Importance of emergent effects in modeling

Why didn't we get diversity right the first time?

Norman L. Johnson

Theoretical Division
Los Alamos National Laboratory

http:// ishi.lanl.gov
NLJ@LANL.GOV

A Surprising Result

The original question:

- How can groups of individuals using the Internet solve problems without knowing they solve problems?

In the absence of data, I did some idealized simulations of collective problem solving:

- Solution of a maze by "dumb" agents.

The "emergent" result:

- Groups of non-competing and non-cooperating individuals can solve a problem that is not expressed by the individual and can solve it better than an "expert."

Honesty about Complexity?

Question #1: Status of Complexity "Theory"

1. It's changed the world (*it's useful*).
2. It's oversold (*sounds good but where's the beef*).
3. The payoff has yet to be realized.
4. All of the above.

Primer on Complexity "*Theory*"

Complexity:

You know what it is when you see it, but you can't define it.

Fundamental concepts

- Emergent properties
- Chaotic behavior *or* non-linear response
- Structure in chaos

Defining Emergent Property

Popular (scientific) definition:

- An emergent property is a property of a system that is surprising and unexpected?

A better working definition:

- An emergent property is a global property that cannot be predicted from knowledge of the subcomponents (agents).

Challenges with Emergent Properties

An emergent property is dependent on what you define as the system, its internal parts and its surroundings.

A system with emergent properties puts the emphasis on “dynamics between parts,” instead of “states of the system.”

The predictive burden is on the model, rather than the modeler.

Examples of Systems with Emergent Properties

Ecosystems and Artificial Life

Path design after construction of a new building.

A system that has exclusively distributed processing; all capability is an emergent property; we rely daily on its functioning; we have almost no understanding how it works.

Y2K and social/economic function.

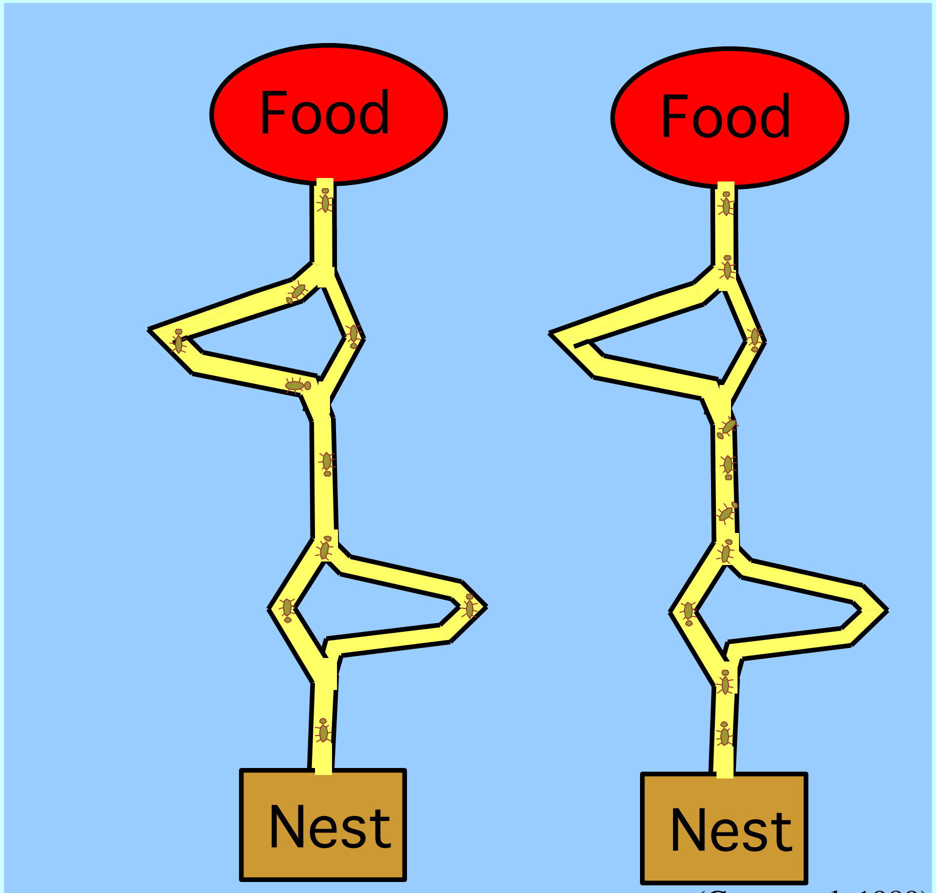
The stock market.

Social insects.

All present significant challenges to an “Expert” trying to describe how these work and to predict their future.

Ants & Bees and Self-Organization

Most ants foraging for food find the shortest path.



(Goss, et al. 1989)

Highly decentralized - autonomous

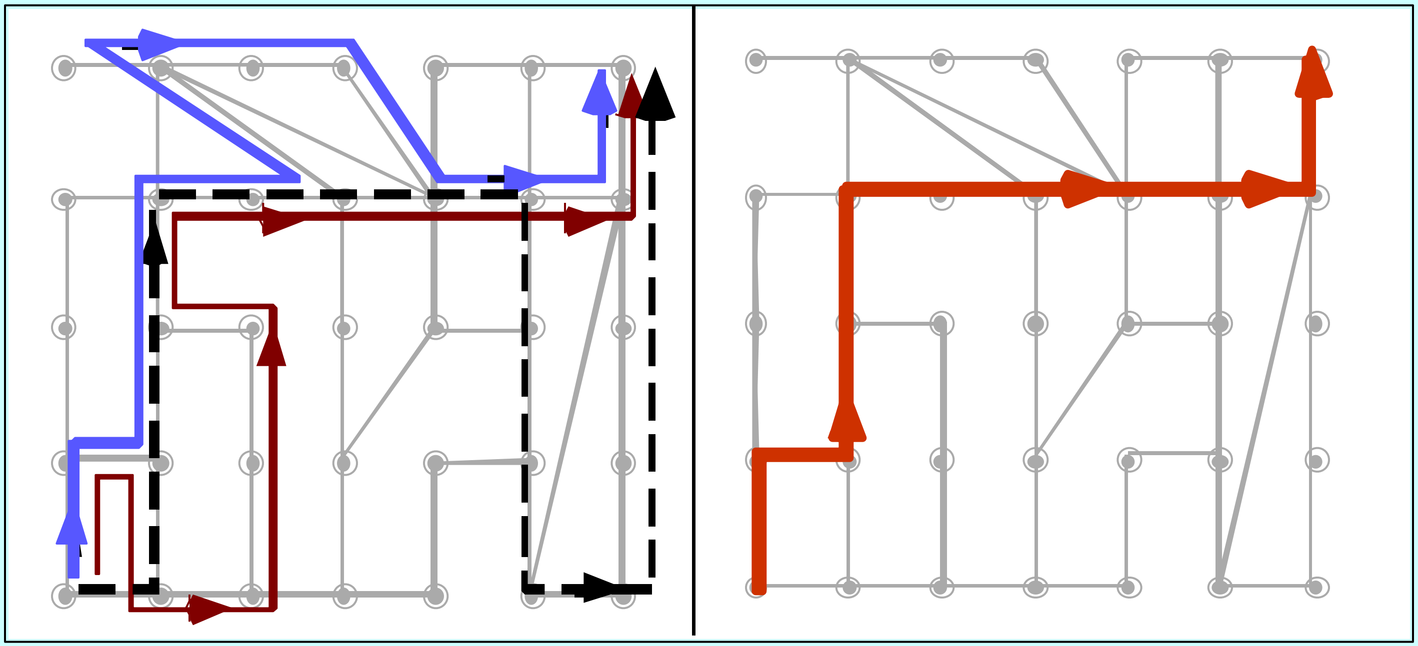
Individual behavior is “dumb” and chaotic

- Shortest path is an emergent property
- Structure in chaos

How does it work?

Non-linear response?

How groups find the Shortest path



Paths of three individuals   Collective path

Models, Agents and Trends

Two extreme approaches to modeling:

- **Direct Model**
- **Emergent Model**

One extreme: Direct or Traditional Modeling

Centralized, premeditative, analytical, scientific

- Process:

  Experiment -> analyze & understand -> model & predict -> control & test. Repeat.
- Applicable systems:

  Small systems of high complexity or large systems of low complexity.
- Typical goal:

  What is the most simple model that will describe the system?
- Advantages:

  Optimal performance and use of resources.
  Predictive within application space (interpolation).
- Disadvantages:

  Limited prediction outside applications (extrapolation).
  Limited capability to explain origins of capabilities or properties.
  Limited by modeler’s understanding.
- Failure mode:

  Extension outside of range of applicability.
  No adaptability, resilience, redundancy.

Other extreme: Emergent Modeling

Decentralized, intuitive, hierarchical, computational

Process:

- Create components as in the Direct Model, define relations.
- A "Solution" arises from the dynamics from a diversity of potential solutions.

Applicable systems:

- Large systems of high *global* complexity.
- Engineering simulations.

Typical goal:

- Modeling a system that cannot be understood or aggregated.

Advantages:

- Dynamics lead to emergent properties and new features.
- Prediction outside application of components (true extrapolation).
- Capability to explain origins of capabilities or properties.
- *Robust, resilient, adaptable, fault-tolerant, scalable*.

- Disadvantages:
  - No theory.
  - No recipes for their creation.

Failure mode:

- Over-specification of the components.

Models, Agents and Trends

Two extreme approaches to modeling:

- Direct Model
- Emergent Model

Agent models – extreme heterogeneity:

- Information and processing is localized.
- Agents can have different rules or capacity.
- Localized interaction.

Trends in simulations are moving from Direct to Emergent models:

- Disaggregation leads to more simple sub-components.
- Information in the dynamics rather than the state.

New trends in simulations:

- Less complex submodels with high spatial resolution are reproducing observations.
- Multiphase flows, epidemiology, turbulence.

Big Picture on Simulations

Study the simplest model system that

- Exhibits better collective performance than for an individual.

Provide insight into:

- How to solve problems that are to difficult for experts.
- An alternative mechanism for higher global performance:

  Without *competition of* or *selection from* participants.
- The role of individual capability and diversity.
- Chaotic dynamics of self-organizing, distributed knowledge systems:

  Persistent disequilibrium, emergent properties, information condensation, robust performance, redundant subsystems.

Demonstrate self-organization and give guidance in developing methodologies for the Net.

Basic Concepts

An Individual

- A single person, organization or government within a larger structure.
- Localized in either physical or knowledge space.
- One of many identical decision-making agents.

  Identical in the sense that they have the *same capabilities* and information.
  Differ only in their learned behavior and their consequential performance.
- Independent - they do not interact in anyway with one another.

A Maze - *the Problem Domain*

- A bounded system that defines the options for the individual at a particular point in the sequential decision process.

The Goal

- A series of sequential decisions that define a path through a problem domain from the beginning to end point (goal).

Basic Approach

Individuals do two sequential phases –> Optimal individual solution:

- *Learning Phase* uses a set of *Learning Rules* that specify:
  - Their movement through the maze and
  - How they modify their own *Nodal Path Preference* at each node.
- *Application Phase* uses a set of *Application Rules* that specify:
  - The optimal path of each individual based on the Nodal Preferences from the Learning Phase. These select the preferred path based on typically the largest magnitude of the Nodal Preferences at a node.

Collective solution of many individuals:

- Create a Collective Nodal Preference by combining the Nodal Preferences from the individuals.
- Apply the identical Application Rules to the Collective Nodal Preference.

Examine the effect of different model choices on the Collective solution.

- Compare the performance of the collective relative to the performance of the average individual in the collective (*the collective advantage*).

Motivations for Approach

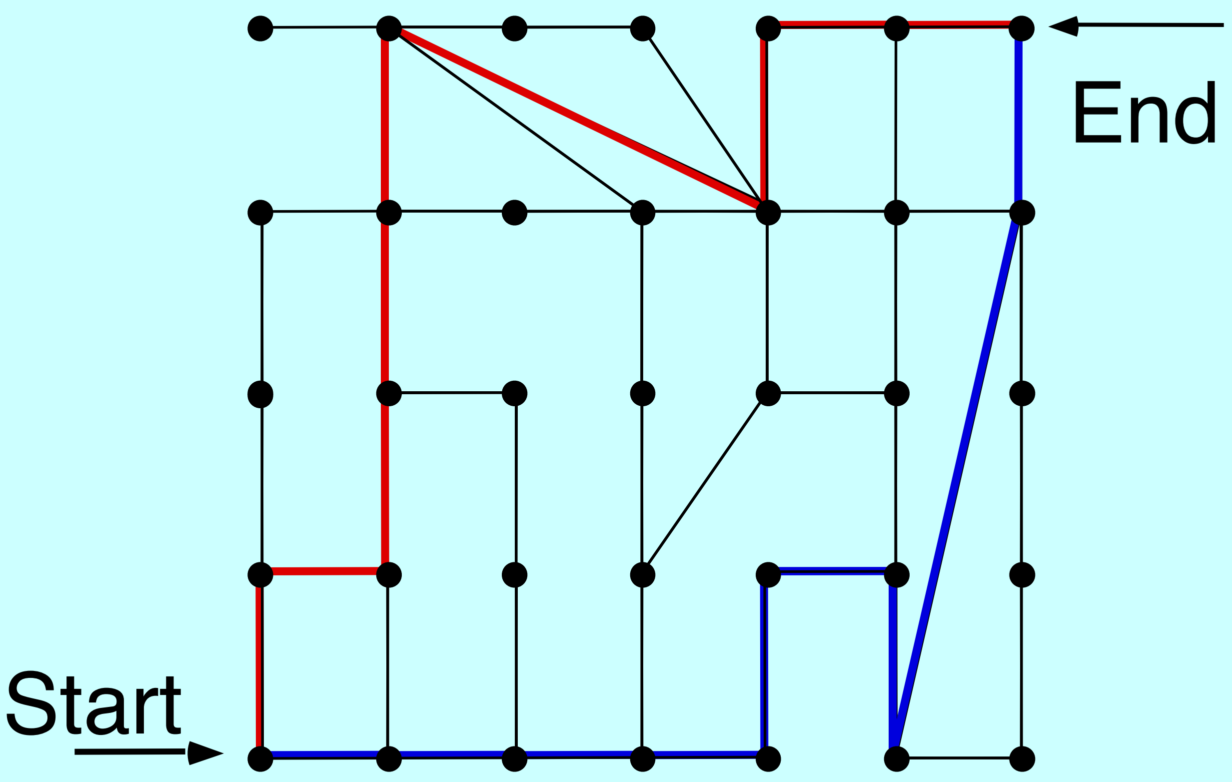
A simple example of a collective self-organizing solution to a maze

- Have everyone solve a difficult maze independently, first by "randomly" searching for the solution and then optimizing their first solution.
- Combine the individual solutions to generate a collective solution.

By analogy to the solution method used by ants foraging for food.

- An ant forages by searching the space – by not knowing where the food is located, it searches randomly until the food is found (Learning Phase).
- Once the food is located, the ant is able to use the pheromones trail in the earlier foraging to optimize its path to the food (Application Phase).
- The combination of many ant's pheromone trails represents a collective solution.

Example Maze



Two possible paths of minimum steps (*length*) are shown, out of 14 possible.

A Model for Solving *Hard* Problems

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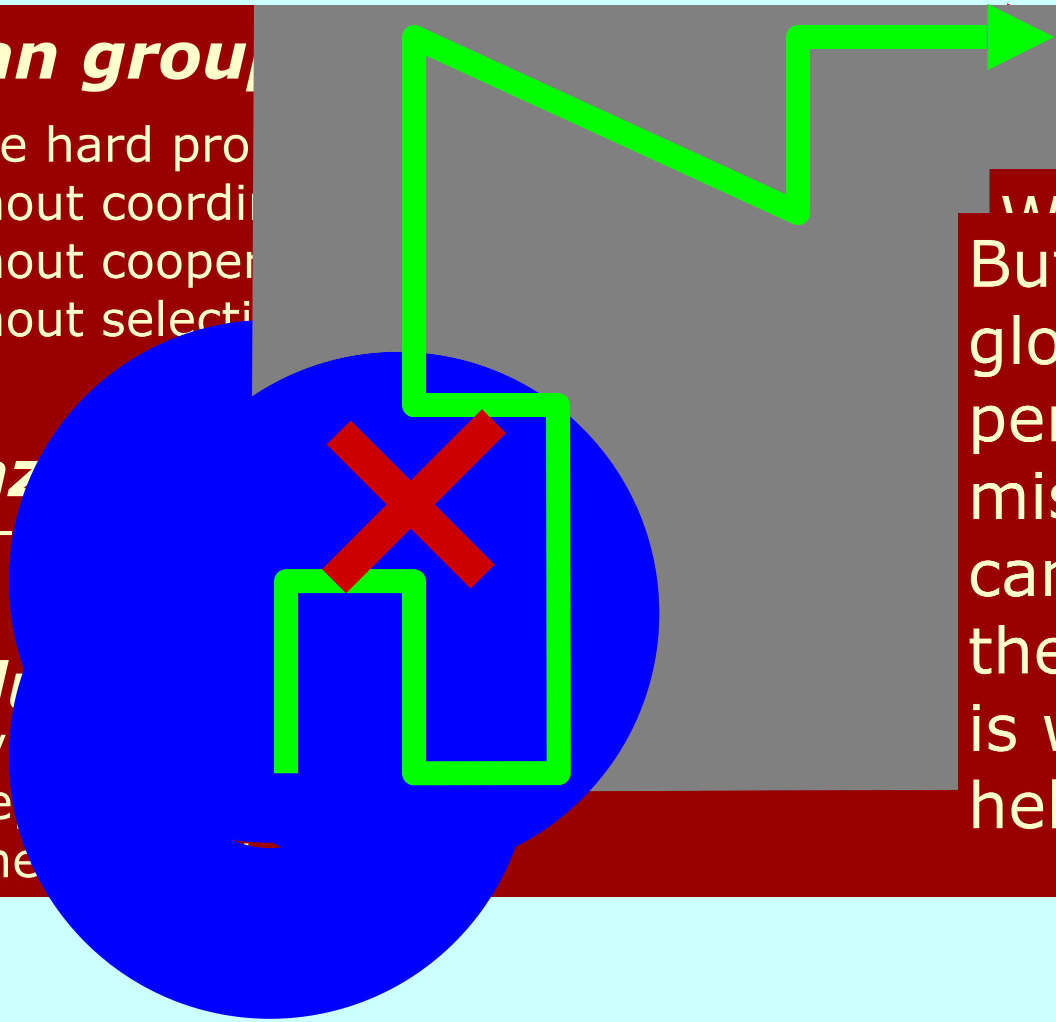


End

But because a global perspective is missing, they cannot shorten their path. This is were diversity helps.

Performance of the Individual

Learning Phase

Application Phase

What’s happening?

Unnecessary loops are removed in the Application Phase

Analysis of the System

Examination of assumptions

- Effect of fuzziness in maximum choice
- Linearity and the probabilistic selection
- Conflicting goals
- Problem complexity versus agent ability

Behavior of the model

- Novice versus Established agent
- Solution with different methods
- Effect of noise
- Expression of Chaotic behavior (Non-linearity)
- Correlation between learning and application
- What global property does this correlate with?
- Effects of loss of information
  - Effect of "flattened" preferences (reducing extremes of opinion)
  - Loss of minor opinions
  - Complete loss of extremes (indecision)
  - Selection of a leader randomly
  - Selection of participation by performance

Extensions of the model

- Interactions

Correlation of the Two Phases

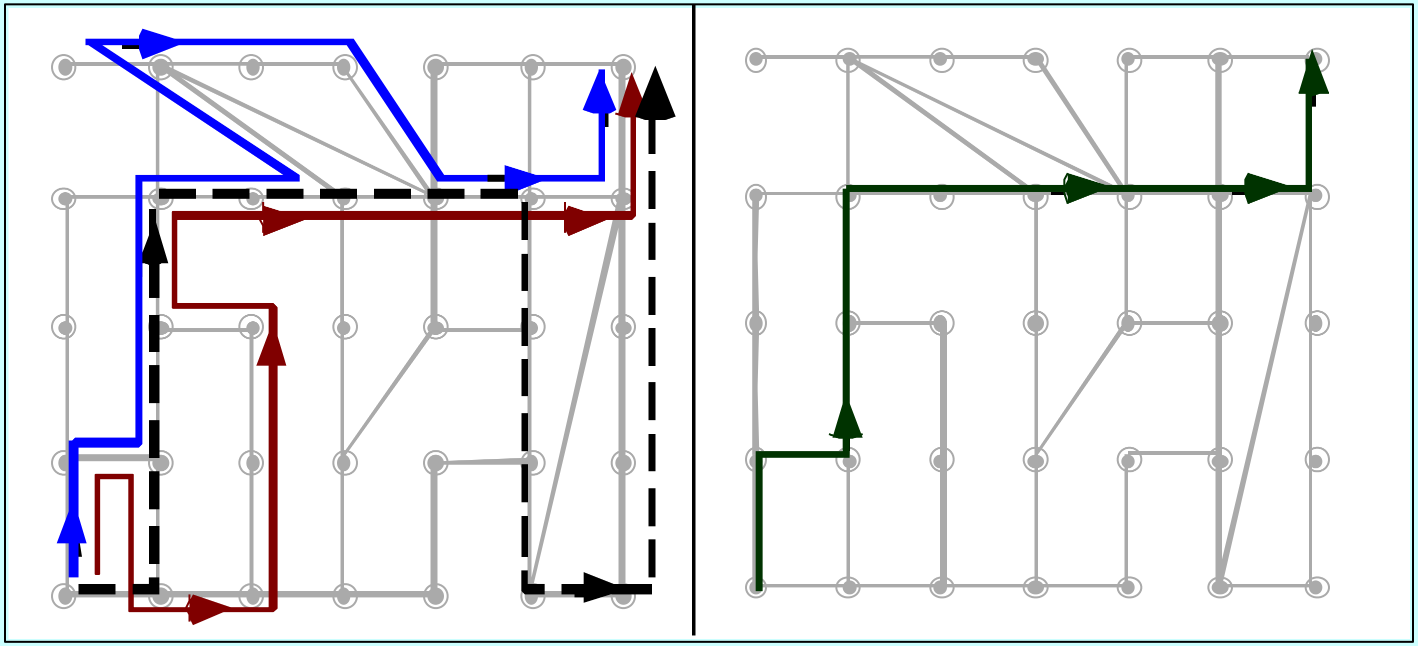
No correlation between the two phases:

A slow learner is not necessarily a poor performer

Collective Solutions

The effect of novice and established information

What's Happening?

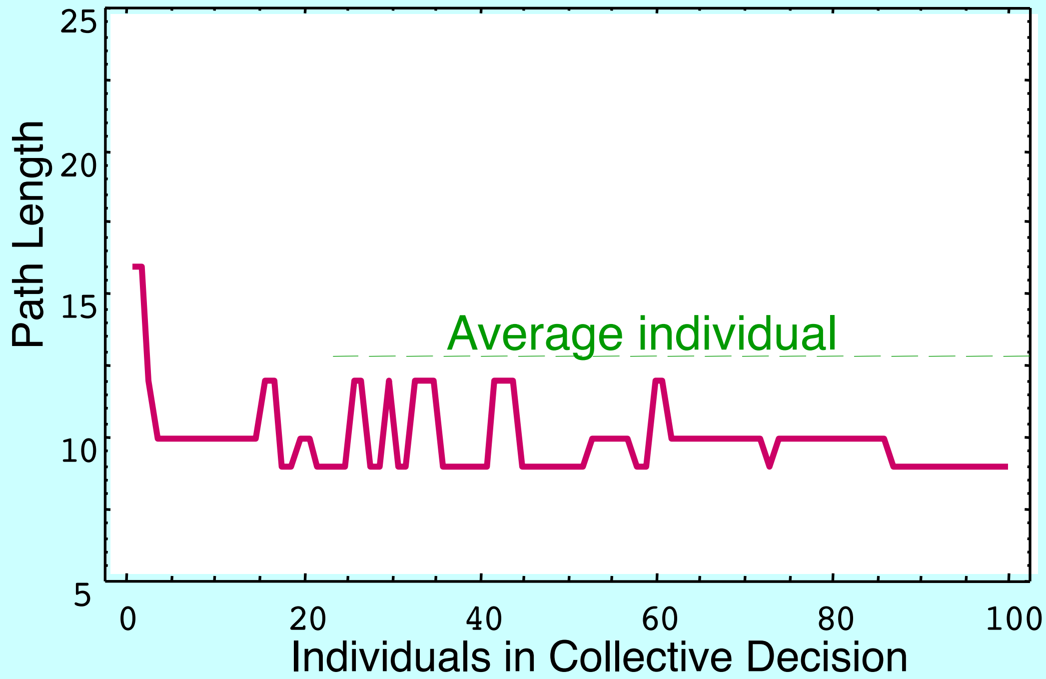


Paths of three individuals

Collective path

Chaotic Behavior of the Collective

Path from adding one individual to an existing collective



Illustrates the sensitivity of the solution to the effect of one individual, even in a large group.

Animation of a Collective Path

Path from adding one individual to an existing collective

Illustrates

- Sensitivity to one individual
- Chaotic nature of details
- Global stability

Randomness and Chaotic Solutions

Source of randomness:

- Random choices are made between paths of equal preference, caused by the system having multiple non-optimal and optimal solutions.

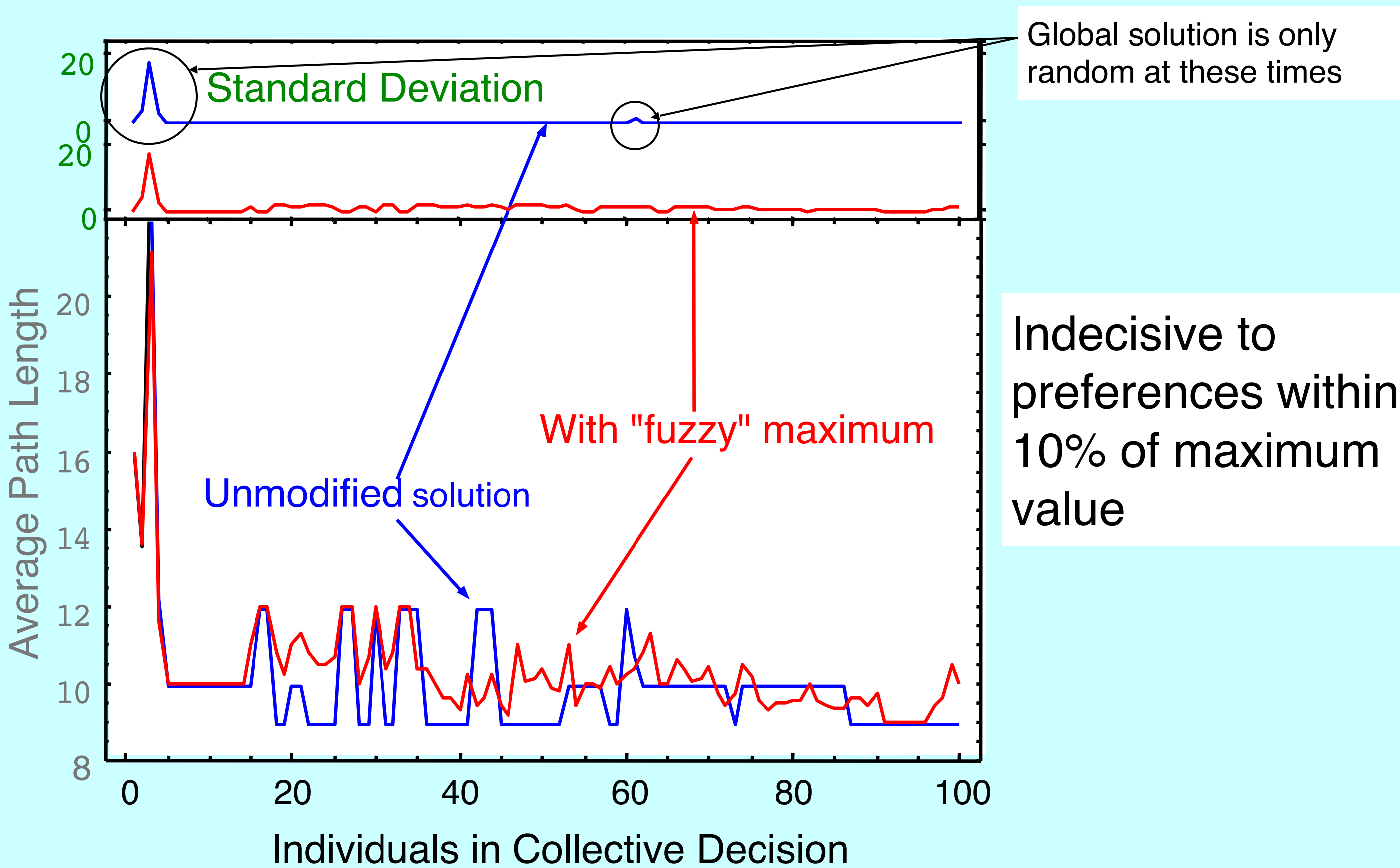
Chaotic behavior, or persistent disequilibrium, is an necessary property of self-organizing systems. Without this, the system would become static and unable to respond quickly to changing conditions.

Randomness leads to diversity of areas frequented in the maze and a diversity of total path lengths (performance). Diversity leads to robustness and global stability.

While the details are random and chaotic, the global properties (the minimum path length) is stable and reproducible. An optimal path is not necessarily reproducible or unique.

Effect of Random seed and *slight* indecision

Repeat solution 20 times with different seeds for the random numbers



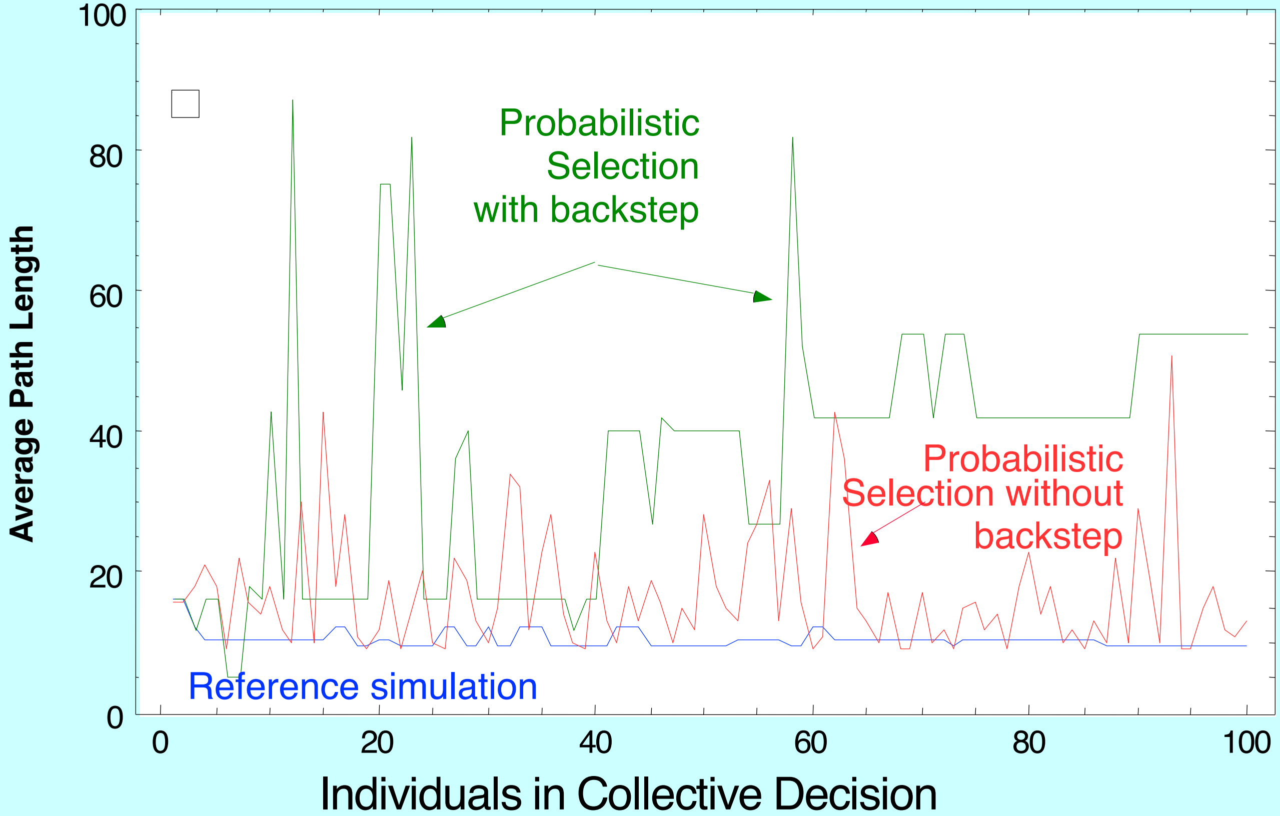
Indecisive to preferences within 10% of maximum value

Random selection between equally preferred paths is rare.

Details, but not emergent properties, are sensitive to slight indecision.

Source of Non-Linearity and Chaos

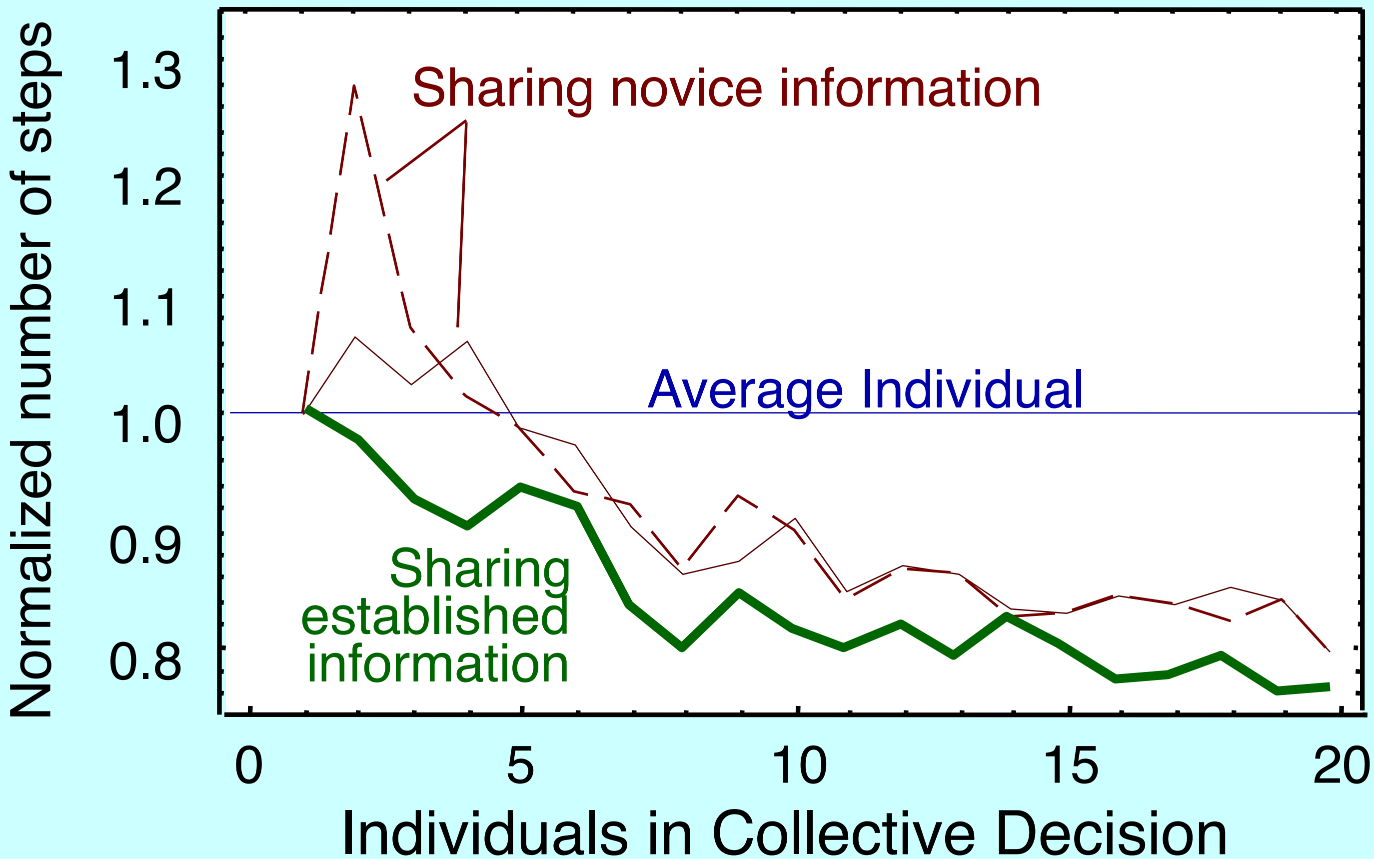
Choice made by probability, rather than maximum preference



Ability to select a maximum preference is an essential aspect of emergence.

Selection of a maximum makes the model non-linear and “biological”.

Ensemble (Averaged) Behavior



Performance correlates with high *unique* diversity

Global measure of an Emergent property?

What global measure correlates with the collective improvement?

conclusions

Insensitivity to noise

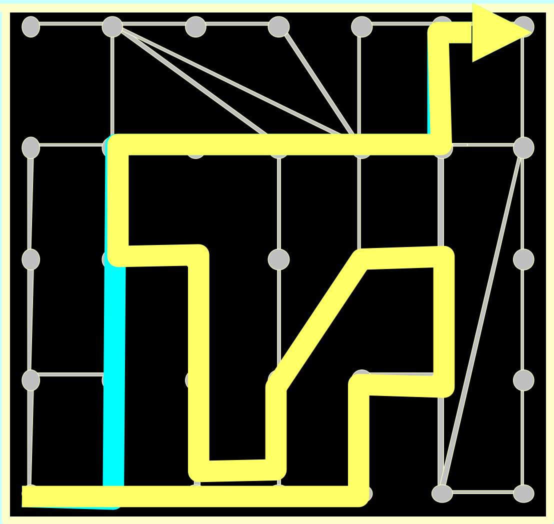
The collective is highly *insensitive* to noise; the individual is very sensitive.

Because noise creates *false information* about preferred paths, the diversity of experience in the collective contains contingencies for false leads.

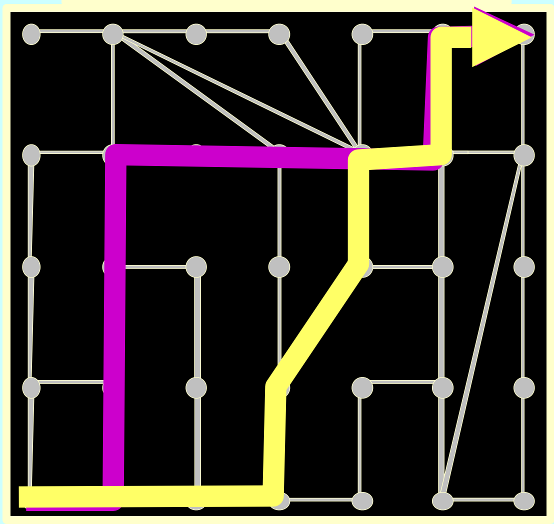
Noise and Robustness

~~Noise: Replace "valid" information with "false" information~~

An "expert" individual



A collective



- Individuals are very sensitive to noise

  10 steps become 21 steps

  Lack of experience

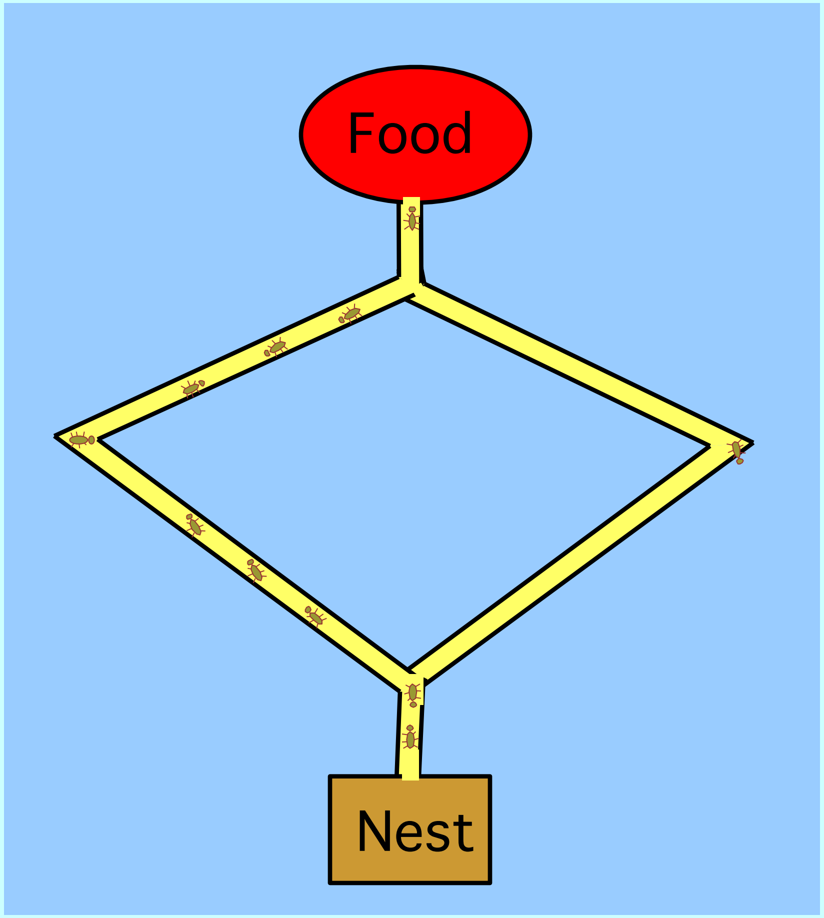
- Collectives are insensitive

  10 steps become 9 steps

  Contingency from diversity

The Problem with Collective Effects

Ants foraging for food chose one path out of two equidistant paths.



(Deneubourg et al. 1990)

Cooperation leads to exclusive behavior in stable environments.

Non-linear effects: Positive reinforcements can amplify small effects globally -> global chaos.

(Does this happen in markets with the "herd effect" by mass-media?)

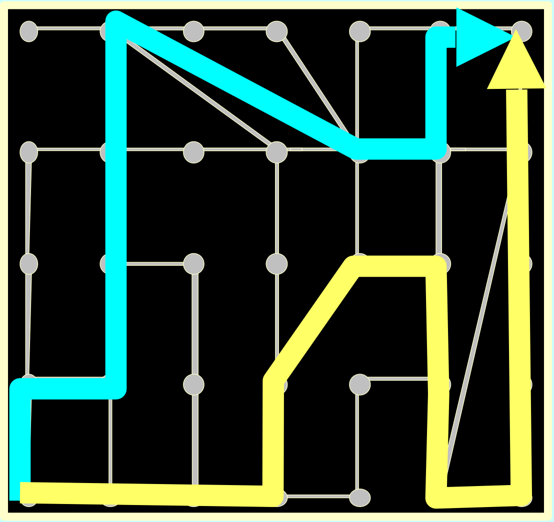
Randomness still required for global robustness.

Three stages of development

Dynamics are different depending on the stage of development

Formative

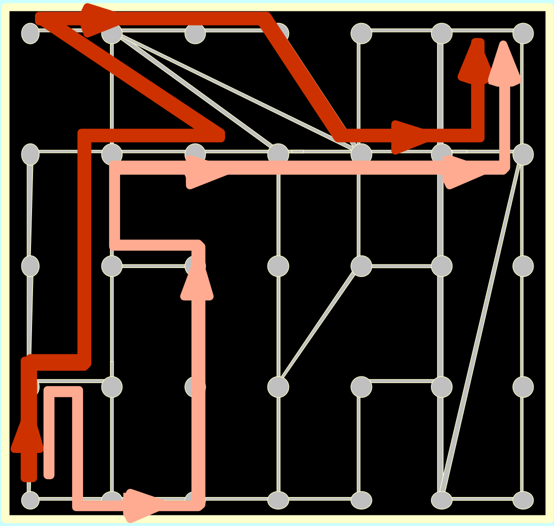
Individual development



Selection gives Agents capability, essential for the next stage.

Co-Operational

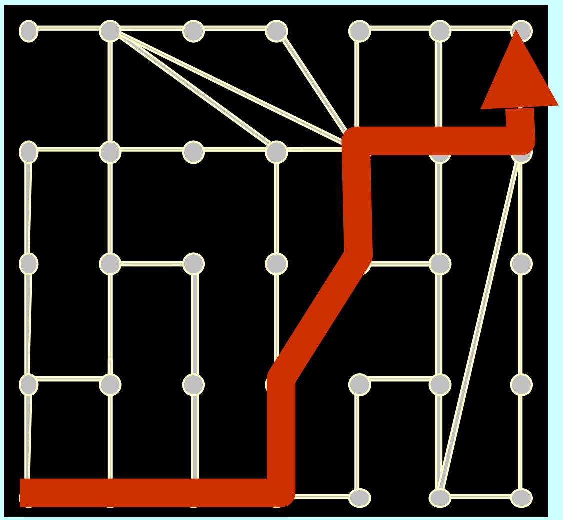
Collective improvement



Agents learn independently then share information during application

Condensed

System “refinement”



Agents share during learning in a stable environment

Summary of All Results

Specific paths are chaotic; the minimum path length is not.

The solution of a minimum path length by the collective is an emergent property. This global property is insensitive to details of the model, with two exceptions:

- Groups of random individuals show no collective advantage. Hence, individual and collective performance are closely coupled.
- Instead of picking a path by a maximum, picking by probability is a disaster.

Diversity - an essential property - from random processes:

- Reductions of extremes of an individual's contribution has minimal effect. Total loss of extremes (indecision) is disastrous.
- Loss of minor preferences has minimal effect.
- Limiting participation by performance degrades the collective solution.
- Shared information during the Learning Phase can improve performance but at the price of diversity and robustness.

Conflicting goals are resolved better by collectives (robustness).

Recent Developments in other Fields

Evolutionary Biology

- Mature systems rely on cooperation and symbiosis, rather than selection and competition, for higher performance and robustness.
- "Survival of the Fittest" is now "Survival of the Adequate."
- Diversity is more than fodder for natural selection, but contributes directly to performance and robustness.
- High interdependency, combined with diversity, is the primary source of robustness.

Economics

- The above observations also apply: mature capitalistic economies are not essentially competitive, but cooperative.
- Diversity of performance can lead to higher group performance, in addition to diversity of capability or experience.

Examples and Projects

Physics Archives (`xxx.lanl.gov`)

- Self-organization of knowledge for users
- Improved searching (like Amazon.com)

Clustering and innovation capture of diverse research

- Who should I be talking to? Interdisciplinary challenges.
- Management aid to identify emerging areas of research

Activating an industrial research database

- Basic Knowledge Management, with self-organization.

The Symbiotic Intelligence Project….

Self-Organizing Approaches to Difficult Problems

Reliability of an essentially chaotic, incomprehensible process?

- Little choice if there are no alternatives.
- Reliability and robustness improve with size. Not for isolated systems or ones with few players. Importance of agent technology.

Who gets the credit when the solution is found globally?

How do I create a system/process which I can't predict or understand? (Origin of Life dilemma)

- Rely on enabling existing social processes by new technology
- But don't force technology on social processes

How can I ensure proper security while encouraging communication and participation?

- Define restricted groups that interact freely within "self", but not with "other"
- The immune system is essentially a self-organizing system.
- Enable the "self" definition and turn loose the troops.

Areas of Critical Development

Cooperation between research groups and commercial developers

- Need for standardization of tools, methodologies and nomenclature

  But not approaches or systems - resist premature standards.
- Development of core technologies and interdisciplinary efforts.
- Combating information block by developers.

Methods for automated knowledge representation

- Capturing structure and content.
- Capturing semantics and meaning.
- Fuzzy logic is still limited due to category pre-specification.

Encouraging and capturing diversity

- Bill of Rights for information systems.

Autonomous agent development

- Particularly important for addressing synchronicity of information

  - how to make few have the presence of many - right place, right time.

Lessons Learned

Understanding the need for a variety of approaches

- Difficult problems require diverse approaches.
- Needs change over time.
- Mature systems cooperate, not compete.
- Experts are needed for local solutions.

Technology must enable and enhance social processes.

- We're in trouble when a major message is "90% humans/10% technology".
- Focus on how to use maximize human contributions, enabled by technology.

  Humans are the ultimate processors of complex information!

Diversity already exists. How to tap diverse resources?

- Diversity means unique problem solving approaches in groups.

  Personality and experience are primary sources of diversity.
- A question of culture and organizational procedures.

  ”Beware of mid-level sabotage”
  Information revolution is really a revolution in access and expression.

Organizational Guidelines for Innovation

Define many groups with overlapping jurisdictions

- Don't organize flat across all groups. Small, stand-alone approaches fail.
- Only use tightly-coupled interactions/control in ideal situations.
- Develop multiple information and decision pathways.

Develop an error-tolerant system (at least internally) which encourages expression and risk taking.

- Unanticipated results are treated as errors, inconsistent with policies/goals.
- Clarity of vision is *not* a property of successful innovation.
- Some protection and isolation is needed at early stages of innovation.

Communication and interaction must result from need, not policy

- But should have a random component (water cooler effect).

Plan for the future by solving immediate problems and distribute results

- Future solutions come from the interaction of present solutions, not from strategic development plans.

Perspectives

Why you should not listen to me

- Question role of experts in solving difficult problems.

Traditional views of decision-making systems

- Even academic approaches are suspect.

Prediction of the stock market

- Prediction of collective processes require collective predictions.

Planning of paths after construction of a building

- Ditto.

Reasons people become managers

- Mangers as enablers and executors, instead of as decision makers.

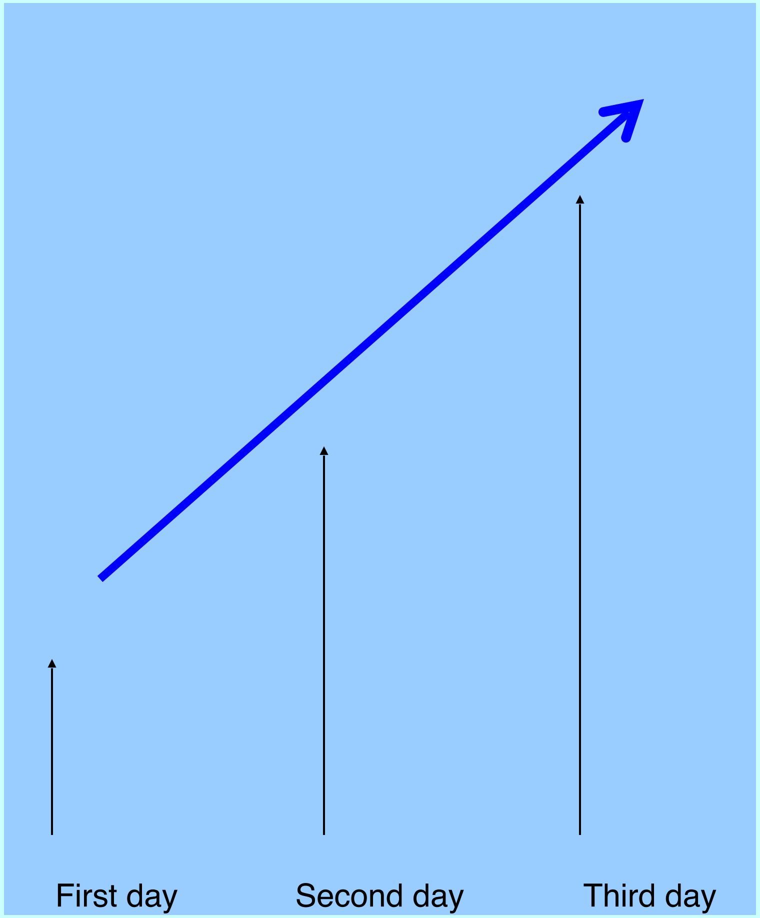
Is Knowledge Management Artificial Intelligence revisited?

- Focus on self-organizing social processes, not technology.

Visit to Los Alamos by Agency researchers

- Rethink how existing organizations work.

Why care about Emergent properties? Researching Bee Talk



Prediction is a useful capability for bees.

- But where is the prediction taking place?

Where is memory located?

- Bee memory - 1 week
- Bee life - 6 week.
  Hive memory - 12 weeks.

Why are social insects so disturbing?

- Who is (are) the Organism?
- Higher performance without selection
- Lack of understanding of the mechanisms

Do economies/market express the same mysteries?

Resources on Self-Organizing Knowledge

On the Conference CD are three papers.

- Overview of this talk.
- The Science of Social Diversity - a new perspective on diversity.
- Collective Problem Solving: Functionality beyond the individual.

Symbiotic Intelligence Web Site: `http://symintel.lanl.gov`

- Collection of relevant papers on approaches and techniques.
- Links to other sites.

Network security based on the Immune system

- Prof. S. Forrest, Univ. of NM, Albuquerque.

Historical Perspective:

- "The Development of the B-52 and Jet Propulsion: A case study in Organizational Innovation" by Dr. Mark D. Mandeles