Modelling and analysis of collective adaptive systems

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quanticol

Based on joint work with
Yehia Abd Alrahman, Rocco De Nicola, Jane Hillston

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Singapore, 12-16 September 2016

Collective Systems

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 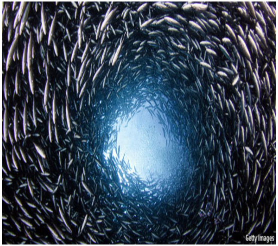 

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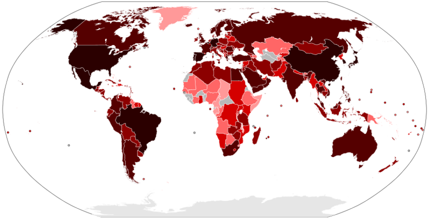

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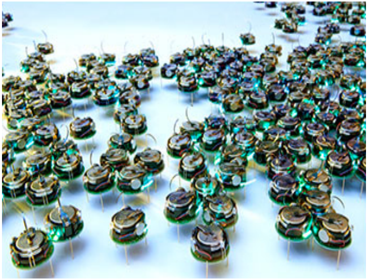
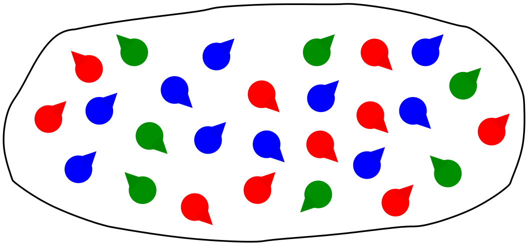


Collective Adaptive Systems

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



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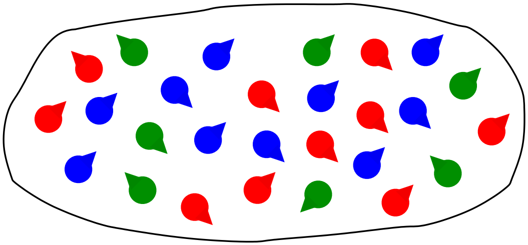

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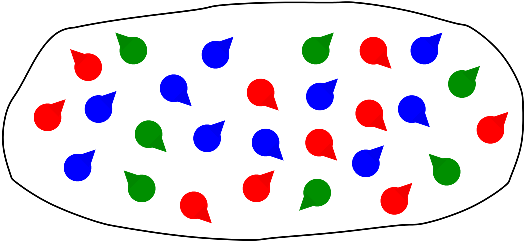
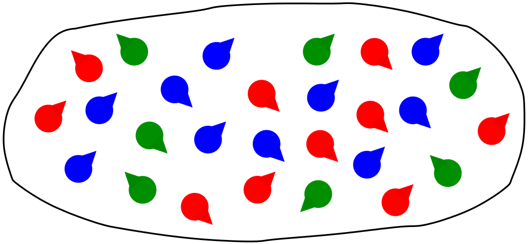


Each entity may have its own properties, objectives and actions.

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

Collective Adaptive Systems

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



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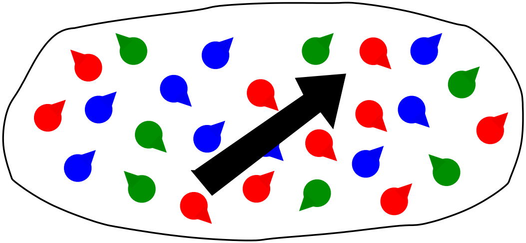

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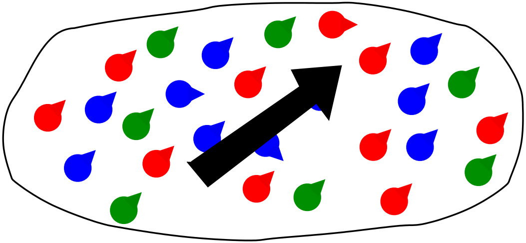

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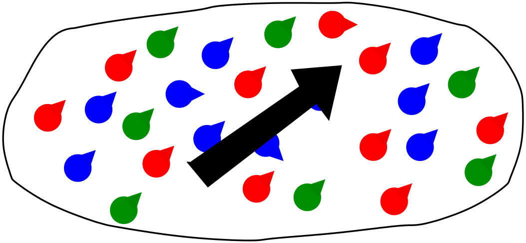
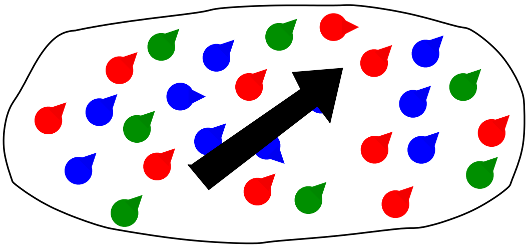


And the behaviour of the individuals will be influenced by the state of the overall system.

Collective Adaptive Systems

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



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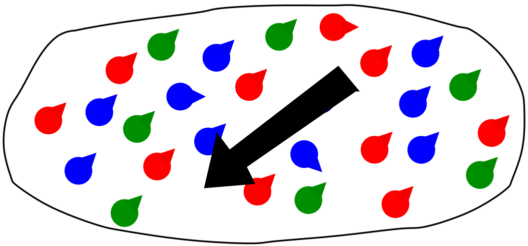

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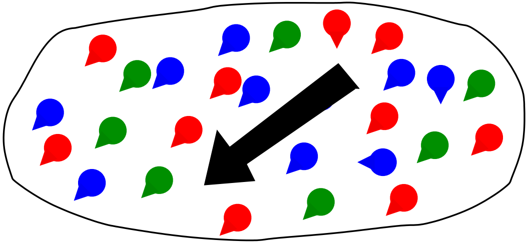

Moreover when conditions within the system change it may not be feasible to have human intervention to adjust behaviour appropriately.

Thus systems must be able to autonomously adapt.

Challenges for modelling CAS

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- The influence of *environment* on behaviour

Modelling and analysis of CAS

Our goal is to develop a coherent, integrated set of linguistic primitives, methods and tools to build systems that can operate in open-ended, unpredictable environments.

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In this talk:

1. *attribute based communication* for modelling interactions in CAS;
2. CARMA: a language for modelling CAS;
3. a simple example.

Attribute-based communication

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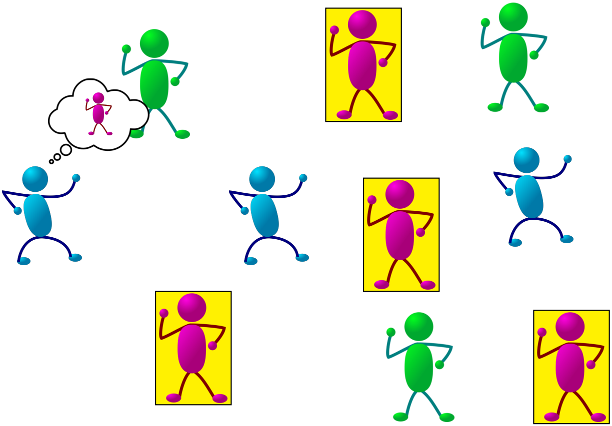

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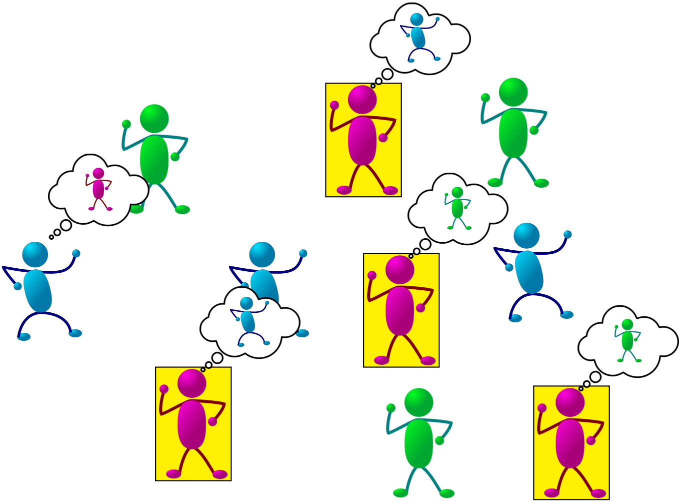

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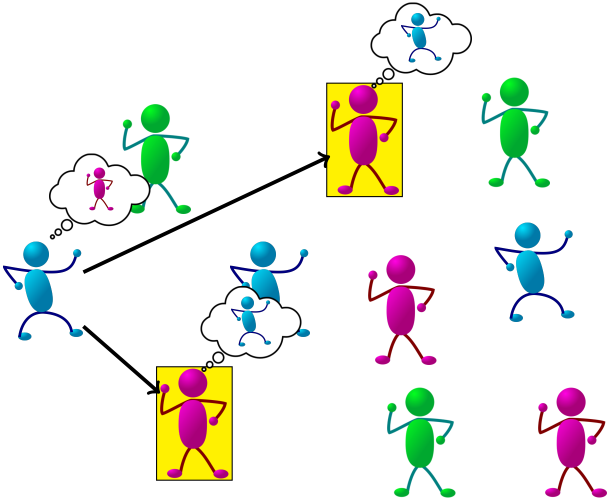

Attribute-based communication

Abd Alrahman et al.[1] presented a general theory for *attribute based communication*:

- *AbC*, a calculus for attribute-based communication;
- encoding of classical *interaction patterns* via *attribute based* communications;
- a behavioural theory for AbC.

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This work is focussed on *qualitative aspects* of CAS. In this talk we will focus on *quantitative aspects*.

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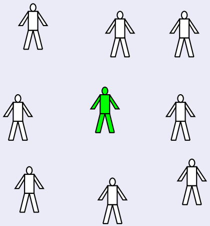

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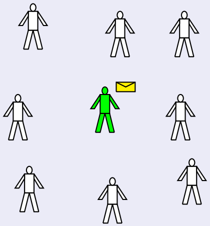

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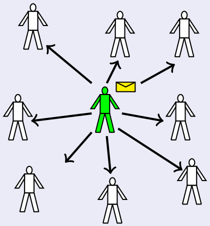

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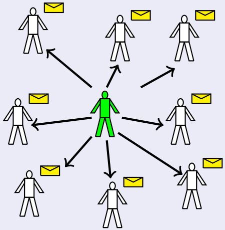

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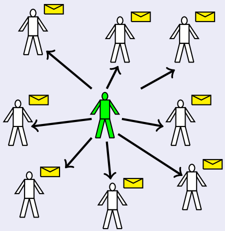

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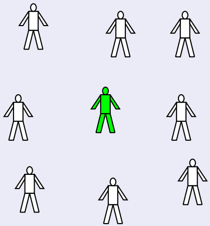

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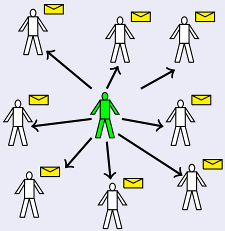

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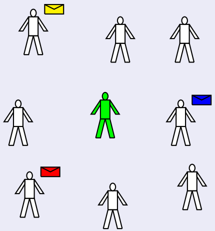

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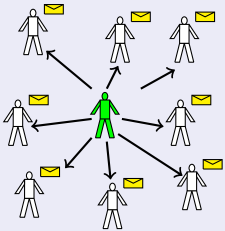

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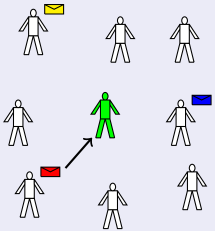

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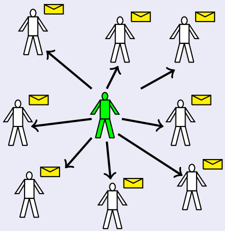

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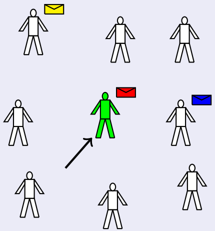

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- **Broadcast output**: a message is sent to all the components satisfying a predicate π;
- **Broadcast input**: a process is willing to receive a broadcast message from a component satisfying a predicate π;
- **Unicast output**: a message is sent to one of the components satisfying a predicate π;
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CARMA: a process specification language for CAS

To support design of CAS we introduced CARMA[2] (*Collective Adaptive Resource-sharing Markovian Agents*). This is a process specification language which handles:

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

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CAS: CARMA perspective

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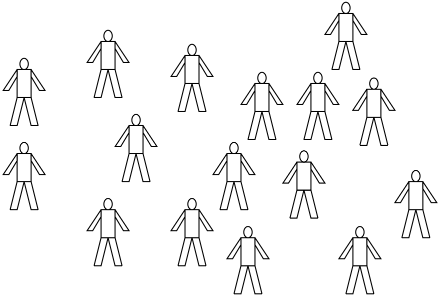

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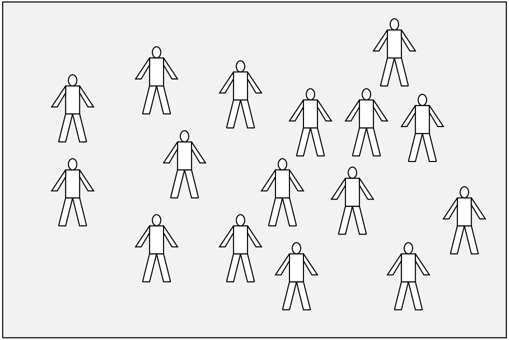
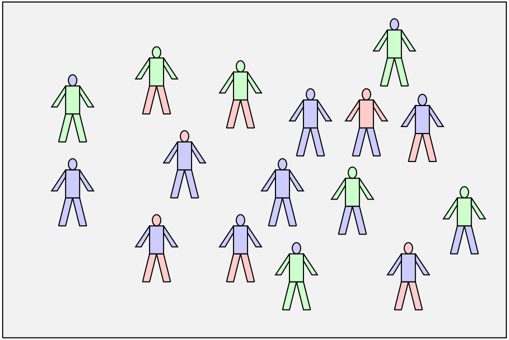
Collective **Environment**



CAS: CARMA perspective

Collective **Environment** **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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Agents in CARMA are defined as components C of the form (P, γ) where...

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Store γ is a mapping from *attribute names* to *values*.

Interaction primitives

Syntax

$$
\begin{array}{rcll}
act & ::= & \alpha^{\star}[\pi]\langle\overrightarrow{e}\rangle\sigma & \text{Broadcast output} \\
 & \mid & \alpha^{\star}[\pi](\overrightarrow{x})\sigma & \text{Broadcast input} \\
 & \mid & \alpha[\pi]\langle\overrightarrow{e}\rangle\sigma & \text{Unicast output} \\
 & \mid & \alpha[\pi](\overrightarrow{x})\sigma & \text{Unicast input}
\end{array}
$$

- 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:

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Remark:

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

More on synchronisation

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Example:

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Pattern matching can be encoded in CARMA.

Examples of interactions...

Broadcast synchronisation:

$$
\begin{array}{l}
(\ \mathrm{stop}^{\star}[\mathrm{bl} < 5\%]\langle v\rangle\sigma_1.P\ ,\{role = \text{``}master\text{''}\})\ \|\\
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Modelling the environment

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

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

The evolution rule ρ

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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1. the function $\mathbb{C}$ that describes the behaviour of a single component;
2. the function $\mathbb{N}_{\varepsilon}$ builds on $\mathbb{C}$ to describe the behaviour of collectives;
3. the function $\mathbb{S}_{t}$ that shows how CARMA systems evolve.

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).

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.

CASL: Component Prototypes

The BSS scenario...

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:

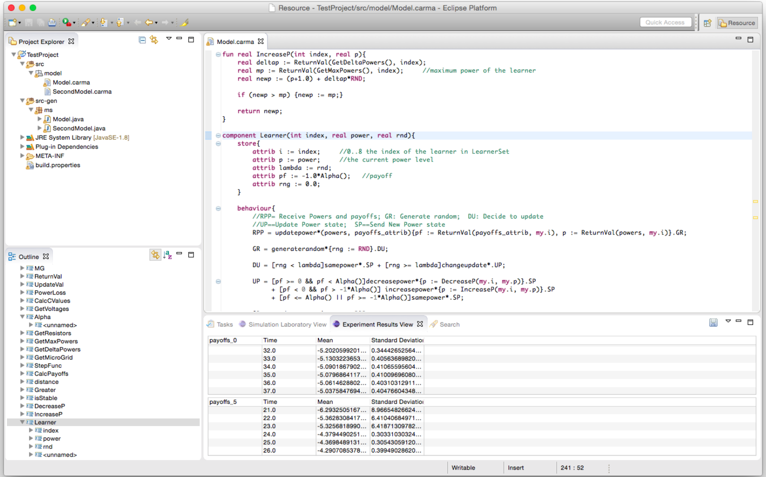
- **zone**: indicates where the station is located;
- **capacity**: the number of slots installed in the station;
- **available**: the number of available bikes.

User attributes:

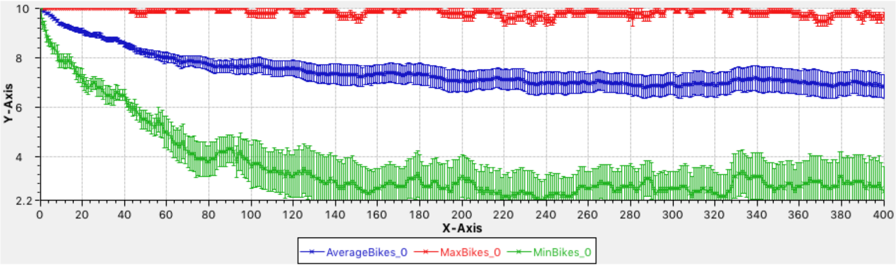
- **zone**: current user location;
- **dest**: user destination.

The CARMA Eclipse Plug-in

http://quanticol.sourceforge.net/



CASL: BSS Analysis



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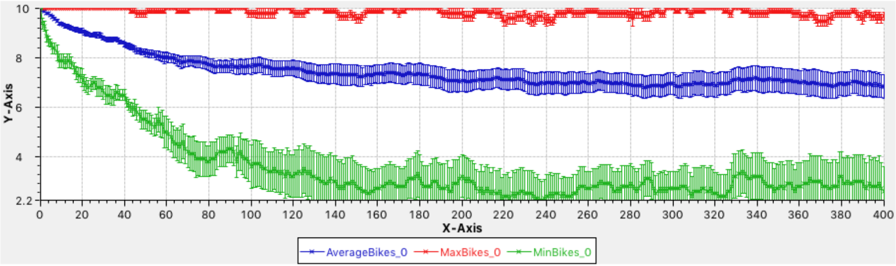

In this scenario the use of stations is not well balanced!

CaSL: an alternative model for BSS

To overcome this problem we can consider a model where stations located at the same zone do not compete but cooperate.

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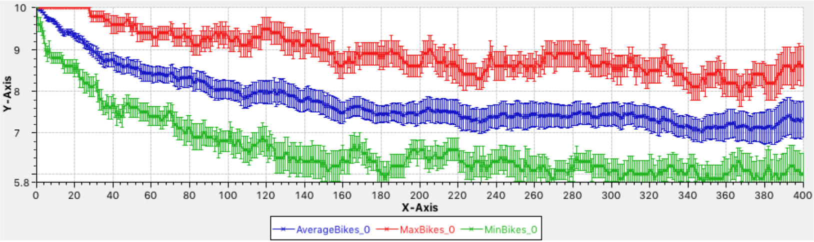
Each station can use broadcast to advertise other agents about the use of resources!

CASL: modified BSS model Analysis



Concluding remarks

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Concluding remarks

- Collective Systems are an interesting and challenging class of systems to design and construct.
- Their role within infrastructure, such as within smart cities, make it essential that quantitative aspects of behaviour are taken into consideration, as well as functional correctness.
- The complexity of these systems poses challenges both for model construction and model analysis.
- CARMA aims to address many of these challenges, supporting rich forms of interaction, using attributes to capture explicit locations and the environment to allow adaptivity.

thank you!