# Formal Modelling and Analysis of IoT Systems with Bigraphs

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## 1: Background

The Internet of Things (IoT) consists of networked objects capable of interacting with the external environment via embedded sensors and transmitting sensed data over the Internet. The scope of IoT covers a wide range of devices and goes beyond traditional computer systems such as laptops, tablets and smartphones. Example objects are domestic appliances, connected medical devices, industrial robots, connected children's toys, etc.

## 2: Issues with current IoT

New media reports emerge daily on the latest threat posed by the adoption of poorly-designed IoT devices. This situation will likely deteriorate as technology advances enable us to build increasingly larger and more heterogeneous systems. The scale, complexity and interoperability issues will soon be unmanageable and traditional Software Engineering techniques fall short already especially in areas such as safety, security and privacy.

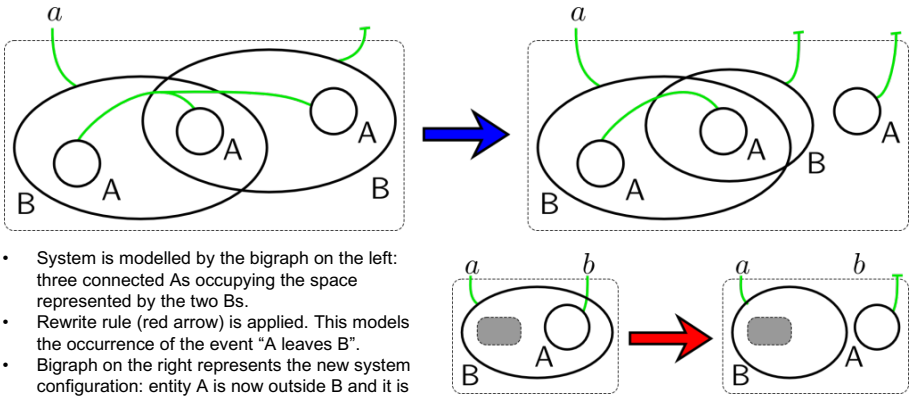
## 3: Our proposal

New modelling and automated reasoning techniques to allow developer and end-users to understand, deploy, control and predict the behaviour of IoT systems and overcome the limitations of current Software Engineering practice. We propose new mathematical frameworks and tools, based on the theory of bigraphs, building on our previous experience in rigorous, yet realistic modelling complex and safety-critical systems.

## 4: Bigraphs

Novel graphical formalism for modelling interacting systems that evolve in time and space. The appeal of this formalism is that it allows us to express graphically how the spatial arrangement of entities might drive computational effects within the system through a series of reaction rules. This allows systems designers to use directly these graphical forms as the principal modelling representation.

## Example: evolution of a bigraph over time




- System is modelled by the bigraph on the left: three connected As occupying the space represented by the two Bs.
- Rewrite rule (red arrow) is applied. This models the occurrence of the event "A leaves B".
- Bigraph on the right represents the new system configuration: entity A is now outside B and it is disconnected from the two other As.

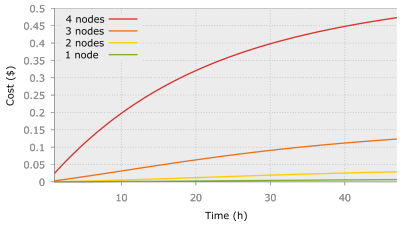
## 5: Service interoperability

Guarantee (mathematically) that a set of services can be composed in a meaningful way to provide an aggregate service satisfying a set of desired properties. Example applications:

- Docker compose yml files
- IFTTT recipes

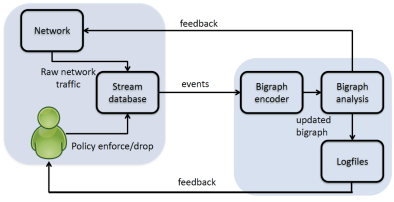
## 6: Automatic deployment

Quantitative analysis allows to determine upper bounds of resources during the evolution of the system. Strategies can then be optimised and synthetised to assist and automate system management.



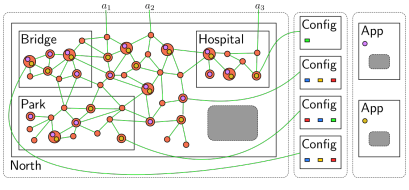

## 7: Dynamic reconfiguration

The operational conditions of the infrastructure may evolve. To ensure quality of service, we verify continuously the availability of resources and provides feedback to the owner of the infrastructure.




## 8: IoT programming

Leverage the graphical notation of bigraphs to hide complexity and develop sane DSLs that allow formal reasoning on properties of interest.

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