COUPLING ANALYSIS AND INSTABILITY PREVENTION IN MULTI-AGENT SYSTEMS

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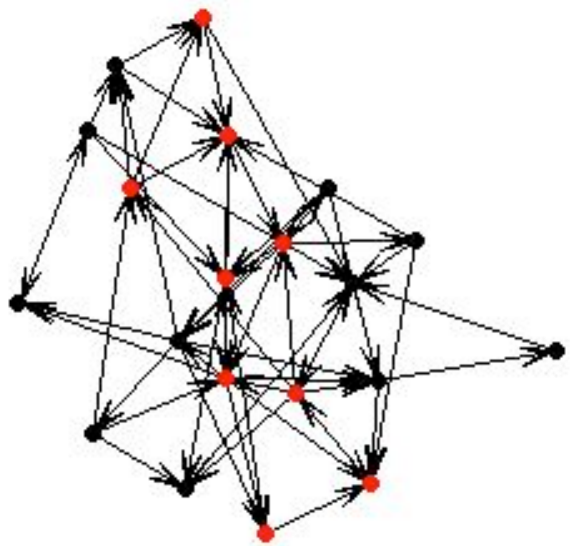
Introduction

- Ambient Intelligence and Pervasive Computing have been found to suffer from cyclic instability, due to interdependent sets for rules.
- Thus, devices such as lights, heaters, TVs, telephones, etc. could be programmed (manually or automatically) to perform a task according to certain rules, based on the behaviour of other devices.



Introduction

- If the state of the system at time *t* is denoted by *S(t)*, the cyclic instability can be represented by

$$S(t) = S(t + np \pm \delta)$$

  where p is the period and δ denotes network delays, latency, different processing speeds of the devices.

- From the user's perspective, deviations from the perfect periodicity are unimportant. What is important is the recurrent and unplanned changes in the state of the devices.

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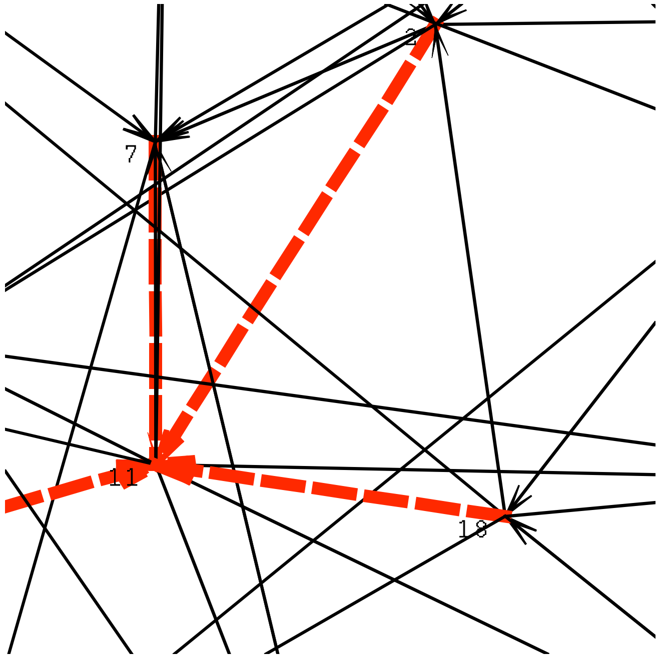
Introduction

This is a very challenging problem due to:

- Complexity of the rules
- Complexity of the topology
- User interaction
- Nomadic devices
- Synchronizations problems, temporal delays (network latency, speed of processing, etc).



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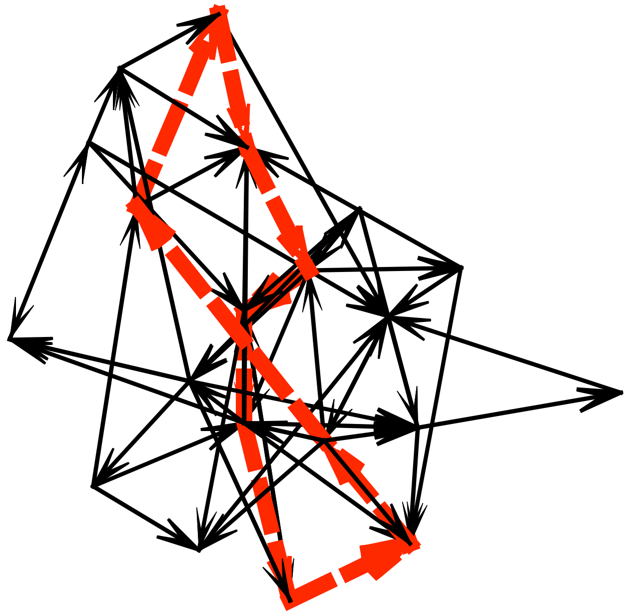
Introduction

- From complex system theory it has been shown that it is not possible to predict theoretically whether an arbitrary set of rules will suffer from instability.

- However, it is possible to prevent it.



Background Theory

Autonomous Agents

An autonomous agent A is an autonomous device with a boolean state $s \in \{0,1\}$, where 0 and 1 mean *on* and *off* respectively. If we have n autonomous devices agents $A_1, A_2, \ldots, A_n$ the state of the system is $S = (s_1, s_2, \ldots, s_n)$. Each agent A_i has two consistent rules:

$$\text{If } \varphi_i \text{ then } s_i = 1$$

$$\text{If } \psi_i \text{ then } s_i = 0$$

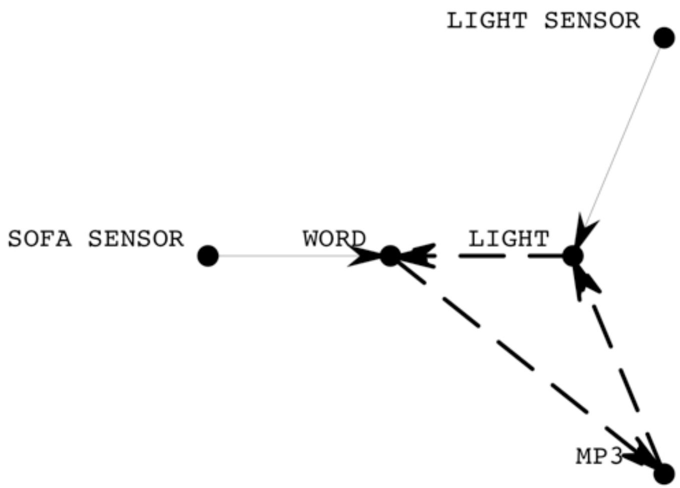
where

$$\varphi_i, \psi_i : S_n \rightarrow \{0,1\}$$

Background Theory

Interaction Networks

An Interaction Network (IN) is a digraph (V,E) in which the vertex $v \in V$ is a pervasive autonomous agent A and $(v_i, v_j) \in E$ if the Boolean functions φ_j or ψ_j of the pervasive autonomous agent A_i depends on the state s_i of the agent A_j.



Background Theory

Instability Prevention System INPRES

Find the set of all the cycles
$C = \{c_i\}$
in the IN

For each cycle c_i lock the agent A that satisfy

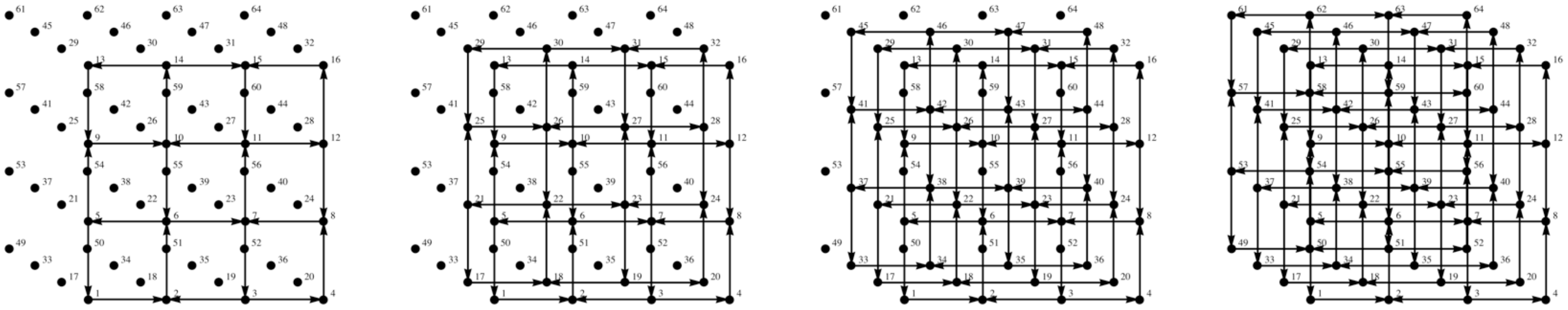
$$A = \min_{A_i \in c_i}\{f(A_i)\}$$

where *f(A)* is the ***functionality of the node A,*** defined as the number of nodes reachable from the node *A* in the *Interaction Network* associated

Background Theory

INPRES

- INPRES has been tested successfully using simulations with different topologies/rules and real implementation in the iDorm, our testbed
- Example of the topology of a 40 cycle system, using the Interaction Benchmark (IB):

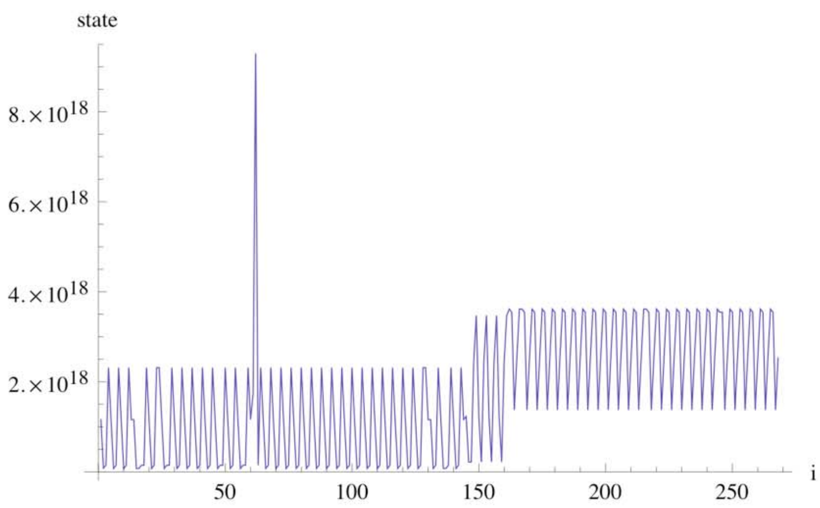


(a) (b) (c) (d)

Background Theory

INPRES

- Unstable behaviour of the system with 40 cycles:



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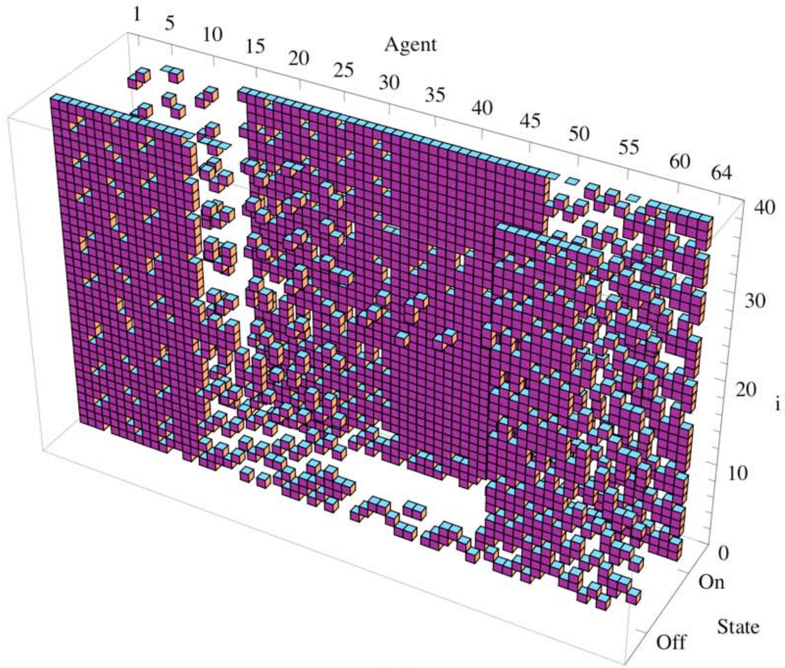

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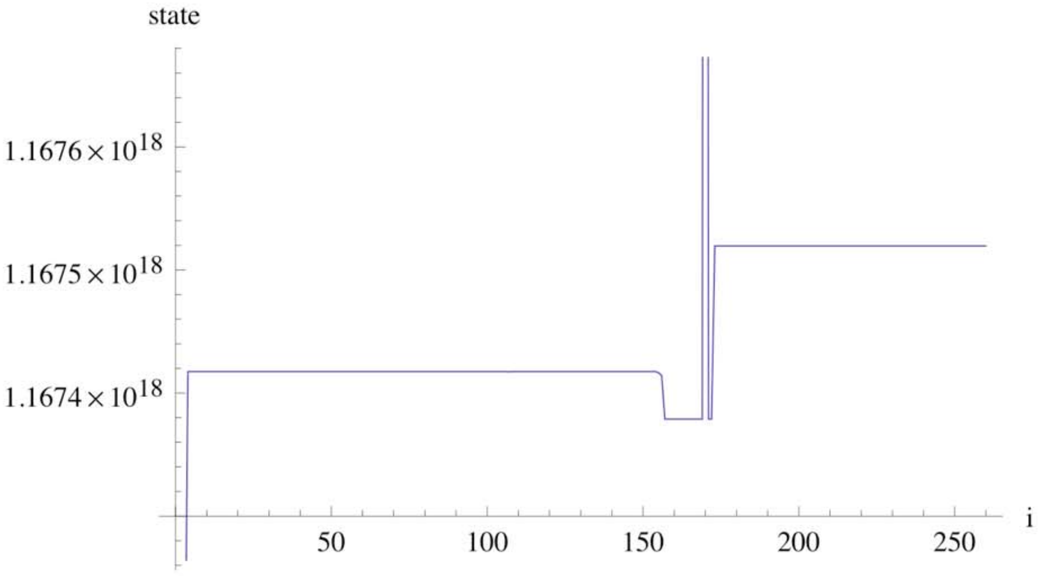
Background Theory
INPRES

- INPRES removed the instabilities:



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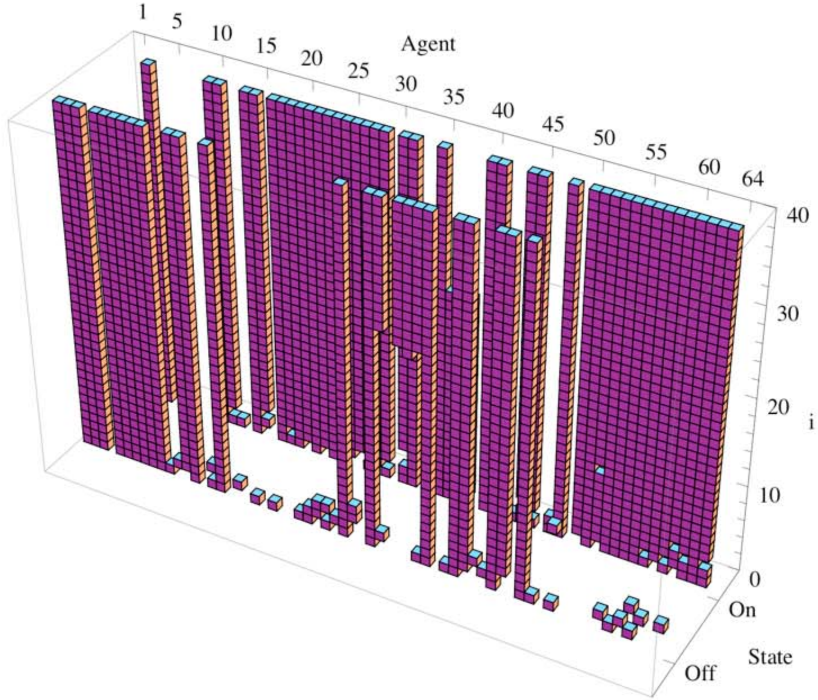

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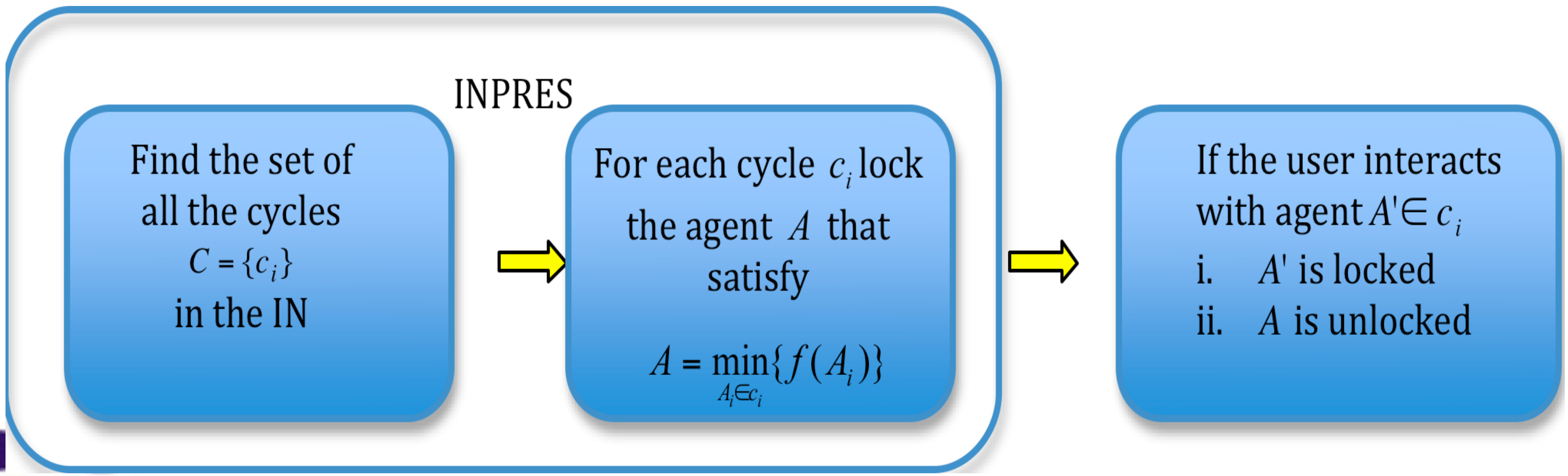
Background Theory

INPRES+User-based Locking

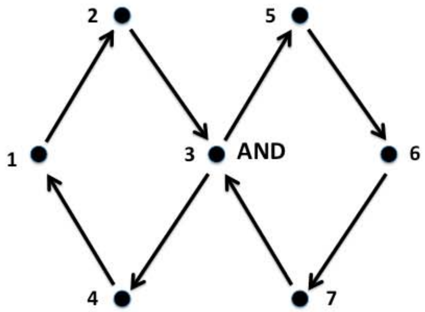
- We have also tested an hybrid solution, adding the user's interaction to INPRES:



Local Analysis

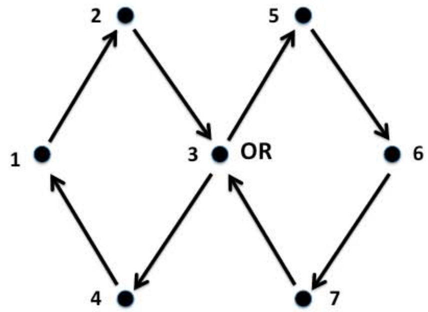
- Two potential oscillators (i.e. two sets of nodes with feedback) coupled in one point are *weakly coupled* if the coupling node was assigned an OR rule; on the contrary, if the coupling node was assigned an AND rule, they would be *strongly coupled*.
- Weak coupling lets either of the closed paths oscillate, or not, independently of the other.
- In the strong coupling if any of the subsystem is oscillating, the other will also be oscillating.

Local Analysis



(a)

Strong



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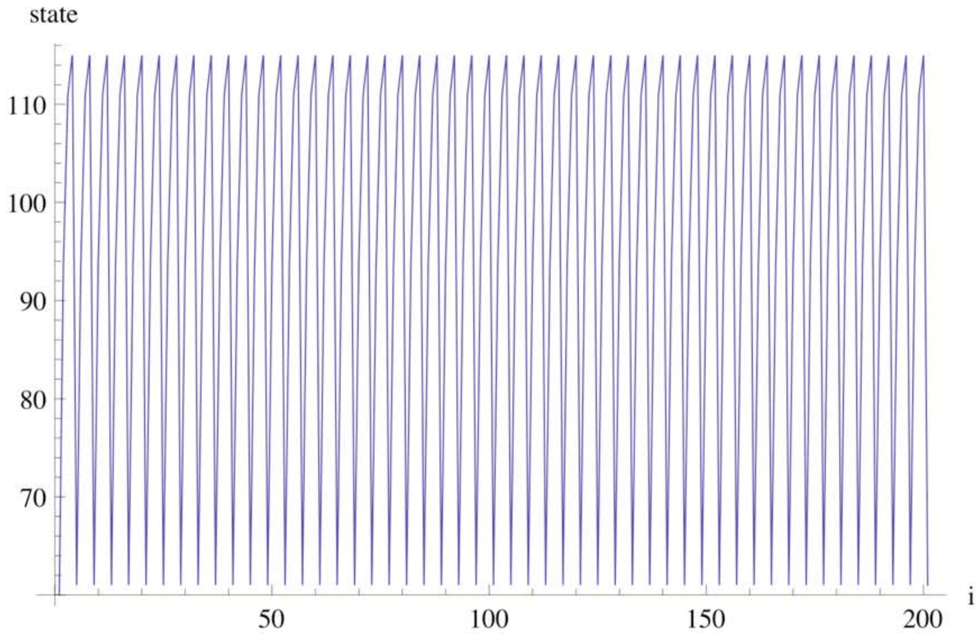
Weak

- In the following example, all the agents are oscillating without locking

Example: Weak Coupling



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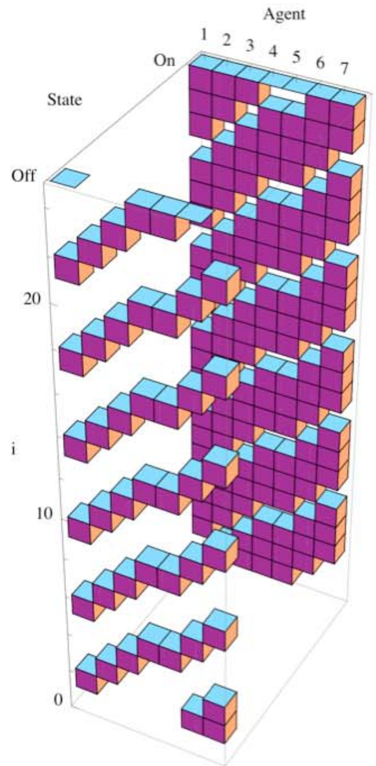

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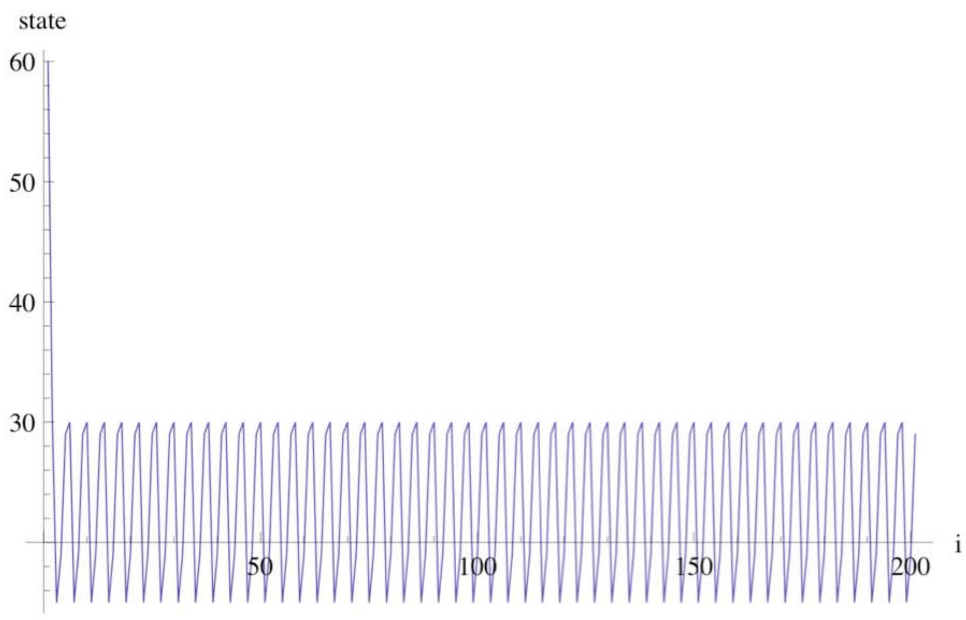
Example: Weak Coupling

- After Locking agent 1, the system is still oscillating



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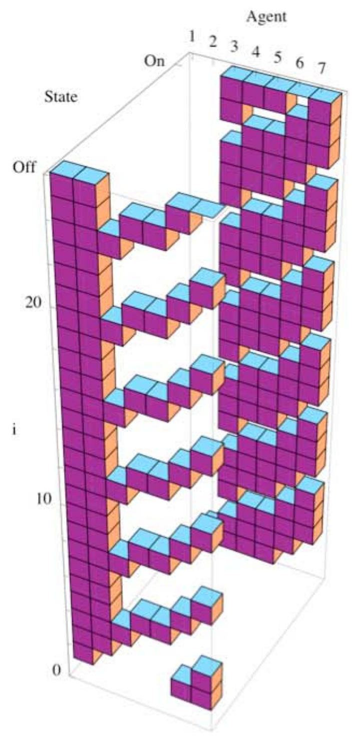

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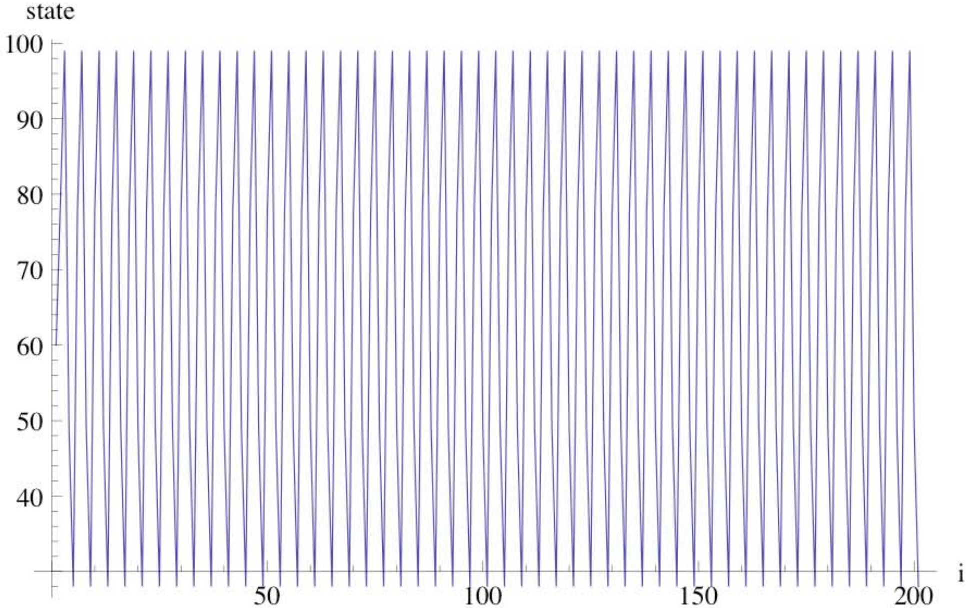
Example: Strong Coupling

- A strong coupled system can be obtained by reassigning node 3 to an AND rule.



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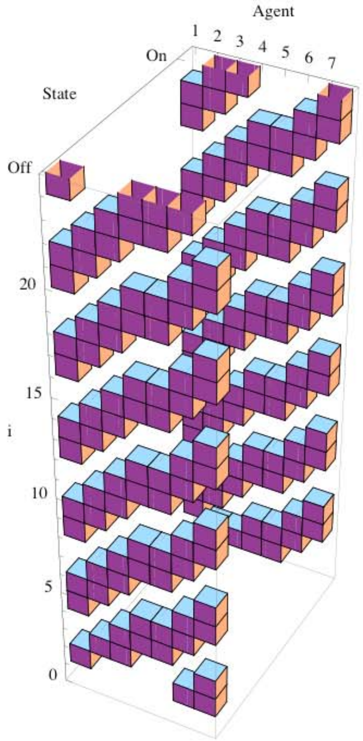

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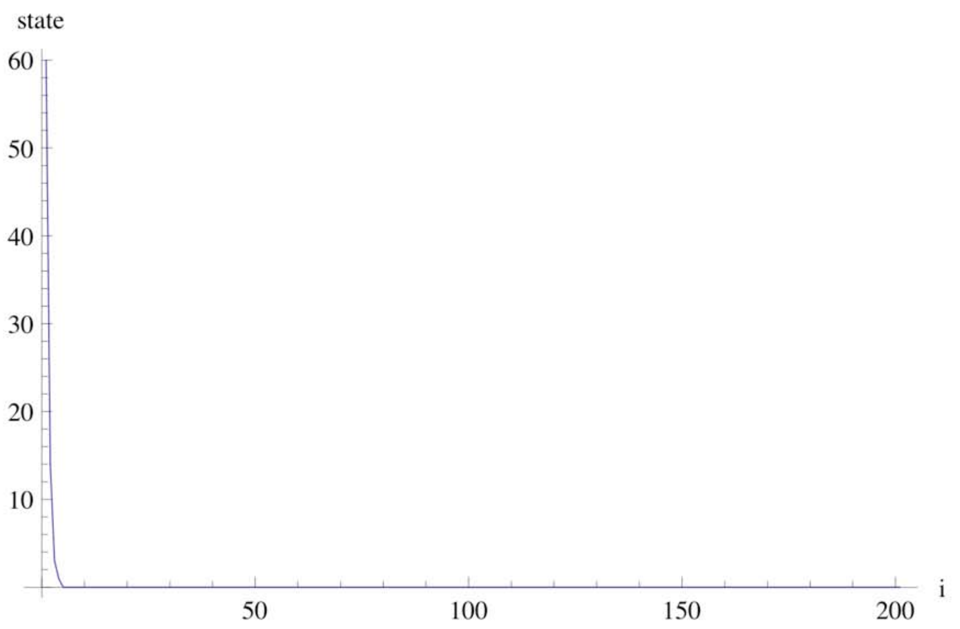
Example: Strong Coupling

- If node 1 is locked, the system stabilized:



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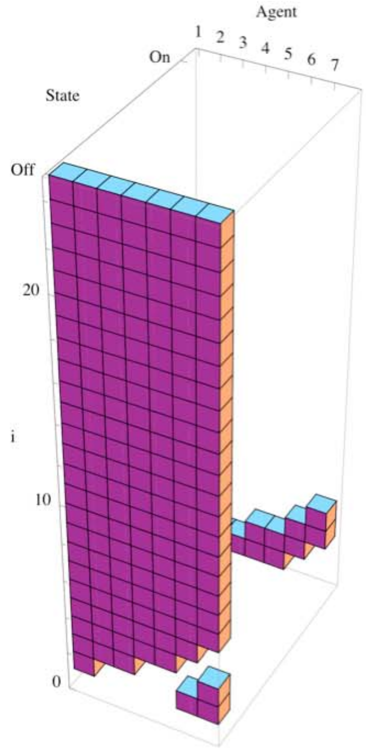

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Discussion

- INPRES could lock more agents than needed; this impact the performance of the system in terms of the usability.

- The local analysis of the coupling let us minimize the number of agents locked, thereby reducing the extend of the disabling effects of locking.

- If two systems are strongly coupled, it is possible to lock only one node to prevent instabilities or oscillations in the whole system.

- Also, as this introduces more locking options, it may be possible to choose which agents to lock based on aspects such as convenience (in terms of the connectivity).

- Clearly, this process introduces additional computational overheads, in terms of calculations, but results in a less disabled system.

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Future Work

We want to test our approach in the iSpace, a multi-room apartment, which provides a flexible testbed for future digital-home technology.

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Future Work

- Also, we are characterizing the range of usability of a given system, in terms of the number of cycles and the number of agents (density of cycles)

- In the last years, the area of social networks has been shown to provide, together with multi-agent systems, useful tools to analyse and represent our world as a complex socio-technical system .

- Economies, culture, companies and societies can be seen as distributed autonomous systems, with complex time-dependant rules and dynamic interconnections.

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Future Work

- Work has been done in this direction, in particular trying to analyze and destabilize terrorist networks, finding and removing the leaders of such organizations .

- In this domain, the presence of loops in the network could suggest redundant leadership and therefore a robust system; our strategy offers a way to analyze and reason about this problem, exposing redundant leaders in a given organization.

Acknowledgements

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