Law-Governed Multi-Agent Systems: From Anarchy to Order

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Example: An ad hoc Mission Team

Actuation
Coordination—to ensure mutual exclusion, say.

Monitoring + control = management

Necessary: rules of engagement that are complied with by all
The General Problem with Wireless Multi-Agent Systems (MASs)

- A wireless MAS consists of inherently autonomous agents, which are increasingly heterogeneous, and thus anarchical.

- And anarchical systems tends to be unmanageable, unsafe and insecure—this is particularly true under wireless communication.

- But the anarchy of a MAS—like that of a social system—can to be tamed by a regulatory mechanism, that imposes appropriate laws over it.

- I will discuss some of the principles of such regulation, and their realization by Law-Governed Interaction (LGI), recently released via http://www.moses.rutgers.edu/
Principles of Regulation of Multi-agent systems

- A law of a MAS can only be about the interaction between agents—not about their internal behavior.
- **High expressive power**: a law needs to be, in particular:
  - **Stateful**—sensitive to the history of interaction, and
  - **Proactive**—able to force actions to be carried out.
- Laws should be **enforced**, so they can be relied upon to be universally observed.
- Enforcement of laws should be **decentralized**—for scalability—and it should be **secure**.
- Multiplicity of laws needs to be supported, and different laws should be able to **interoperate**, and be organized into "conformance hierarchies".
- This goes far beyond conventional access control (AC)
Conventional Access-Control (AC): Two Approaches

Recipient-centric AC

Centralized AC (with state)

Legend:
P--- Explicit statement of a policy.
I--- Policy interpreter
S--- the interaction-state of the community

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Limitation of Recipient-Centric AC

- The state of the sender is not available to the policy of the recipient.
- No secure way to ensure that all recipients employ the same policy.
- Thus, no support is provided to coordination or management.
Limitation of Centralized Access-Control

- Lack of scalability — which, for stateful policies, cannot be achieved by replication.
- Centralization provides distorted representation of the distributed interaction.
- Impractical for wireless communication
Distributed Law-Enforcement under LGI

\[ \text{actor} \xrightarrow{\text{Move}(2)} \text{controller} \]

\[ \text{controller} \xrightarrow{\text{Move}(2)} \text{moved(2)} \]
The local nature of laws, and their global sway

- A law must be local—to enable decentralized enforcement—although its sway should be global.
- The locality of LGI laws.
  - Laws deals explicitly only with local events—such as the sending or arrival of a message.
  - the ruling of a law for an event \( e \) at agent \( x \) is a function of \( e \), and of the local control state \( CS_x \) of \( x \).
  - a ruling can mandate only local operations at \( x \).
- Under LGI, locality does not reduce the expressive power of laws!!
On Interoperability and Hierarchy of Laws

- A large and complex MAS is likely to be governed by multiple laws that regulate different parts of the MAS, or different kinds of activities in it.

- This requires laws to be able to interoperate, and be organized into hierarchies.

- A case in point is the phenomenon of Coalition...
Governance of Dynamic Coalitions (a Case Study)

Consider a coalition $C$ of groups $\{G_1, \ldots, G_n\}$, governed by a coalition-law $L_C$—assuming that the participation of each $G_i$ in this coalition is governed by its own internal-law $L_i$.
The Main Challenges

- The ensemble \( \{L_C, L_1, \ldots, L_n\} \) of laws must be consistent, and its formulation and evolution must be flexible, in the following sense:
  - New groups should be able to join the coalition, and leave it, dynamically—subject only to the coalition law \( L_C \)
  - It should be possible to formulate the individual laws \( L_i \), and to change them, dynamically, independently of each others.

- The decentralized enforcement of this law ensemble—including \( L_C \)
The LGI-based Coalition
(Hierarchical Organization of Laws)

Given $L_c$, each group $G_i$ would formulate its own law $L_i$ as subordinate to $L_c$ and thus, in conformance to it—this is done independently of other local laws $L_j$.

$L_i$—defined as subordinate to $L_c$—is built to conform to it.
The LGI-based Coalition
(Interoperability within a Hierarchy)

Let us focus on the interoperability between $G_1$ and $G_2$
Interoperability within a Hierarchy

\[ \text{imported}(x, L_2, m) \]

\[ \text{export}(m, y, L_1) \]

\[ \text{imported}(x, L_2, m) \]

\[ \text{export}(m, y, L_1) \]
Conclusion

- As long as a wireless MAS is homogeneous, the conventional access control is quite satisfactory for it.
- But an heterogeneous MAS requires the more sophisticated LGI-like control—particularly if it needs to be managed, and if it requires coordination.
Questions, 
Or Lunch?
The Conventional Compositions-Based Approach...

- Given the set \( \{P_C, P_1, \ldots, P_n\} \) of policies (by “policy” I mean, the traditional, less general, analog of a law)

- Compose all these policies to a single one:
  \[ P = \text{composition} (P_C, P_1, \ldots, P_n) \]

- Provide \( P \) to a central controller, which will mediate all coalition-relevant interactions.
... and its Problematics

- Composition is *computationally intractable* (McDaniel & Prakash 2002).
- It is unlikely for arbitrary, and independently formulated, policies to be consistent—so such composition is likely to simply fail.
- **Inflexibility**: any change of a single $P$—and any change in membership—requires re-composition of the entire ensemble, and is likely to require changes in other local policies, to achieve consistency.
- Our solution rests on: hierarchy & interoperability
A Beta version of LGI is to be released in May 2005, via: http://www.cs.rutgers.edu/moses/
- This release would not include law-hierarchy, and hot-update of laws

Papers about this subject are available through my website: http://www.cs.rutgers.edu/~minsky/

LGI is very much work-in-progress. There is much work to be done, on both the LGI mechanism itself, and on its various applications and implications.

And I hope some of you will take a look at these issues.
Roles: each $E_i$ should have its director $D_i$ (*); and the coalition $E$ a director $D_E$. A director $D_i$ can mint $E_i$-currency $S_i$ needed to pay for services provided by $E_i$ and it can give $D_E$ some of this currency. A director $D_i$ can mint $E_i$-currency $S_i$ needed to pay for services provided by $E_i$ and it can give $D_E$ some of this currency.

$S_i$ Currency cannot be forged—by anyone!

A director $D_2$ can distribute its $S_i$ budget among agents at its enterprise.

Servers at $E_1$ can send their earning in $S_i$ back to their director.

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Beyond Access Control (AC)

- Access control is concerned with “who has the right to do what to whom”
- But we are also concerned with the dynamic process of interaction.
  - For analogy: traffic laws require not only than the driver has a license, but also that he stops on a red light.
- A regulatory mechanism that
Distributed Law-Enforcement under LGI

\[
\begin{array}{c}
\text{actor} \quad \text{controller} \\
\text{agent } x
\end{array}
\]

\[
\begin{array}{c}
\text{Move(2)} \\
\text{Moved(2)}
\end{array}
\]