



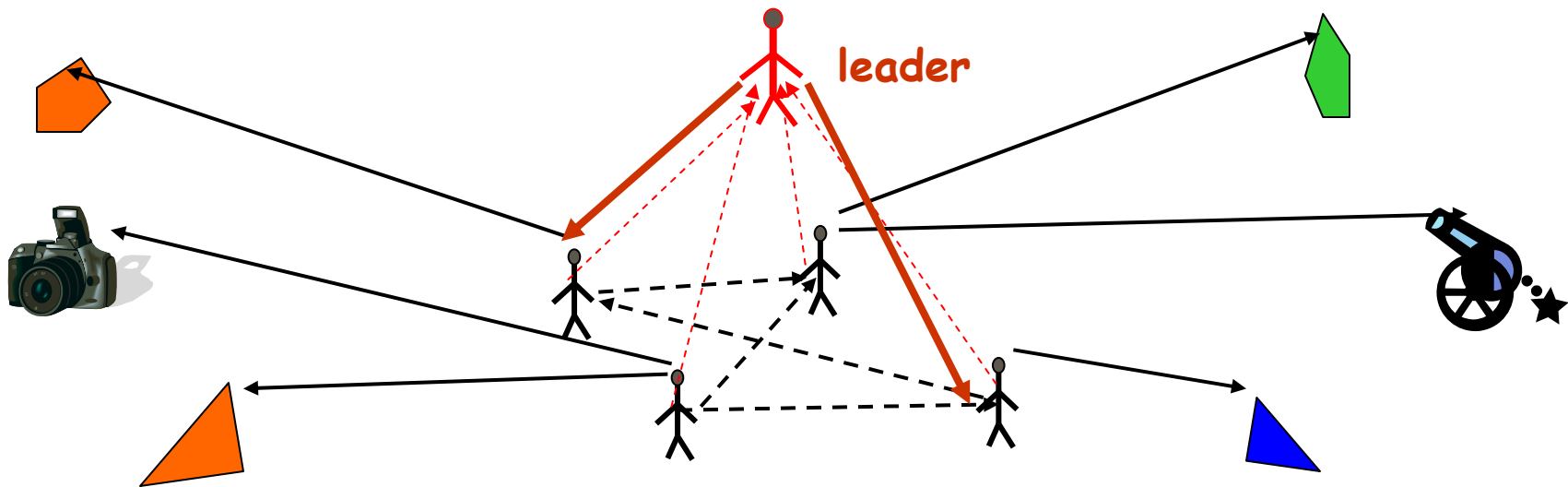
wireless

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)

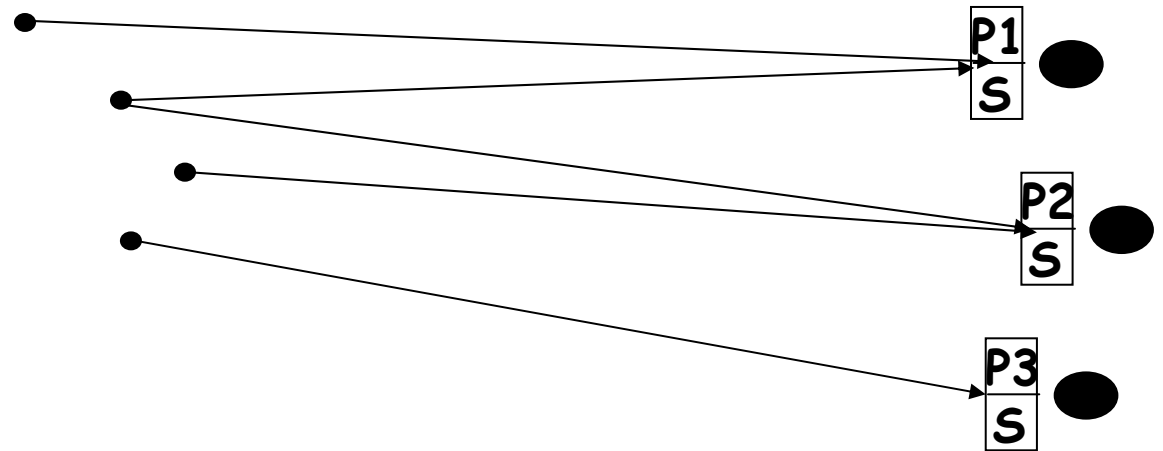
- A wireless MAS consists of inherently autonomous agents, which are increasingly heterogeneous, and thus anarchical.
- And anarchical systems tends to be **unmanageable, unsafe and insecure**—this is particularly true under wireless communication.
- But the anarchy of a MAS—like that of a social system—can 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

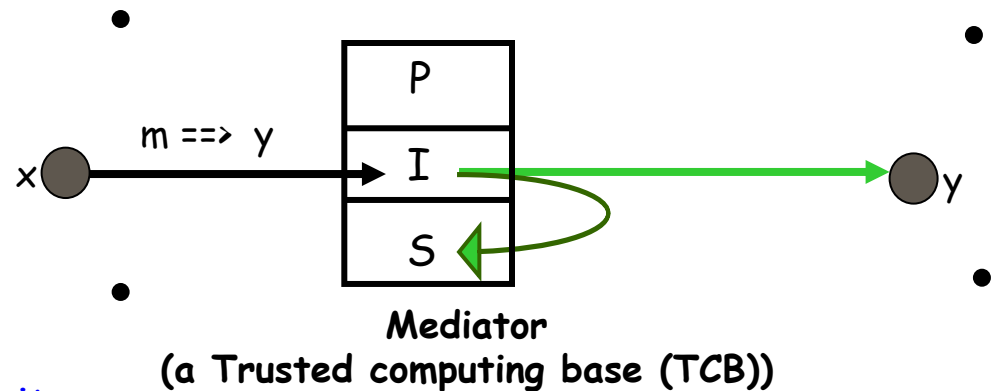
- A law of a MAS can only be about the interaction between agents—not about their internal behavior.
- High expressive power: a law needs to be, in particular:
 - Stateful—sensitive to the history of interaction, and
 - Proactive—able to force actions to be carried out.
- Laws should be enforced, so 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)



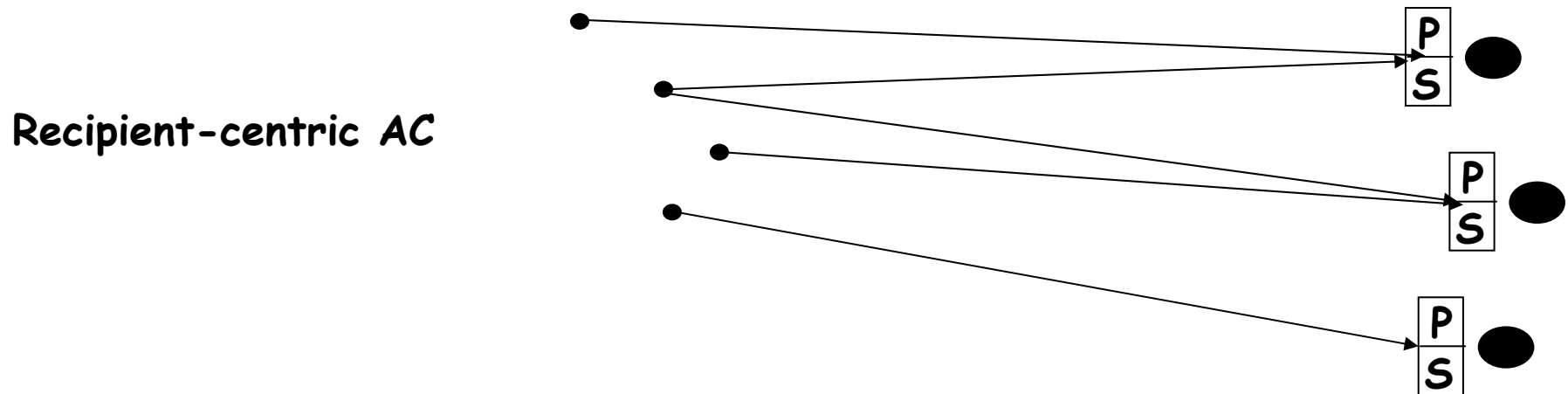
Legend:

P---Explicit statement of a policy.

I--- Policy interpreter

S---the interaction-state of the community

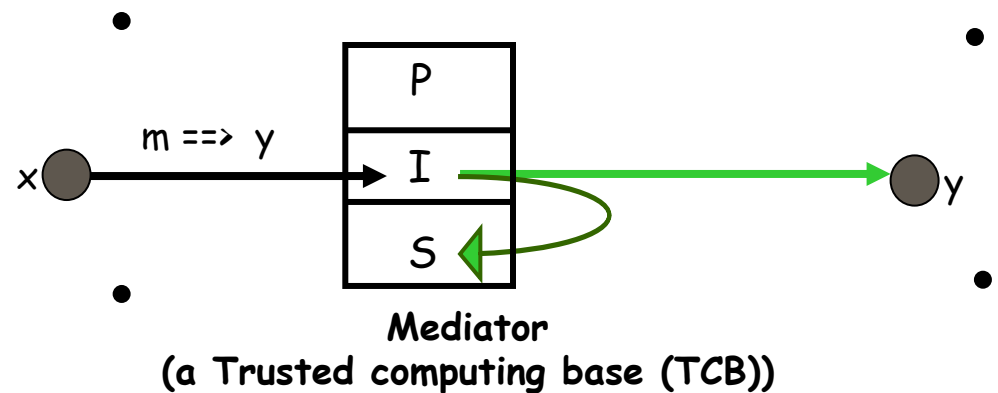
Limitation of Recipient-Centric AC



- 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.

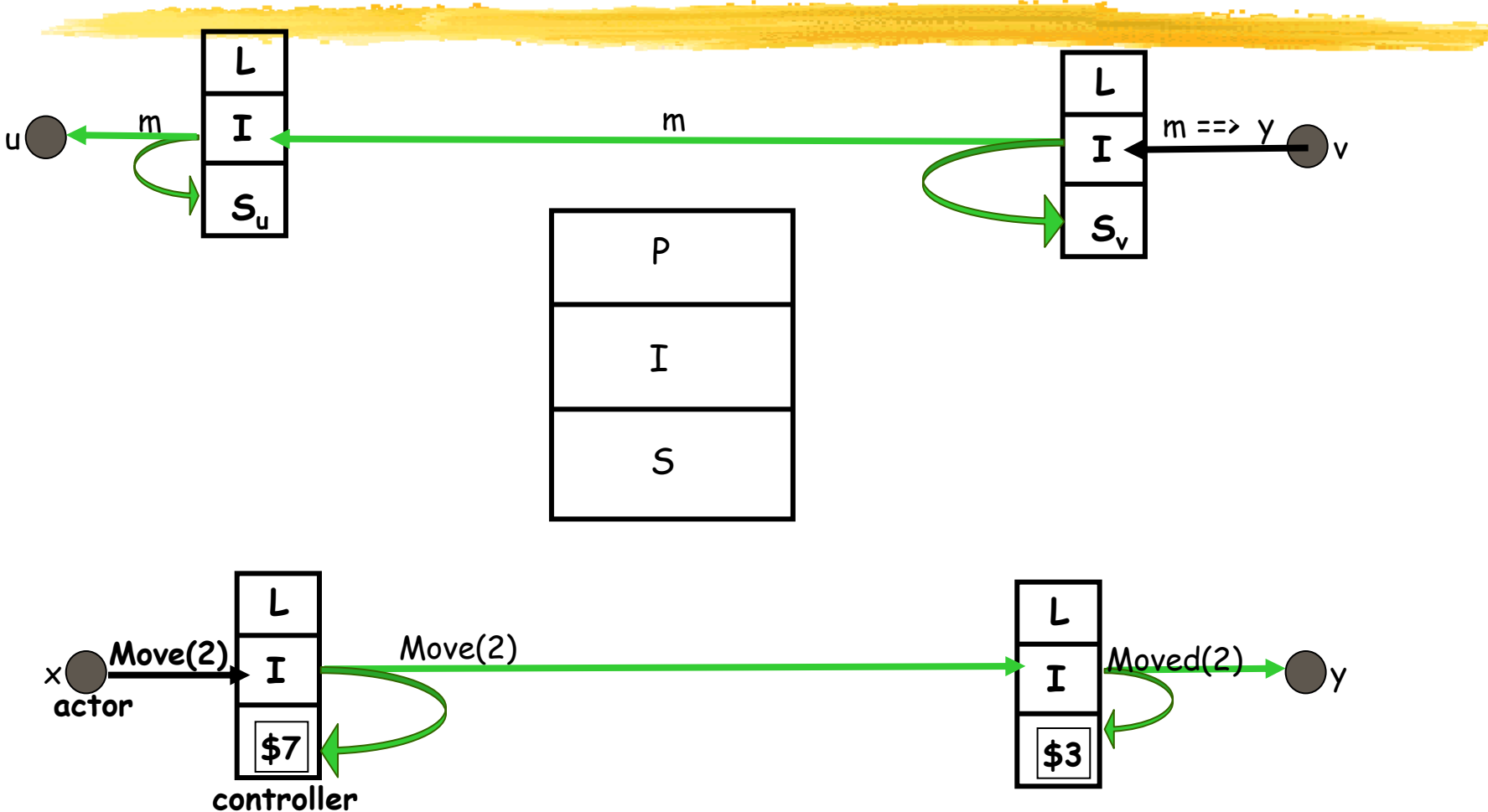
Limitation of Centralized Access-Control

Centralized AC (with state)



- 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



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!!

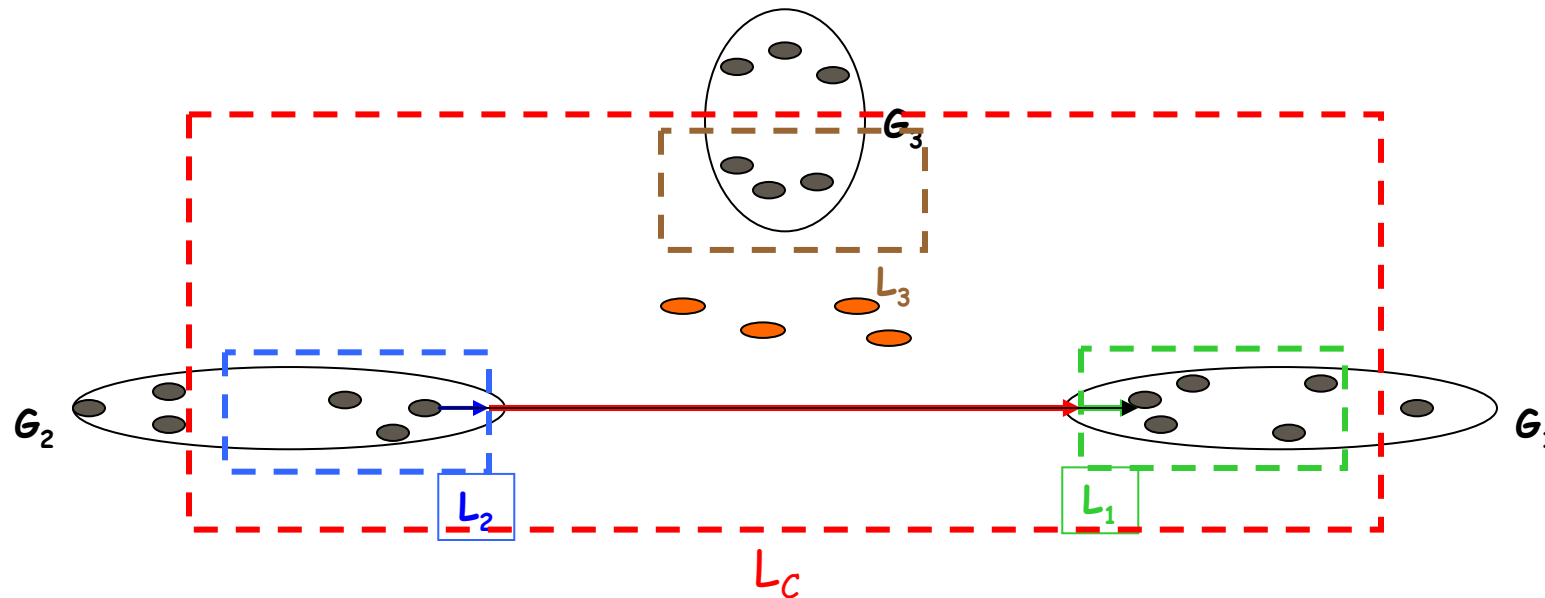
On Interoperability and Hierarchy of Laws



- A large and complex MAS is likely to be governed by multiple of 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 $\{G_1, \dots, G_n\}$, 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 .

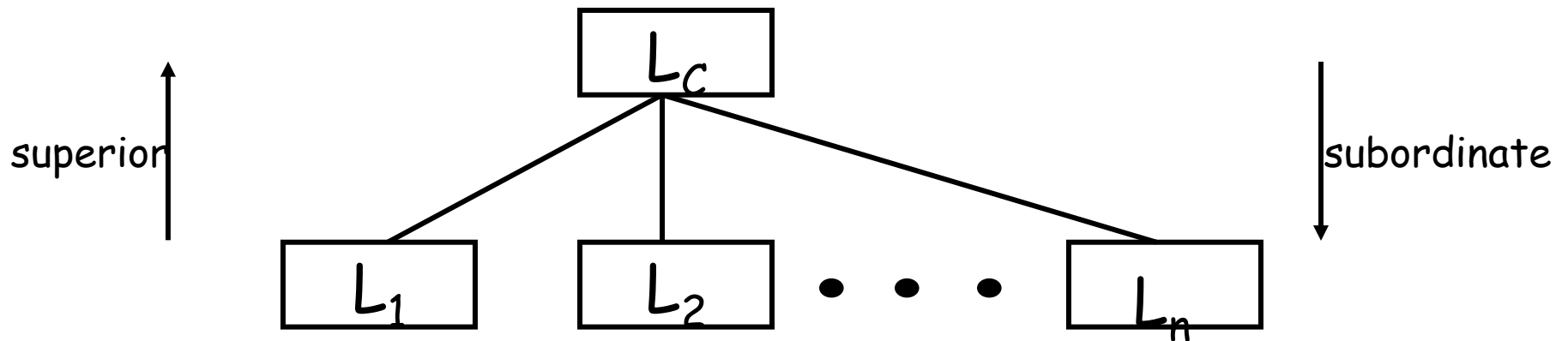


The Main Challenges

- The ensemble $\{L_C, L_1, \dots, L_n\}$ 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)

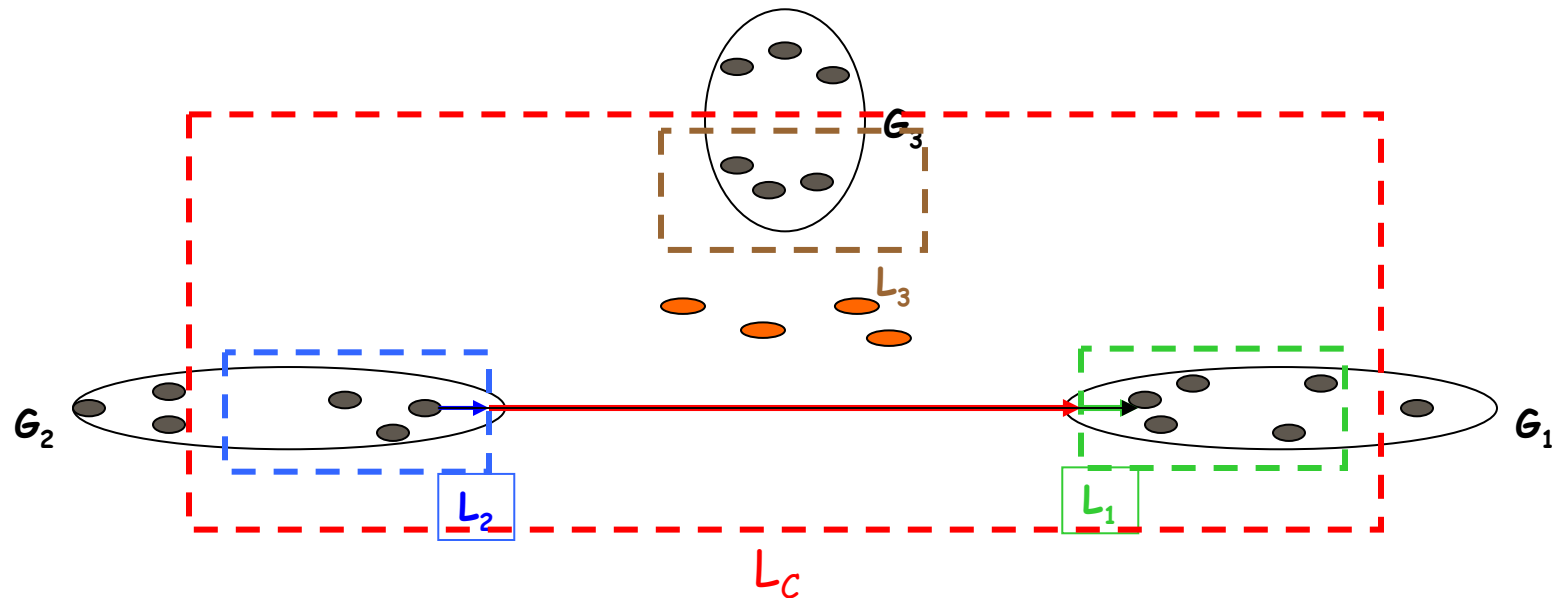
- Given L_c , each group G_i would formulate its own law L_i as subordinate to L_c and thus, in conformance to it-this is done independently of other local laws L_j



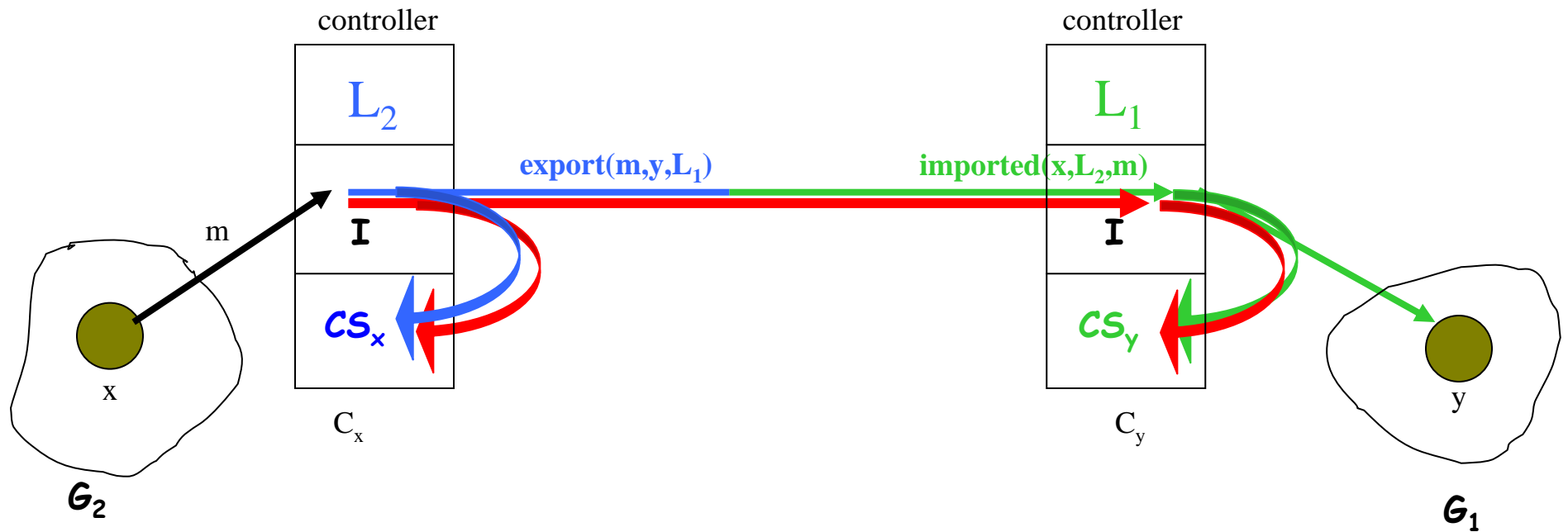
L_i -- defined as *subordinate* to L_c -- is built to *conform* to it.

The LGI-based Coalition (Interoperability within a Hierarchy)

- Let us focus on the interoperability between G_1 and G_2



Interoperability within a Hierarchy



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 $\{P_C, P_1, \dots, P_n\}$ of *policies* (by "policy" I mean, the traditional, less general, analog of a law)
- Compose all these policies to a single one:
 $\{P = \text{composition}(P_C, P_1, \dots, P_n)\}$
- 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_i --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

Conclusion (cont)



- 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.

Policies Governing a Virtual Enterprise (an Example)

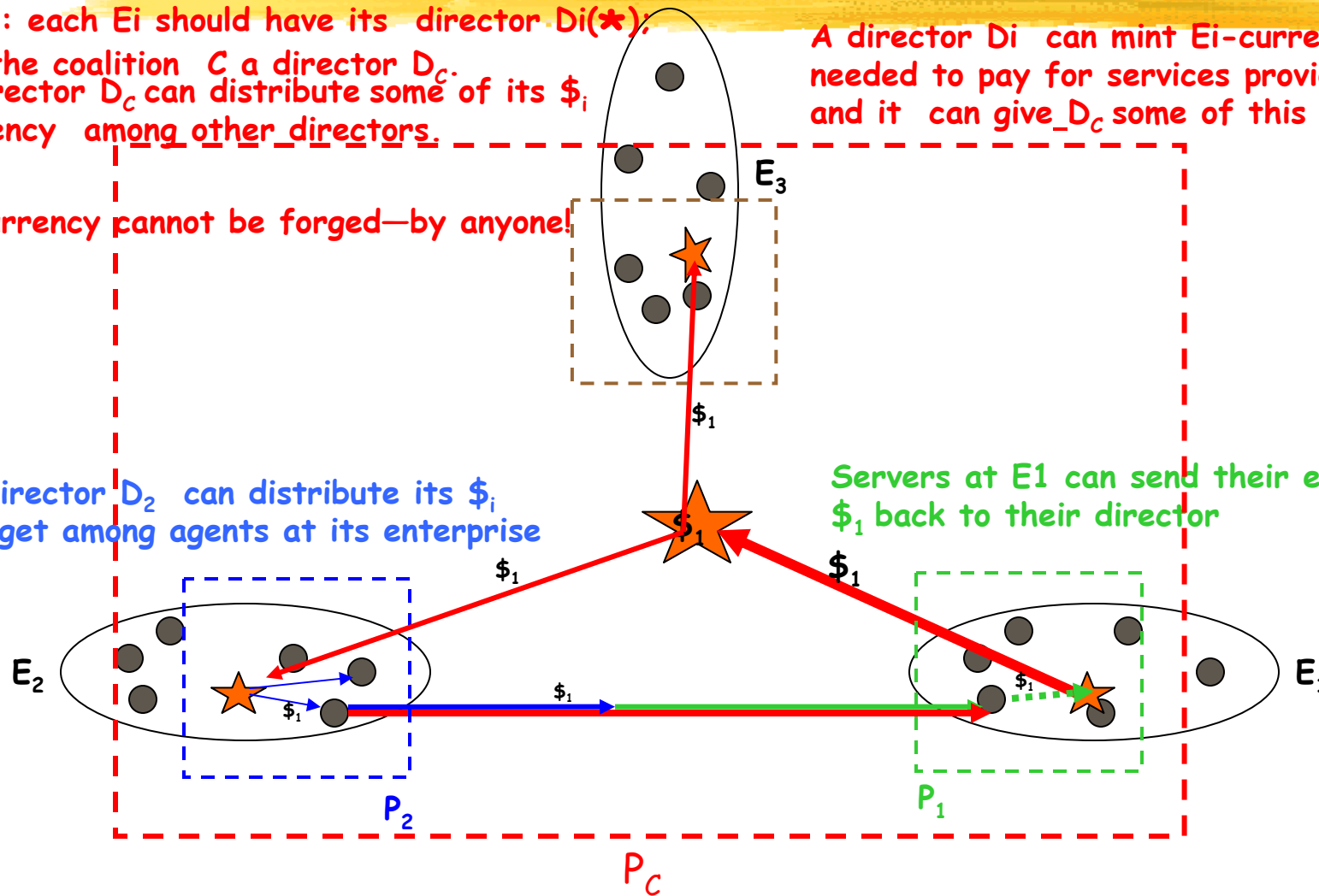
Roles: each E_i should have its director $D_i(\star)$,
and the coalition C a director D_C .
A director D_C can distribute some of its $\$i$
currency among other directors.

A director D_i can mint E_i -currency $\$i$,
needed to pay for services provided by E_i
and it can give D_C some of this currency

$\$i$ Currency cannot be forged—by anyone!

A director D_2 can distribute its $\$i$
budget among agents at its enterprise

Servers at E_1 can send their earning in
 $\$1$ back to their director



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 that the driver has a license, but also that he stops on a red light.
- A regulatory mechanism that

Distributed Law-Enforcement under LGI

