lab}$ with only input labels:

$$\begin{array}{rcll} \ell & ::= & \alpha^{\star}[\pi_s](\overrightarrow{v}), \gamma & \text{Broadcast Input} \\ & | & \alpha[\pi_s](\overrightarrow{v}), \gamma & \text{Unicast Input} \end{array}$$

$$\frac{}{\mathbb{N}_{\varepsilon}[\mathbf{0},\ell] = \emptyset}\ \textbf{Zero}$$

$$\frac{\mathbb{C}[(P,\gamma),\alpha^{\star}[\pi_s](\overrightarrow{v}),\gamma] = \mathscr{N} \quad \mathscr{N} \neq \emptyset \quad \varepsilon = \langle \mu_p, \mu_w, \mu_r, \mu_u \rangle}{\mathbb{N}_{\varepsilon}[(P,\gamma),\alpha^{\star}[\pi_s](\overrightarrow{v}),\gamma] = \frac{\mu_p(\gamma,\alpha^{\star})}{\oplus\mathscr{N}} \cdot \mathscr{N} + [(P,\gamma) \mapsto (1-\mu_p(\gamma,\alpha^{\star})]}\ \textbf{Comp-B-In}$$

$$\frac{\mathbb{N}_{\varepsilon}[N_1,\alpha^{\star}[\pi_s](\overrightarrow{v}),\gamma] = \mathscr{N}_1 \quad \mathbb{N}_{\varepsilon}[N_2,\alpha^{\star}[\pi_s](\overrightarrow{v}),\gamma] = \mathscr{N}_2}{\mathbb{N}_{\varepsilon}[N_1 \parallel N_2,\alpha^{\star}[\pi_s](\overrightarrow{v}),\gamma] = \mathscr{N}_1 \parallel \mathscr{N}_2}\ \textbf{B-In-Sync}$$

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This function only considers synchronisation labels $\textsc{Labs}$:

$$\begin{array}{lcll} \ell & ::= & \alpha^\star[\pi_s]\langle \overrightarrow{v} \rangle, \gamma & \text{Broadcast Output} \\ & | & \tau[\alpha[\pi_s]\langle \overrightarrow{v} \rangle, \gamma] & \text{Unicast Synchronization} \end{array}$$

$$\frac{\rho(t,\gamma_g,N)=\varepsilon=\langle\mu_p,\mu_w,\mu_r,\mu_u\rangle \quad \mu_u(\gamma_g,\alpha^\star)=(\sigma,N') \quad \sum_{C\in N} N(C)\cdot \mathsf{bSync}(C,N-C,\alpha^\star[\pi_s]\langle\overrightarrow{v}\rangle,\gamma)=\mathscr{N}}{\mathbb{S}_t[N \textbf{ in } (\gamma_g,\rho),\alpha^\star[\pi_s]\langle\overrightarrow{v}\rangle,\gamma]=\mathscr{N} \parallel N' \textbf{ in } (\sigma(\gamma_g),\rho)} \textbf{ Sys-B}$$

where

$$\frac{\varepsilon=\langle\mu_p,\mu_w,\mu_r,\mu_u\rangle \quad \mathbb{C}[C,\alpha^\star[\pi_s]\langle\overrightarrow{v}\rangle,\gamma]=\mathscr{C} \quad \mathbb{N}_\varepsilon[N,\alpha^\star[\pi_s](\overrightarrow{v}),\gamma]=\mathscr{N}}{\mathsf{bSync}_\varepsilon(C,N,\alpha^\star[\pi_s]\langle\overrightarrow{v}\rangle,\gamma) \quad = \quad \mu_r(\gamma,\alpha^\star[\pi_s]\langle\overrightarrow{v}\rangle,\gamma)\cdot\mathscr{C} \parallel \mathscr{N}}$$

Quantitative Analysis

The semantics of CARMA gives rise to a Continuous Time Markov Chain (CTMC).

This can be analysed by

- by numerical analysis of the CTMC for small systems;
- by stochastic simulation of the CTMC;
- by fluid approximation of the CTMC under certain restrictions (particularly on the environment).

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CARMA is equipped with linguistic constructs specifically developed for modelling and programming systems that can operate in open-ended and unpredictable environments.

However, CARMA is a SPA:

- concise syntax;
- parametric with respect to the used *expressions* and *data types*.

To facilitate the use of CARMA in the specification/analysis process of CAS we developed:

- a *specifiation language*;
- an Eclipse plug-in as a container for CARMA tools.

A running example...

Bike Sharing System...

We want to use CARMA to model a bike sharing system where:

- bikes are made available in a number of stations that are placed in various areas of a city;
- Users that plan to use a bike for a short trip
  - can pick up a bike at a suitable origin station
  - return it to any other station close to their planned destination.
- we assume that the city is partitioned in homogeneous zones...
  - and that all the *stations* in the same zone can be equivalently used by any user in that zone.

Each CARMA specification, also named CARMA *model*, provides definitions for:

- structured *data types*;
- *constants* and *functions*;
- prototypes of *components*;
- *collective* of components;
- *systems* composed by collective and environment;
- *measures*, that identify the relevant data to *retrieve* during simulation runs.

CASL: Data types

Basic data types

- `bool`, for booleans;
- `int`, for integers;
- `real`, for real values.

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- Arrays: `[:` $exp_1, \ldots, exp_n$ `:]`

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- Arrays: `[:` $exp_1, \ldots, exp_n$ `:]`

Custom data types

- Enumerations: `enum` *name* `=` $elem_1, \ldots, elem_n$`;`
- Records: `record` *name* `= [` $type_1$ $field_1, \ldots,$ $type_n$ $field_n$`];`

CASL: Expressions

In CASL syntax of *expressions* includes:

- standard arithmetic and logical operations ($+, -, \ldots$)
- common functions (log,sin,...)
- conditional expression `(`*exp*1`?`*exp*2`:`*exp*3`)`
- special value `now`, indicating the current time
- ...

A limited set of expression has to be used when specific analysis tools (*fluid semantics*) are used.

CASL: Operators

[Add here a table with a list of relevant operators!]

A Carma specification can also contain *constants* and *functions* declarations having the following syntax:

```
const name = expression;

fun type name( type_1 arg_1 , ... , type_k arg_k ) {
  ...
}
```

Variable declaration, assignment and return:

```
type var = exp;
var = exp;
return exp;
```

If-then-else:

```
if (exp) { ... } else { ... }
```

Iterators:

```
for (var=exp1 ; exp2 ; exp3 ){ ... }
for var in exp { ... }
```

[ADD HERE TWO EXAMPLES OF FUNCTIONS]

CASL: Component Prototypes

A *component prototype* defines the general structure of a component:

$$
\begin{array}{l}
\textbf{component}\ \mathit{name}(\ \mathit{type}_1\ \ \mathit{arg}_1\ ,\ldots,\ \mathit{type}_n\ \ \mathit{arg}_n\ )\ \{ \\
\quad \textbf{store}\ \{\ \cdots \\
\quad\quad \textbf{attrib}\ \ \mathit{aname}_i\ :=\ \mathit{expression}_i\ ;\ \ \cdots \\
\quad \} \\
\quad \textbf{behaviour}\ \{\ \cdots \\
\quad\quad \mathit{proc}_i\ =\ \mathit{pdef}_i\ ;\ \ \cdots \\
\quad \} \\
\quad \textbf{init}\ \ \{\ \ P_1 \,|\, \cdots \,|\, P_w\ \ \} \\
\}
\end{array}
$$

Two kinds of components, one for each of the two groups of agents involved in our BSS, can be considered:

- *parking stations*;
- *users*.

PS attributes:

- zone: indicates where the station is located;
- capacity: the number of slots installed in the station;
- available: the number of available bikes.

User attributes:

- zone: current user location;
- dest: user destination.

```
component Station( int zone , int capacity , int
    available ) {
  store {
    zone = zone;
    available = available;
    capacity = capacity;
  }
  ...
}
component User( int zone , int dest ) {
  store {
    zone = zone;
    dest = dest;
  }
  ...
}
```

Behaviour...

The block `behaviour` is used to define the component behaviour...

... it consists of a sequence of *process definitions*

$$
\begin{array}{l}
\textbf{behaviour}\ \{ \\
\quad proc_1 = pdef_1\,; \\
\quad \ldots \\
\quad proc_n = pdef_n\,; \\
\}
\end{array}
$$

... that associate each *process name* with alternative actions.

Output actions:

$$[\ \mathit{guard}\ ]\ \texttt{act}\ [\ \mathit{pred}\ ] < \mathit{exp}_1\ ,\ \ldots\ ,\ \mathit{exp}_n > \{$$
$$\quad \mathit{attr}_1 = \mathit{exp}_1\,;$$
$$\quad \ldots$$
$$\quad \mathit{attr}_n = \mathit{exp}_n\,;$$
$$\}$$

Input actions:

$$[\ \mathit{guard}\ ]\ \texttt{act}\ [\ \mathit{pred}\ ]\ (\ x_1\ ,\ \ldots\ ,\ x_n\ )\ \{$$
$$\quad \mathit{attr}_1 = \mathit{exp}_1\,;$$
$$\quad \ldots$$
$$\quad \mathit{attr}_n = \mathit{exp}_n\,;$$
$$\}$$

Two processes are defined at `Station` component that model the procedures to *get* and *returning* a bike:

```
G = [my.available>0] get<> { my.available := my.
    available-1 s}.G;

R = [my.available<my.capacity] ret<>{ my.available :=
     my.available+1  }.R;
```

Procedures *get* and *returning* are modelled via *unicast output* over `get` and `ret`:

- `get` is enabled when there are bikes available (`my.available>0`);
- `get` is enabled when there are available slots (`my.available<my.capacity`).

Each user can be in three different states. . .

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... `P`, denoting a *pedestrian*:

```
P = get[ my.loc == loc ]().B;
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... a *pedestrian* executes unicast input `get` to collect a bike from a station located in his/her current zone (`my.zone == zone`) and then becomes a *bikers*:

```
B = move*[ false ]<>{ my.loc := my.dest }.W;
```

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B = move*[ false ]<>{ my.loc := my.dest }.W;
```

... in that state a user *move* to the final destination and then *waits* for a slot:

```
W = ret[ my.loc == loc ]().kill;
```

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B = move*[ false ]<>{ my.loc := my.dest }.W;
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```
W = ret[ my.loc == loc ]().kill;
```

... when a slot in the same zone is found, the user *disappear*.

Example: Station


```
component Station( int zone , int capacity , int
    available ) {
  store {
      zone = zone;
      available = available;
      capacity = capacity;
    }
    behaviour {
    G = [my.available >0] get<> {
        my.available := my.available -1
    }.G;
    R = [my.available <my.capacity] ret<>{
        my.available := my.available+1
    }.R;
  }
  init { G|R }
}
```

Example: User


```
component User( int loc , int dest ) {
  store {
    loc = loc;
      dest = dest;
    }
    behaviour {
      P = get[ my.loc == loc ]().B;
      B = move*[ false ]<>{ my.loc := my.dest }.W;
      W = ret[ my.loc == loc ]().kill;
    }
    init { P }
}
```

Example: Arrival

To model the of new users, another component is considered in our model:

```
component Arrival( int loc ) {
  store {
    attrib loc := loc;
  }
  behaviour {
    A = arrival*[false]<>.A;
  }
  init {
    A
  }
}
```

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To model the of new users, another component is considered in our model:

```
component Arrival( int loc ) {
  store {
    attrib loc := loc;
  }
  behaviour {
    A = arrival*[false]<>.A;
  }
  init {
    A
  }
}
```

Above `zone` indicates the zone indicates the location where users arrive.

Block `collective` can be used to define groups of components:

collective *name* ($type_1$ var_1 , ... , $type_n$ var_n) {
  ...
}

Block `collective` can be used to define groups of components:

```
collective name ( type_1 var_1 , ... , type_n var_n ) {
  ...
}
```

BSS Collective:

```
collective bssCollective( int zones , int n ) {
  for ( i ; i<zones ; 1 ) {
    new Station( i , C, A )< n >;
  }
  new Arrival( i );
}
```

A system definition consists of two blocks, namely `collective` and `environment`:

```
system name {
  collective collective
  environment { ···
  }
}
```

A system definition consists of two blocks, namely `collective` and `environment`:

```
system name {
  collective collective
  environment { ···
  }
}
```

BSS System:

```
system Scenario {
  collective bssCollective( 10 , 10 , 10 )
  environment { ···
  }
}
```

Syntax of an block `environment` is the following:

```
environment {
  store { ··· }
  prob { ··· }
  weight { ··· }
  rate { ··· }
  update { ··· }
}
```

In our scenario use a global attribute to count the amount of *active users* in the system:

```
store {
  attrib users := 0;
}
```

```
weight {
  get {
    return ReceivingProb(#{User[P]|my.loc==sender.loc
        })
  }
  ret {
    return ReceivingProb(#{User[W]|my.loc==sender.loc
        });
  }
  default {
    return 1;
  }
}
```

```
rate{
   get { return get_rate; }
   ret { return ret_rate; }
   move* { return move_rate; }
   arrival* { (global.users<TOTAL_USERS?arrival_rate
       :0.0); }
}
```

```
update {
  arrival* {
    users := global.users+1;
    new User( sender.zone , U[0:ZONES-1] );
  }
  ret {
    users := global.users-1;
  }
}
```

To extract observations from a model, a CARMA specification also contains a set of *measures*:

measure *m_name*(*type*$_1$ *var*$_1$, ... , *type*$_1$ *var*$_n$) = *expr* ;

```
measure AverageBikes( int z ) =
    avg{ my.available | my.zone == z };
measure MinBikes( int z ) =
    min{ my.available | my.zone == z };
measure MaxBikes( int z ) =
    max{ my.available | my.zone == z };
```

Outline

1 Introduction
- Collective Adaptive Systems
- Quantitative Analysis

2 Modelling CAS

3 CARMA
- The CARMA Modelling Language

4 CARMA Operational semantics

5 CASL:CARMA Specification Language

6 CARMA Eclipse plug-in

7 CARMA and its tools in Action

CARMA Eclipse Plug-In provide tools for specification and quantitative analysis of CARMA models.

The CARMA Eclipse Plug-in

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Frontend

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Frontend

CARMA Editor
(Xtext based)

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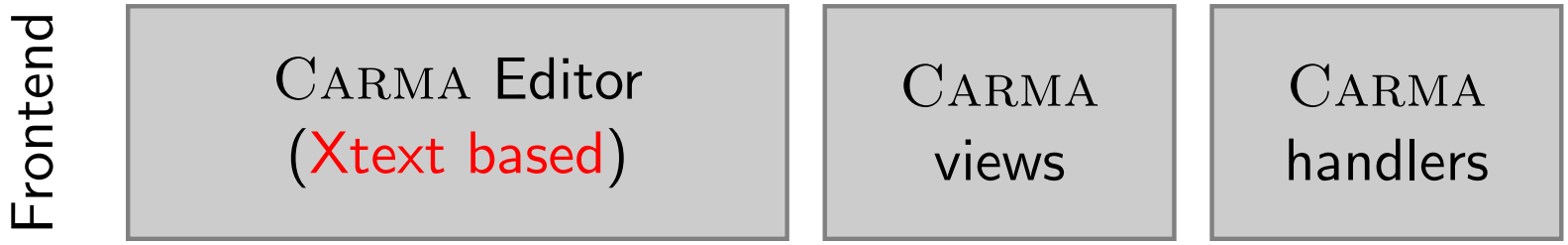

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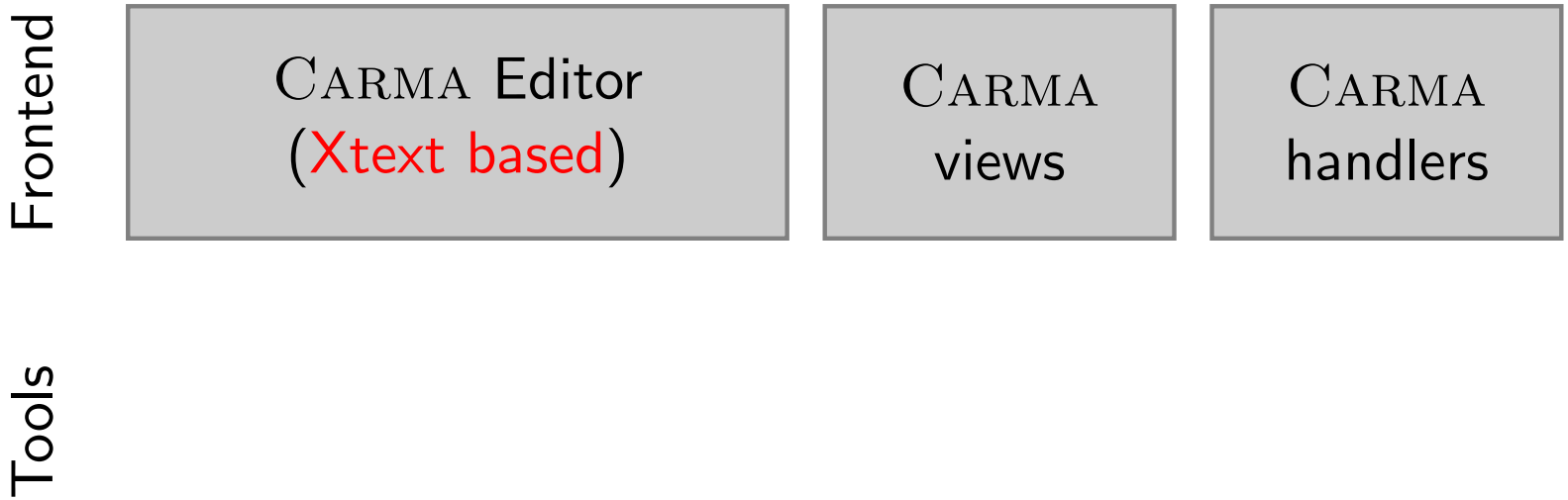

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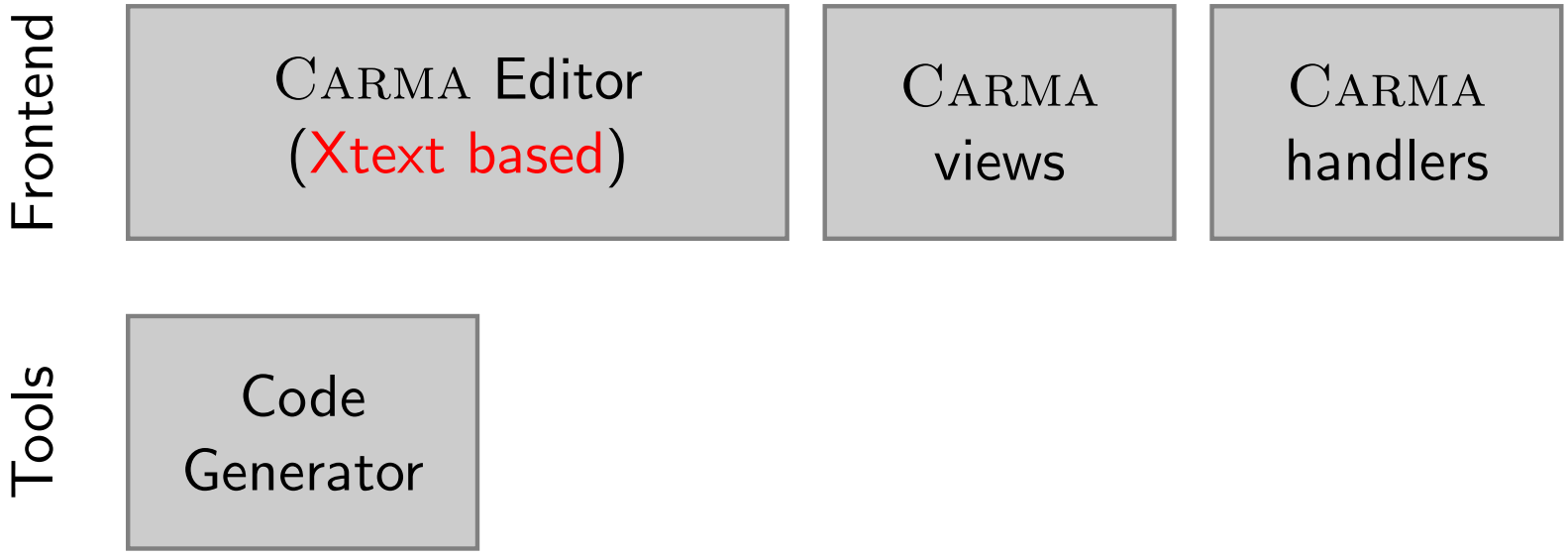

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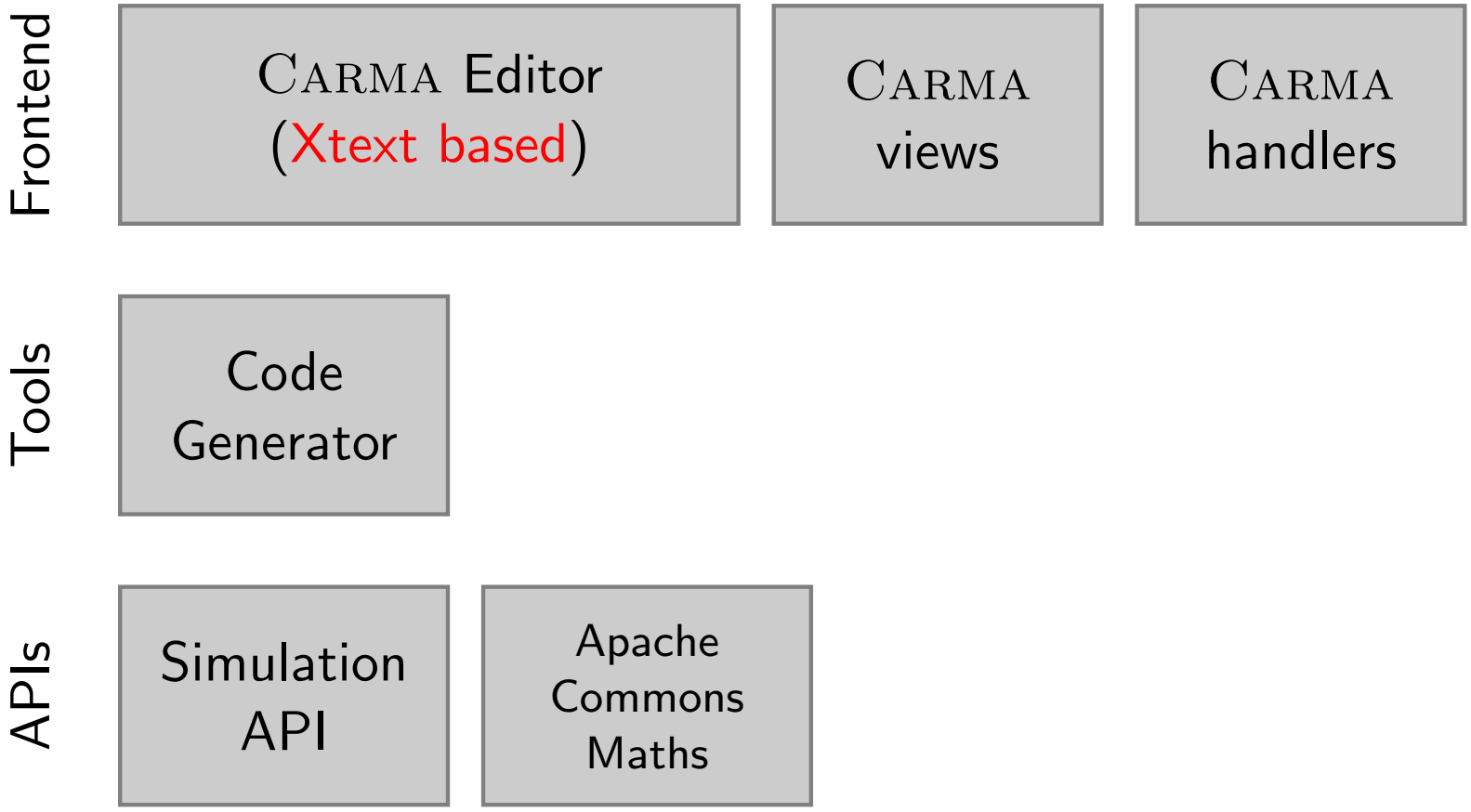

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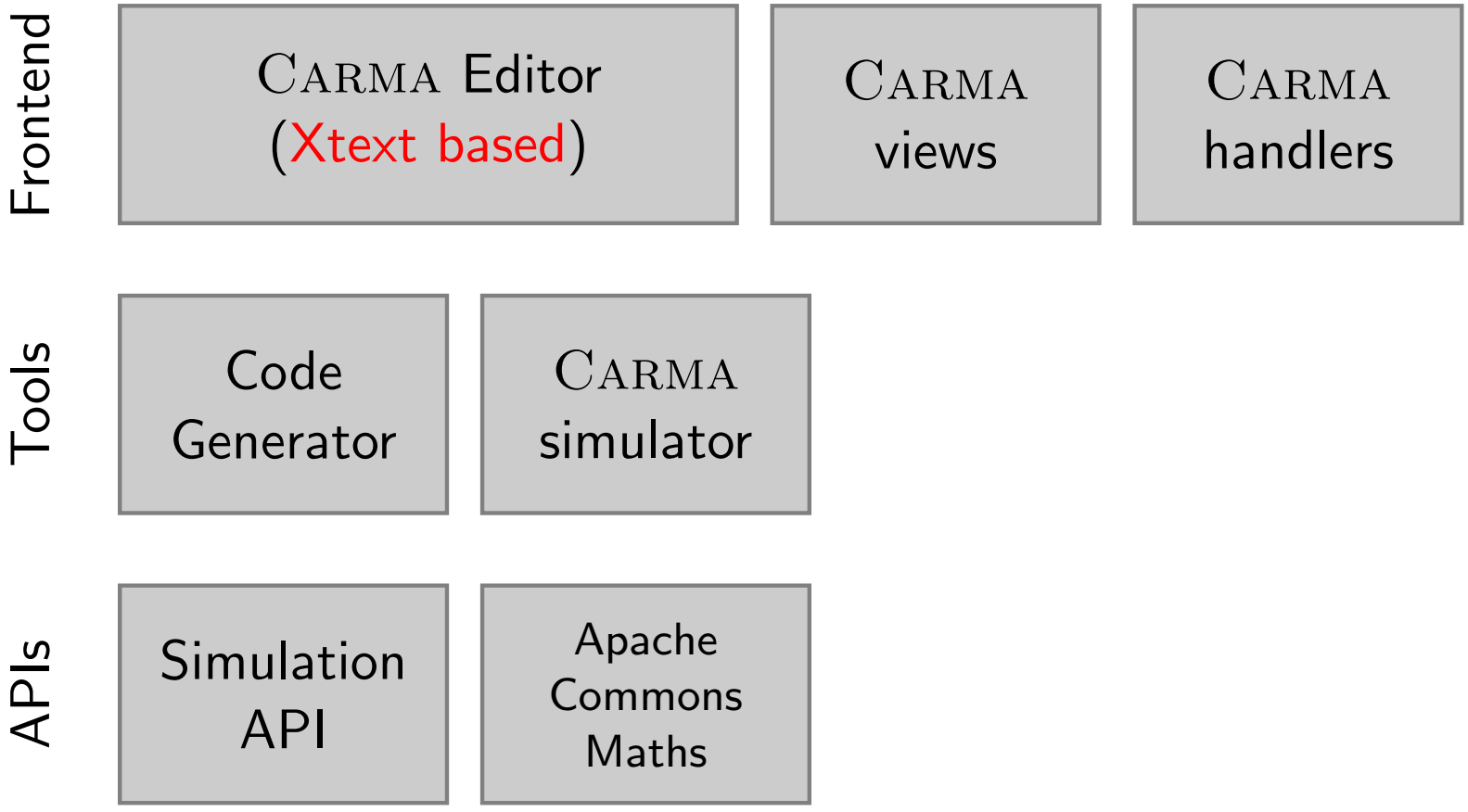

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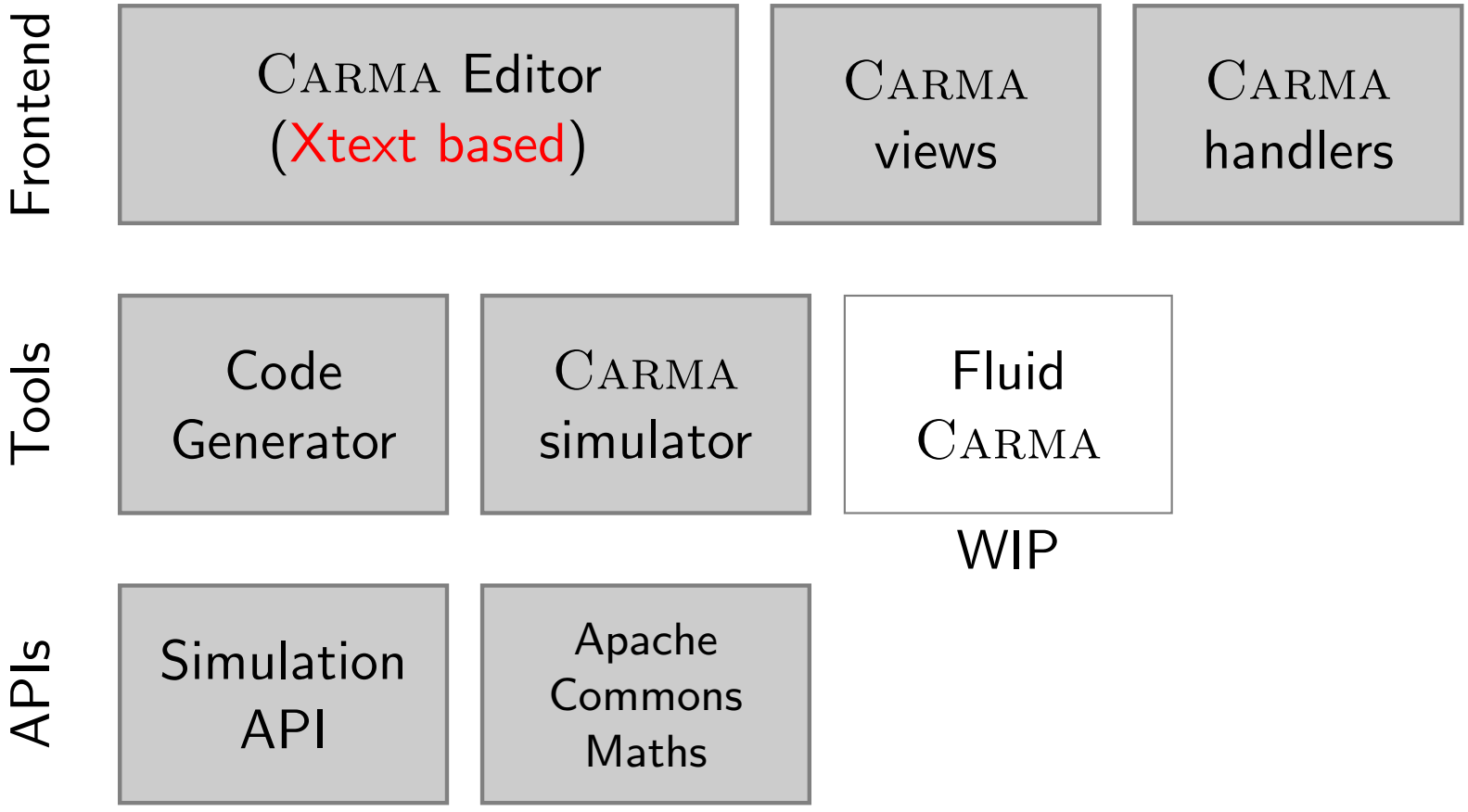

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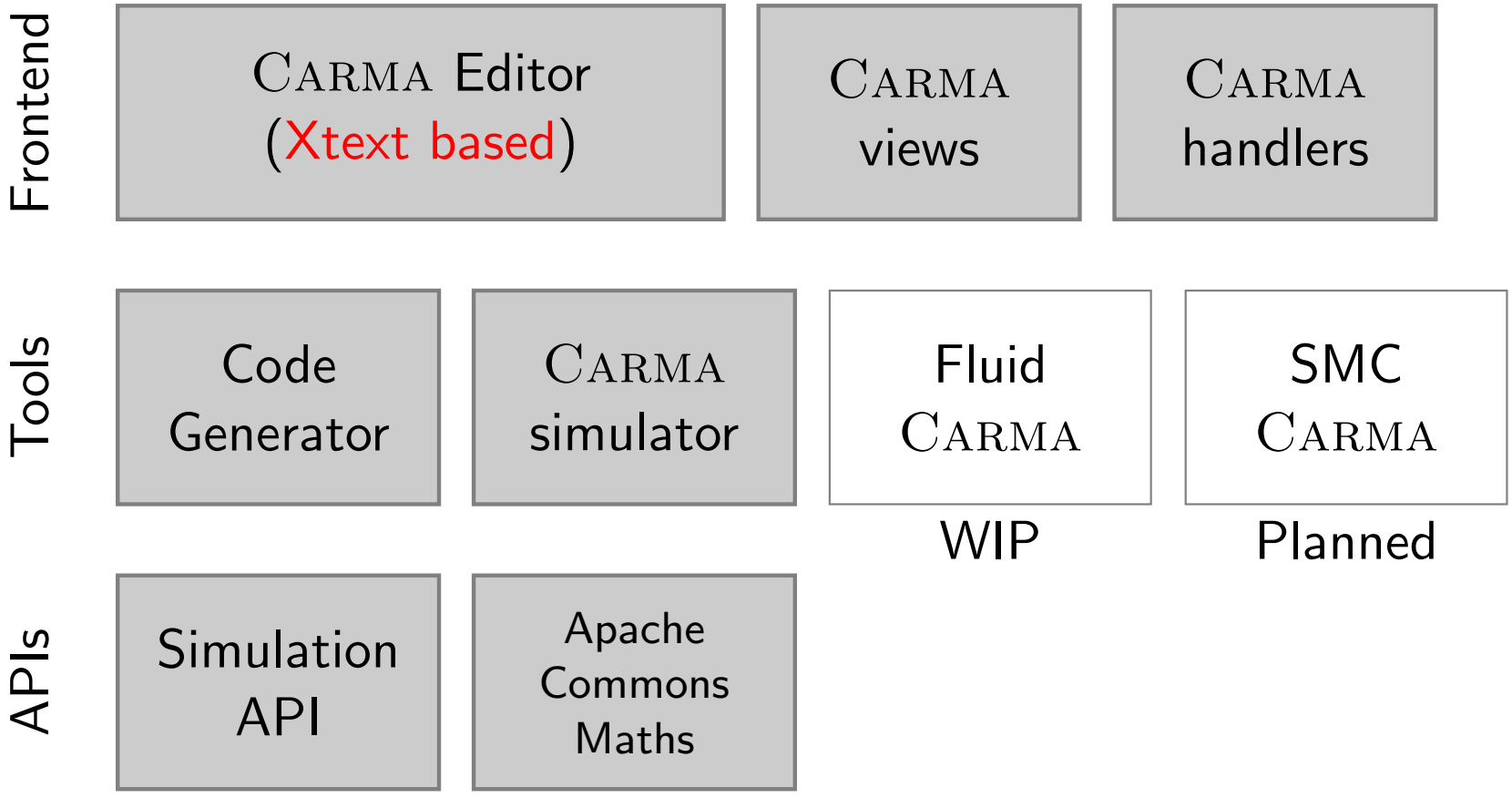
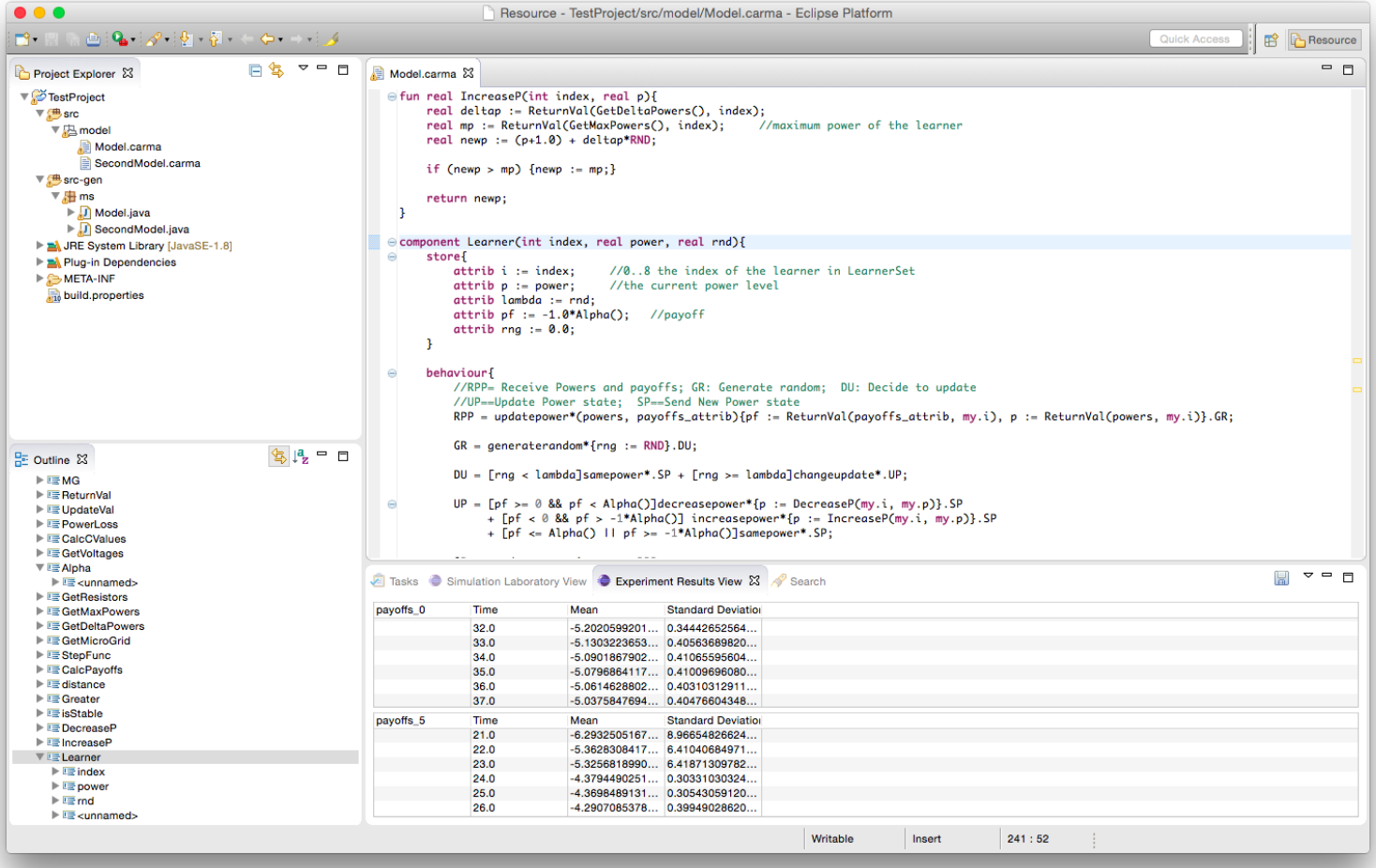


LIVE DEMO


Resource - TestProject/src/model/Model.carma - Eclipse Platform
Project Explorer
TestProject
src
model
Model.carma
SecondModel.carma
src-gen
ms
Model.java
SecondModel.java
JRE System Library [JavaSE-1.8]
Plug-in Dependencies
META-INF
build.properties
Outline
MG
ReturnVal
UpdateVal
PowerLoss
CalcCValues
GetVoltages
Alpha
<unnamed>
GetResistors
GetMaxPowers
GetDeltaPowers
GetMicroGrid
StepFunc
CalcPayoffs
distance
Greater
isStable
DecreaseP
IncreaseP
Learner
index
power
rnd
<unnamed>
Model.carma
fun real IncreaseP(int index, real p){
real deltap := ReturnVal(GetDeltaPowers(), index);
real mp := ReturnVal(GetMaxPowers(), index); //maximum power of the learner
real newp := (p+1.0) + deltap*RND;
if (newp > mp) {newp := mp;}
return newp;
}
component Learner(int index, real power, real rnd){
store{
attrib i := index; //0..8 the index of the learner in LearnerSet
attrib p := power; //the current power level
attrib lambda := rnd;
attrib pf := -1.0*Alpha(); //payoff
attrib rng := 0.0;
}
behaviour{
//RPP= Receive Powers and payoffs; GR: Generate random; DU: Decide to update
//UP==Update Power state; SP==Send New Power state
RPP = updatepower*(powers, payoffs_attrib){pf := ReturnVal(payoffs_attrib, my.i), p := ReturnVal(powers, my.i)}.GR;
GR = generaterandom*{rng := RND}.DU;
DU = [rng < lambda]samepower*.SP + [rng >= lambda]changeupdate*.UP;
UP = [pf >= 0 && pf < Alpha()]decreasepower*{p := DecreaseP(my.i, my.p)}.SP
+ [pf < 0 && pf > -1*Alpha()] increasepower*{p := IncreaseP(my.i, my.p)}.SP
+ [pf <= Alpha() || pf >= -1*Alpha()]samepower*.SP;
Tasks
Simulation Laboratory View
Experiment Results View
Search
payoffs_0
Time
Mean
Standard Deviatio
32.0
-5.2020599201...
0.34442652564...
33.0
-5.1303223653...
0.40563689820...
34.0
-5.0901867902...
0.41065595604...
35.0
-5.0796864117...
0.41009696080...
36.0
-5.0614628802...
0.40310312911...
37.0
-5.0375847694...
0.40476604348...
payoffs_5
Time
Mean
Standard Deviatio
21.0
-6.2932505167...
8.96654826624...
22.0
-5.3628308417...
6.41040684971...
23.0
-5.3256818990...
6.41871309782...
24.0
-4.3794490251...
0.30331030324...
25.0
-4.3698489131...
0.30543059120...
26.0
-4.2907085378...
0.39949028620...
Writable
Insert
241 : 52

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