Classifying Complex Systems

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Complexity

- Algorithmic complexity: the length of the minimal algorithm that generates a sequence: maximal for sequences without structure.
- Computational complexity: how the resources required to solve members of a class of problems grows with problem size.
- System complexity: what we are concerned with here.

Complex Systems (1)

- A *complex system* can be defined as one that *cannot* be successfully approximated as a collection of constituents each responding independently to the situation jointly created by all (Auyang 1999).
- Counterexample: a molecular gas.
- When this is not possible, understanding requires the identification of intermediate levels of structure.
- Attempts to devise a general theory of complex systems have not been successful.

Reference:

- Auyang, S.B. (1999) *Foundations of Complex-system Theories In Economics, Evolutionary Biology, and Statistical Physics*. Cambridge University Press.

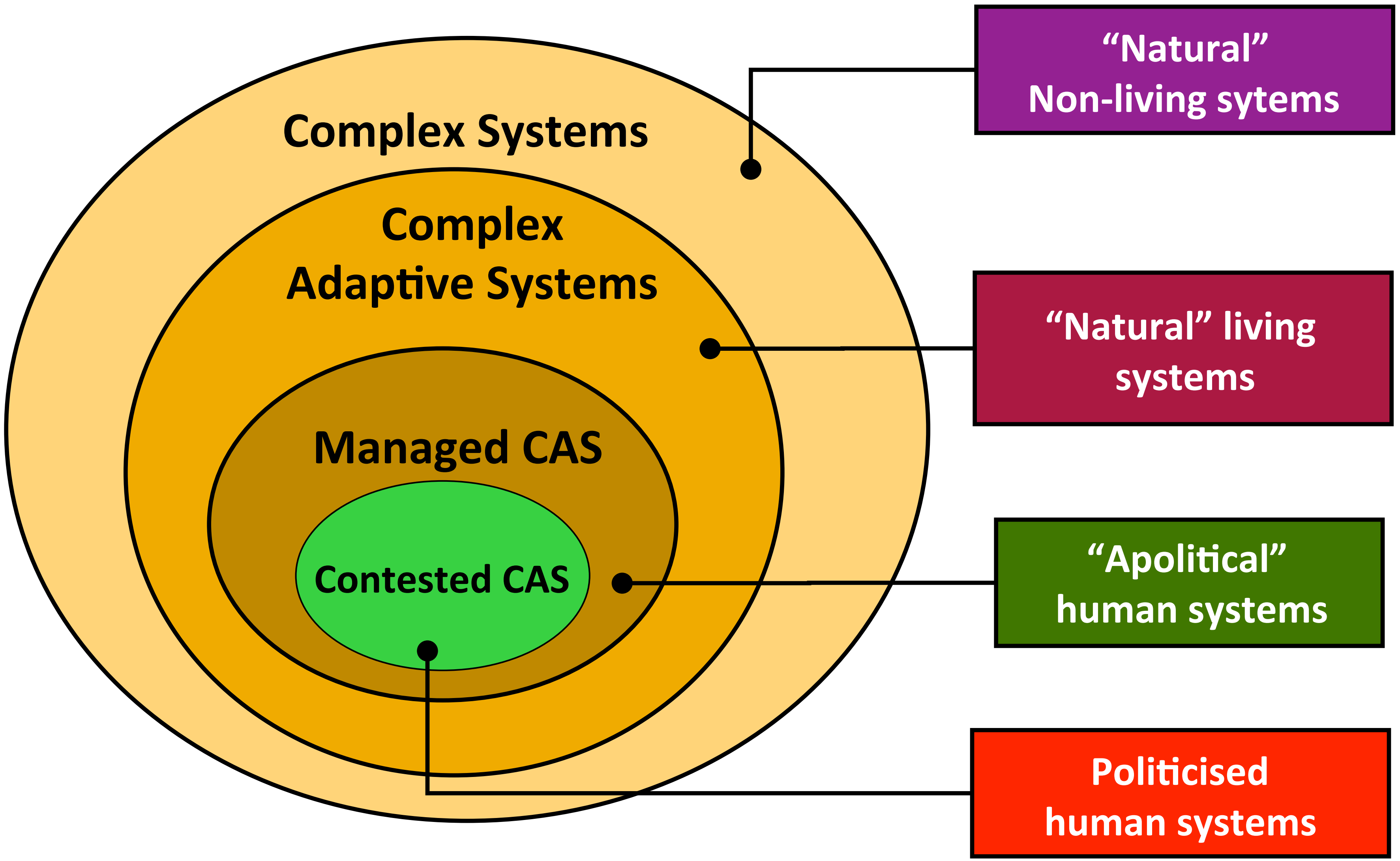
Complex Systems (2)

- Complex systems typically show a cluster of symptoms and features:
  - Statistical symptoms in observed variables: e.g. leptokurtic distributions, heteroskedastic time series (Moss 2002; LeBaron et al. 1999)
  - Descriptive features: e.g. decentralisation, non-ergodicity, far-from equilibrium dynamics, multiple heterogeneous interacting system components, micro/macro structure interactions (Arthur et al. 1997)
- Alternative goal to that of a general theory: a principled taxonomy of complex systems, linking taxonomic classes to the appropriate formal and theoretical tools.
- The properties of both constituents and intermediate structures (spatial properties and relations, networks, basins of attraction…), can be used to define classes of complex system. One way of doing so is outlined here.

References:

- Arthur, W.B., Durlauf, S. N. and Lane, D. (1997) Introduction. In Arthur, W. B., Durlauf, S. N. and Lane, D. (eds.) *The Economy as an Evolving Complex System II*. Reading, MA: Addison-Wesley.
- LeBaron, B., Arthur, W. B. and Palmer, R. (1999). Time series properties of an artificial stock market. *Journal of Economic Dynamics & Control* 23, 1847-1516. (1999)
- Moss, S. (2002). Policy analysis from first principles. *Proceedings of the National Academy of Sciences of the United States of America* 99(suppl. 3), 7267-7274.

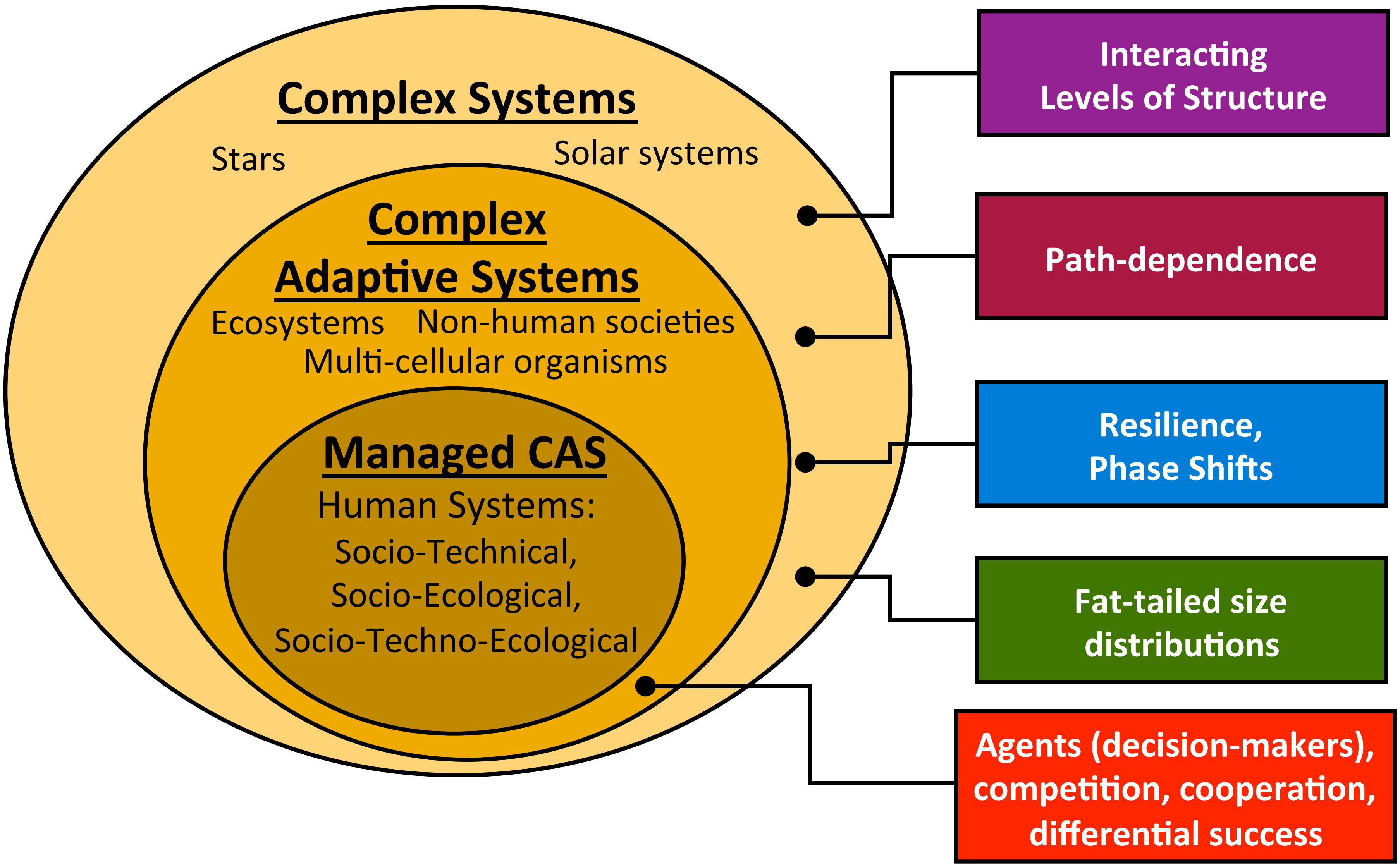
Classes of Complex Systems (1)



Multi-level complex systems

- A complex system in which there are components that are themselves complex systems.
- Examples:
  1. planetisimals in a developing solar system;
  2. the lipid globules that arise in certain synthetic biology and abiogenesis experiments;
  3. firms within an economy.
- Example 1 is not a complex *adaptive* system (CAS); example 3 is a CAS; example 2 is borderline.
- Any ecosystem or social system is both a multi-level complex system and a CAS – but *models* of them need not be.

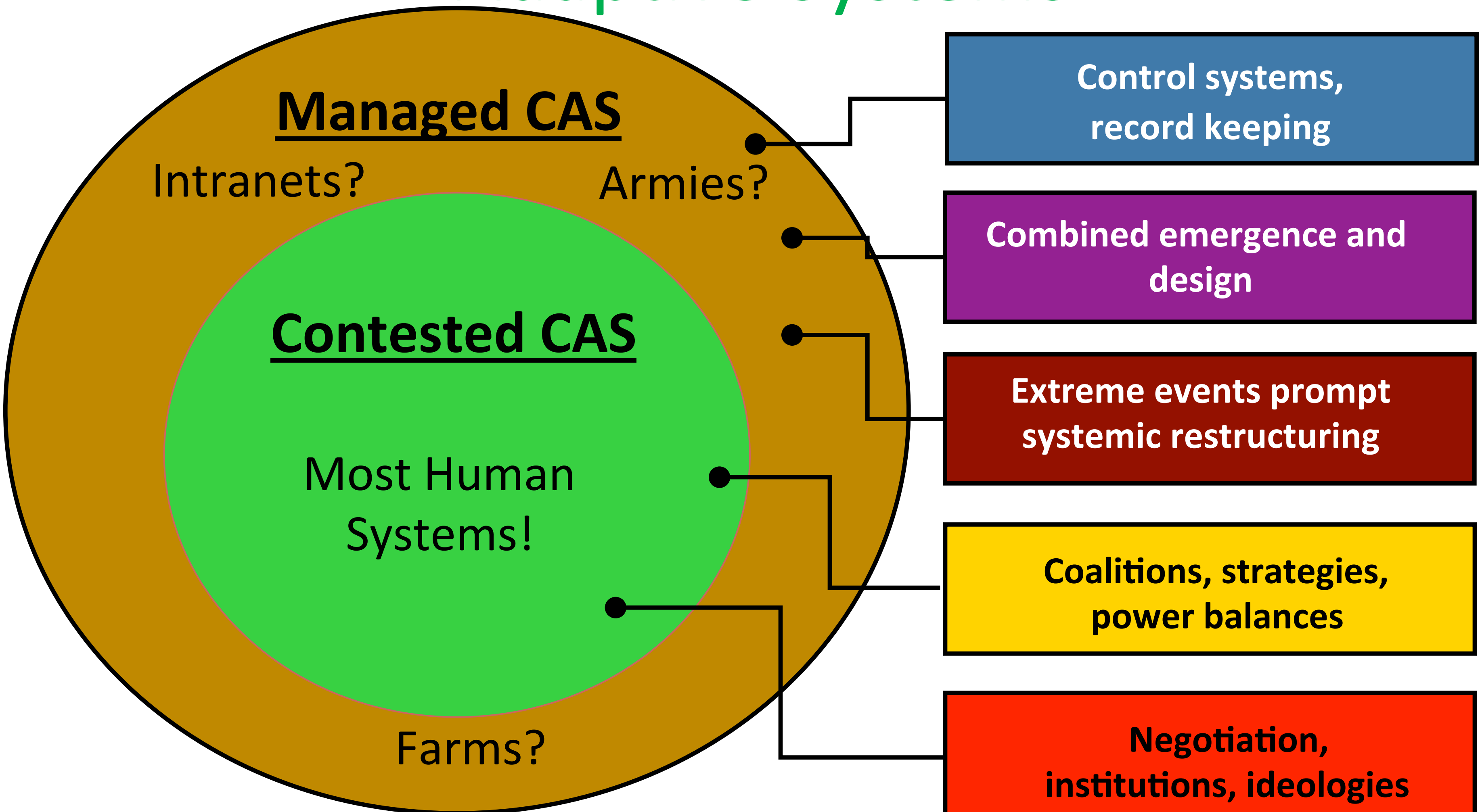
Complex System Classes (2)



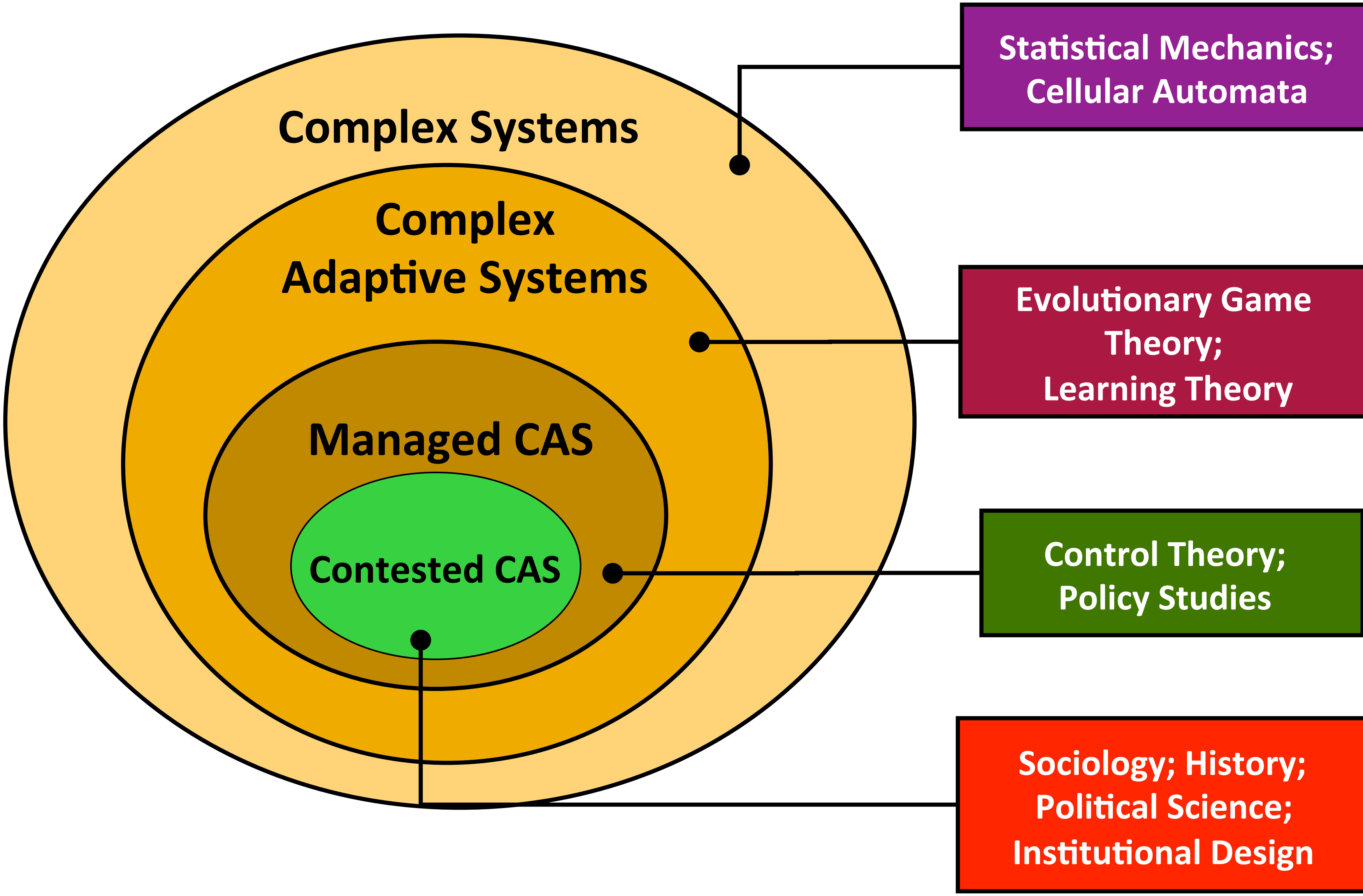
Why Socio-*Techno*-Ecosystems

- Social-Ecological System (SES):
  - Human societies both depend on and transform ecosystems.
  - Social and ecological systems need integrated, multi-scale study.
- However:
  - The SES literature largely ignores the effects of *technological* change on ecosystems.
  - Technical knowledge tends to *accumulate* and *spread*.
  - The acceleration of technological change has fundamentally changed interactions between processes at different spatial and temporal scales:
    - Transport and communications
    - Armaments
    - Energy use (fossil fuels)

Managed and Contested Complex Adaptive Systems



Complex Systems: Theoretical Domains



Agent-based models as theoretical testbed for complex system classification

- Distinctions drawn in the initial taxonomy presented depend mainly on properties of system *components*, and of those components' *interactions*.
- Agent-based (or in ecology, "individual-based") models: are generally *themselves*, at some level of abstraction, complex systems: control is distributed among the agents, the overall path of a run emerges from their interaction.
- However, depending on how agents are implemented, they may or may not themselves be *multi-level* complex systems.
- Rarely if ever are they managed (or contested) complex systems: we have little idea how to devise agents that can critique the systems within which they operate.

Varying Agent Implementation

Systematically varying agent implementation (decision trees, neural nets, production systems) and capabilities (trial and error, imitation, episodic memory, induction, planning) might:

- produce complex systems with properties ranging more widely across the taxonomy outlined;
- thus enabling detailed comparison of the dynamics of artificial systems ranging across that taxonomy;
- and suggesting hypotheses to be tested against the real-world complex systems being modelled.

Saving the World?

But…

- To save the world we need to understand *managed* and *contested* CAS.
- To model such systems, we need to model political decisions and actions.
- What should the model agents represent? (Individuals or groups/collectives/organisations?)
- What capacities do the agents need?
  - Planning?
  - Internal models of the system?
  - Internal models of other agents?