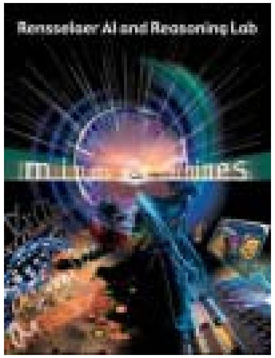
# Applications of Dynamic Systems Theory to Effects-Based Operations and Adversarial Modeling




**Paul Bello* & Mitch Mailman**

Department of Cognitive Science

Rensselaer Polytechnic Institute

*Air Force Research Laboratory – Information Directorate

**Paul.Bello@rl.af.mil  mailmm@rpi.edu**

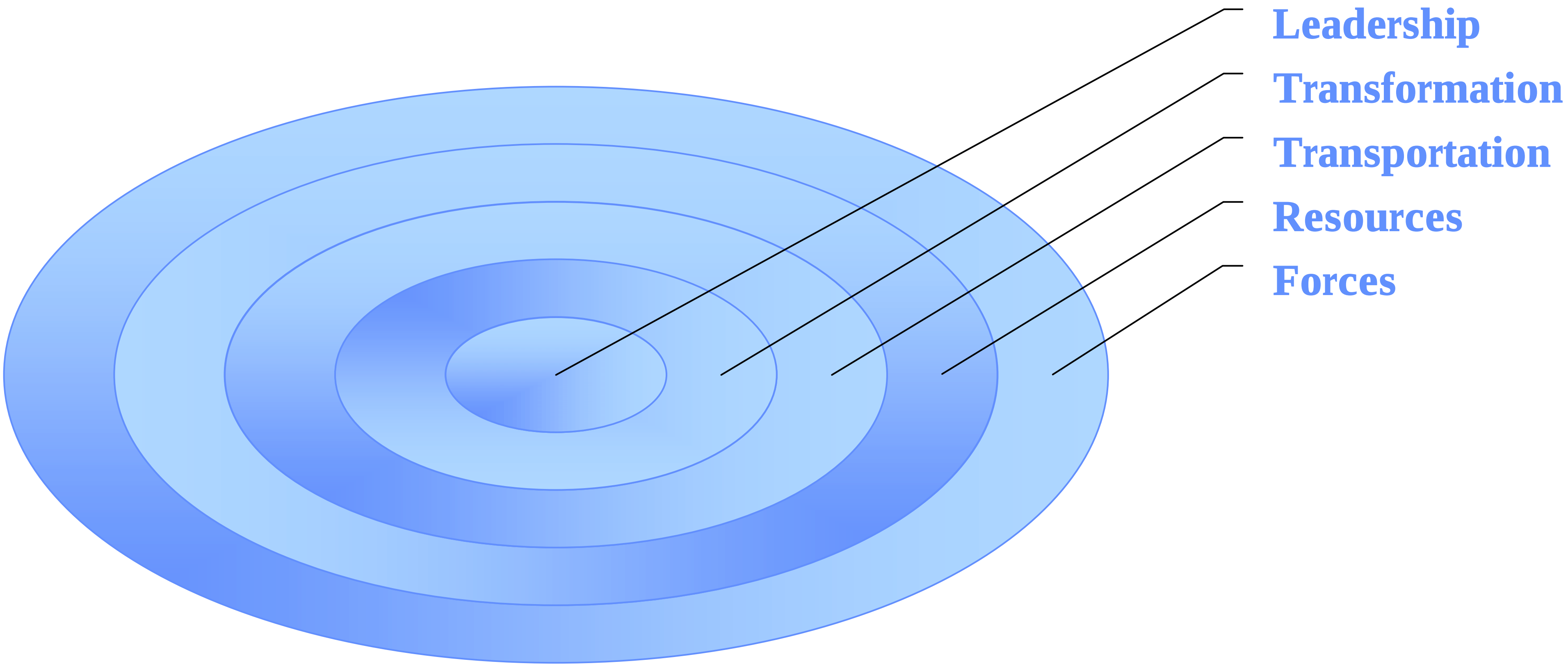
# Presentation Outline

- Introduction
  - EBO & System-on-System Engagements
  - New Challenges
- Formal Model
- Some Preliminary Results
- Discussion

# System-On-System Engagement: Objectives

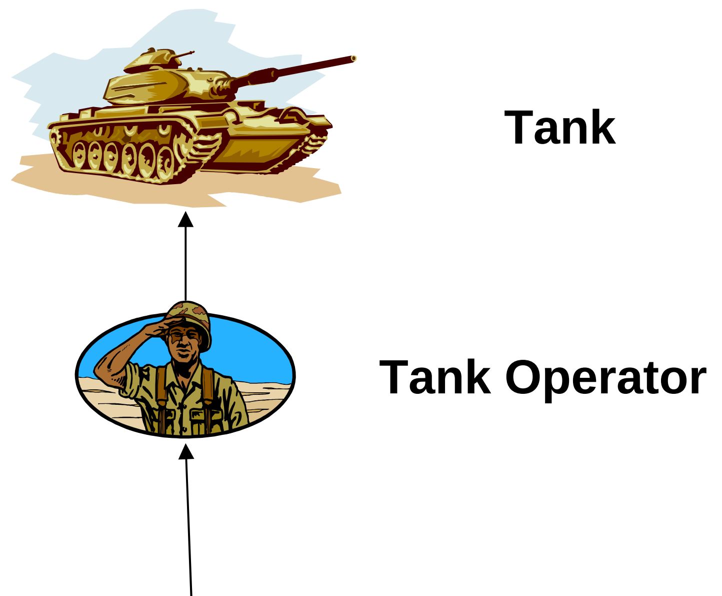
- To better understand, and subsequently model the vast number of interactions between entities in the battlespace.
- To produce a theoretical framework able to capture those interactions, bridging the realms of the physical (environment) and the cognitive (agent).
- To predict unintended consequences of action (both bad and good), and learning stimulus-response patterns of agents for exploitation (PSYOPS).
- To better understand organization in large-scale systems in order to more effectively disrupt our enemies while reinforcing our own organizations.

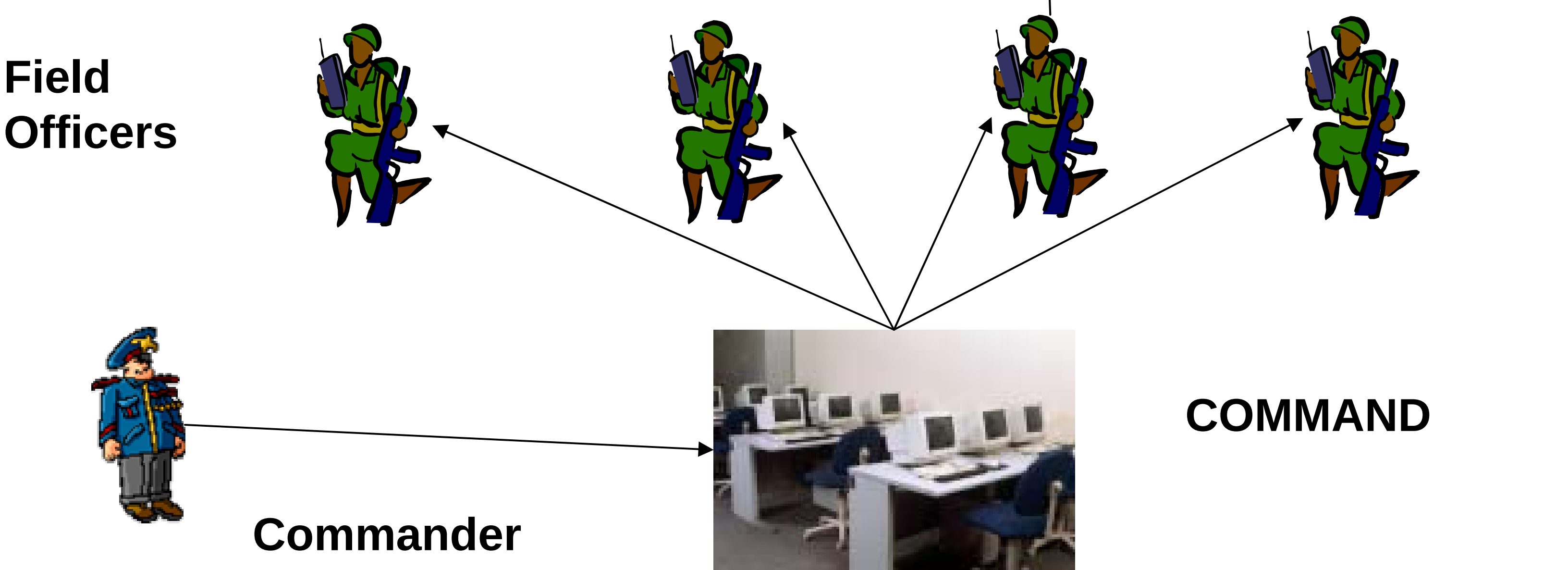
# Effects-Based Operations



# Systems-Level Modeling

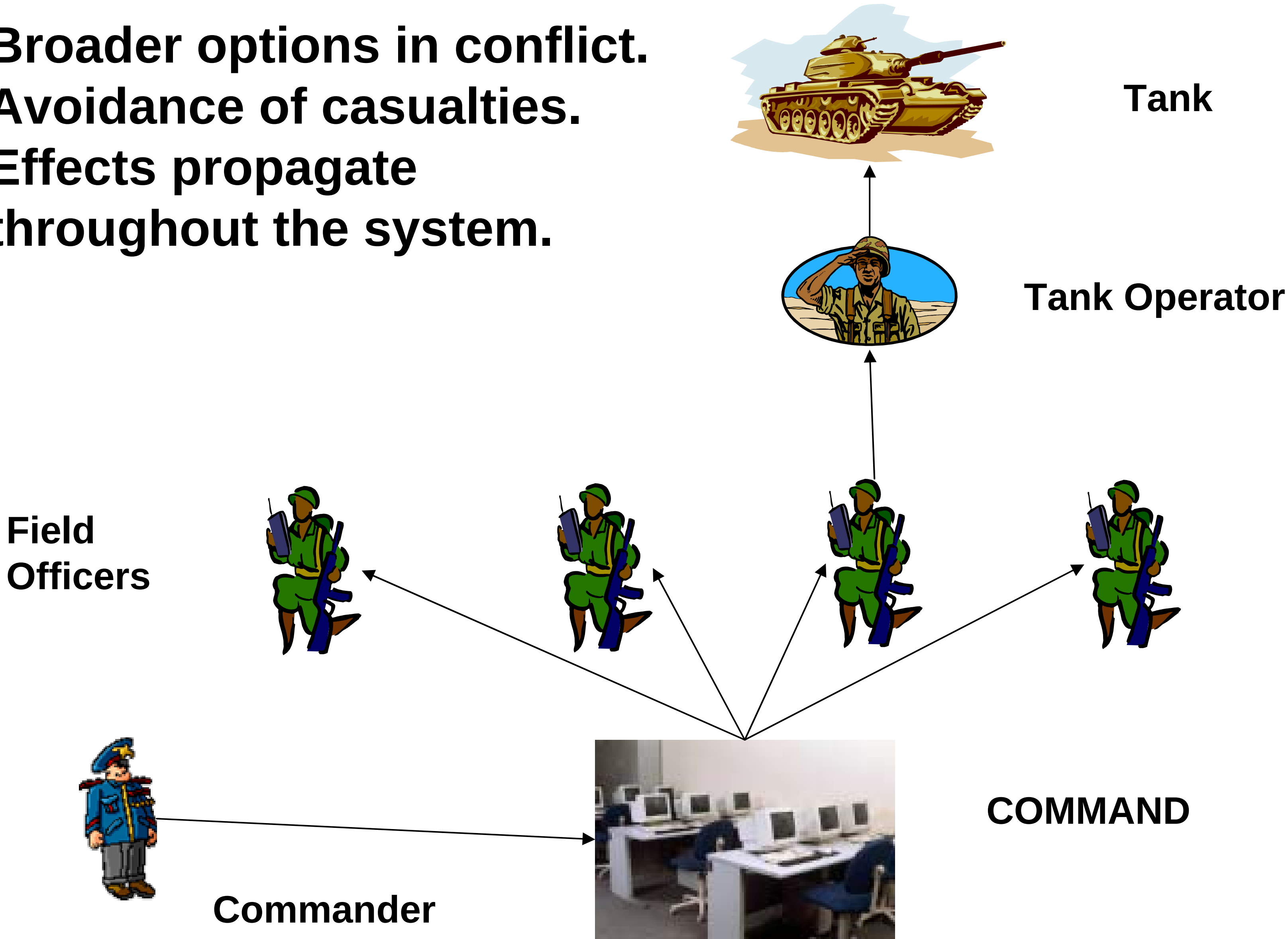
**Military entities are not always directly responsible for the decisions made in the battlespace. Much larger picture to be considered, and potentially influenced.**



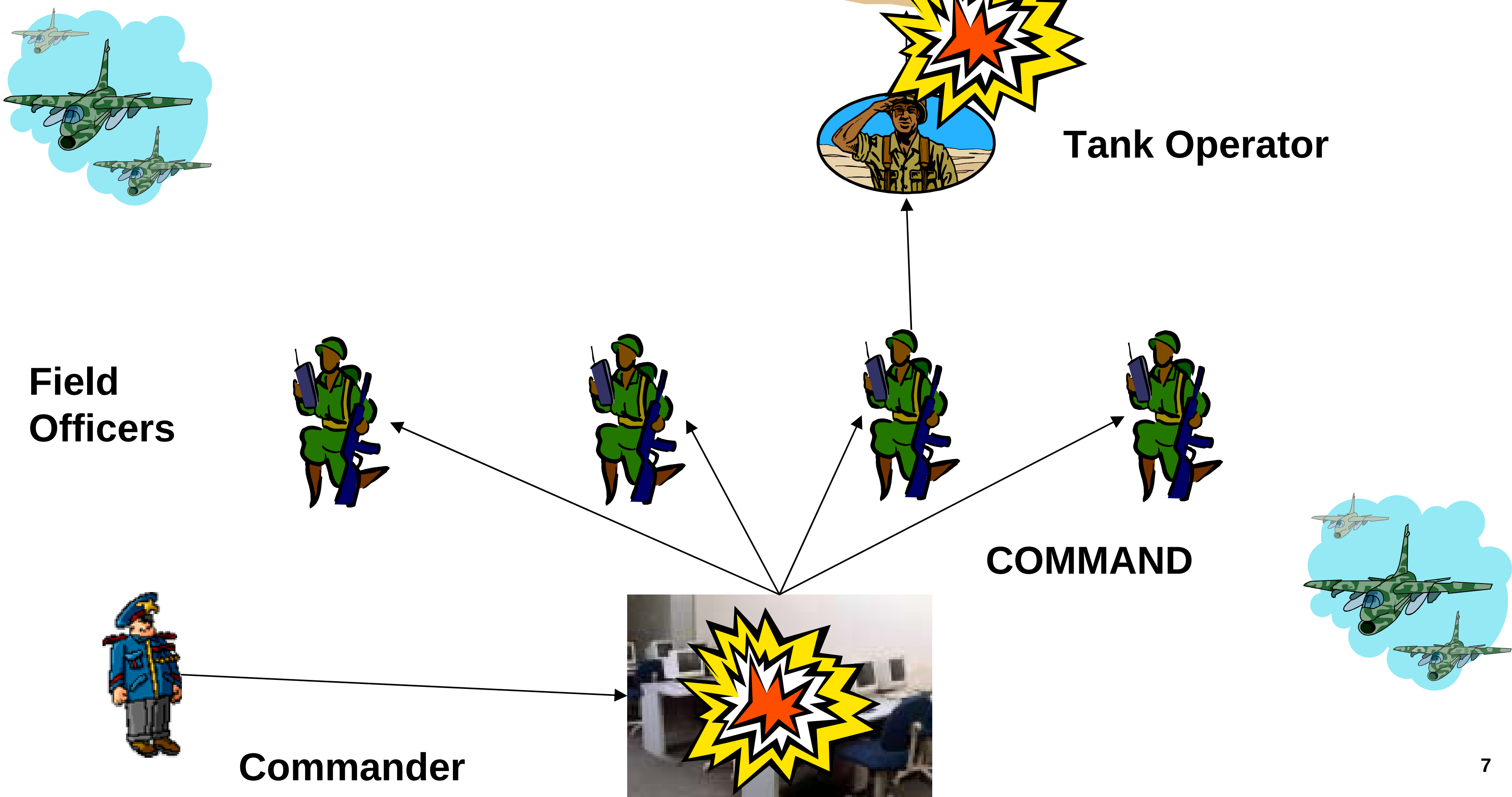
# Why is Systems-Level Modeling So Important?

**Broader options in conflict.**
**Avoidance of casualties.**
**Effects propagate throughout the system.**



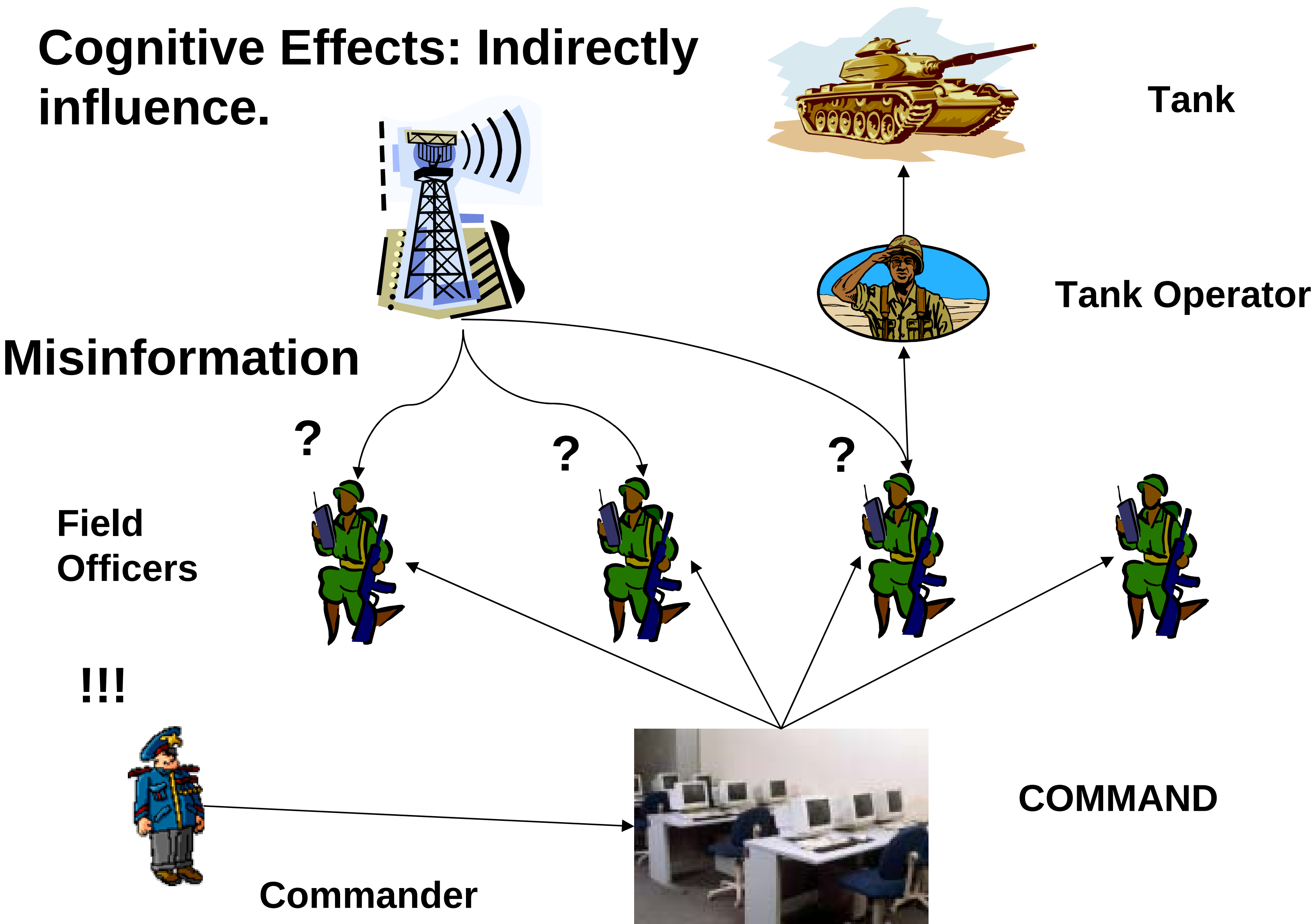
# Why is Systems-Level Modeling So Important?

**Physical Effects… Isolate and destroy.**

# Why is Systems-Level Modeling So Important?

**Cognitive Effects: Indirectly influence.**



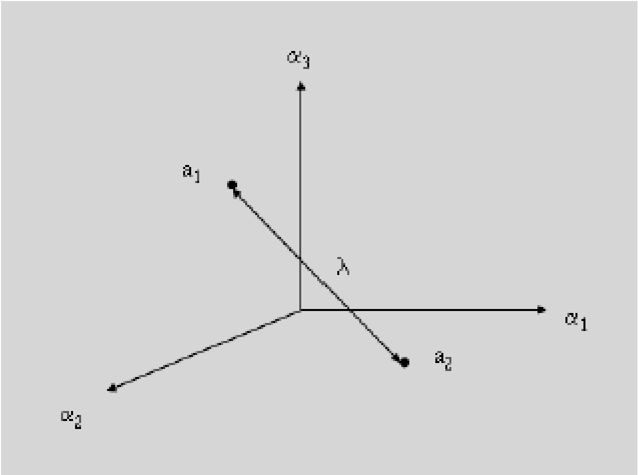
# New Challenges

- Can impacting one agent’s beliefs have an effect on other agents who are “close” to him?
- Can this be modeled using a “system-of-systems” model?
- What kind of mathematical locutions shall we resort to?
- What does all of this buy us in the end?

# Lexicon

- Information Parameters: describe belief and ethical concern functions.
- Alphabet: collection of information parameters for an organization.
- Agents: specified by an alphabet.
- Organization: Collection of agents sharing the same alphabet.

# Interaction Space




$$\lambda = \alpha_{ibn} \log \left[ \frac{\alpha_{ibn}}{\alpha_{jbn}} \right]$$

- "Distance" between two agents belief in a certain proposition.
- Agents defined in this space are assumed to have knowledge of all beliefs which define the dimensionality.
- Modeled after the Kullback-Leibler information-theoretic metric.

# Defining Interactions

$$I_{ij} = \sum_{1}^{m} \sum_{1}^{n} \frac{\alpha_{ibn} \alpha_{jbm}}{\lambda \alpha_{jem}}$$

$$I_{ij}(\alpha_{ibn}) = \sum_{1}^{m} \frac{\alpha_{ibn} \alpha_{jbm}}{\lambda \alpha_{jem}}$$

- Interactions defined as multiplicative relation.
- Normalized by ethical consideration, and by "closeness" between agents beliefs.
- Interaction wrt an individual belief is shown on the bottom left.

# Solution Concept

$$\Delta(\alpha_{ibn}) = \frac{\partial I_{ij}}{\partial t}(\alpha_{ibn})$$

$$\left\{ \Delta(\alpha_{ib1}) = \frac{\partial I_{ij}}{\partial t}(\alpha_{ib1}) \right.$$

M

$$\left\{ \Delta(\alpha_{ibp}) = \frac{\partial I_{im}}{\partial t}(\alpha_{ibp}) \right.$$

- First-order differential equation describing the change in belief with respect to other beliefs.
- Solution concept is a set of these equations.
- Very similar to the infamous “three-body problem” in physics.

# Simple a1/a2 Interaction

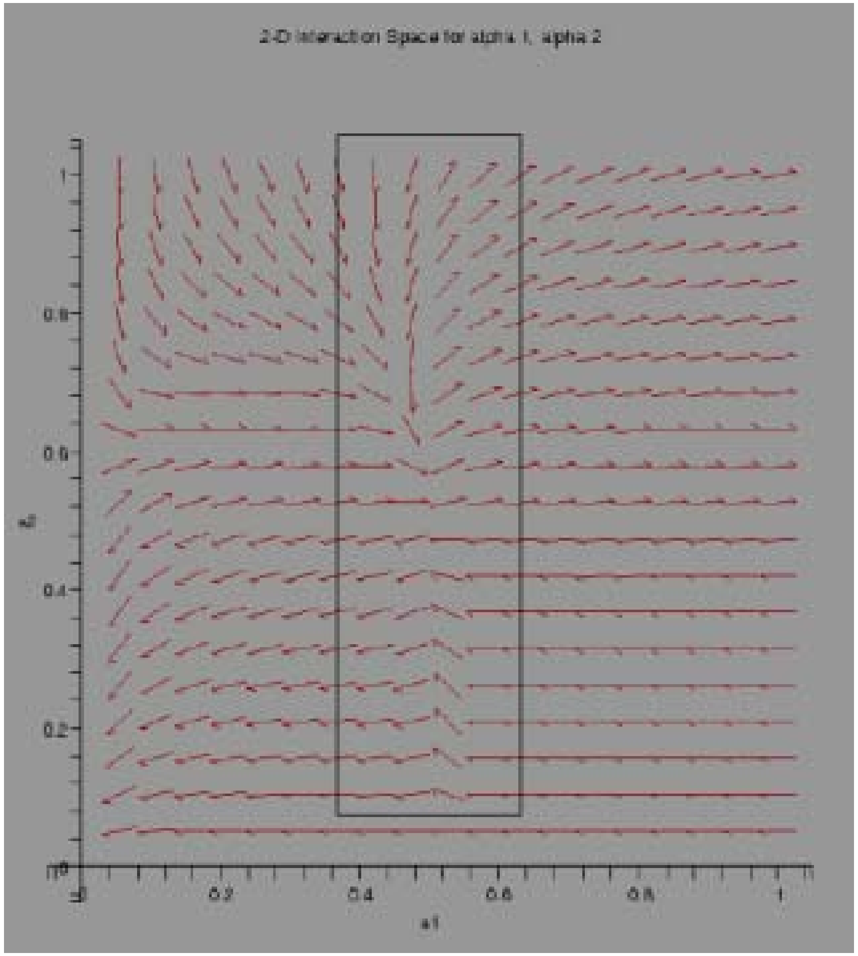
$$\Delta\alpha_1 = \left(\frac{b_1(t)}{\left(be_1 \cdot \ln\left(\frac{a_1(t)}{b_1(t)}\right)\right)}\right) + \left(\frac{b_2(t)a_1(t)}{\left(be_2 \cdot \ln\left(\frac{a_2(t)}{b_2(t)}\right) \cdot a_2(t)\right)}\right)$$

$$\Delta\alpha_2 = \left(\frac{b_2(t)}{\left(ae_2 \cdot \ln\left(\frac{a_2(t)}{b_2(t)}\right)\right)}\right) + \left(\frac{b_1(t)a_2(t)}{\left(be_1 \cdot \ln\left(\frac{a_1(t)}{b_1(t)}\right) \cdot a_1(t)\right)}\right)$$

- Two beliefs: alpha(b1) and alpha(b2).
- Interaction only affects agent 1 (alpha 1 & 2 held constant for agent 2).
- Model the change in alphas with time as two first-order diffeq's.

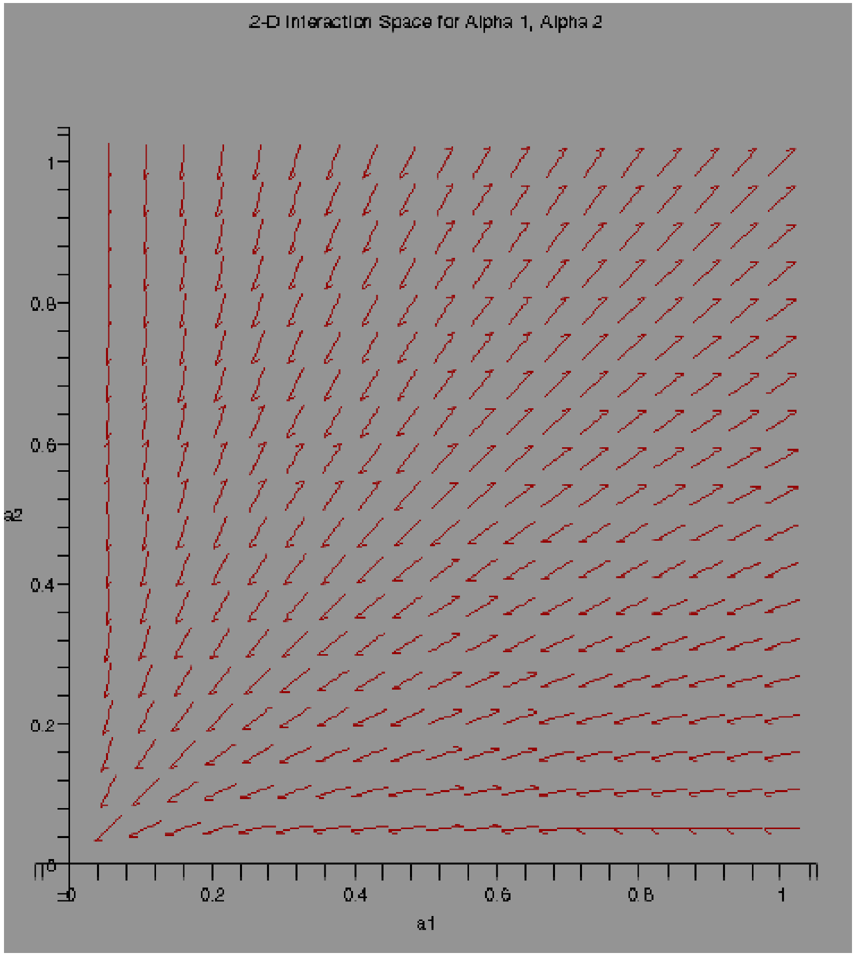
# Some Preliminary Results

- This plot shows the change in alphas given different ethical parameters for each agent.
- The boxed region represents the most unstable regions (where equilibrium could be most easily broken).



# Some Preliminary Results

- This plot shows the changes in alpha given similar ethical parameters for each agent.
- In general, much more stable.



# Discussion

- Higher-order interactions are easy to model through supervenience, but makes the equations significantly more complex.
- Successfully modeled “system-of-systems” cascading belief revision for agent organizations.
- As soon as computing power catches up, and assuming our intelligence is reasonably accurate, we hope to be able to:
  - Isolate important figures in the organization by exploiting “closeness” parameters.
  - Influence those figures, and have a reasonable idea of how organizational dynamics may be altered.

# The End

**Questions?**