Self-Organizing Knowledge Systems: Enabling Diversity

Super-Intelligence: How groups solve problems better than Experts

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Viewgraphs at *http:// ishi.lanl.gov/Documents1.html*
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Introduction

Why you should not listen to me

Traditional views of decision-making systems

Prediction of the stock market at

- `http://www1.investorsforecast.com`

Planning of paths after construction of a building

Reasons people become managers

Is Knowledge Management Artificial Intelligence revisited?

Visit to Los Alamos by Agency researchers

Two Extreme Approaches to Problem Solving

Traditional problem solving:

- *Centralized, linear, 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.

- Advantages:

  Optimal performance, optimal use of resources, predictive.

- Disadvantages:

  Limited by human understanding.
  Limited adaptability, resilience, redundancy.

- Failure mode:

  Centralized control in a rapidly changing system.
  System -wide strategic planning can be an impediment.

Self-organizing, distributed problem solving...

Self-Organizing, Distributed "*Problem Solving*"

Self-organizing "problem solving" in a dynamical and distributed system of localized problem solvers

Examples

Biological evolution and ecosystems, Social insects, "Free" economies, Large corporations, Modern battlefields, Telcom system, Internet routing, Air traffic control, Power grids…. Human societies.

Common attributes:

- Distributed resources, processes and information.
- Absent (or limited) centralized control, planning or prediction.
- Diversity (often redundant) of dynamics, capabilities or "goals."
- Dynamics of persistent disequilibrium.
- Mechanisms for information loss, filtering or condensation.
- Limited connectivity of typically local extent.

Global features:

- Higher global functionality or solutions from local actions or rules.
- Robust, resilient, adaptable, fault-tolerant systems.
- Function of the whole not dependent on individual subsystems.
- Scalable without loss of function.

Our Organizational Environment

We as analysts/managers/scientists are no longer in an environment of independent and unique challenges.

In most organizations, the problem solving environment is redundant, diverse, dynamic and decentralized.

The outstanding problems are greater than what any one analyst or institution can solve.

Societal “Problem Solving”

As a society, we rarely are in an environment of independent and unique problem solving.

The approach to societal problem solving is redundant, diverse, dynamic and decentralized.

Outstanding problems are greater than any one human, organization or government can solve.

Complex, Adaptive, Chaotic Systems

Complex global behavior is driven by loosely connected, relatively simple, local processors.

A "Solution" arises as a selection by the system dynamics from a diversity of potential solutions.

Concepts of chaos, self-organization, an emergent property

- Choose not to use “emergence” or “complexity”

Credibility statements

- “Not all problems can be solved with a collection of simple agents.”
- “Complexity Theory does not exist.”

The challenge is to accept a solution that you do not understand.

Examples and Projects

Amazon.com book recommendations as self-organizing knowledge

- Creation of useful knowledge by simple activities of individuals.
- Previously information was lost or available only at extreme expense.

Web access studies at PARC-Xerox

Self-ordering word lists

Physics Archives *(xxx.lanl.gov)*

Clustering and innovation capture of diverse research

Activating an industrial research database

Model simulations of collective problem solving….

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

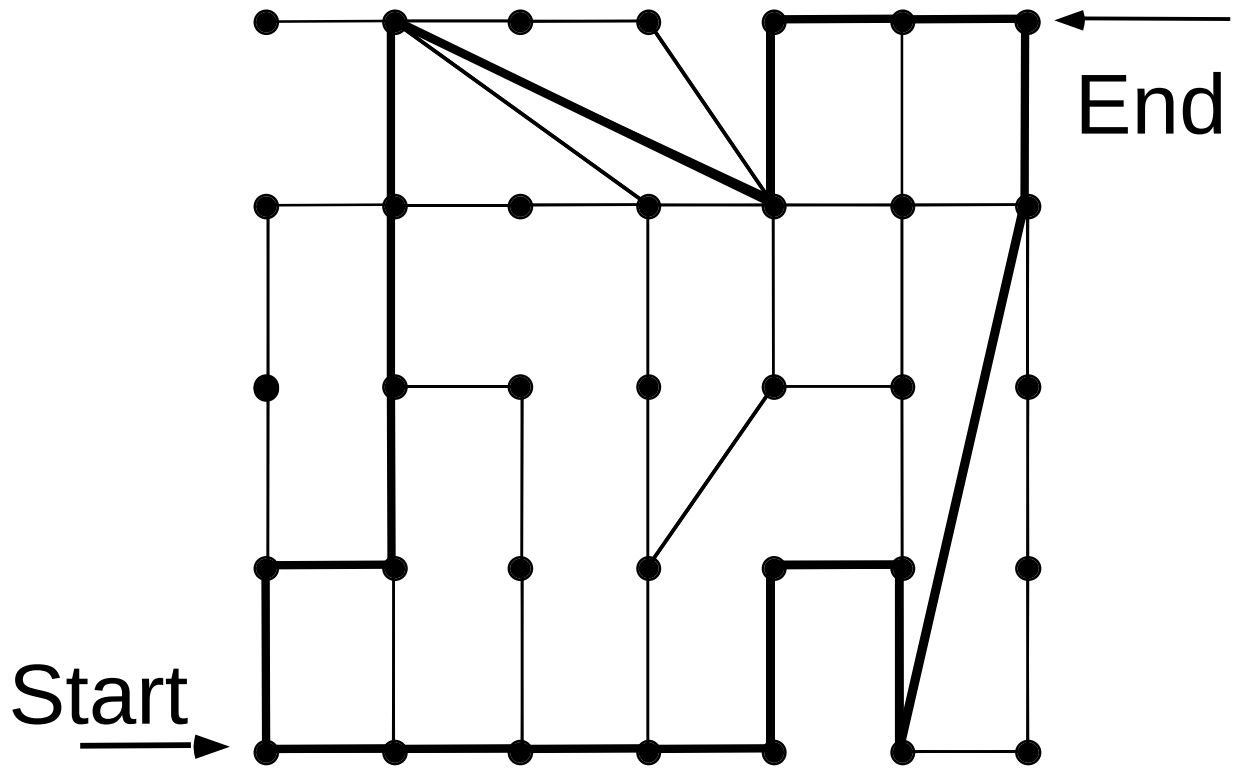
A simple example of a collective self-organizing solution to a maze

- 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.

Performance of the Individual

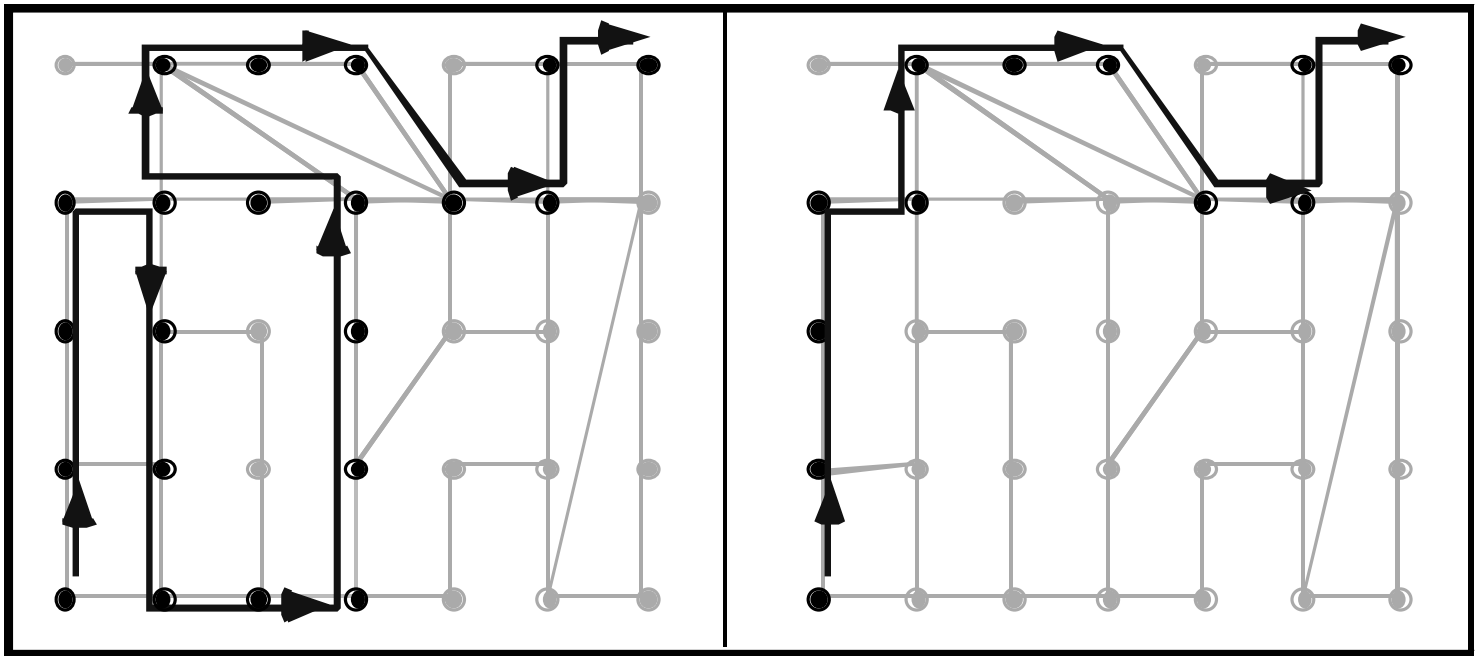
Learning Phase

Simulation method	Average	Standard deviation
Learning Rules	34.3	24.5
Learning Rules (1000)	39.2	30.2
Random walk	123.	103.
Random walk (1000)	129.	105.
Self-avoiding Random walk	50.8	52.3
Self-avoiding Random walk (1000)	46.8	40.3

Application Phase

Simulation method	Average	Standard deviation
Learning Rules	12.8	3.06
Learning Rules (1000)	13.2	3.30
Random walk	48.8	54.9
Self-avoiding Random walk	33.7	36.2

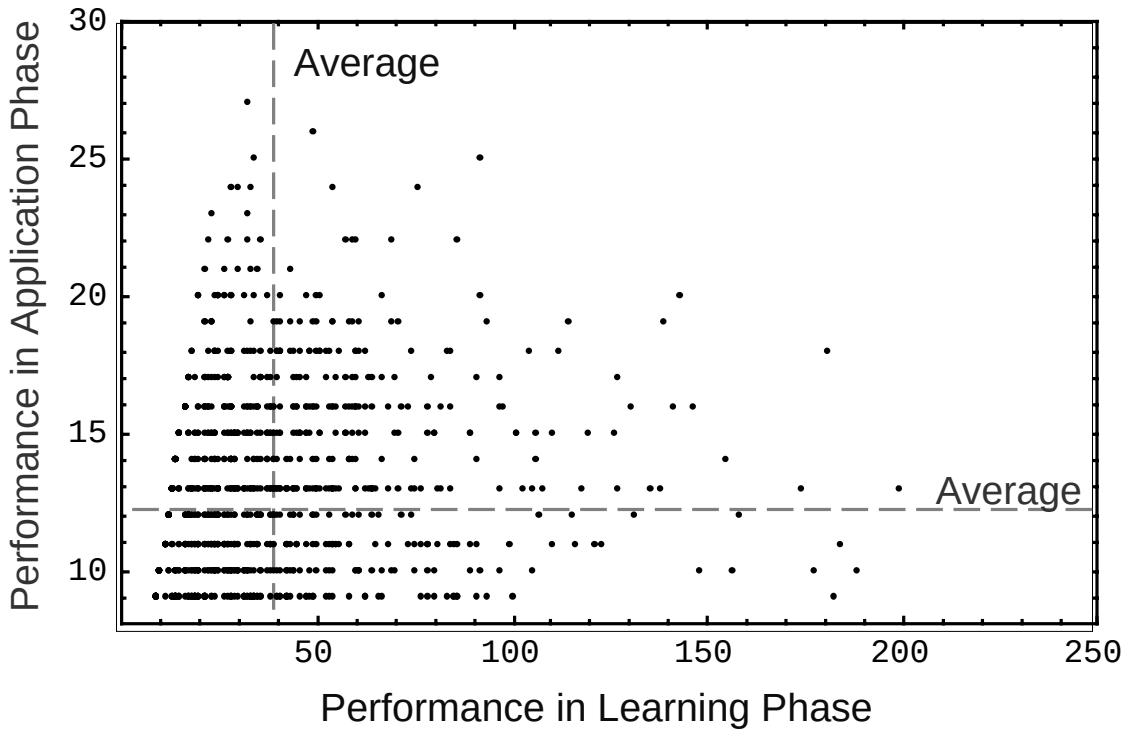
What's happening?



Learning Phase Application Phase

Unnecessary loops are removed in the Application Phase

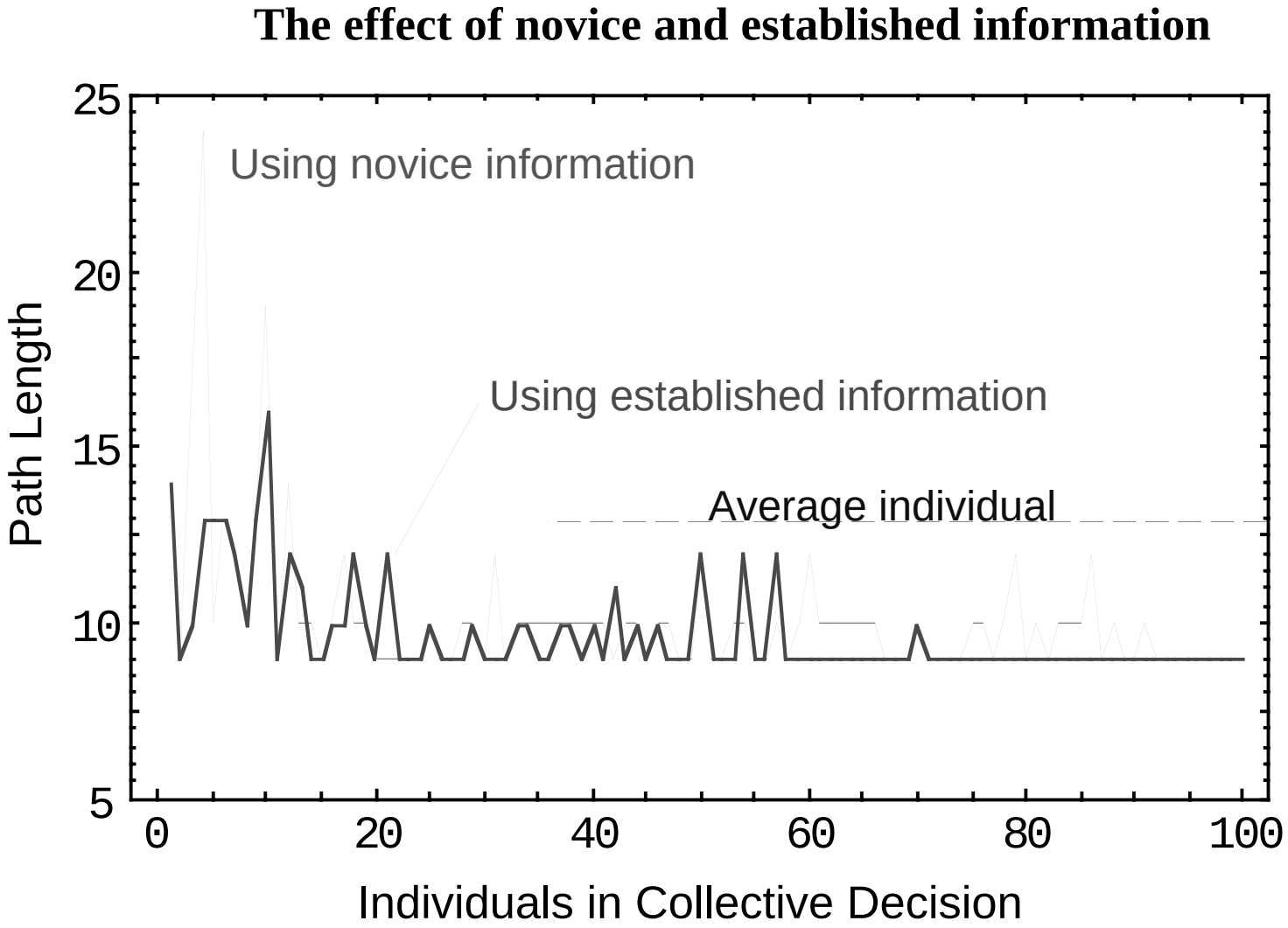
Correlation of the Two Phases



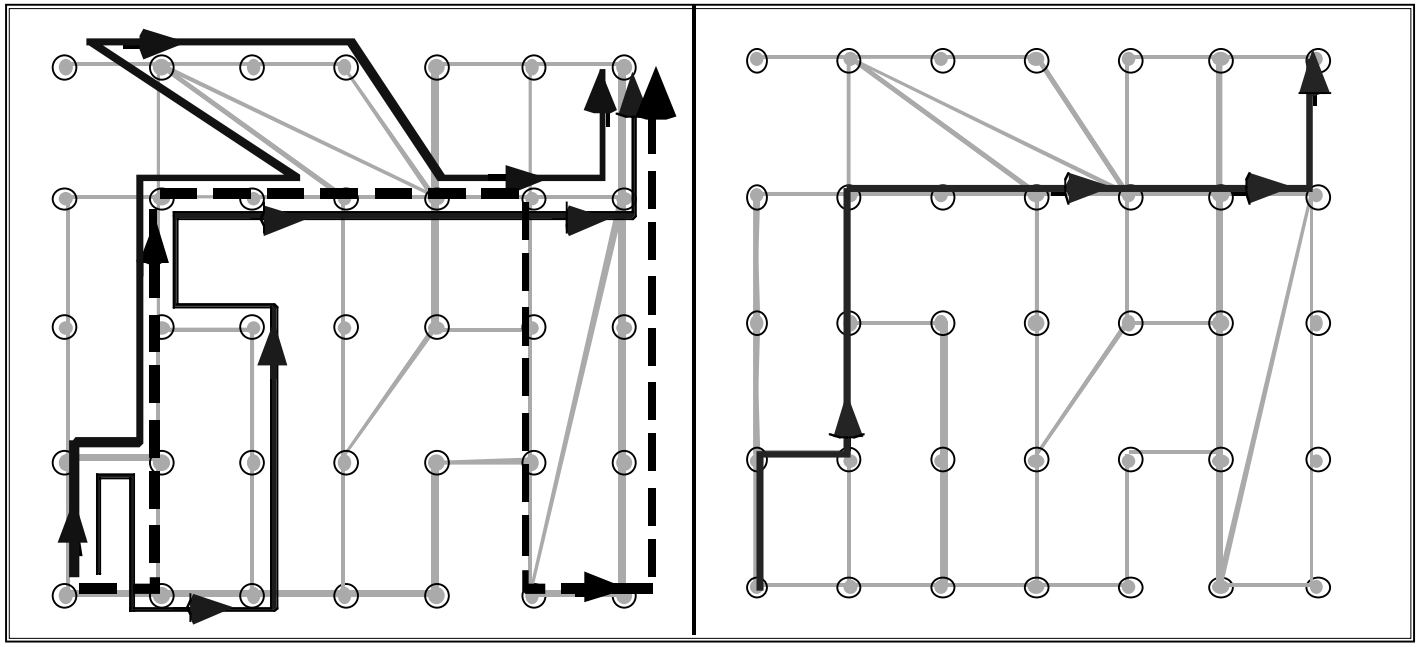
No correlation between the two phases:

A slow learner is not necessarily a poor performer

Collective Solutions



What's Happening?

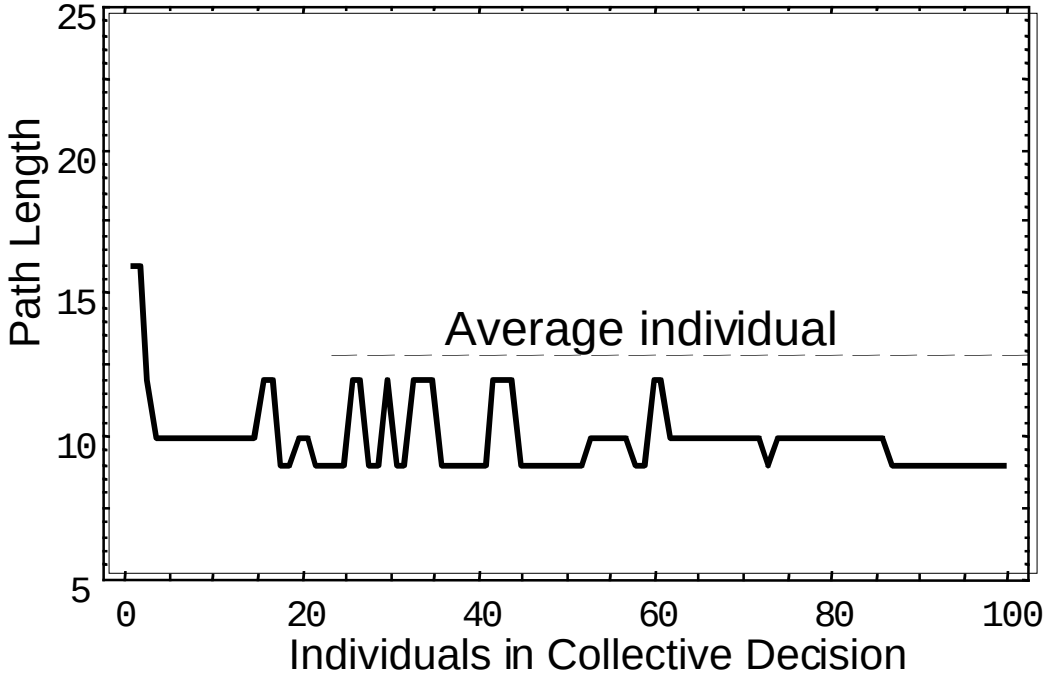


Paths of three individuals

Collective path

Chaotic Behavior of the Collective

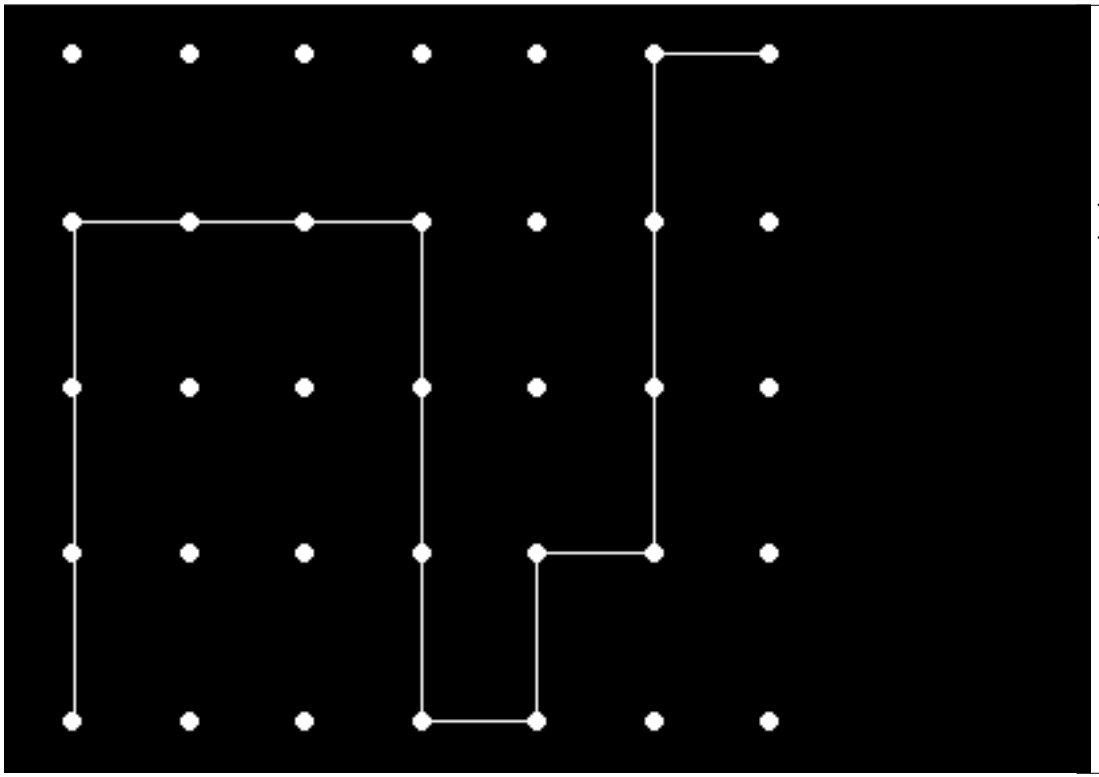
Path from adding one individual to an existing collective



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:

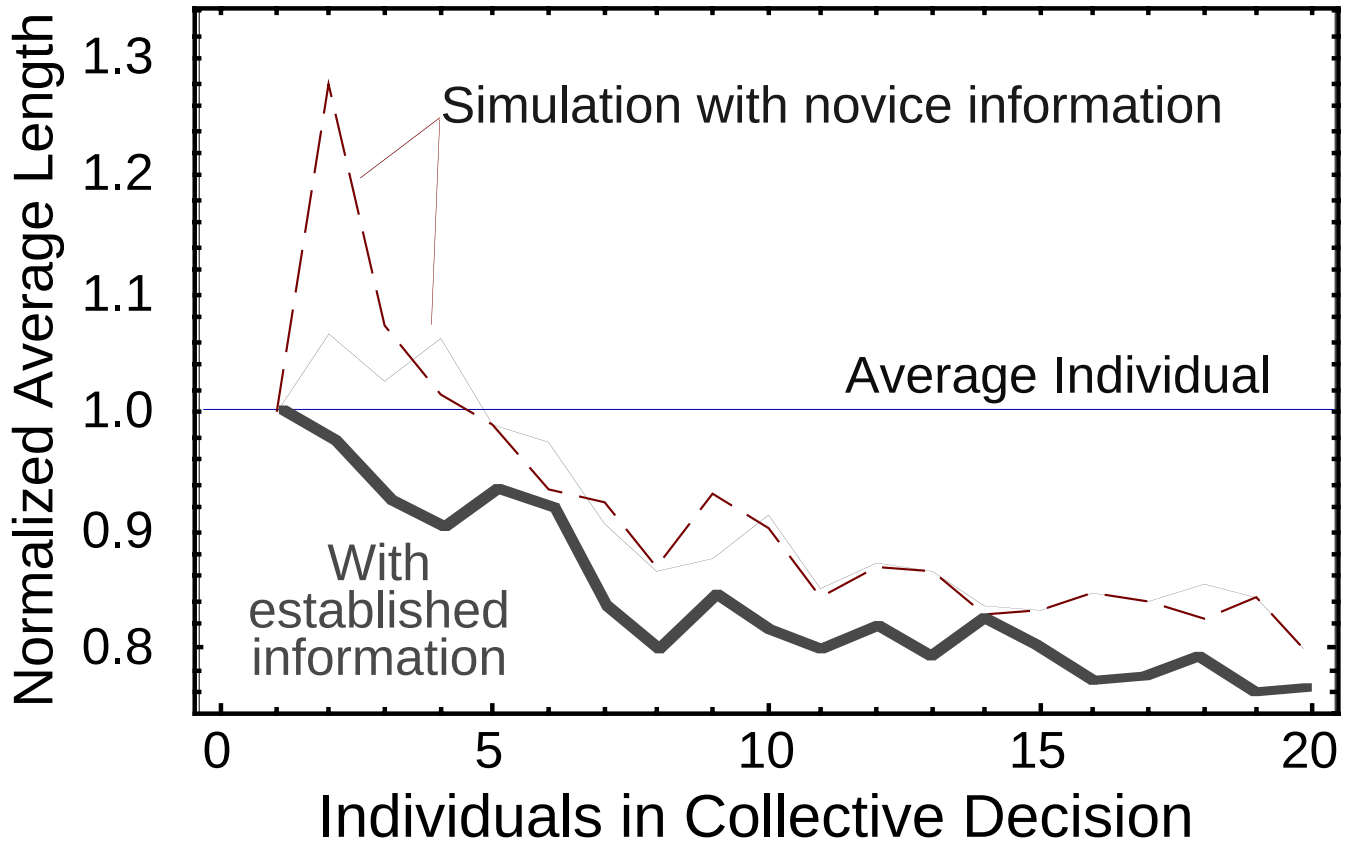
- Random choices are made between paths of equal preference, caused by the system having multiple non-optimal and optimal solutions.

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.

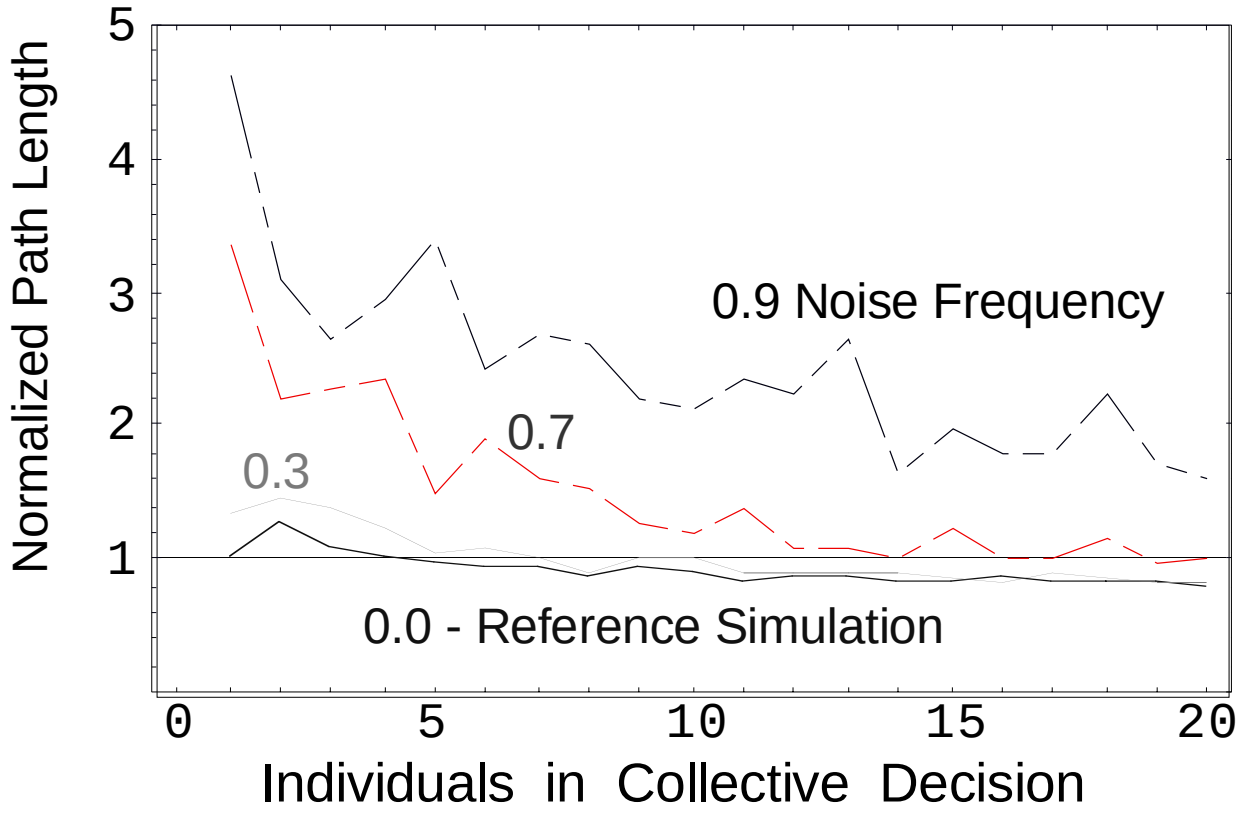
While the details are random and chaotic, the global properties (the minimum path length) is stable and reproducible. An optimal path is not necessarily reproducible or unique.

Ensemble (Averaged) Behavior



Performance correlates with high *unique* diversity

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.

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….

The Symbiotic-Intelligence Argument

Social Evolution is fundamental to humankind:

- Social behavior results in self-organizing, distributed problem solving that has been biologically enhanced and has made genetic adaptation essentially unnecessary.

New technologies can fundamentally change social evolution

e.g. advances in transportation, communication and storage of information

- Increases length scales for global (emergent) capability.
- Reduces time scales of system dynamics.
- Can add hierarchical structure to system.

The unique capabilities of the Net will enable social evolution to perform at unprecedented capability.

Why the Net is Unique

Captures the **Breadth** of Human-Machine-Society interactions

- Information storage
- Transmission and communication
- Traditional computing
- Human problem solving

Captures the **Depth** of interactions

- Retains all traces of knowledge use and creation

Accurately transfers and links the above

- Minimum loss of information exchange

What's Unique about the Project?

Why call it Symbiotic Intelligence?

- Focus on the symbiotic advantage of man and machine.

Relative to other Projects and Research:

- Artificial intelligence:
  The humans are the complex processors, not computers.
- Global Brain effort within PCP.
- Commercial ventures (Alexa, FireFly, …).

Guiding principles

- Include maximum diversity and representation.
- Use only scalable methods.
- Control from the bottom up.
- Accept solutions that you do not understand.

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.

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