AGENT-BASED SYSTEMS: MATHEMATICAL MODELS AND ARMY NEEDS

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Current understanding of agent-based systems is roughly at the level where understanding of physics-based mathematics was 150-200 years ago.

- Widely applicable quantitative models based on first/basic principles are not yet available.
- Development of such models requires modeling in complicated frameworks (equations on complicated, perhaps nonsmooth, manifolds?).
- Classical metrics (often rms-based) are insufficient. New metrics based on first/basic principles are needed.
- Analysis in “metrics” that are not mathematical metrics? ($L_p$ for $0 \leq p < 1$, other non-convex “metrics”?)
• Objective is to understand “emergent behavior,” that is, how simple rules of agents result in complex, seemingly intelligent network behavior.

• Once understood, optimize for human goals.

• Once understood and optimized, this behavior will probably no longer be called “emergent behavior”. 
Models adopted from physics-based areas risky, for example:

- Classical fluid-flow (Navier-Stokes-like) models for “flows” produced by agent systems have been proposed.

- Classical fluid-flow models are based on conservation of mass and Newtonian mechanics $F = ma$ (+ thermodynamics + electromagnetics).

- Why should agent-based systems be well modeled by conservation of mass and Newtonian mechanics?
• Models based on first/basic principles are needed.

  – Interactions in agent-based systems may lead to models similar to classical physics-based models (if so, great).

  – Interactions in agent-based systems may lead to models different from classical physics-based models.

  – In continuum limit, partial differential/integral equations on manifolds? Maybe, maybe not.

  – What is (are) the “metrics”? 
• Many layers
  — Physical substrate (computers, sensors)
  — Network
  — Human interactions
  — Human intentions

• Many disciplines
  — Human factors expertise may need to be included. ("What is the model?" and "What is the metric?" are not just questions about physical issues.)
ARMY INTERESTS IN AGENT-BASED SYSTEMS

• Army/DoD interests
  – Data fusion (large arrays of microsensors—sensorwebs)
  – Dynamics of sensor/actuator networks
  – Information mining (next step beyond data mining)
  – Cooperative information dynamics
  – Discovering collaborative behavior (detection of terrorist collaboration—asymmetric conflict)
  – Network tomography
  – Swarming; social behavior of robots
  – Design of networks for optimal performance under overload