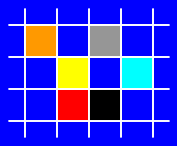
Co-Evolution of Computing Systems and the Social Sciences

Rob Axtell
Center for Social Complexity / George Mason University
Center for Social and Economic Dynamics / Brookings Institution
External Faculty Member / Santa Fe Institute

raxtell@gmu.edu



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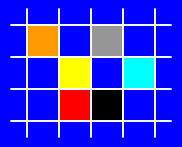
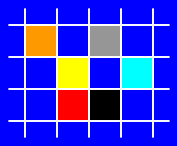
The *Hard* Sciences

- Increasingly, engineering is *challenging* because:
  - Projects are *large-scale* (multi-scale) and *complex*…
  - …with many *interacting* (smart) components…
  - …yet need to provide *robust* solutions.
- Social science has always been *difficult* because:
  - People are *heterogeneous*...
  - …and cognitively *complex* (but *sub-rational*)...
  - …and interact through *social networks* while…
  - …social regularities emerge (agent-level equilibrium *sufficient* but not necessary)
- Existing mathematical tools are inadequate



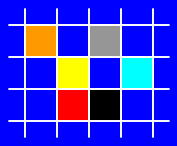
Historical Interface of Engineering and Social Science

- Supportive role of social science in engineering:
  - Psychology and cog sci for designing *user interfaces*
  - Economics and finance for bringing ideas to *market*
  - Political science and the law for appropriate *regulation*
- Supportive role of engineering in social science:
  - Technology makes social science research *more productive* (e.g., running a million regressions)…
  - …while facilitating *new kinds* of research (e.g., survey analysis via phone interviews or large scale simulation via high performance computing)



Few Strategies For Dealing with Complex Systems

- Homogeneous components, heterogeneous behavior: *statistical mechanics (physics)*
- Heterogeneous components, homogeneous behavior: *general equilibrium (economics)*
- 'Well-mixed' systems: *mean field theory*
- 'Scaleable' systems: *representative* components and *aggregation*



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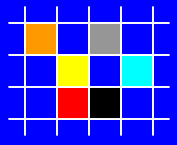
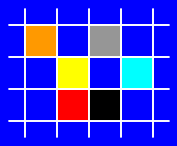
Computing Systems

- Used to resemble physical systems:
  - Homogeneous components
  - Single or few functions
  - Closely located ‘off’ switch with human backup
  - Dominant methodology: design and optimization
- But today increasingly resemble social systems:
  - Heterogeneous components
  - Diverse functionality
  - Maybe impossible to disable—single human or team not viable as backup
  - Dominant methodology: ???



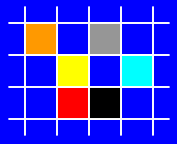
Need New Methodology for Large-Scale, Complex Systems

- Before we understood the whole by focusing on the parts (reductionism)
- Today we need to focus on the *interactions* between the parts to understand the whole
- We need a new science of the *emergence* of higher-level structure and function
- Need to replace *design* with *evolution*
- Replace *optimization* (best) with *regulation* (robust)



Beyond Optimization...

- In a world dominated by *analysis* and *first order conditions*, we care about the *optimum*
- *Nature* may be more concerned with performance *improvements* than optima (satisficing)…
- …and with *robustness* instead of extremes
- Solving for optimality...
  - …may lead to *brittle* solutions
  - …is vestigal from top-down, *centralized* mindset



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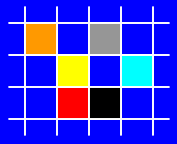
- Need to replace *centralized mindset*



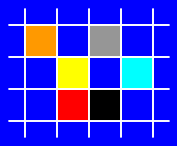
Constrasting Mindsets

1950s:

- *Global* information, *centralized* control
- Math. programming: *scalar* value function
- Firm as *rational* actor
- Neoclassical utility: constrained *maximization*
- Arrow-Debreu markets: *single* price vector
- *Decision* theory
- Conventional *AI*

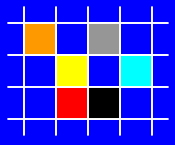
Now:

- Local info., networks, *distributed* control
- *Diverse* representations: competing world views
- *Many-agent* firms
- Behavioral economics: *multiple* selves
- *Decentralized* markets: heterogeneous prices
- *Game* theory
- DAI and *MAS*



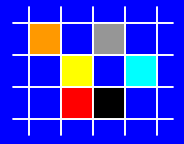
New Methodology: *Multi-Agent Systems (MAS)*

- *Autonomous* software objects (10-10^9)
- Agents have *local* state information, heterogeneous *goals* and *behavior*
- Agents interact on a *graph*
- Agents are *intelligent* but not perfectly rational; *adaptive*, not omniscient
- Agents learn socially and may *evolve*
- Agents may reach equilibrium, or not!



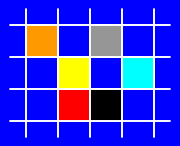
Agent Examples

- Engineering:
  - BT: software ‘ants’ to seek out network problems
- Epidemiology
  - Bioterror smallpox, SARS, avian flu: vaccinate or isolate?
- Traffic
  - 10^6 agent models of Albuquerque, Dallas, Portland, etc.
- Finance
  - High fidelity model of the NASDAQ (pre decimalization)
- Military
  - Combat simulations used to develop policy
- Anthropology
  - Microsimulation of the Anasazi (2000 BP - 700 BP)



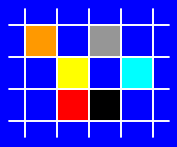
MAS Macroeconomics
(aka Macro from the Bottom Up)

- Full-scale model of the U.S. economy:
  - 150 million agents (workers, consumers)
  - 6 million firms (each firm a MAS)
- Calibration by micro-data (e.g. Census)
- How to run such a model?
  - 10^8 agents x 10^3 bytes/agent = 100 gigabytes
  - *O*(100) CPUs each with 1 GB memory
  - Parallelize into ‘artificial cities’
  - Intra-city communication faster than inter-city



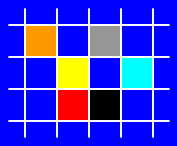
MAS are Social Systems

- Active research areas in MAS have direct analogs in social science:
  - communication/speech acts/linguistics
  - social networks
  - strategic behavior
  - learning
  - coalition formation
  - emotions
- Social science an alternative foundation for CS?
  - work of Peter Wegner on *interactive computing*



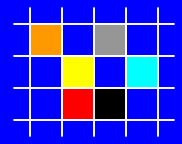
Co-Evolution of Computing Technology and Social Science

- Today:
  - Ideas from social science useful for computer science
  - Resulting technologies will enrich the social sciences
- This leads to *co-evolution*:
  - More powerful technologies make us better able to understand societies
  - This new understanding will lead to better computing technologies



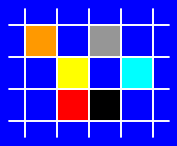
Example: IT as Social Systems

- Decentralized systems via *market-oriented programming*
- Automated *negotiation* and *allocation* via auction protocols (e.g., Dutch, English auctions)
- Better agent services by recognizing the *bounded rationality* of users
- Ultimately, *regulation* of IT systems by trust mechanisms and *enforcement* agents



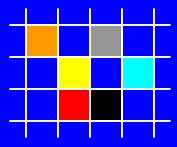
Example: Mechanism Design

- Within game theory, *mechanism design* yields environments with optimal welfare properties *iff* all agents are rational
- Example: Vickery (second price) auction
- Mechanism design widely adopted in IT
- Practical problems:
  - Mechanisms can be NP-hard to synthesize
  - Required (rational) behavior of agents may be NP-hard for them to figure out



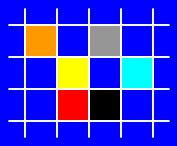
Example: Network Design

- Before, a network was explicitly designed
  - Single agent understood all states of network
  - Global optimization meaningful
- Today, network implicitly designed
  - Design of local protocols only
  - Macro performance emerges
  - Only local optimization meaningful
- Future, network evolves
  - Optimization gives way to adaptive changes



Summary and Conclusions

- Need *new methodology* for large-scale, complex systems
- Social science deals with *similar problems*
- *Agents* are the interface
- Meaningful *coevolution* of computing systems and social science underway
- *The future is wide open!*



Popular Accounts

- J. Rauch (2002) "Seeing Around Corners" *The Atlantic Monthly* (April)
- E. Bonabeau in *Harvard Business Review*
  - (2001) "Swarm Intelligence: A Whole New Way to Think About Business
  - (2002) "Predicting the Unpredictable"
- C. Bourges (2002) "Artificial Societies May Make Policy" *UPI* (May 12)
- M. Crichton (2002) *Prey* Harper-Collins
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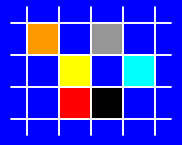
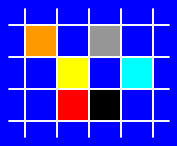


Decision Theory ⊂ Game Theory

- Decision theory:
  - Strategic behavior (‘games’) against possibly dynamic but non-adaptive opponent (Nature)
  - Nature represented stochastically (stationary)
  - Normative (what you ‘should’ do)
- Game theory:
  - Strategic behavior against strategic opponent
  - Opponent arbitrarily complex
  - Both *normative* and *positive* aspects
    - Weak empirical support for positive predictions



OR ⊂ MAS

- Operations research:
  - Characterize operation with *single* formal representation (mathematical or simulation model)
  - *Extremize* (scalar) value function (e.g., LP, DP) yielding...
  - ...*Normative* prescriptions for operating policies
  - More comfortable with decision theory than game theory
- Multi-agent systems:
  - Each *agent* has an internal representation…
  - …and acts to *improve* its value function
  - Key question: What *emerges* at the societal level?
  - Both *positive* and *normative* aspects
  - Game theory more useful than decision theory