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 $\delta$ 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.
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).
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.
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:

If $\varphi_i$ then $s_i = 1$

If $\psi_i$ 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 \(\varphi_j\) or \(\psi_j\) of the pervasive autonomous agent \(A_j\) depends on the state \(s\) of the agent \(A_j\).
where \( f(A) \) is the \textit{functionality of the node A}, defined as the number of nodes reachable from the node \( A \) in the \textit{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) ![Image](a.png)  
(b) ![Image](b.png)  
(c) ![Image](c.png)  
(d) ![Image](d.png)
Background Theory

INPRES

• Unstable behaviour of the system with 40 cycles:
Background Theory

INPRES

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

\[
\begin{align*}
C &= \{c_i\} \\
A &= \min_{A \in c_i} f(A_i)
\end{align*}
\]

If the user interacts with agent \(A' \in c_i\):

- \(A'\) is locked
- \(A\) is unlocked

Find the set of all the cycles in the IN

For each cycle \(c_i\) lock the agent \(A\) that satisfy

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

In the following example, all the agents are oscillating without locking.
Example: Weak Coupling

(a) Graph showing state vs. i.

(b) 3D graph illustrating agent states.
Example: Weak Coupling

- After Locking agent 1, the system is still oscillating
Example: Strong Coupling

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

- If node 1 is locked, the system stabilized:

(a)

(b)
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.
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.
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.
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

Victor Zamudio would like to acknowledge the support of the National Mexican Council for Science and Technology (CONACyT).