Organizations and MAS

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Aims of This Tutorial

- **Present an overview and motivations for research into MAS organizations**
- **Communicate major perspectives of the field**
- **Create links to Multi-Agent Systems R&D issues**
- **Survey several major systems, experiments, and results**

(Personal, current) Motivations for thinking about organization

- **A primary concern of Library Science is "information organization and access"**
- **A principle LIS theme is:**

  Access to *organized* information is {*easier, more effective, more efficient*} than access to unorganized information...

  So both information and access should be organized
- **"Mutual structuration" of access and information (and hence of information-using communities)**
- **Viewing information (e.g. "documents") as active, with agency, not as passive, objective**

→ ***Collective (Self-)Organization of Information***

Current Projects

I. Collective (Self-)Organization of Information

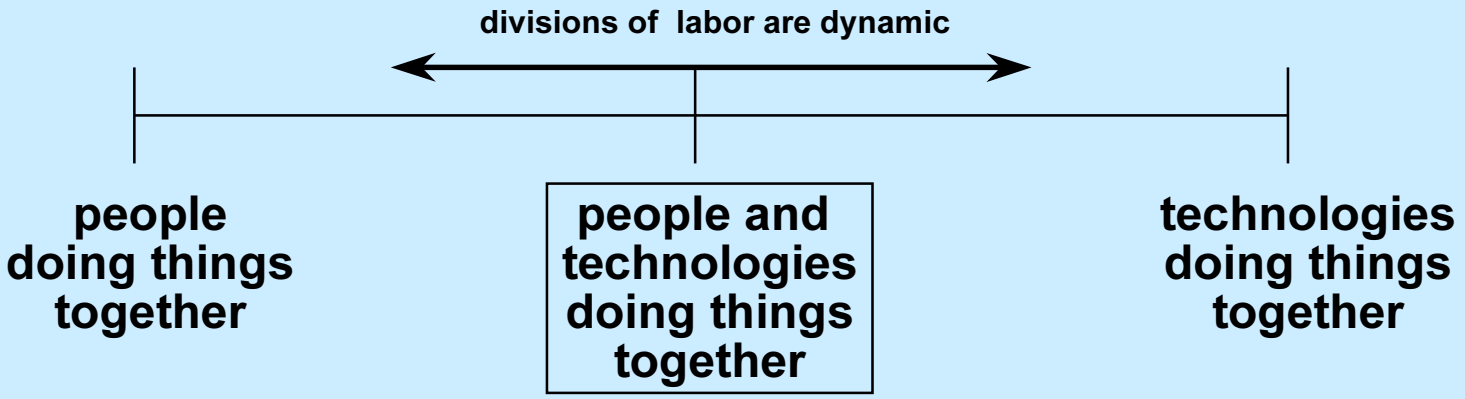
- **Language evolution: Creation and dynamics of language, (lexicon, syntax, dynamic semantics, use)**
- **Collective dynamics of web (hypermedia) structure (+access)**
- **Dynamically adaptive life-long personal information collections**
- **Information quality dynamics**
- **Resource description/discovery for agent systems**

II. MACE/MAST

- **Scalable (to very large scale) experimental infrastructure for MAS *research***
- **Java-based, “large-grain agent” focus**
- **Distributed deterministic discrete-event simulation; data mgmt**
- **PC to supercomputer (cluster) platforms**

Why Consider Organizations?

The MAS Landscape



Corkill and Lander's Principles of Agent Organization

Organization becomes more important with:

- **Increases in number of agents**
- **Increases in duration of agent activities**
- **Increases in repetitiveness of activities**
- **Increases in resource sharing**
- **Increases in collaboration**
- **Increases in agent specialization**
- **Decreases in agent capability**
- **Decreases in resource slack**

….All of which are occurring in MAS applications areas

Other Motivations….

- **Current conditions and forces mean the online information and services landscape will be non-uniform**
- **Patterns of activity will thus be non-uniform, i.e. organized**
- **Patterns will conform to (and influence) existing social arrangements**
- **Patterns are likely to be localized and semi-redundant**
- **Organization, (e.g., specialization and division of labor) can be a response to resource limitation and local opportunity**
- **Patterns provide stability and predictability**

Hypotheses About MAS Organizations

1. MAS are fundamentally organizational systems.

2. As such they will exhibit many features common to existing organizational systems.

3. Hence,

- **To understand/build them we can leverage existing organizational concepts and tools;**
- **The better we do this, the better MAS ill integrate with their contexts of use;**
- **Certain evolutionary and contextual features of MAS will necessarily drive them toward 2 above.**

Basic Questions

Conceptualization:

How do we describe organization?

***Empirical & Theoretical Taxonomy*:**

What forms of organization exist?

Theory:

What elements and relationships govern the nature, form, and behavior of organizational systems?

Mechanism and Implementation:

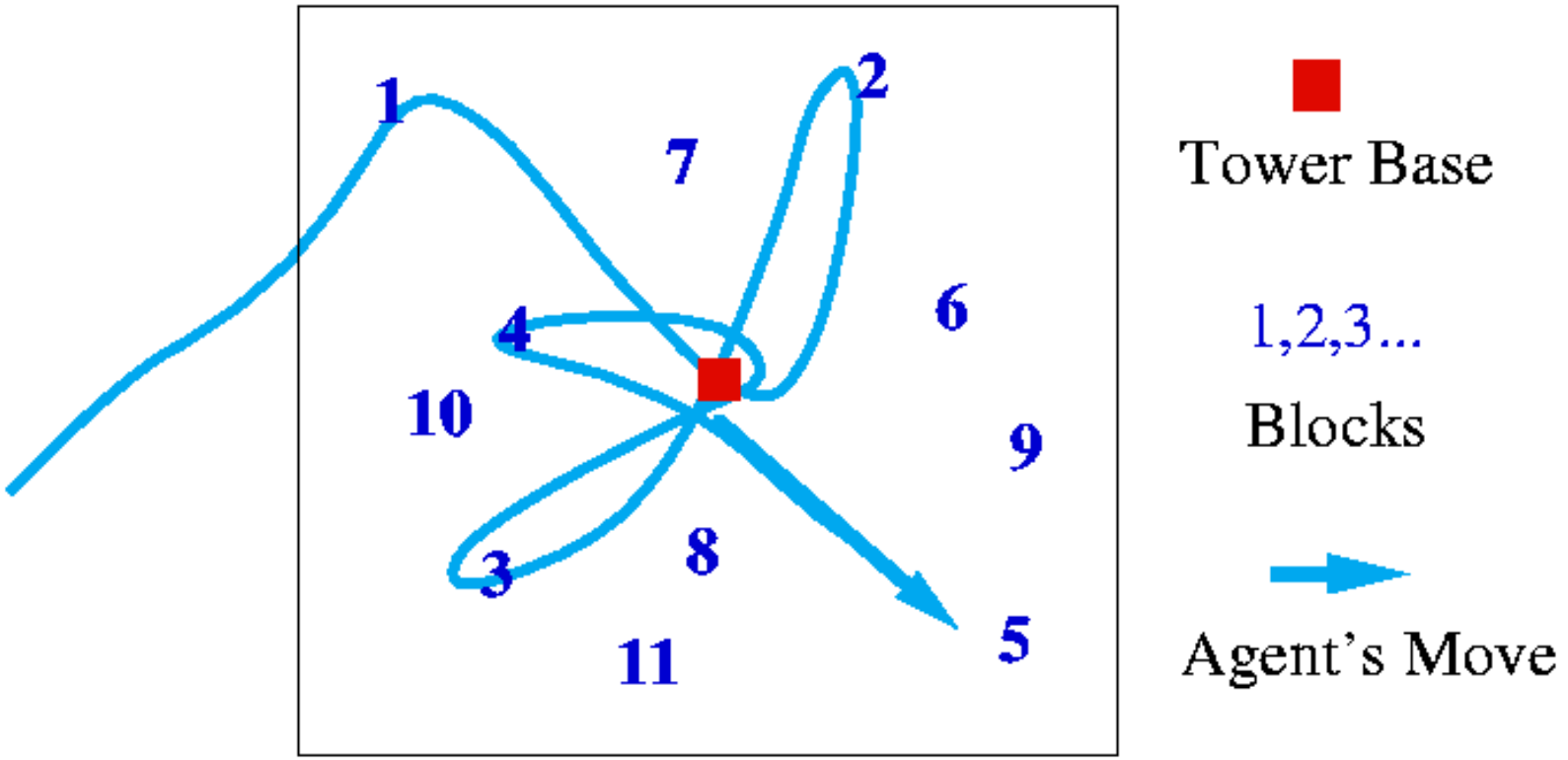
What organization mechanisms are possible and tractable?

Let's take a simple example….*

* thanks to Toru Ishida

The *Tower of Babel*

A New Testbed for Organization Design



Goal: To build a tower by stacking the blocks starting from number 1 as efficiently as possible.

The *Tower of Babel* (Details)

1) ***Problem space:*** In a grid space, sequentially numbered blocks are randomly scattered. The base of the tower is located at the center of the grid.

2) ***Move:*** Each agent can move to any neighboring node in a unit of time. When an agent and a block are placed on the same node, the agent can carry that block.

3) ***Space conflicts:*** Except for the base, only one block at a time can ocuppy a node. Agents cannot share a node with any other agent.

Why the *Tower of Babel* ?

1. The Tower of Babel includes a good amount of parallelism, but also requires sequential planning.

   (Not like making an ant hill, but is similar to constructing a building.)

2. The Tower of Babel is easy to solve with a single agent, but becomes more difficult as the number of agents increases.

   (As parallelism increases, conflicts among agents frequently occur.)

Experiments on Various Agent Types

1. **Basic Agents**

   Plan to solve the *Tower of Babel*.

   No communication among agents.

2. **Coordinating Agents**

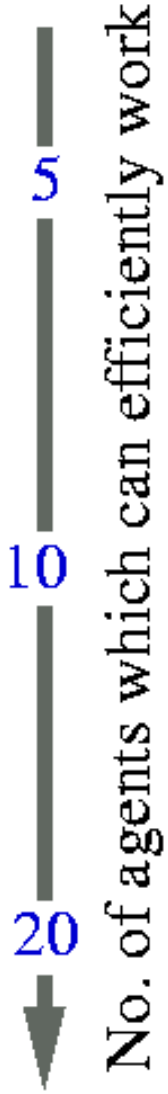
   Select goals depending on other agents' decisions.

   Agents inform their goals to other agents.

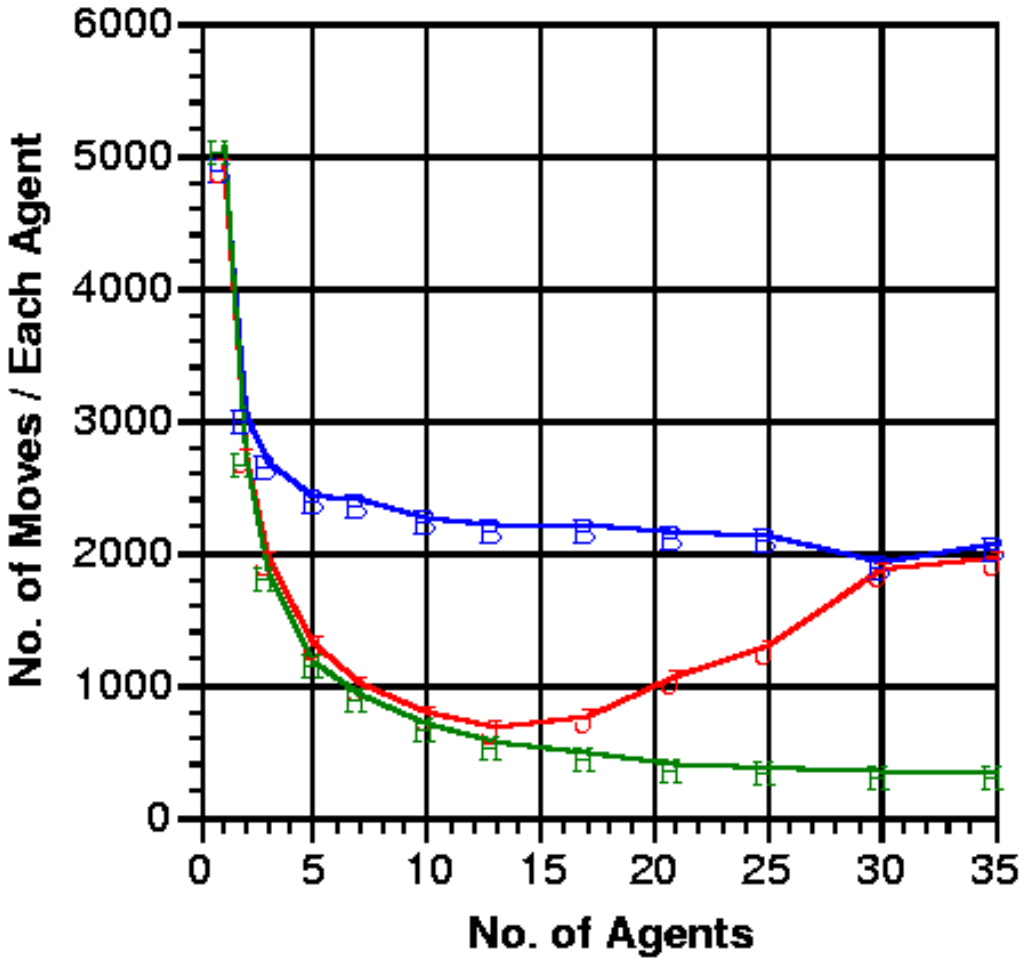
3. **Organizational Agents**

   Change goals depending on organizational situations.

   Agents can leave blocks halfway to the base,
   so that they can pickup other blocks.



Experimental Evaluation



50 x 50 grid space

100 blocks

200 obstacles
(randomly positioned)

Basic Agents

Coordinating Agents

Organizational Agents

Implicit Organization

Designing utility functions so that organizations emerge.

Utility Function

w Local_Contribution + $(1\text{-}w)$ Global_Contribution

Local Contribution

Individual Efficiency: Move any block towards the base.

Conflict Avoidance: Avoid being blocked by other agents.

Global Contribution

Group Efficiency: Move a block to be stacked next.

Conflict Avoidance: Avoid blocking other agents.

How to design such an appropriate utility function in general?

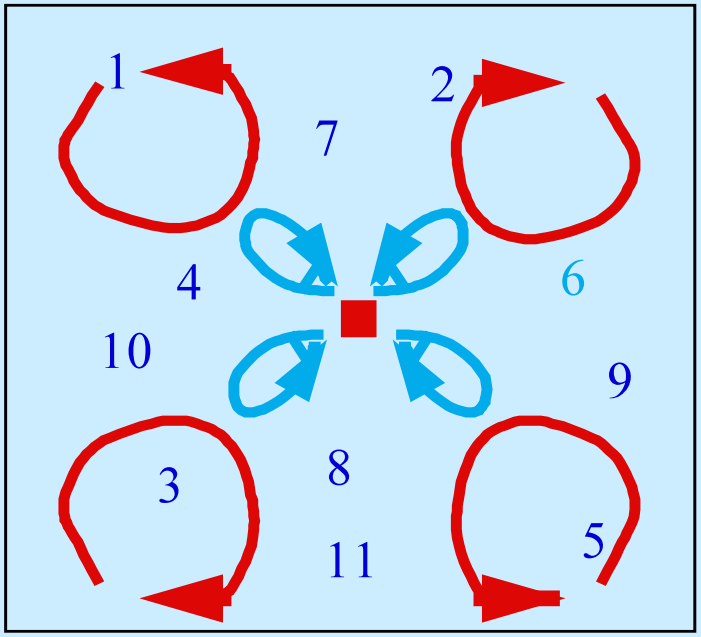
Explicit Organization

Designing constraints to restrict a pattern of actions.

To divide the agents into two groups:

1) One group works at a distance from the base, and carries blocks near (but not too near) the base.

2) The other group works near the base, and stacks blocks on the base.



How to synthesize such appropriate constraints in general?

High-Level Outline…….

Motivations

Introduce three interlocking perspectives

- ***Theoretical:*** **Organizational models and concepts**
- ***Phenomenological:*** **Organizations as phenomena**
- ***Technological:*** **Organizations as technologies**

Examine a variety of systems and projects from these three views

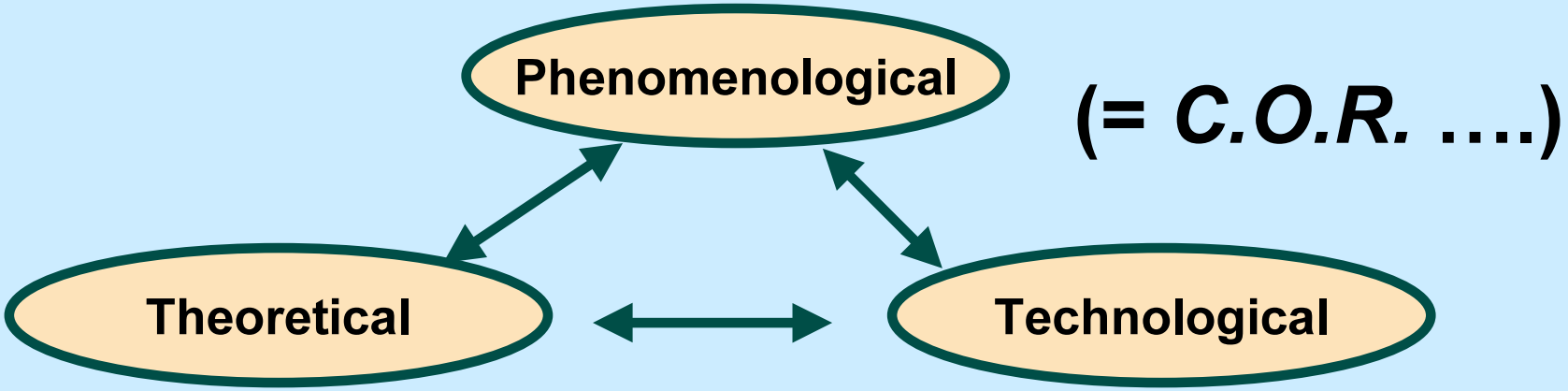
Conclusions

Perspectives on Organizations

I. ***Phenomenological***: description/analysis/explanation of existing (human, computational, biological, physical, etc.) organizations.

II. ***Technological:*** Organizations as social technologies for solving complex problems, for overcoming "individual" limitations (cognitive, physical, temporal, institutional…), and as efficiency/optimization strategies.

III. ***Theoretical:*** Abstract and general models of possibilities, limits, and mechanisms of organization.



(= C.O.R. ….)

Vision

Science: **Are there general principles of organizing?**

Industry: **Organizational Engineering**

what if analysis to evaluate:

- **redesigns**
- **restructuring**
- **impact of new technologies**
- **impact of policies**

Pedagogy: **Learning about organizing & organizations through hands on simulated experimentation down to the gradeschool level**

Theoretical Perspective

Abstract and general models of possibilities, limits, and mechanisms of organization.

Theory:

What elements and relationships govern the nature, form, and behavior of organizational systems?

= structural elements of theory

= content of theory

- **What conditions lead to the formation or dissolution of particular organizational forms?**

- **How do complexity and uncertainty in environments, tasks, and technologies shape organizational forms? *(contingency theory)***

- **What are the fundamental limits to organizational forms and behavior and how are these limits constituted?**

"People living and working in a business system cannot change it. Their perspectives are foreshortened, their information gathering and measurement systems reinforce the past, and their incentives encourage continuity. Archimedes proclaimed, 'Give me where to stand, and I will move the earth.' But where should those who might change a business system be standing?

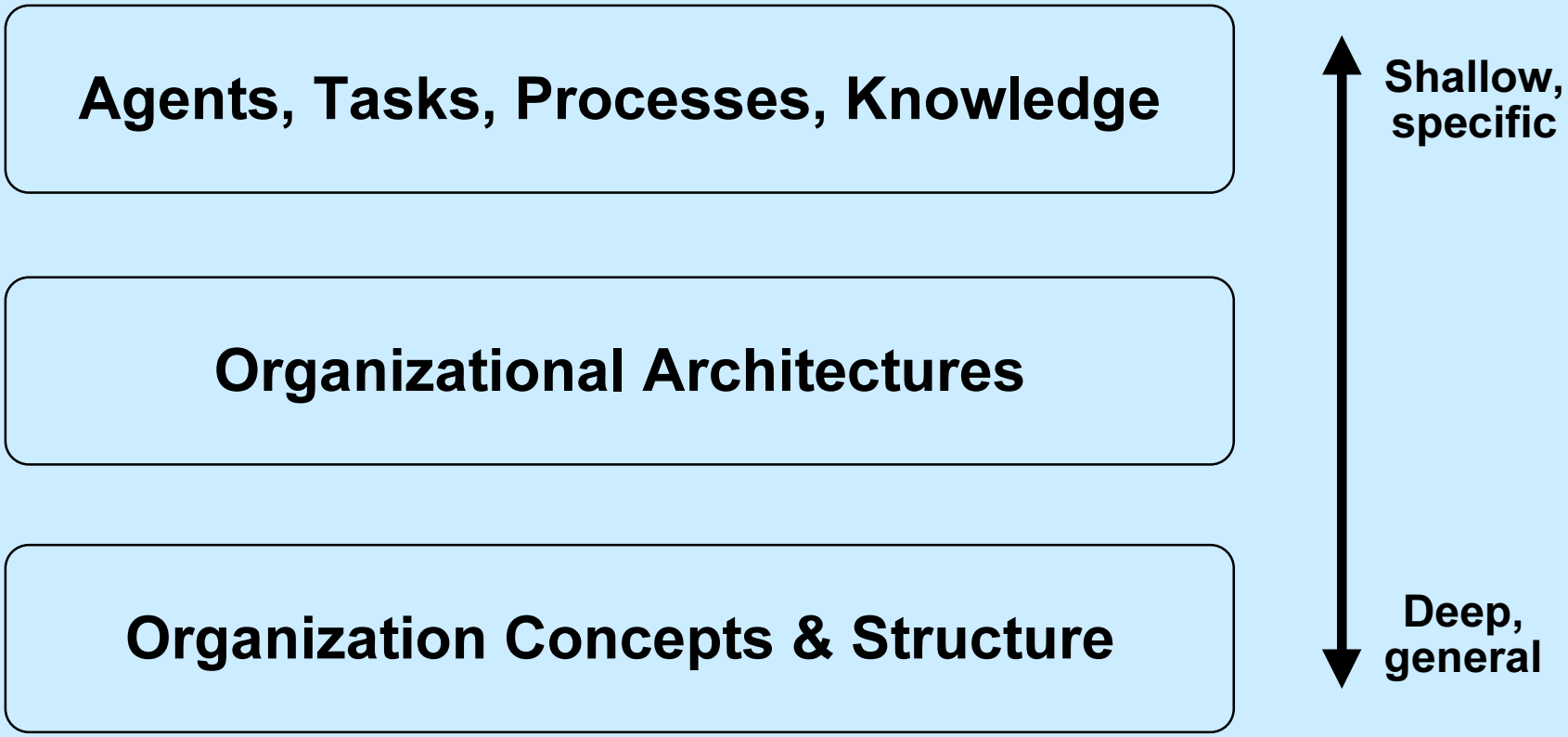
"The answer is that every organization needs two business systems…..the 'surface system' and the 'deep system.' The surface system is comprised of the organized tasks of the business processes, with their attendant jobs, structures, systems, and values. But this surface system is in periodic need of major change. Accomplishing that change is the job of the deep system.

"The deep system creates no customer value; it makes no products and delivers no services. It doesn't process orders, develop new products, or create value for customers. Rather it monitors, governs, adjusts, and reforms the surface system that does create customer value. A company's deep system bears the responsibility for detecting external changes, determining what those changes mean, and intervening to modify or transform the surface system accordingly. The deep system, working beneath the surface, embodies the capacity to change.

"The deep system continually hurls challenges: Is this still the right way or the best way to do things? If not, what is? The deep system ensures that the appropriate internal change-moderate or radical-takes place, shaping and reshaping the organization to take account of, and whenever possible take advantage of, ongoing external change."

Michael Hammer,
"Beyond Reengineering: How the Process-Centered Organization is changing Our Work and Our Lives."

Deep Systems of Organization



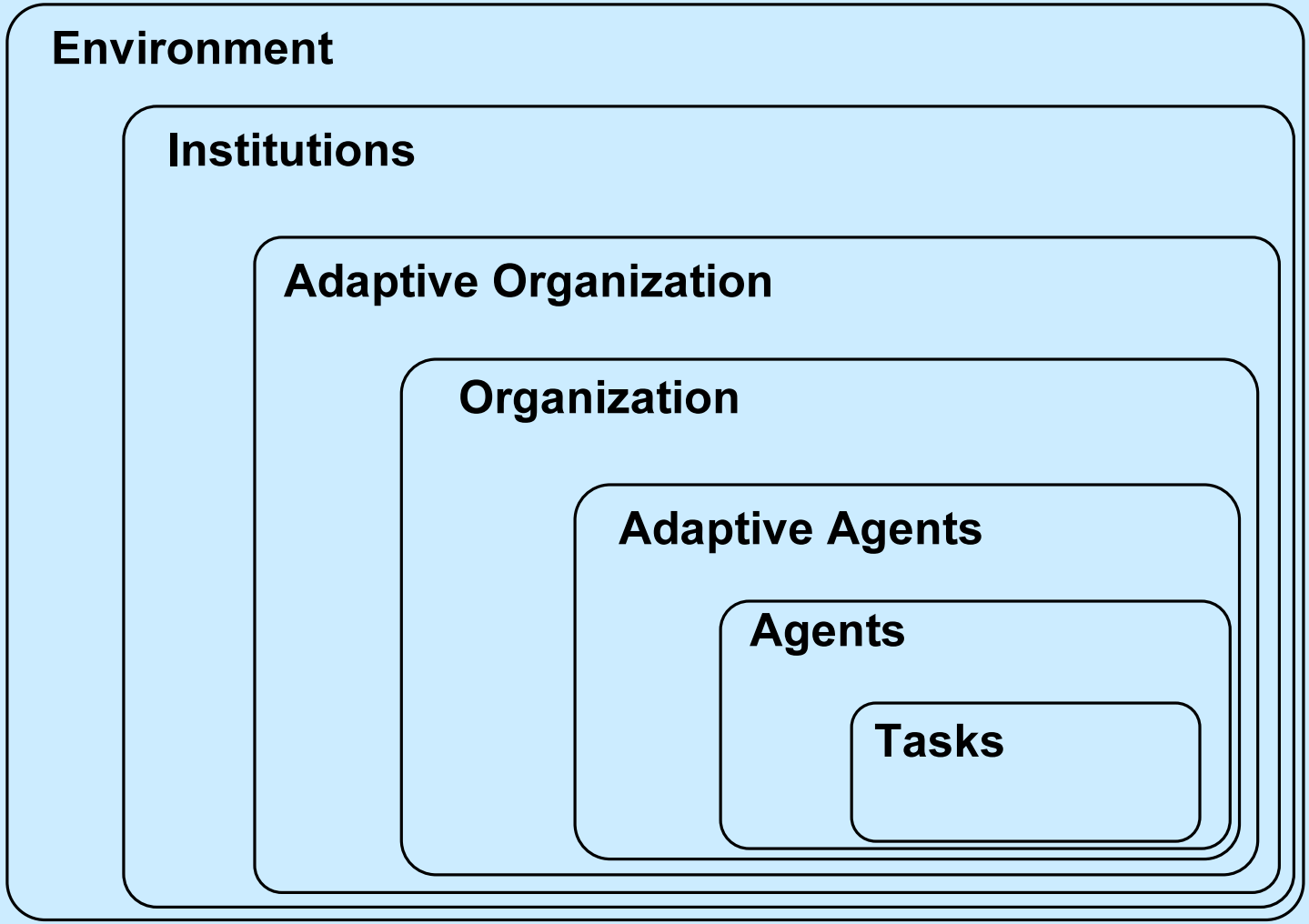
Levels of Abstraction in MAS

Theory of Social Organization

Theory of Modeling/Problem Solving
(e.g., problem frameworks; algorithms)

Theory of Implementation
(e.g. programming languages; communication)

Multiple Levels of Analysis Needed



Ashby's Concepts

("Principles of the Self-Organizing System", 1962)

The "hard core" of the concept of organization is "conditionality": the relationship between A and B is conditional on the state or value of C.

Thus:

- **The general theory of "organization" is coextensive with the theory of functions of >1 variable.**

- **The opposite of "organized" is "reducible"**

A system is described by a "product space" - a set of configuration *possibilities* - some subset of which indicates *actual configurations* of the system.

Conditionality implies "communication" among parts (whose converse is independence)

Communication implies *constraint*: a *correlation* between events/state A and event/state B (i.e., a constraint on which (A,B) pairs can occur).

Organization* is a *constraint on the product space of possibilities

This view of organization is *subtractive* (limits in the product space), whereas some other conceptions (e.g., in biology and sometimes in MAS) are *additive*.

Product space contains more than is manifested in actuality. Thus:

- **Product space represents the uncertainty of the *observer*: what could happen**

- **Changes in observer can lead to changes in product space.**

- ***Theory of organization is concerned with properties that are fundamentally relational between observer and thing***

Conditionality in a system implies thinking of a whole and its parts.

Dynamic analysis may consider parts or wholes, so

- ***Organization* and *Dynamics* are independent concepts**

Any dynamic system can be made to display a variety of arbitrarily assigned "parts"

Whether or not a system is reducible depends on the point of view of an *observer who assigns these parts*.

A “machine” is a set S of internal states, I of inputs or external states, and a mapping IxS into S.

A machine’s (system’s) organization:

- **Specify the system by specifying S and I**
- ***Specify the organization by specifying the mapping, f, i.e., the conditionality among states***

“Good” organizations:

No organization is good in all circumstances

Organization is “Good” if it is stable around some *assigned* (not arbitrary) equilibrium: if it keeps an *assigned* set of variables within *assigned* limits.

Thus goodness is also a relation between organization and observer, who makes the “*assignments*”

Stability must be defined with respect to a *set of disturbances*

Finally, a “good” organization is *a relation between a set of disturbances and an assigned equilibrium*.

Conceptualizations Of "Organization"

Patterns of Action and Knowledge. (*patterning*)

Integration. (interaction, interdependencies)

Compositionality. (…individuals)

Stability/Flexibility. (architecture)

Coordination. (order amplification)

Supra-individuality. ("roles", "tasks", "knowledge")

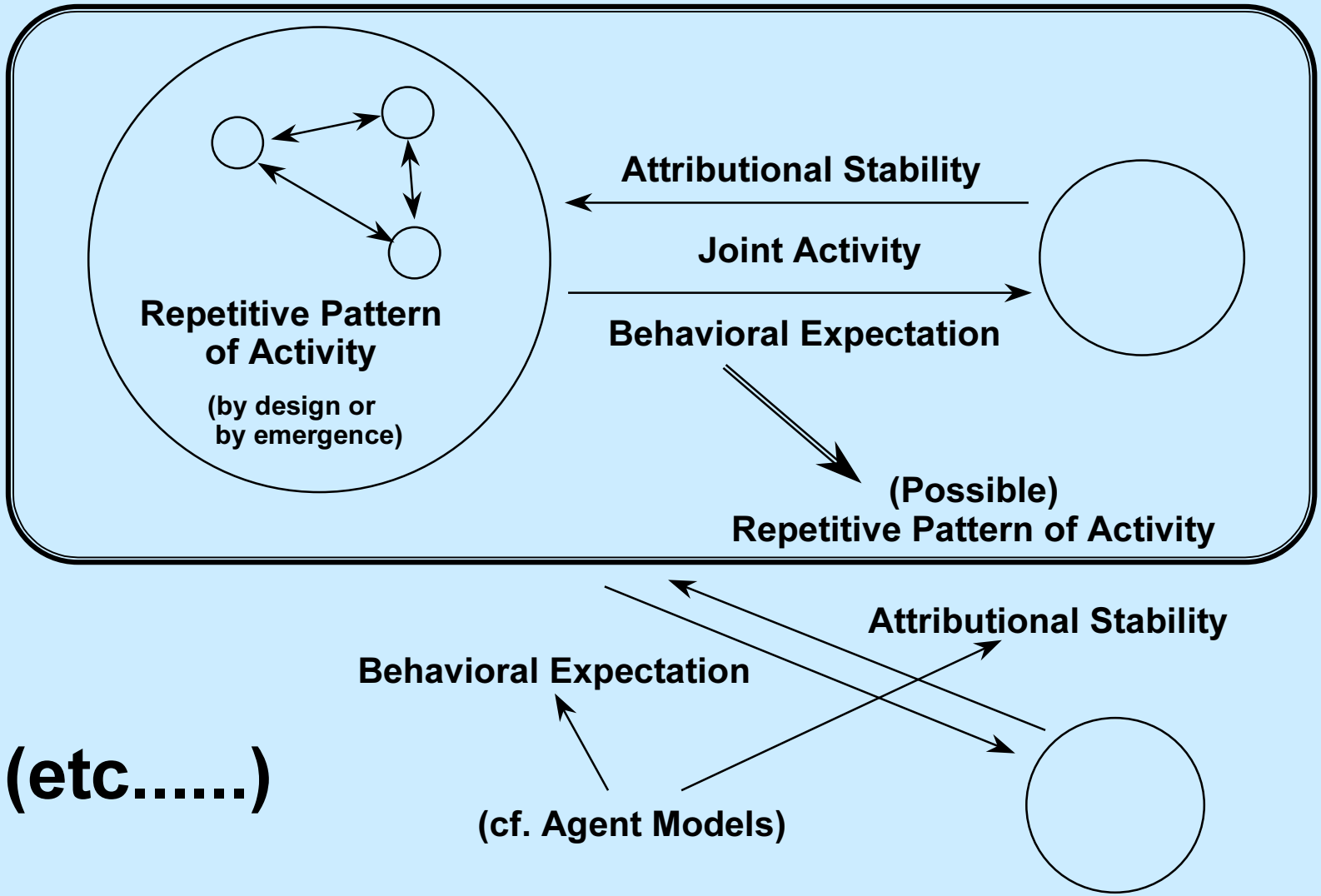
State of Functional Irreducibility. (Ashby)

Recursivity. (suborganizations, overlap)

Multi-level representation/causality. (embedded time cycles)

Potentials/Differentials. (power, affiliation)

Organizations as Activity Patterns



Theoretical Taxonomy & Design:

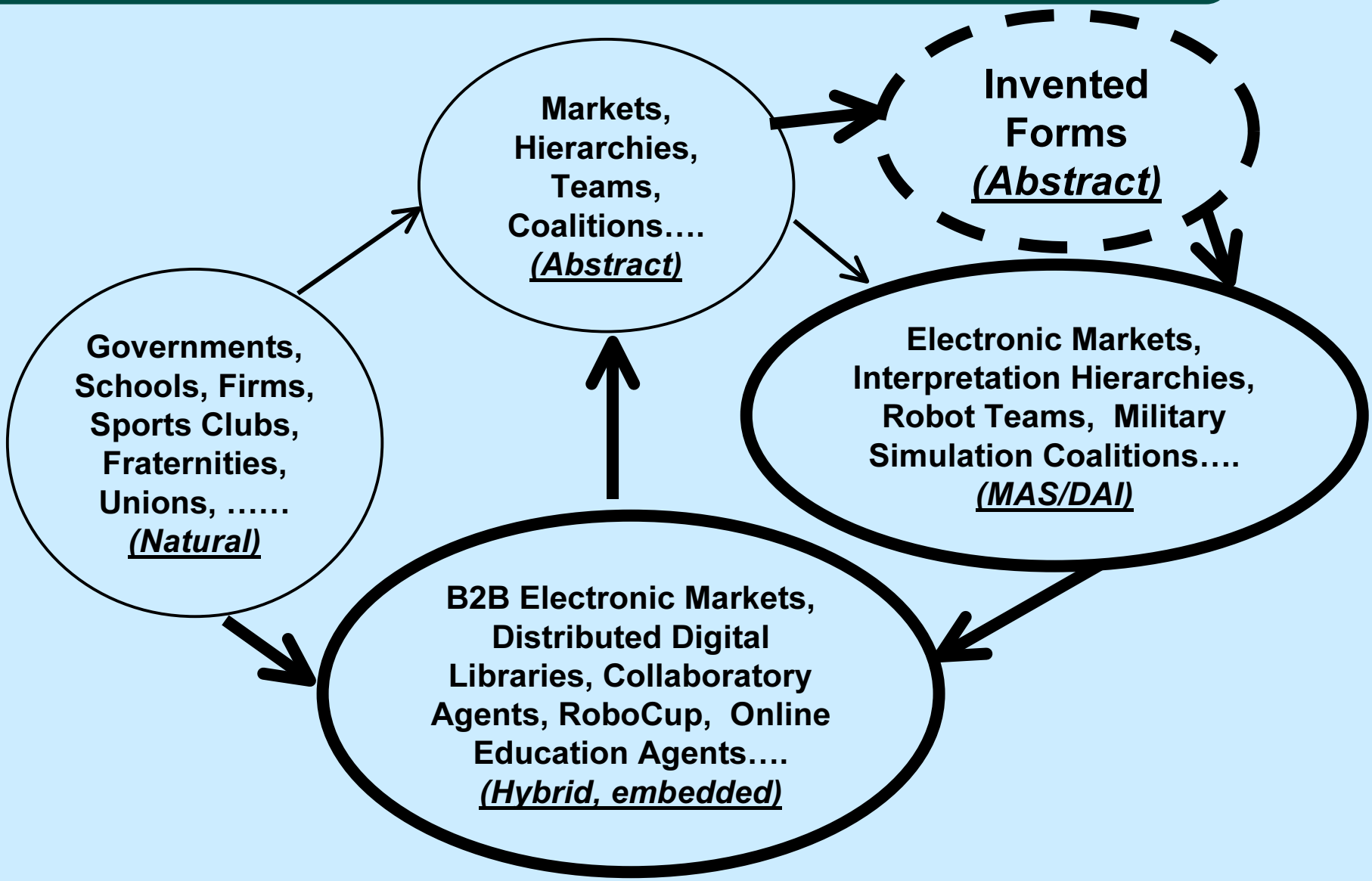
What forms of organization are possible?

Given a body of *theory* (which embodies conceptual machinery) and *empirical taxonomy* (which embodies the present and the past)

- **What forms are missing from the landscape and why?**
- **What new forms can be invented & put in place?**
- **How can we predict their behavior, success, failure, etc.**
- **What forms are impossible, impractical, or unrealistic?**
- **How can we know these things?**

Empirical & Theoretical Taxonomy & Design:

What forms of organization could exist?
How should they be classified and created?



Examples of Specific Modern Theories

Structuration Theory
(Giddens)

Some tenets:

Structures are "dual": they are "both the medium and the outcomes of the practices which constitute social systems."

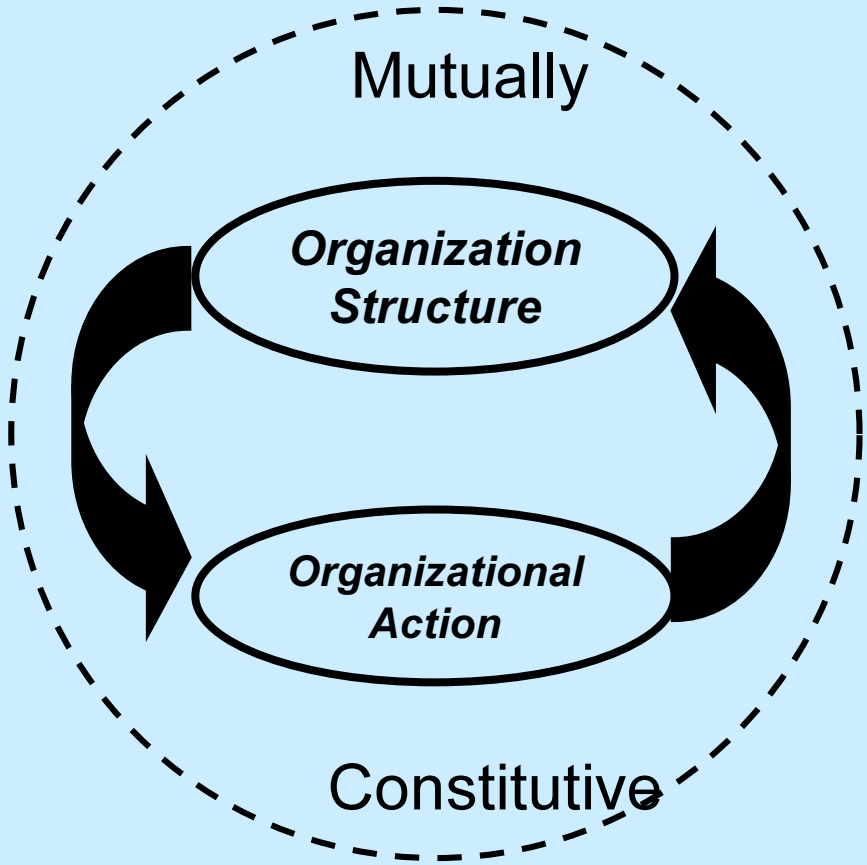
Peoples' practices constitute structures

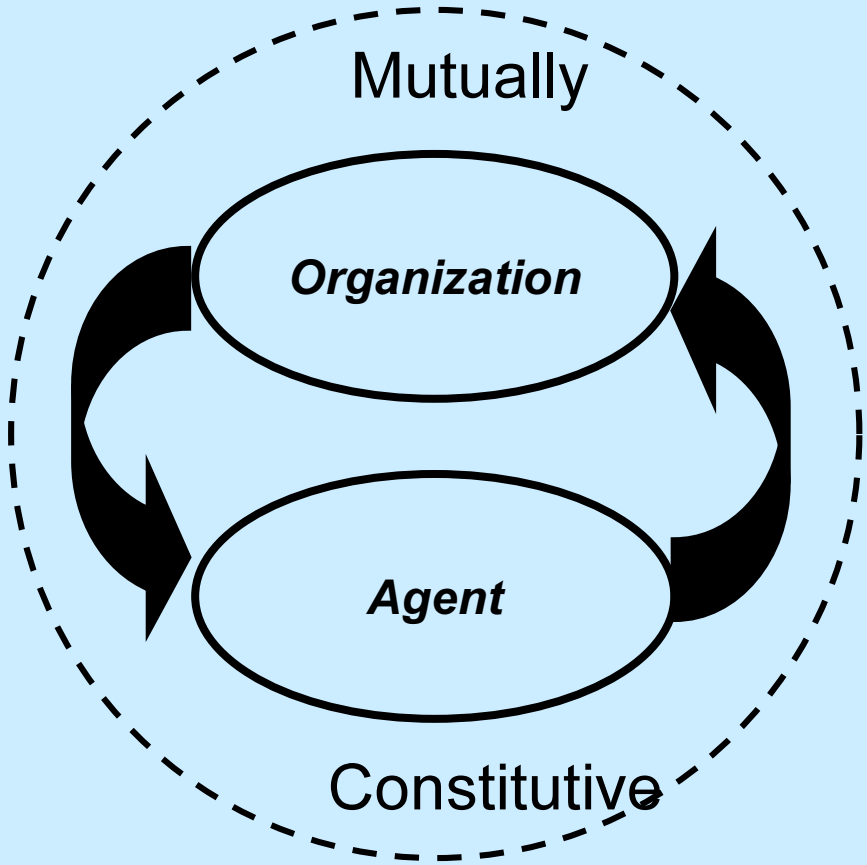
Practices reproduced by the recursive enactment of structures

Practice and structure presuppose each other

Structures are the principles that pattern practices

Intricacies of Structuration Theory





Sensemaking Theory

(K. Weick, Sensemaking in Organizations,1995)

Definitions:

Sense *Making* (i.e., *active construction*)

“Structuring the unknown”

“Placing stimuli into a framework”

“A recurring cycle that uses retrospective accounts to explain surprises”

7 Properties of Sensemaking Theory

(K. Weick, Sensemaking in Organizations,1995)

Grounded in identity construction

Retrospective

Enactive of sensible environments

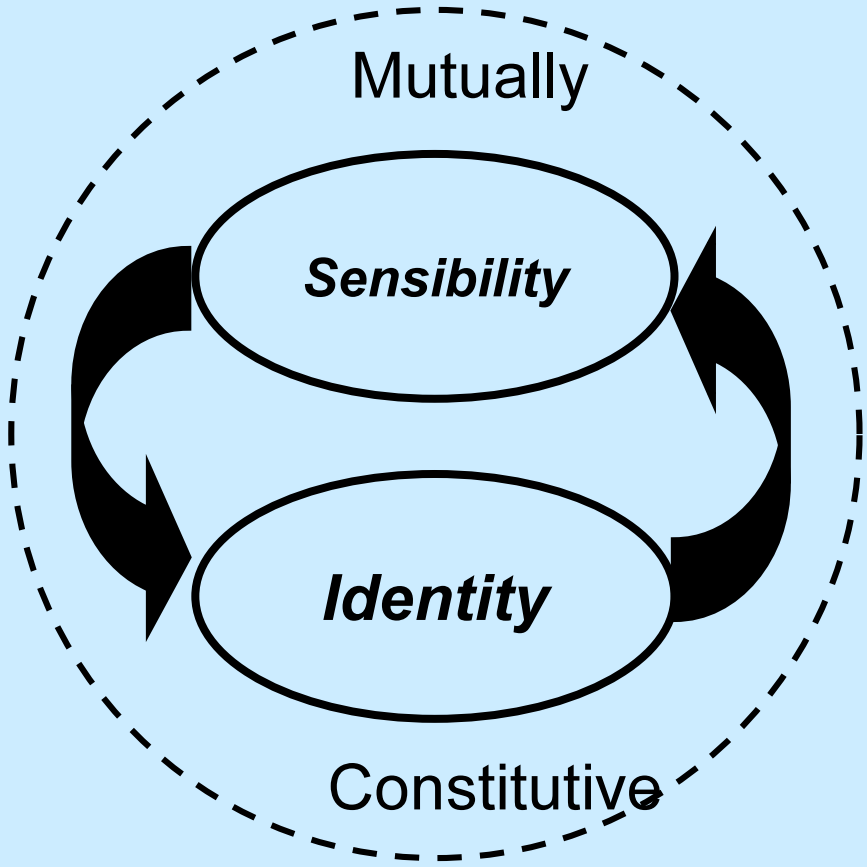
Social [collective sensemaking]

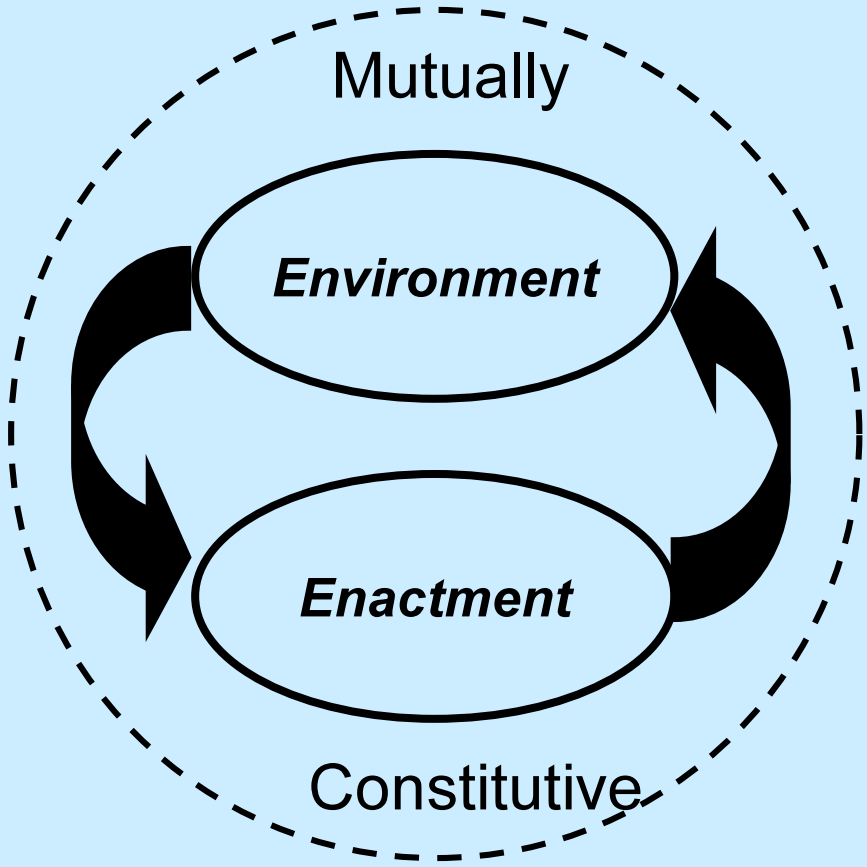
Focused on and by extracted cues

Ongoing

Driven by plausibility rather than accuracy

Two Cyclic Aspects of Sensemaking Theory





Perspectives Often Missing from the Social Science View

- ***Constructive experimental*** **methodologies**

- **Clear accounts of the *computational limitations* of social processes**

- ***Principled representations*** **of objects, attributes, and processes.**

Perspectives Often Missing from the MAS/DAI View

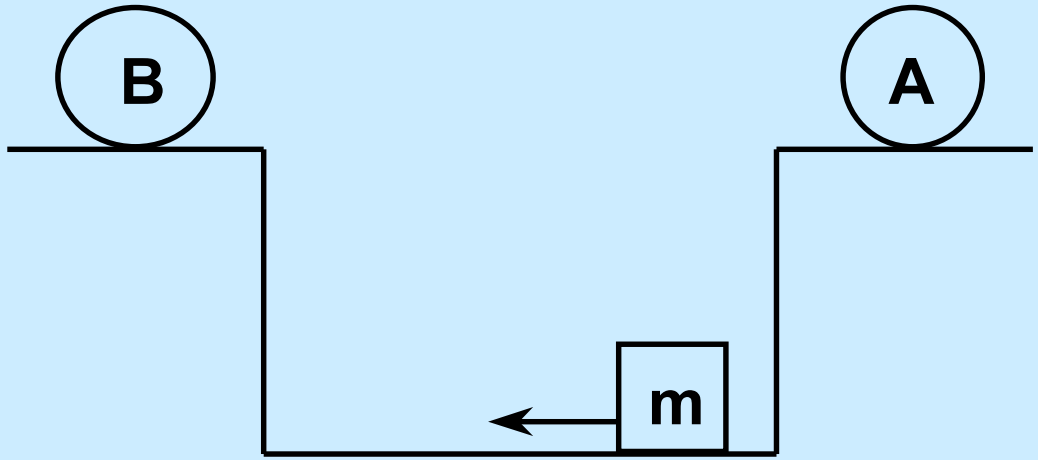
- ***Fundamental mutability*** **and negotiated character of order and structure at all levels of representation and action**

- ***Mutual construction*** **of structures and realities**

- ***Retrospectively oriented*** **accounts of action and knowledge.** **[This is a more fundamental change in perspective and theory for Computer Science]**

Coordinated Attack

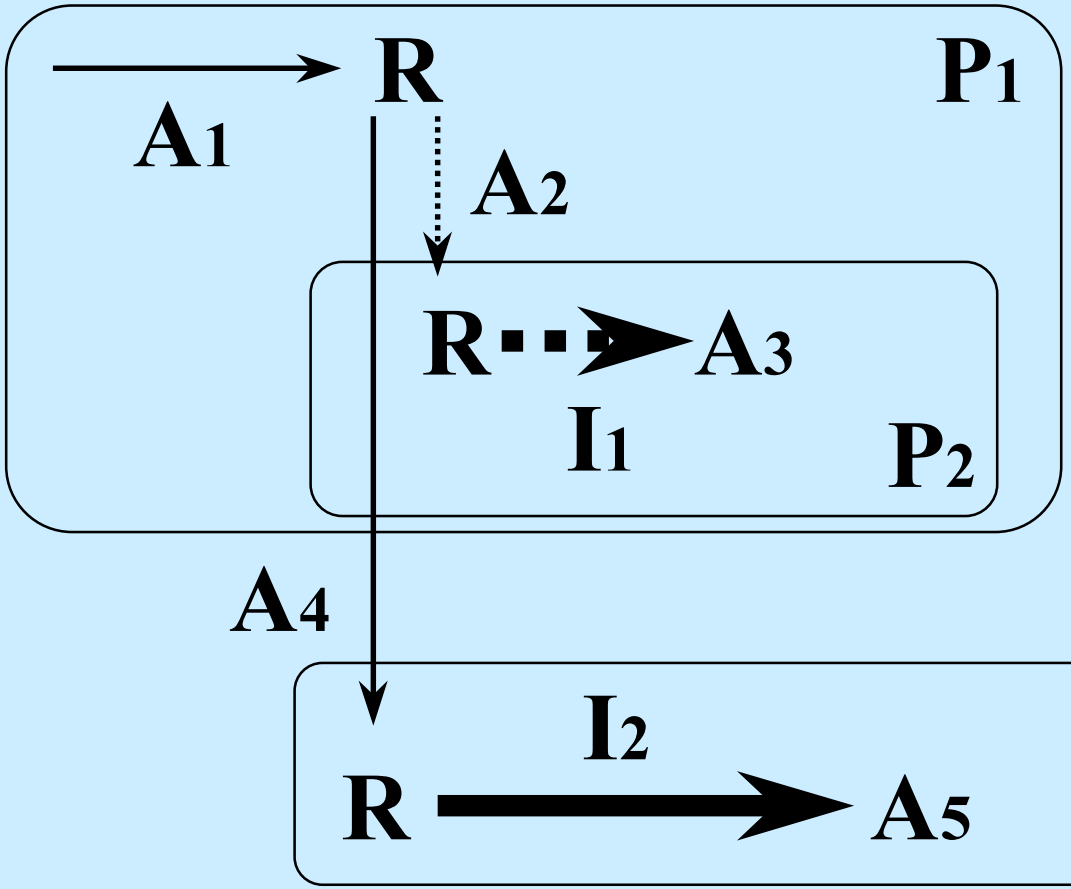
Two allied generals are stationed on opposite hills. In order to successfully attack the enemy in the valley, they must attack together. General A sends a messenger to General B, with the message "Attack at dawn!"



Common Knowledge

Common knowledge of a fact P—that state in which “Everyone knows that everyone knows……that everyone knows P” for any number of ‘everyone knows’.

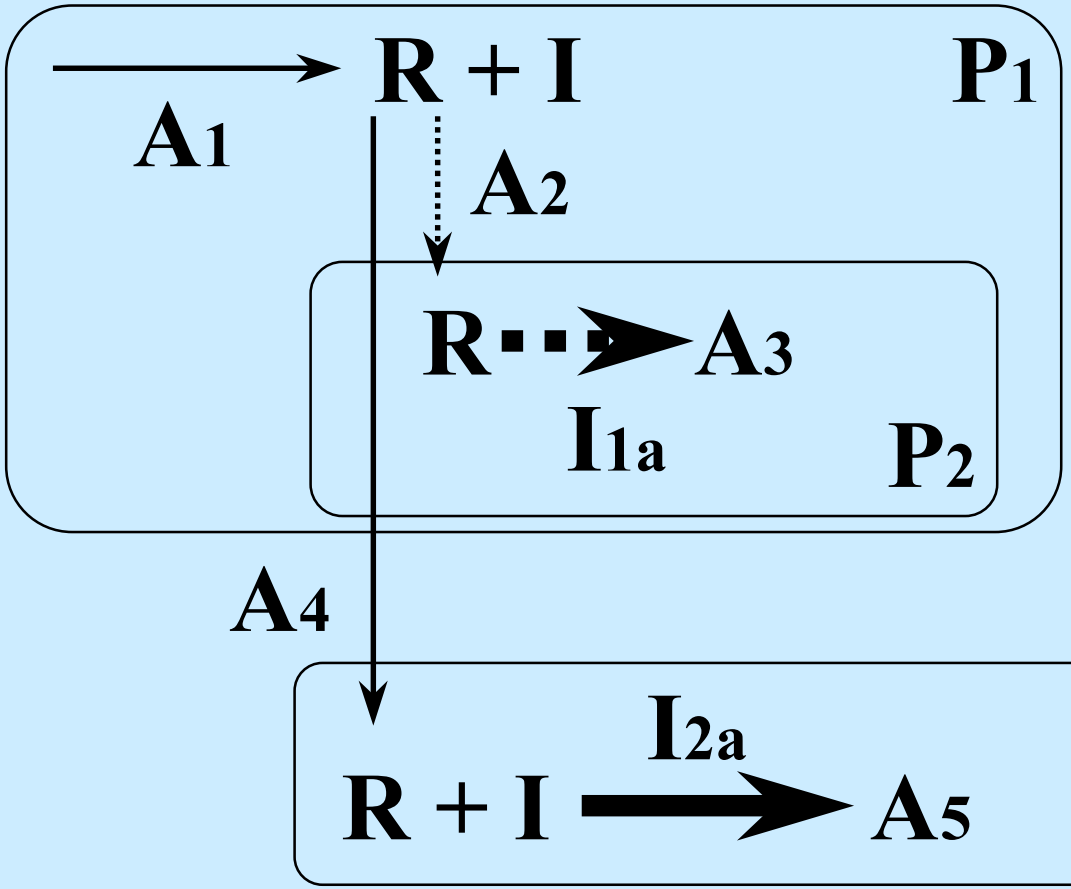
Action-at-a-Distance



$I_1 = I_2$?

$A_3 = A_5$?

Action-at-a-Distance

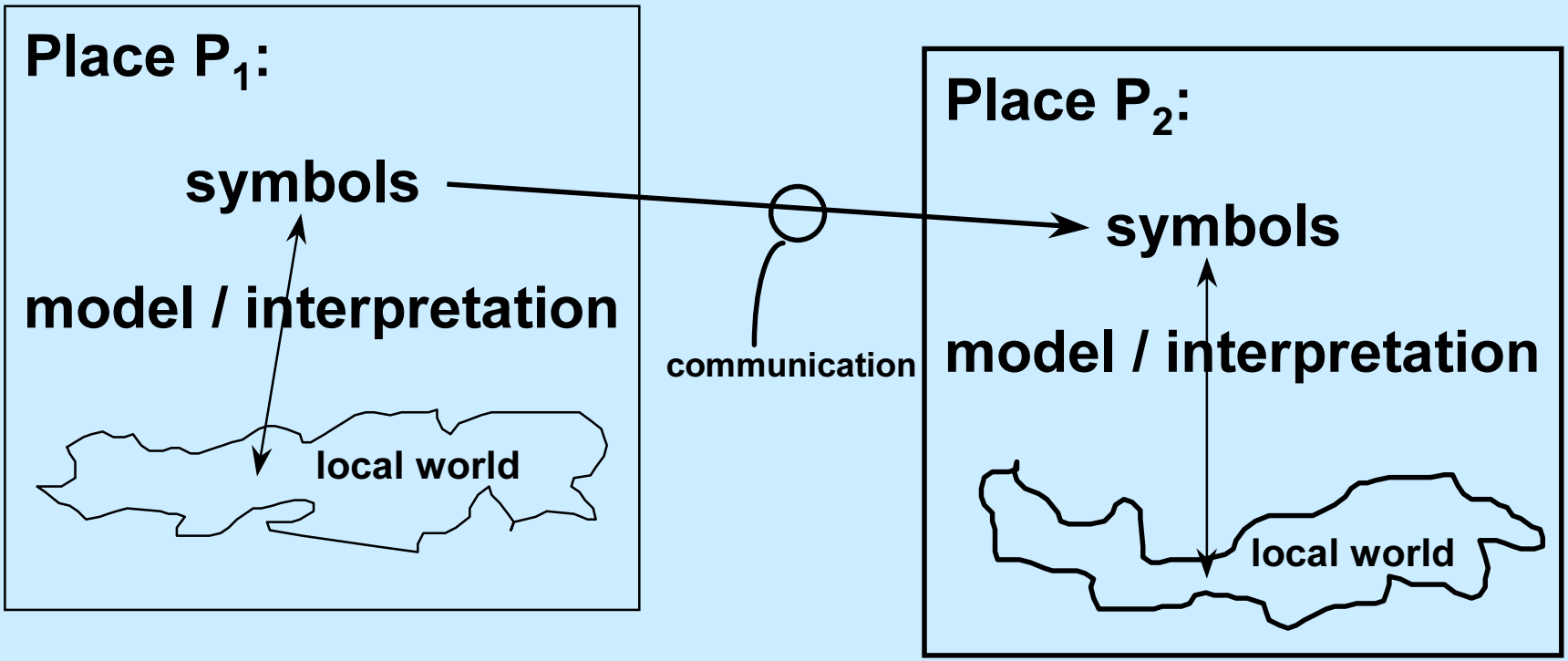


$I_{1a} = I_{2a}$?

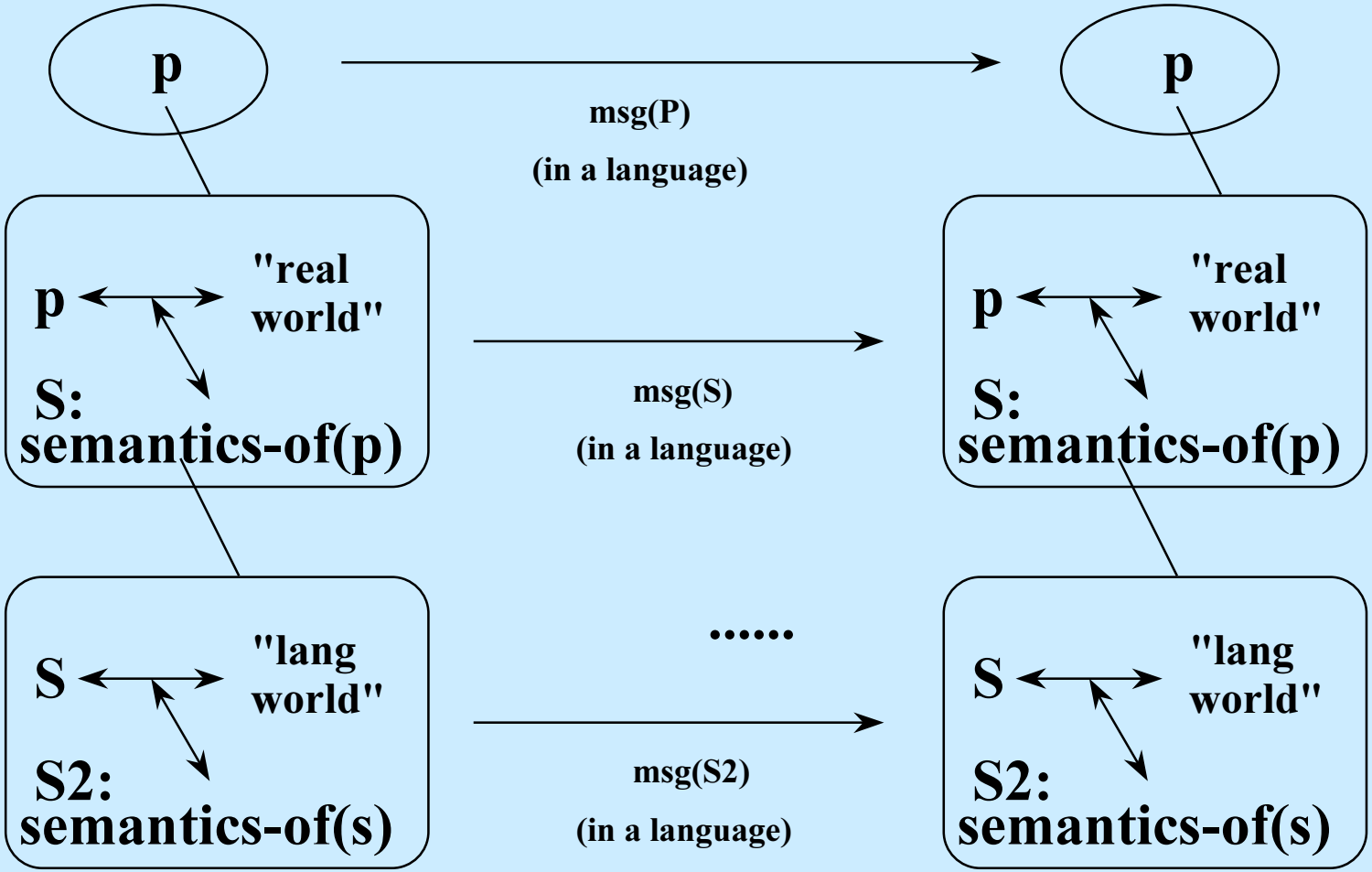
$A_3 = A_5$?

Distributed Semantics

Consider semantic distribution over space, time, etc.



Distributed Interpretations



Understanding Coordination: a Fundamental Aspect of Organization

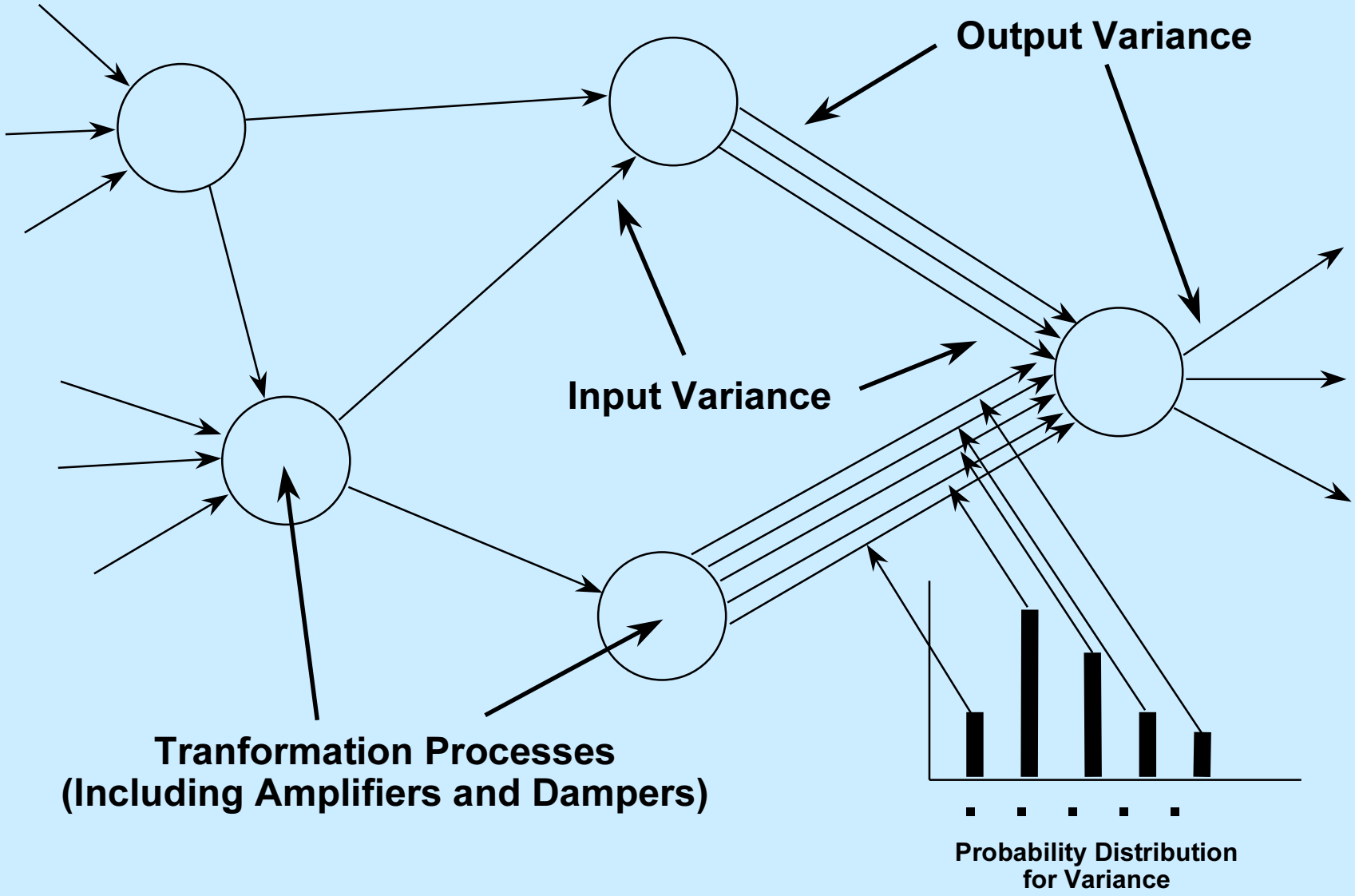
Coordination Definitions

- **"The act of exchanging materials or information to achieve a business purpose."** **(Majchrzak)**

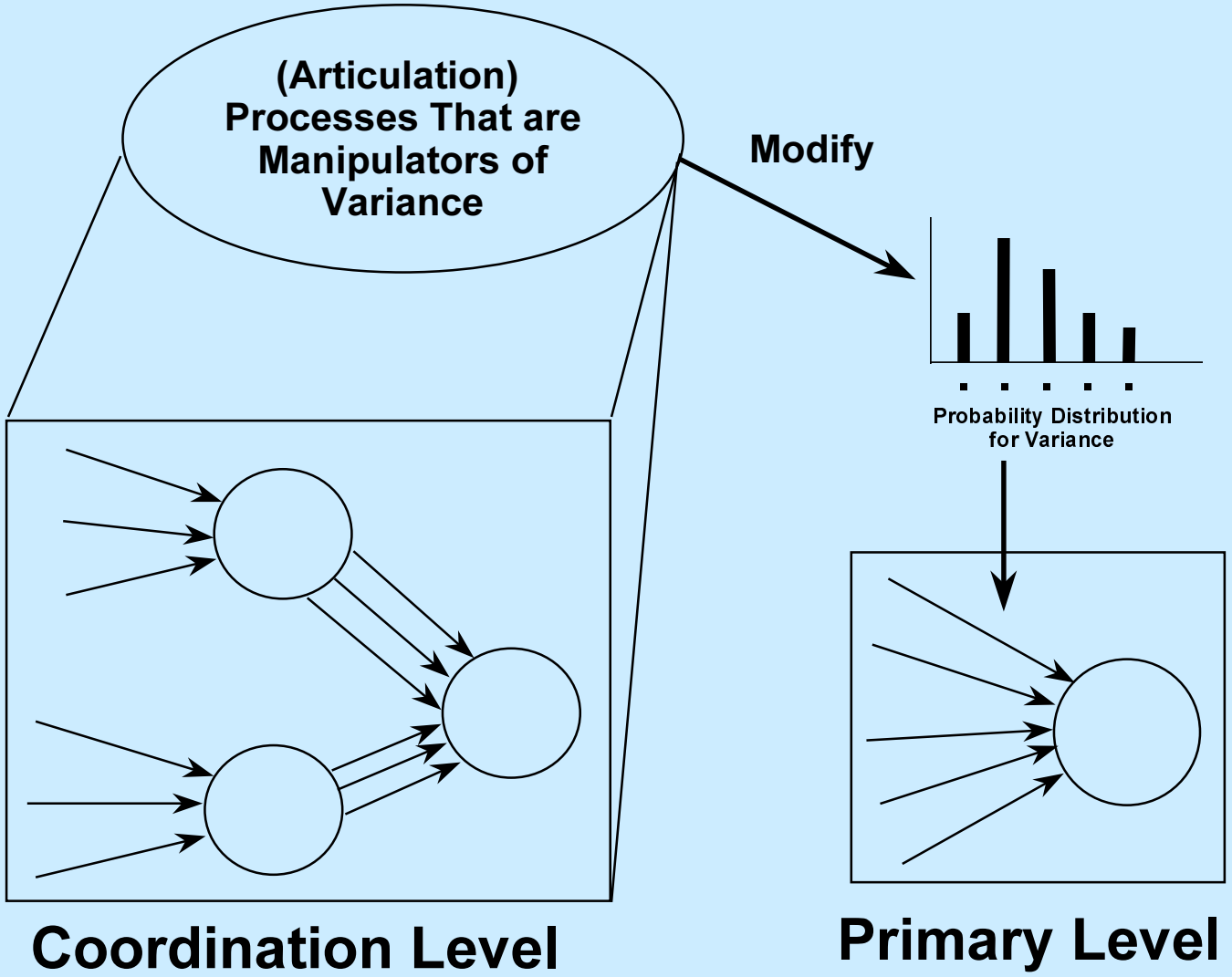
- **"Management of dependencies"** **(e.g. Malone and Crowston, others)**

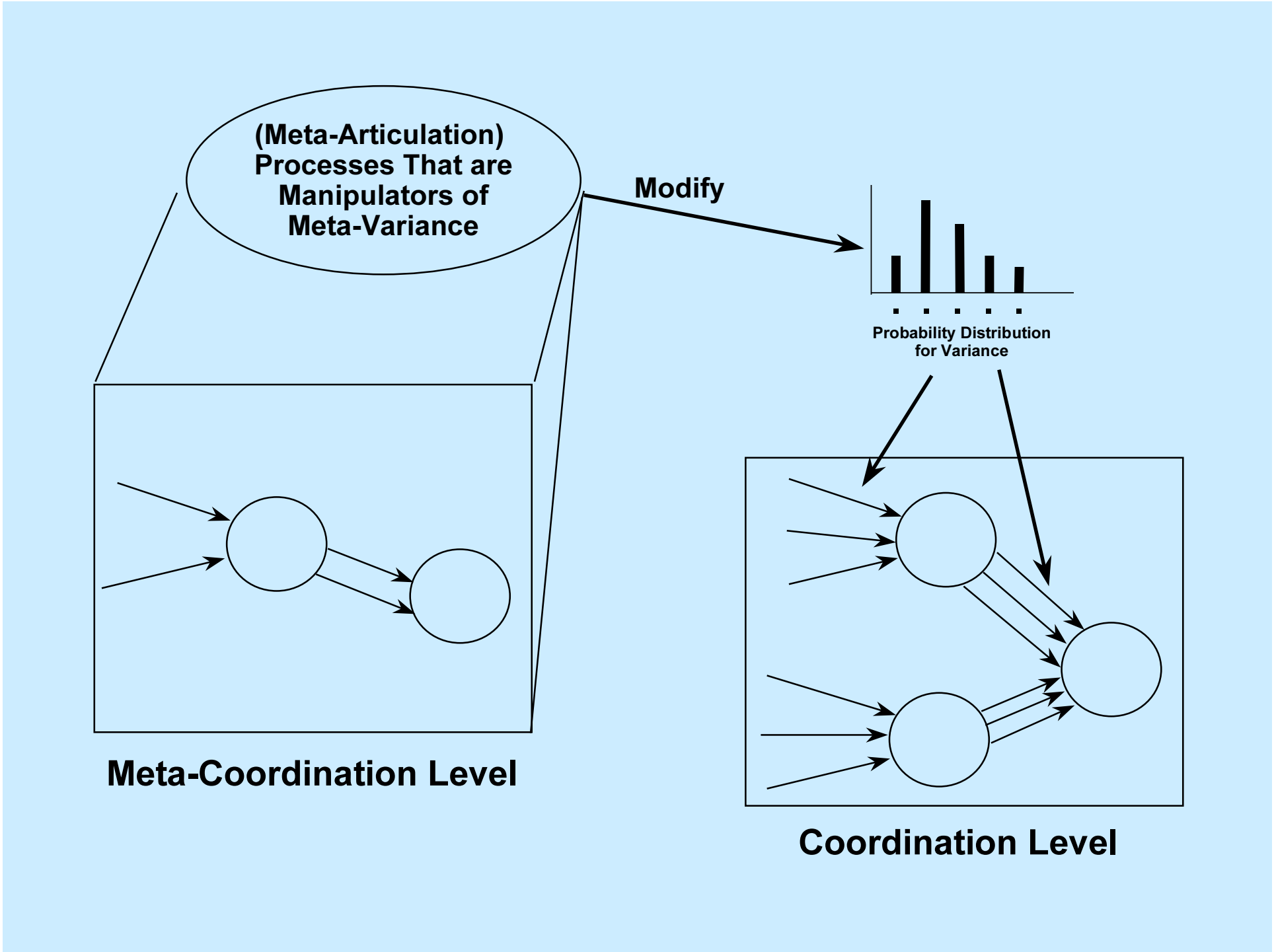
- **"Control of (reduction of) output variance in a multi-component system"** **(Gasser and Majchrzak current working definition, with roots on STS theory.)**

Coordination Model: Primary Tasks & Processes



Coordination is a Meta-Level Activity




(Meta-Articulation)
Processes That are
Manipulators of
Meta-Variance
Modify
Probability Distribution
for Variance
Meta-Coordination Level
Coordination Level

Coordination Space

Nodes:

Alternative primary task architectures.

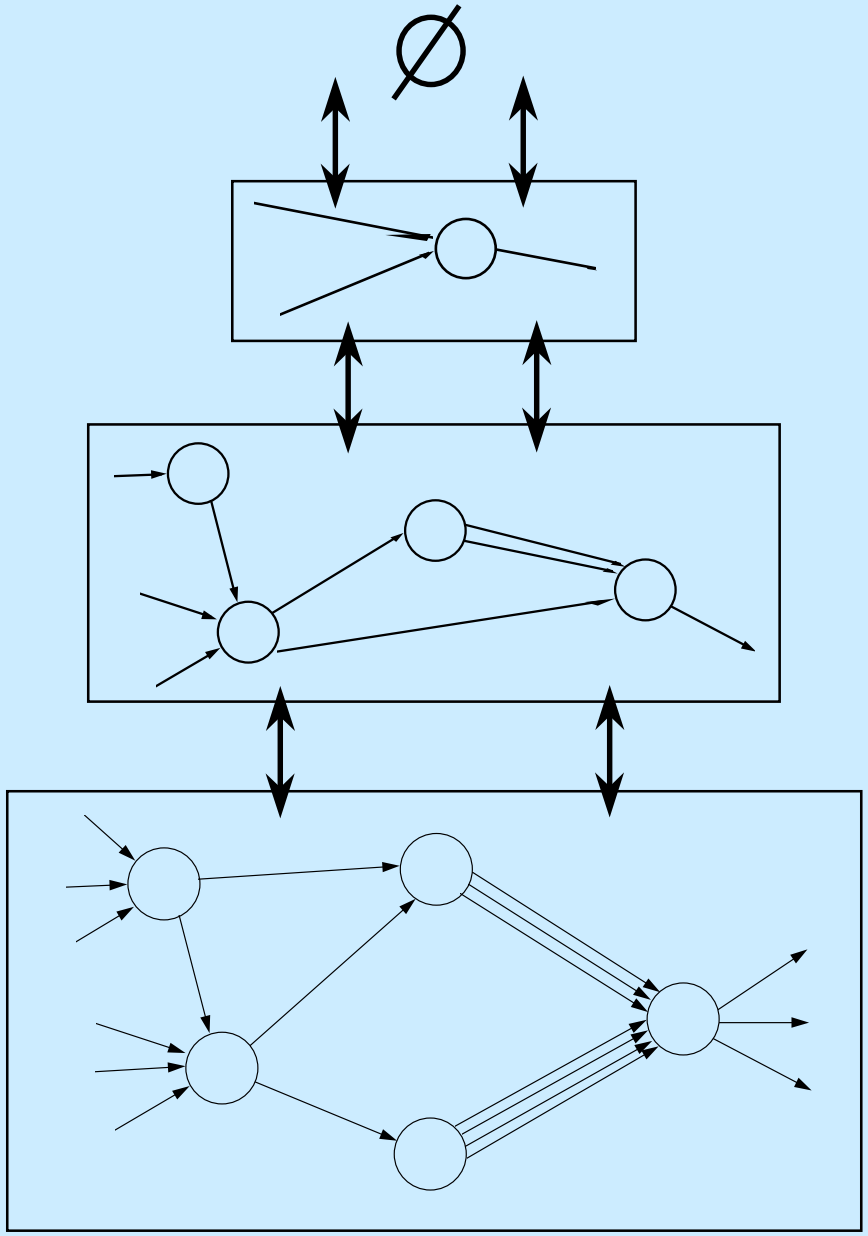
Operators:

1. Manipulations of variance probabilities using meta-level task structures.

2. Manipulations of primary-task architecture (e.g. primary redesign).

Success Measures:

Control of output variance over a range of input conditions



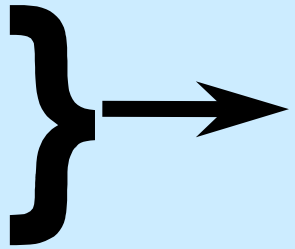
Hypotheses:

1. There must be an upward convergence to zero to effectively control variance.

2. The cumulative cost of successive upward layers of coordination must not exceed the value of the primary level.

Some Predictor Variables

Buffer Sizes
Shared task performance
Cross-activity dependencies
Nature of shared objects
Input variability
Purpose of work



Predict to:
Coordination
Attributes

Example Attributes of Coordination

Need for coordination
(How much variance control is needed?)

Speed (How rapidly is variance controlled?)

Formality (How much variance is controlled via culture?)

Interactiveness (How mutual/negotiated is variance control?)

Direction (How directed is variance control?)

Physical/virtual (Are interdependencies physical?)

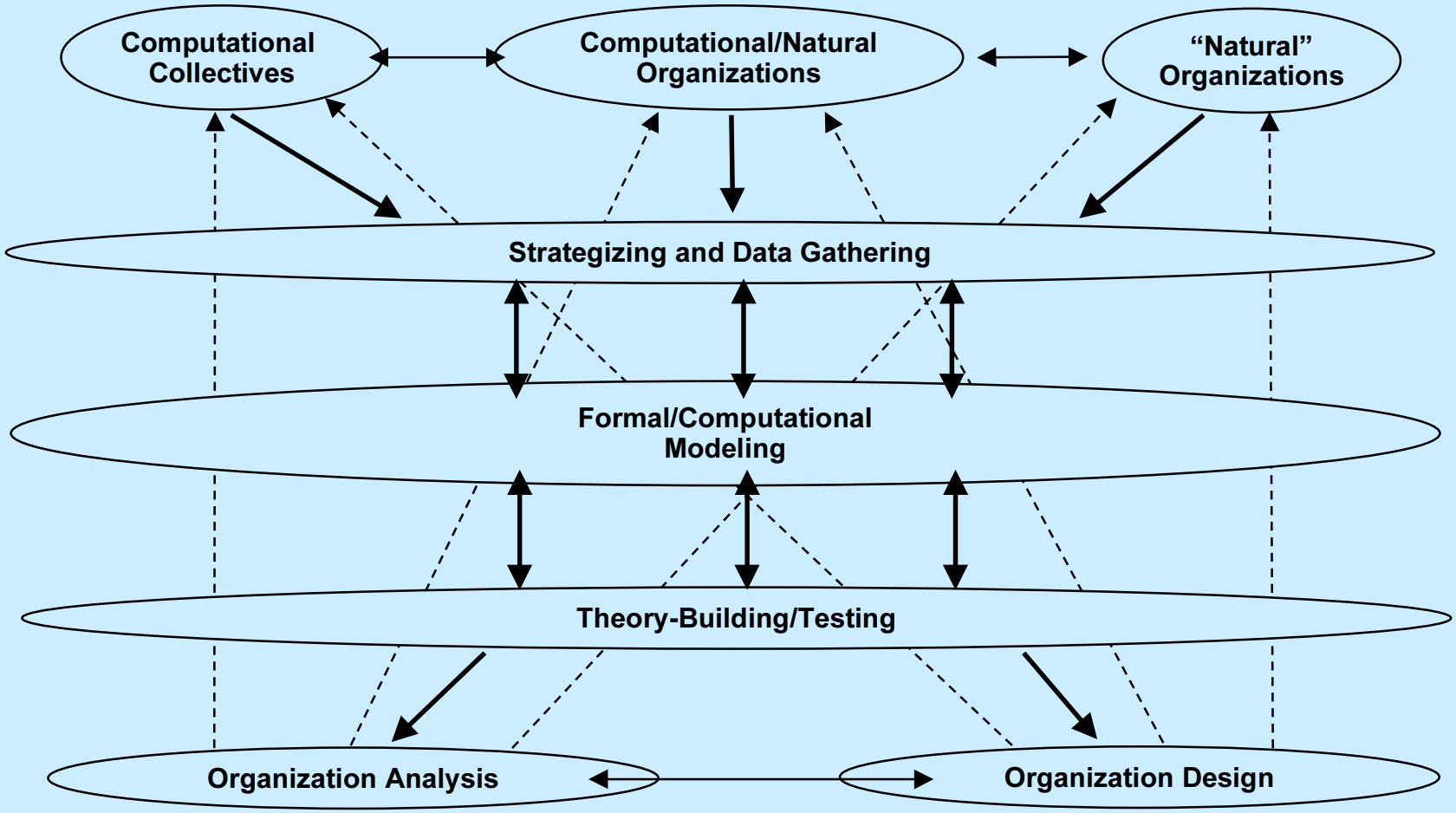
Phenomenological Perspective

Description/analysis/explanation of existing (human, computational, biological, physical, etc.) organizations.

What is COR?

- ***Computational:***
  - **Computational approaches to organizational phenomena: ontologies, theories, activity/structure simulations, coordination algorithms, design/analysis tools**
  - **Computational Organizations: comprising computational participants**
- ***Organization:***
  - **Mid-range, non-individualist focus**
  - **Explications of micro-mezzo-macro links**
- ***Research:***
  - **Innovations in description, analysis, theory, and methods**
  - **Clear principles, descriptions, and theory embodied in tools, methods and applications**

Computational Organization Research



History

- **Builds on**
  - distributed artificial intelligence
  - organization theory
  - social networks
  - team theory
  - multi-agent logic
  - artificial life, chaos theory, complexity theory
  - task analysis
  - computational sociology

- **Annual workshops on Computational and Mathematical Organization Theory (CMOT)**
- **CMOT Journal, Journal of Artificial Societies and Social Simulation**

Convergence of Opportunity and Capability

- **Need for results**
- **Available data**
- **Formalizable theories/models**
- **Modeling technologies**
- **Computational methods and computational resources**
- **Ability to apply results**
- **An emerging community of research and practice with the multidisciplinary skills to bring these together**

Contributions to Organization Theory

- **Adding new representational machinery (e.g., formalization, structure measurement, cognitive features)**
- **Increasing model scale and complexity**
- **Checking logical consistency**
- **Computational model as test of necessity of theoretical explanation.**
- **Computational model as hypothesis generator.**
- **Adding dynamics and exploiting longitudinal relationships**
- **Simulations as encodings of complex knowledge**

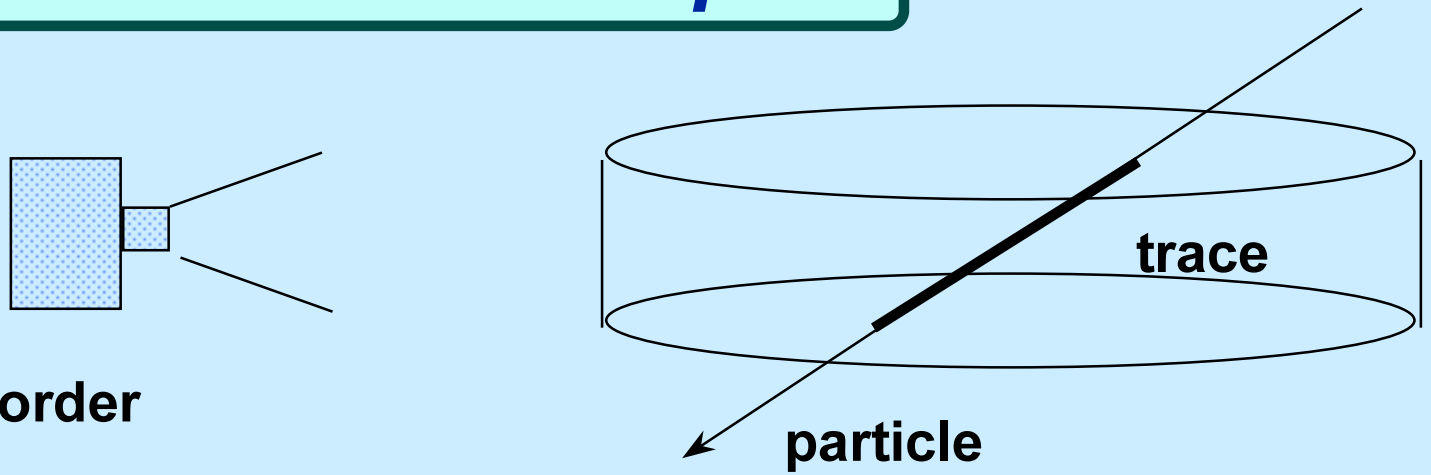
Contributions to CS/AI

- **Large-scale qualitative simulation**
- **Aggregation/disaggregation of distributed objects**
- **Online/offline coordination algorithms**
- **Organizational and multiagent learning**
- **(and more)**

Some More General Scientific Problems Related to MAS, Addressable via COR

- **Empirical and behavioral theories of social dynamics, social dilemmas, and distributed decisionmaking**
- **Distributed semantics: negotiation of workable shared meanings across time, space, culture, situations, etc.**
- **Flexibility/stability: how/why do some collectives persist and adapt over time in the face of change, and how/why do others dissolve?**
- **Uncertainty: How can we generate processes for cost-effective distributed management of uncertainty and outcome variance?**
- **Sociotechnical impacts on organizational performance: How can we link sociotechnical variables to quantitative organizational performance measures for human-machine organizations?**

Cloud Chamber Metaphor



You record the trace, not the particle!

Organizations, too, leave (recordable and recorded) traces of activity:

Records,
Documents
Technological links.....

Organizations can be (are being) instrumented to record such traces (e.g.., data warehouses)

Thus COR Links Phenomenology and Theory

View Organizations as dynamic, temporal, spatial:

1. **Structures of activity (e.g.., process)**
2. **Structures of knowledge and meaning:**

   Meanings captured through networks of association
   Meanings captured through structure of representations

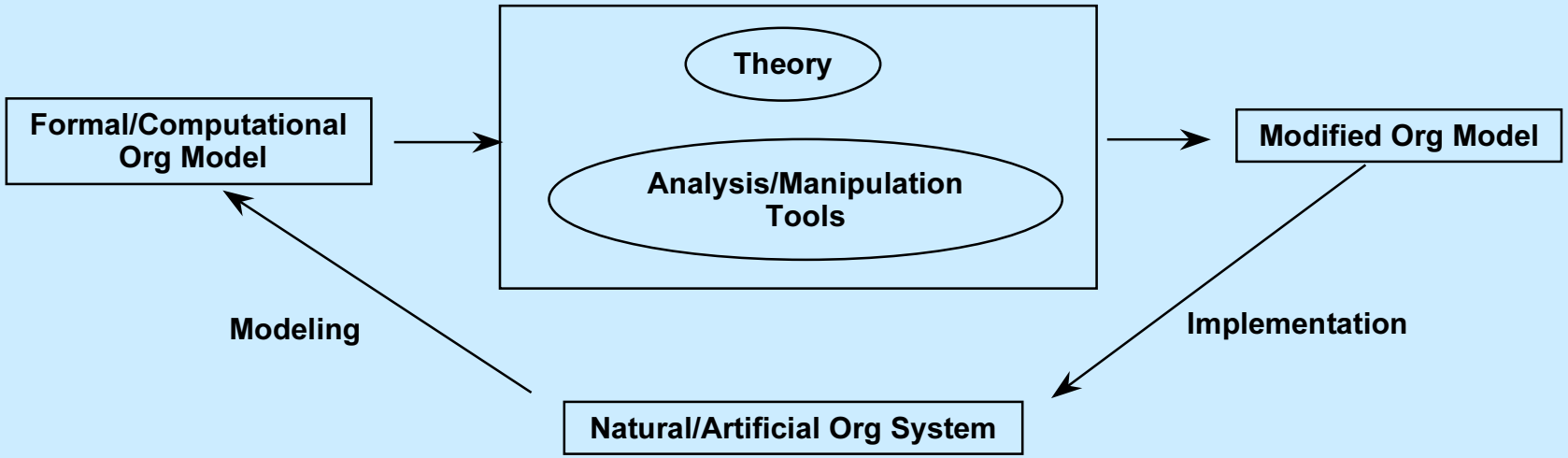
We can now begin to:

1) Recover these structures from traces

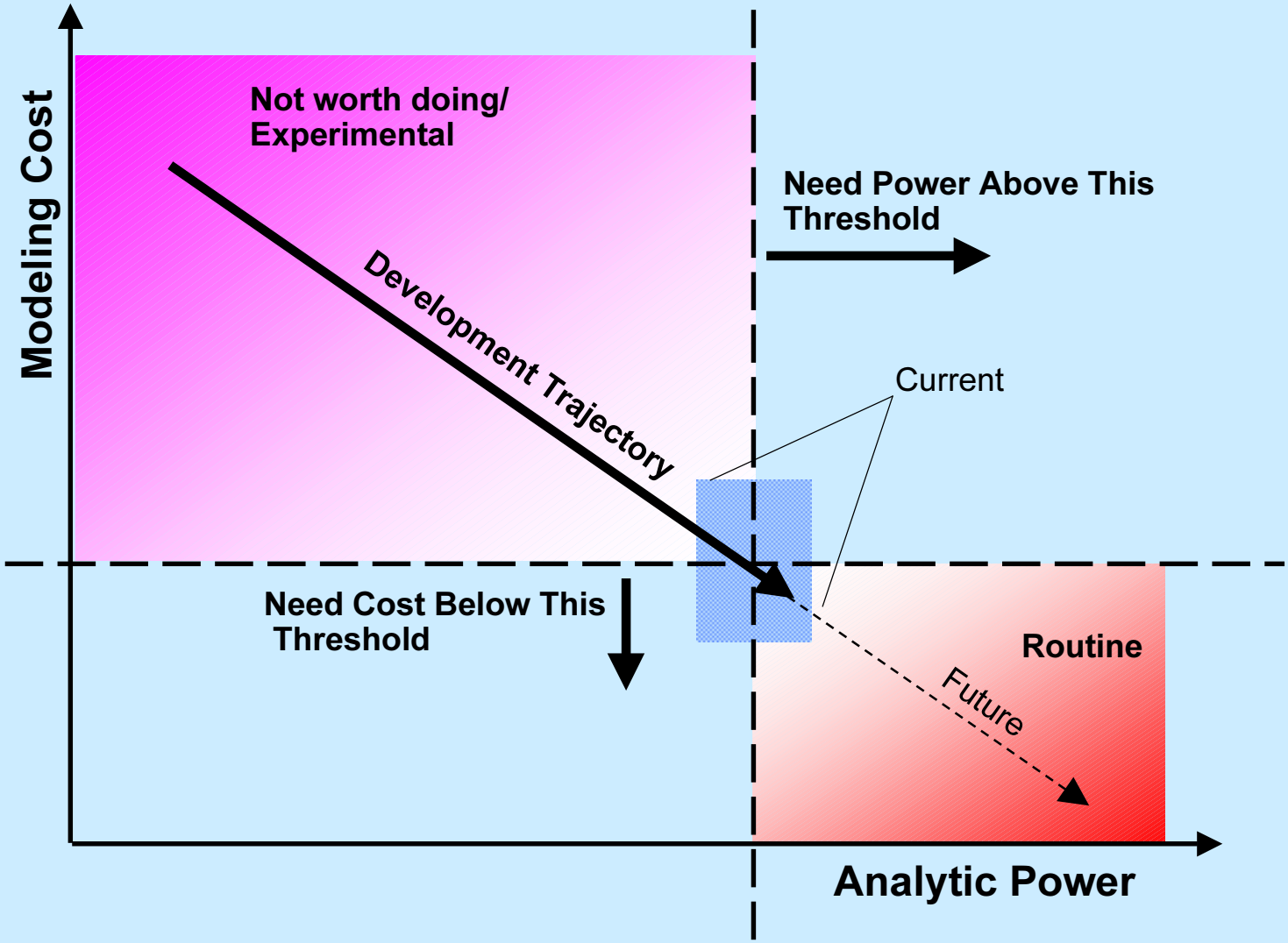
2) Model, simulate, analyze, and design them

3) Link them to other variables for explanation and theory-building

Analytical Process and Assumptions



- **Modelability assumption: Orgs can be modeled**
- **Performance differential assumption: Org performance can be differentiated.**
- **Manipulability assumption: Org models can be manipulated**
- **Designability assumption: Orgs are designable (as vs evolvable or growable)**
- **Practicality assumption: Models can be reduced to practice (implemented)**
- **Pragmatic assumption: The whole process is cost-effective.**


Modeling Cost
Not worth doing/
Experimental
Development Trajectory
Need Power Above This
Threshold
Current
Need Cost Below This
Threshold
Routine
Future
Analytic Power

A few examples...

- **VDT/Vite (Levitt et al.)**
- **ACTS/Plural Soar (Carley, Prietula)**
- **CORPS (Carley)**
- **Elm (Carley)**
- **HITOP-A (Gasser/Majchrzak)**
- **Organizational Learning (Lant, Mezias)**
- **I-Know (N. Contractor)**
- **Logical analysis (M. Masuch)**
- **Org Consultant (Burton/Obel)**
- **TAEMS (Decker, Lesser, et al.)**
- **Articulator/Process MetaModel (Scacchl)**
- ***ACTION/TOP Modeler* (Gasser/Majchrzak)**

ACTION/TOP Modeler Overview

ACTION: 4 year, $10M University/Industry effort
(USC, National Center for Manufacturing Sciences,
HP, Digital, TI General Motors, +++)

Ca. 30,000 lines of LISP/C code, Sun Workstations

35,000 relationships among ca. 1000 elements in 'pluggable' constraint-based theory-driven analysis design system.

TOP Modeler: Commercial version of ACTION

Wintel platforms, Visual Basic. Complete redesign with database-driven architecture

Research Themes of ACTION and TOP Modeler:

1. Theories of Technolgy-Organizations-People (TOP) integration

2. TOP-integration design and analysis processes and methodologies

3. Visualization and display of organizations, TOP-integration factors, and TOP-integration relationships from many perspectives

4. Theories of modeling and implementation for 1, 2, and 3.
   - Qualitative (not numerical/mathematical) models
   - Object and frame-based representations
   - Constraint-based representations
   - Eventually, dynamic process representations

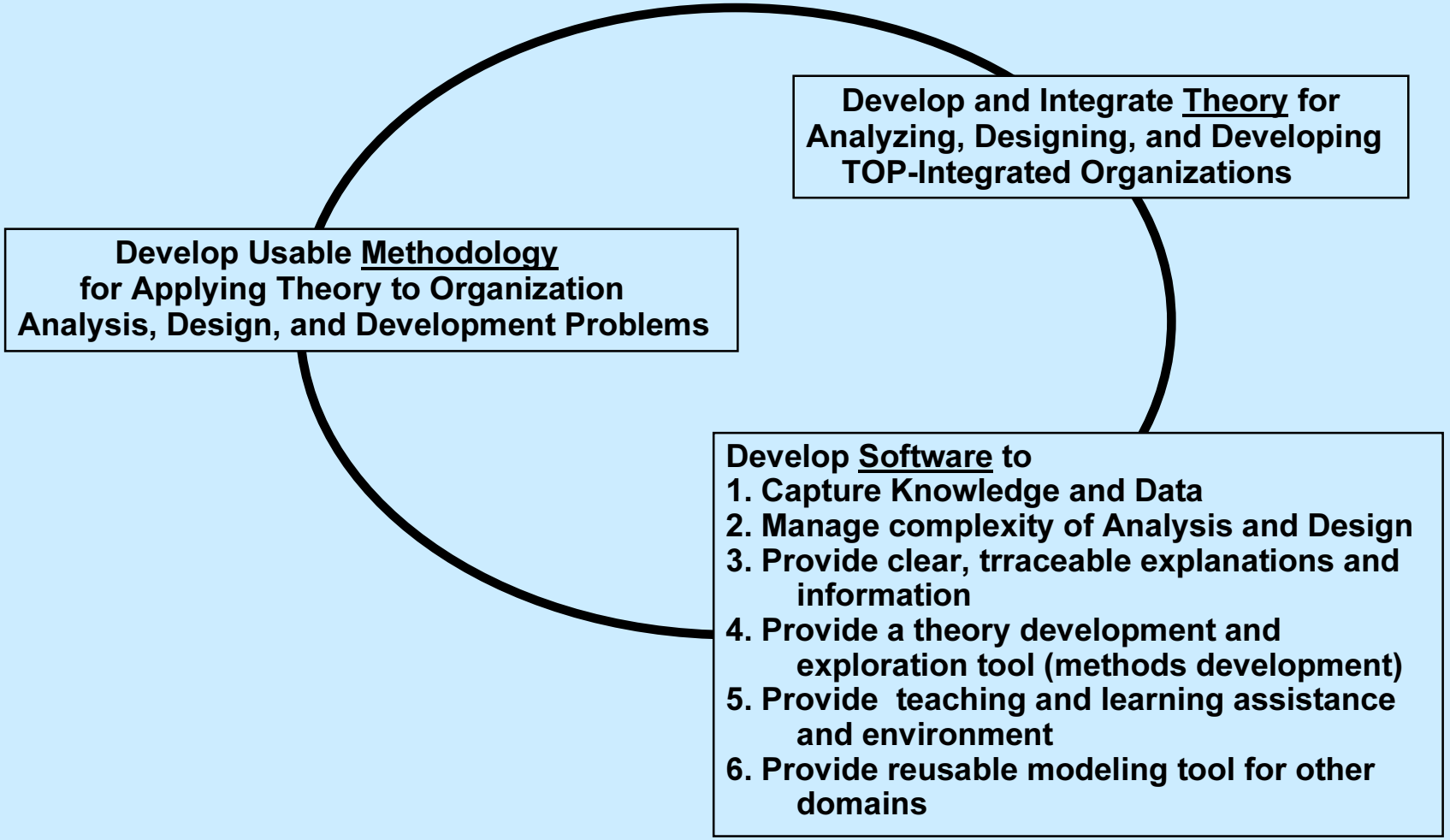
5. Knowledge and mechanisms for explanation, teaching, and learning

6. General mechanisms and frameworks to support 1-5, and that are usable for other MOT-oriented research.

7. Adaptive Processes:
   - Management of significant distributed, multi-party (Industry-University) project
   - Team-oriented local management structures
   - Innovative software development processes (cyclic prototyping)
   - Concurrent enginering of theory and software.

[3] Joint work with I. Hulthage, B. Leverich, J. Lieb, and A. Majchrzak

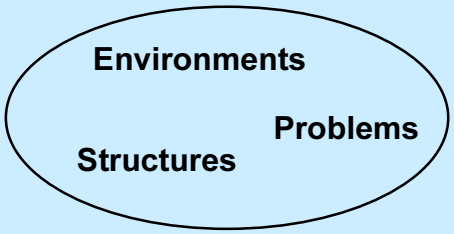
Three Pillars of ACTION/TOP Modeler



TOP Modeler Incorporates Multiple Organizational Perspectives

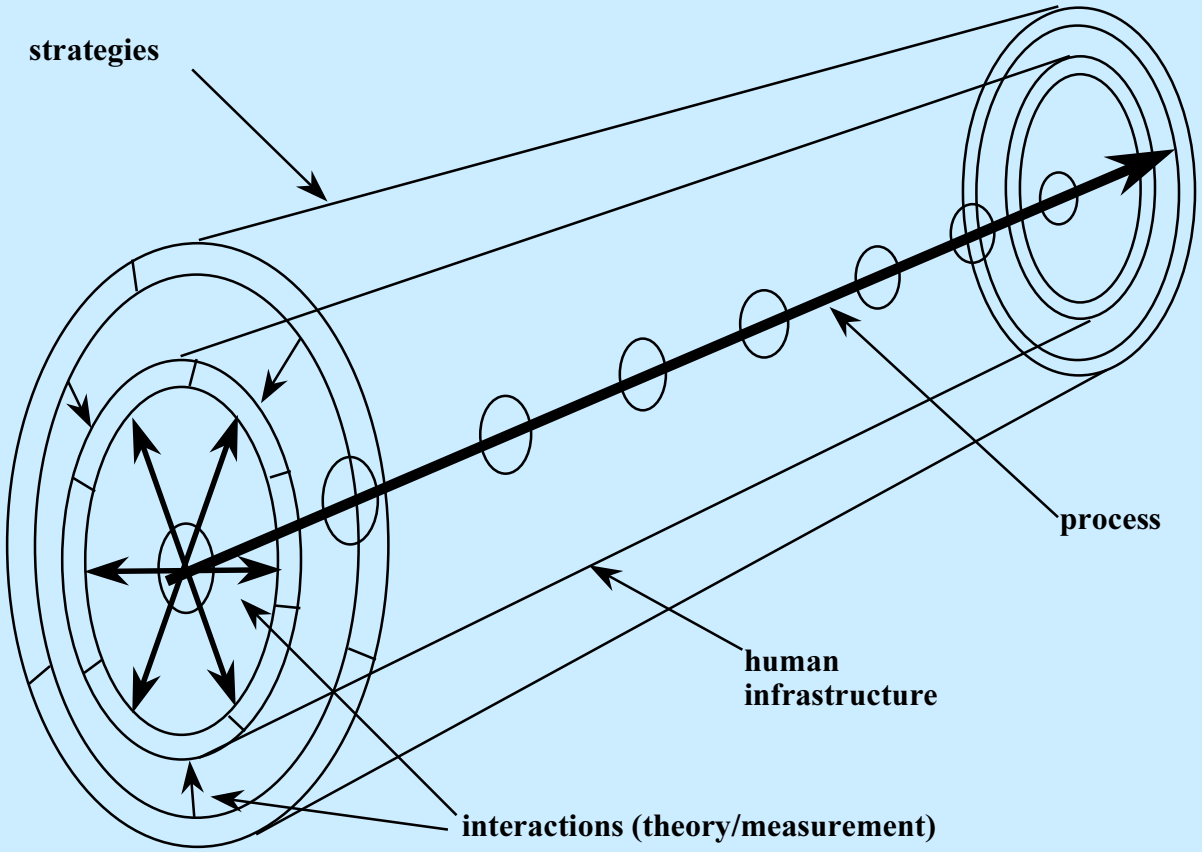
[Organizational meta-views]

- Technology/Process
- Economics/Resources
- Power/Authority
- Performance/Reward
- External Relations
- +++

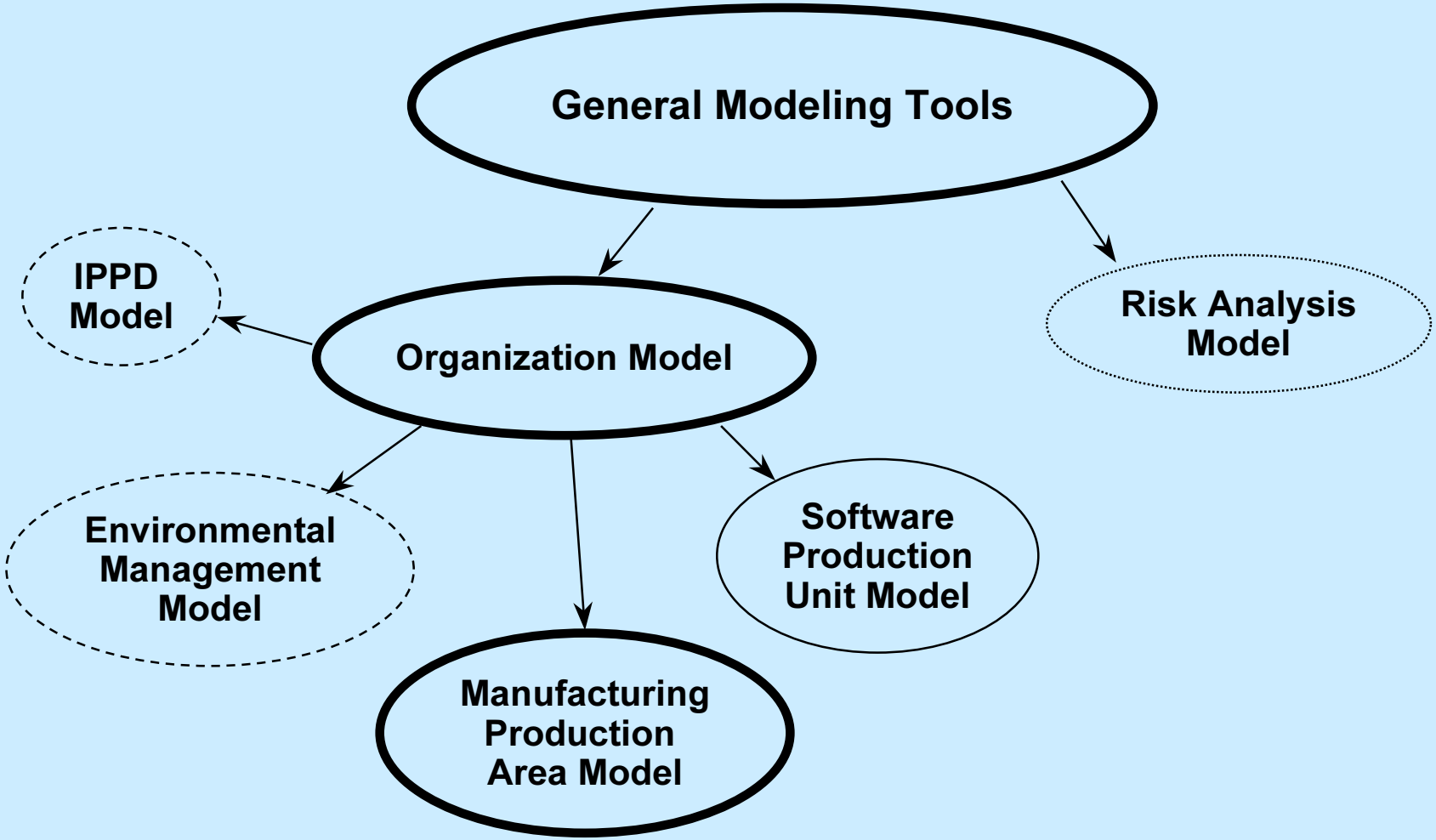


An (Integrative) Organization Theory

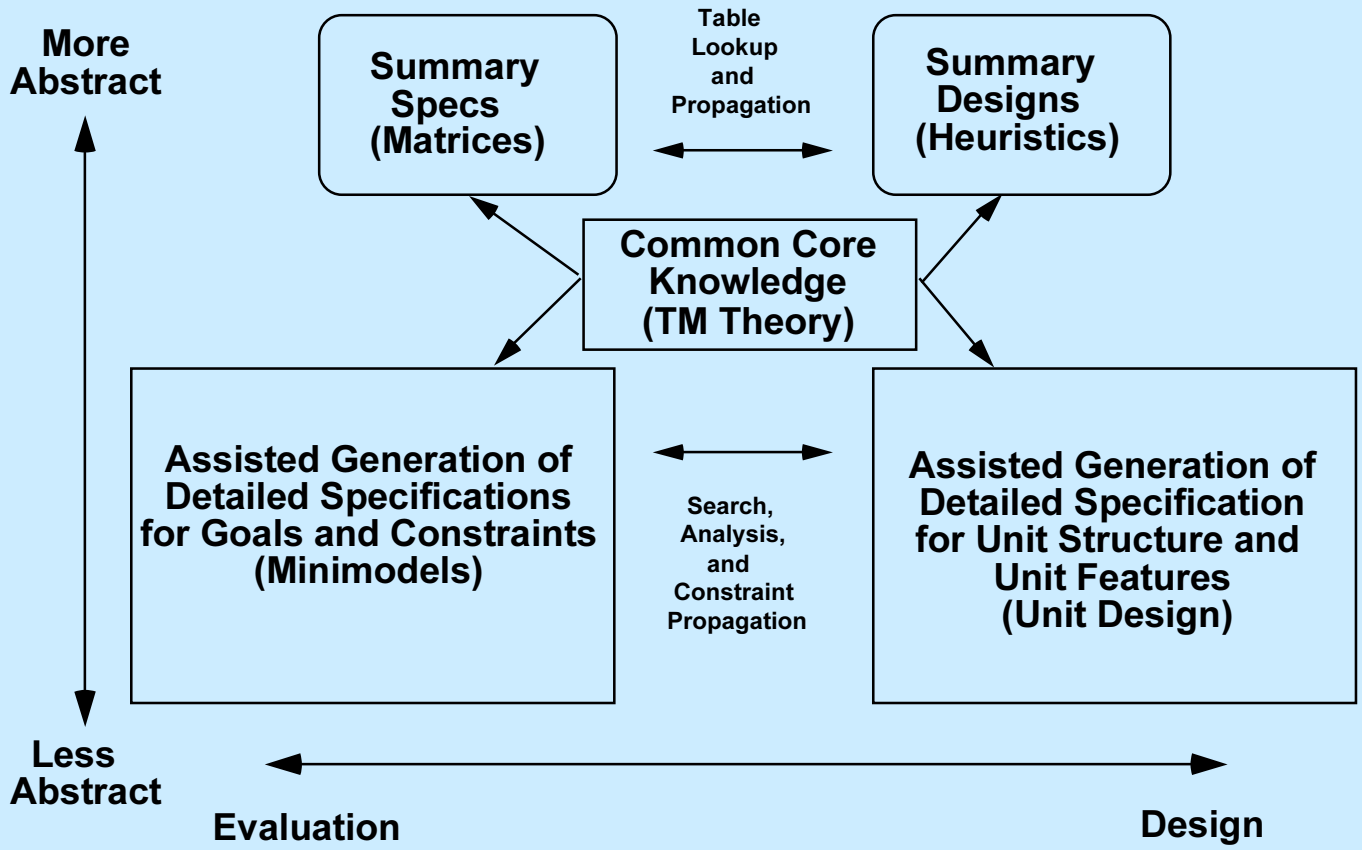
TOP Modeler's Organization Model

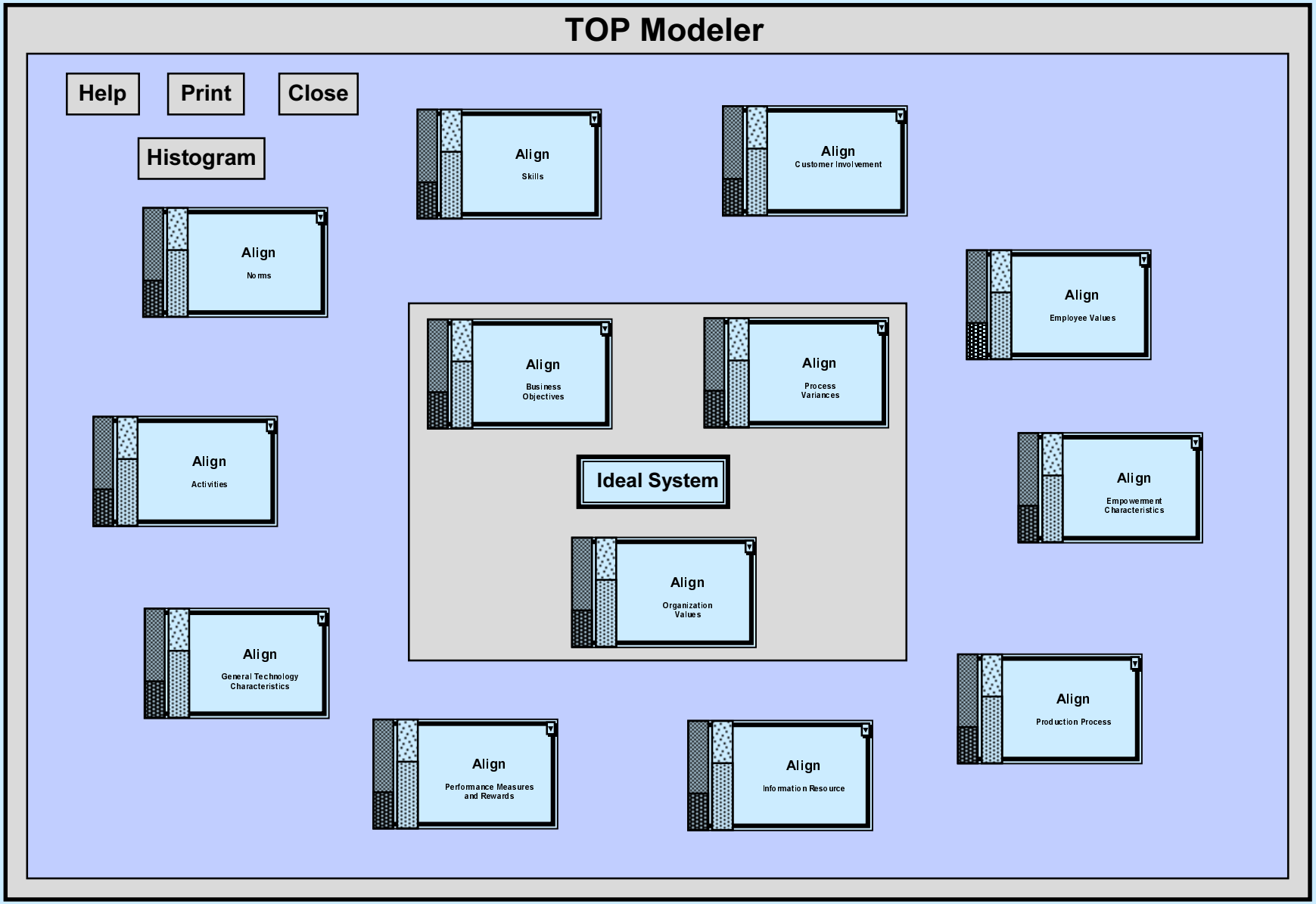


ACTION's Modeling Layers



TOP Modeler Views TOP-Integration at Several Abstraction Levels




TOP Modeler
Help
Print
Close
Histogram
Align
Skills
Align
Customer Involvement
Align
Norms
Align
Employee Values
Align
Business Objectives
Align
Process Variances
Ideal System
Align
Activities
Align
Empowerment Characteristics
Align
Organization Values
Align
General Technology Characteristics
Align
Production Process
Align
Performance Measures and Rewards
Align
Information Resource

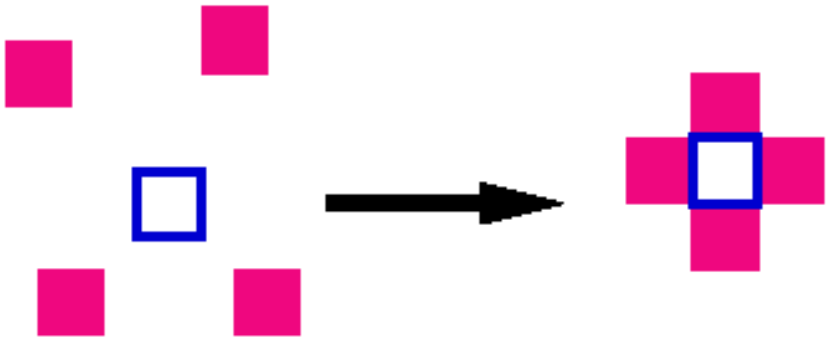
Technological Perspective

Organizations as social technologies for solving complex problems, for overcoming "individual" limitations (cognitive, physical, temporal, institutional…), and as efficiency/optimization strategies.

Pursuit Game

Four problem solvers attempt to surround a target.

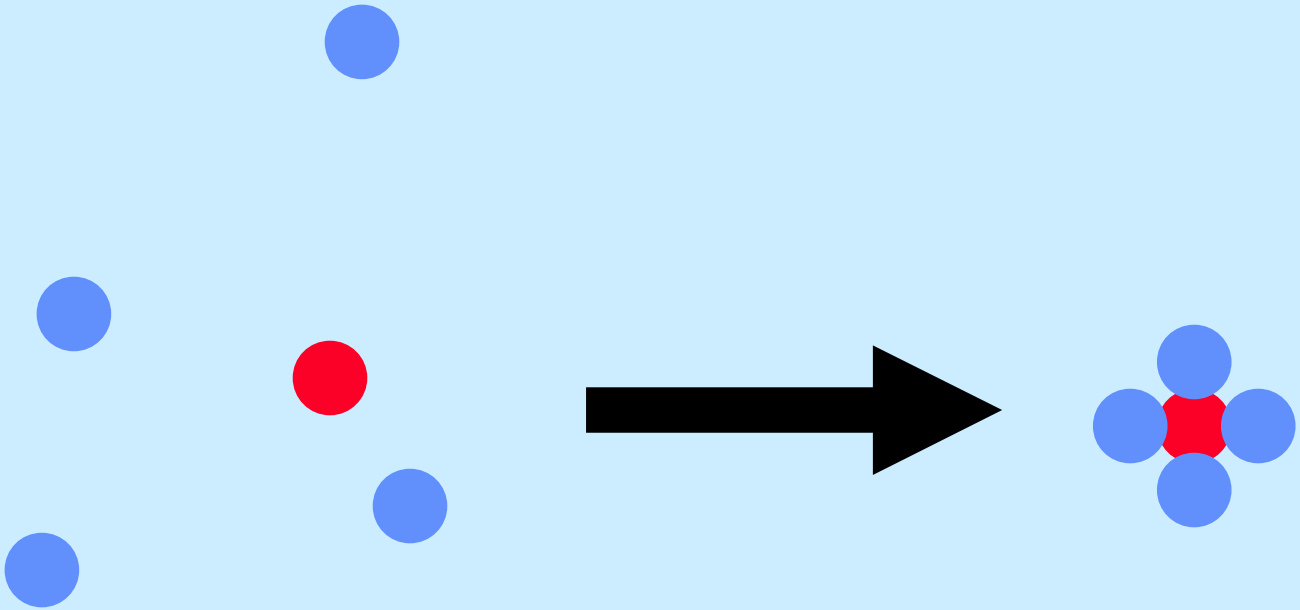
Each agent performs Moving Target Search.



Goal = *Left* Λ *Right* Λ *Top* Λ *Bottom*
Organization = { (*Left*, Agent-1), (*Right*, Agent-2)
(*Top*, Agent-3), (*Bottom*, Agent-4)}

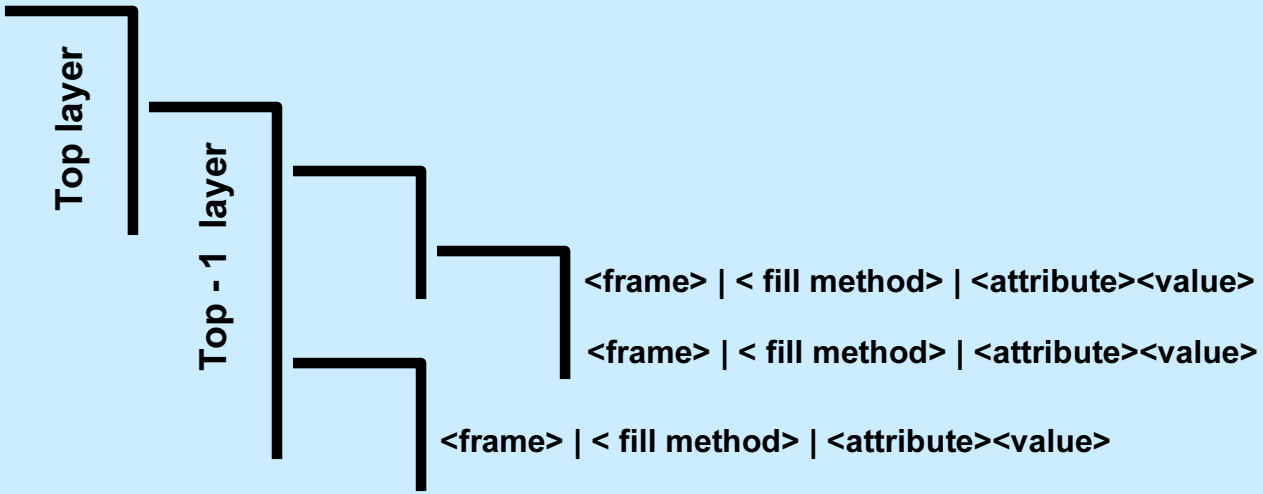
The smallest problem which requires reorganization during the problem solving process.

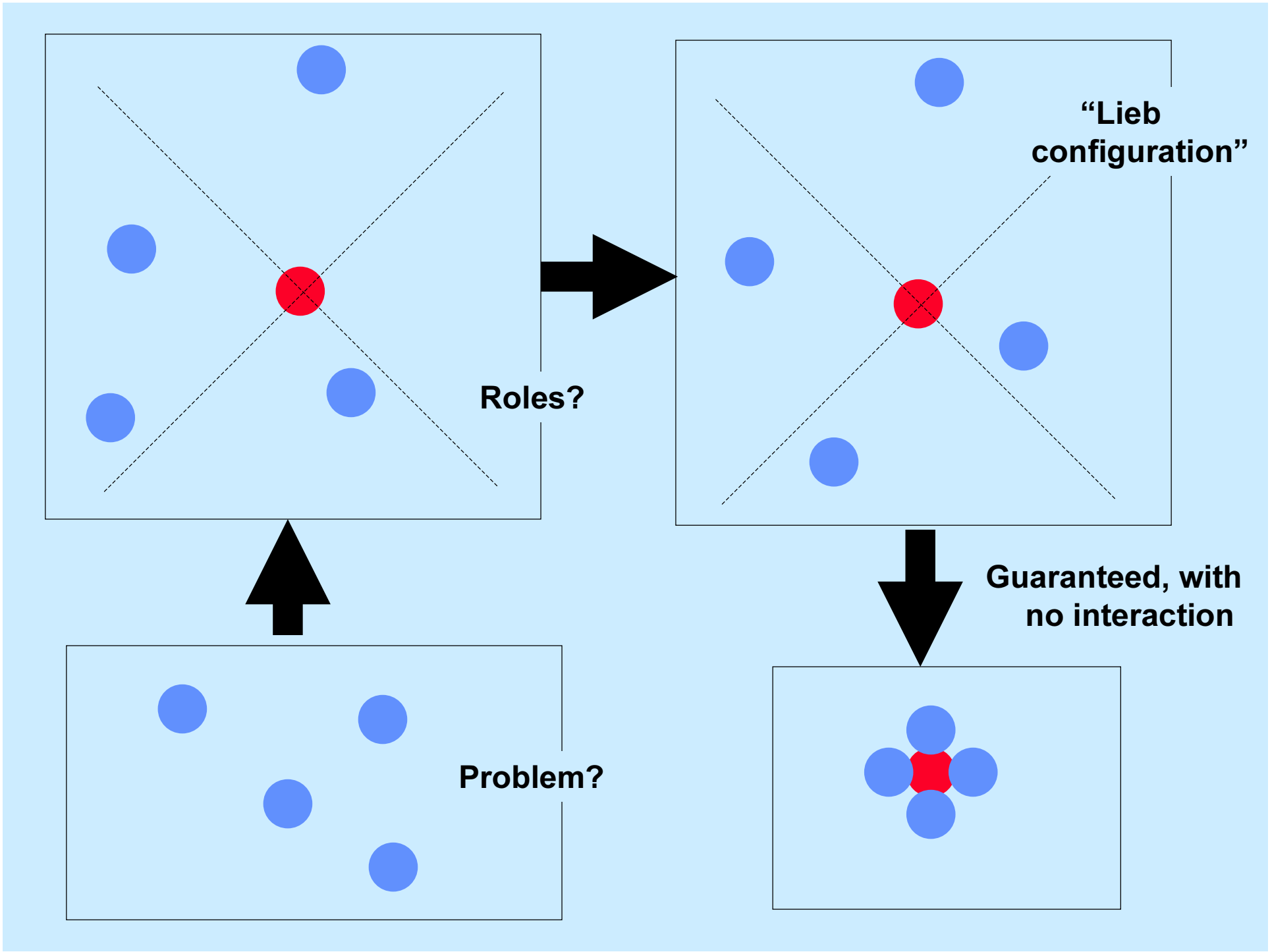
Organizations as Settled and Unsettled Questions
(Gasser, Rouquette, Hill, and Lieb)



Basic model of knowledge and action:

- **Problem structure is cascaded layers of knowledge**
- **Problem solving = filling slots in frames that represent cascaded problem structure**
- **Unfilled slot contains a fill method: "how to settle this question".**
- **Situation change causes slots to become unwound/unfilled**




“Lieb configuration”
Roles?
Guaranteed, with no interaction
Problem?

Time & Roles in Organization

Basic model of knowledge and action:

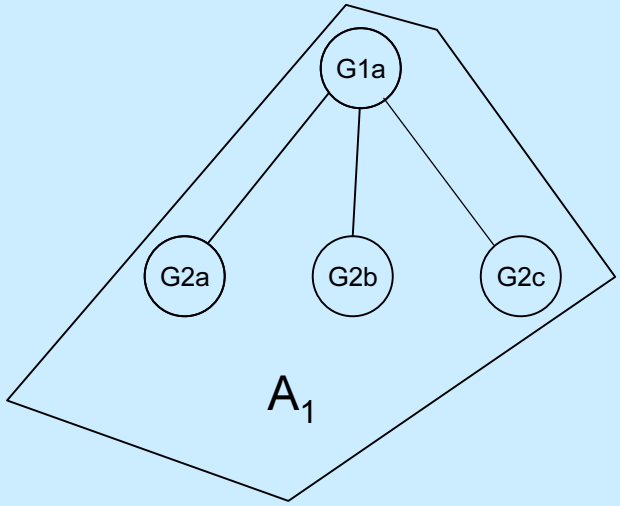
Heuristic decision-making and action under uncertainty

Organization:

Long-term temporal commitment to classes of control choice in agents (each agent has a "role" that is known by other agents and used to structure their control choices).

"Long-term" = committed to continue over many action/communication cycles, so that organization is i) implicit and ii) based on commitment

Representing Organization as Time & Roles

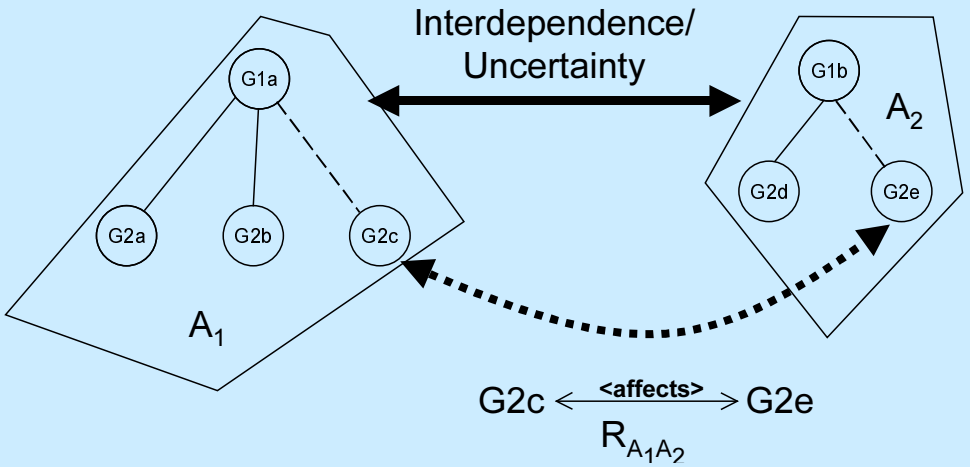


1. Agent A_i has N_{A_i} potential actions (e.g., goals to achieve)
   (N_{A_1} = 3 in this example)

2. Choice in the absence of knowledge is effectively random ($1/ N_{A_i}$)

3. Knowledge could be e.g., refined success probability and/or utility
   Success Probability $P_{A_i}(G_j)$, from some distribution $0 \leq P \leq 1$
   Utility $U_{A_i}(G_j)$
   Expected Utility $E_{A_i}(G_j) = P_{A_i}(G_j) * U_{A_i}(G_j)$

4. Rational Choice is $\max_j[E_{A_i}(G_j)]$

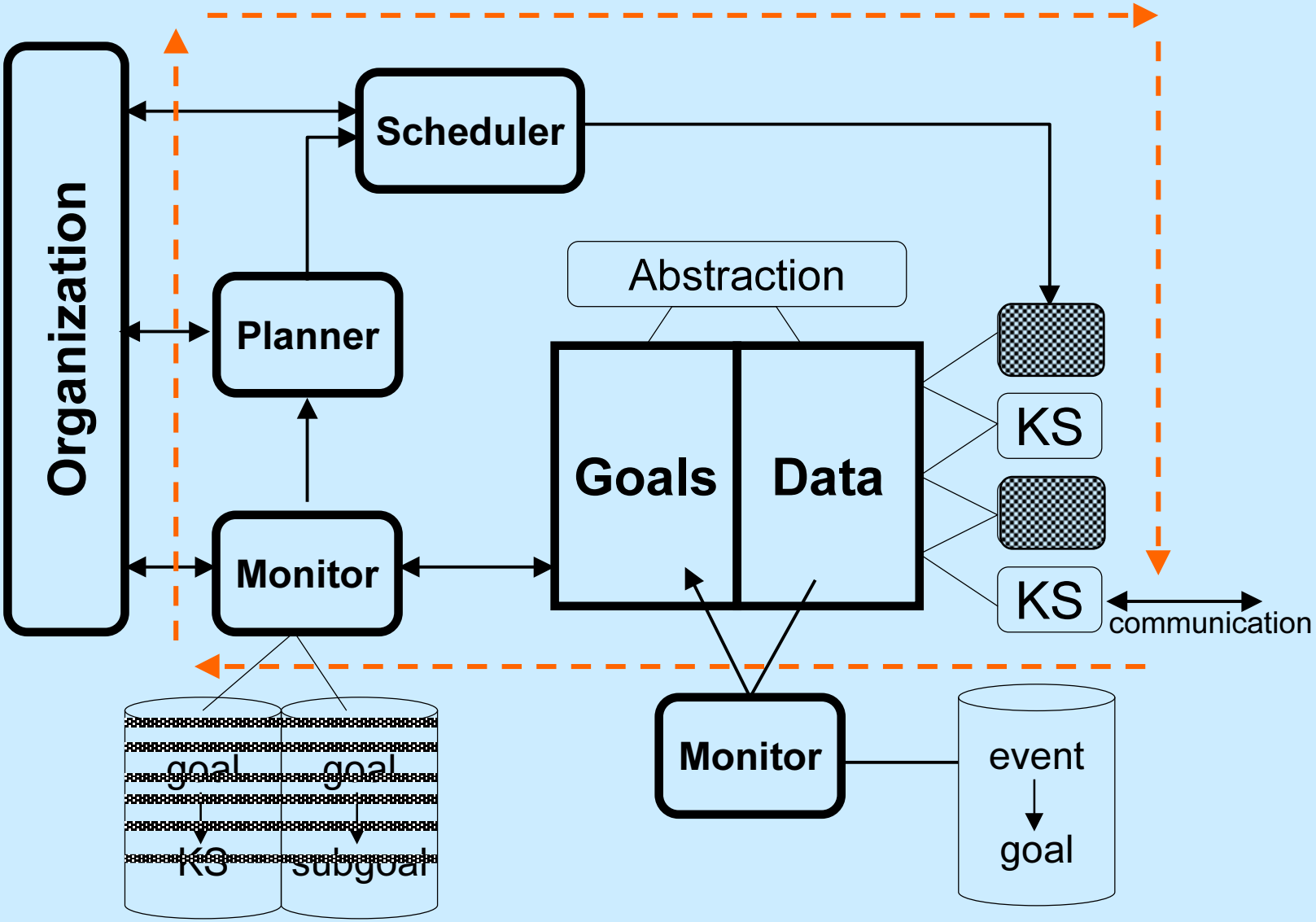


1. **In the presence of A_2 and relation $R_{A_1A_2}$ there are still $N_{A_1} * N_{A_2}$ potential *joint* actions. Again, without knowledge this (joint) choice is $1/ [N_{A_1} * N_{A_2}]$. For each agent A_i this choice with (local) knowledge is $Max(E_{A_i}(G_j))$. Local choice may not be globally good.**

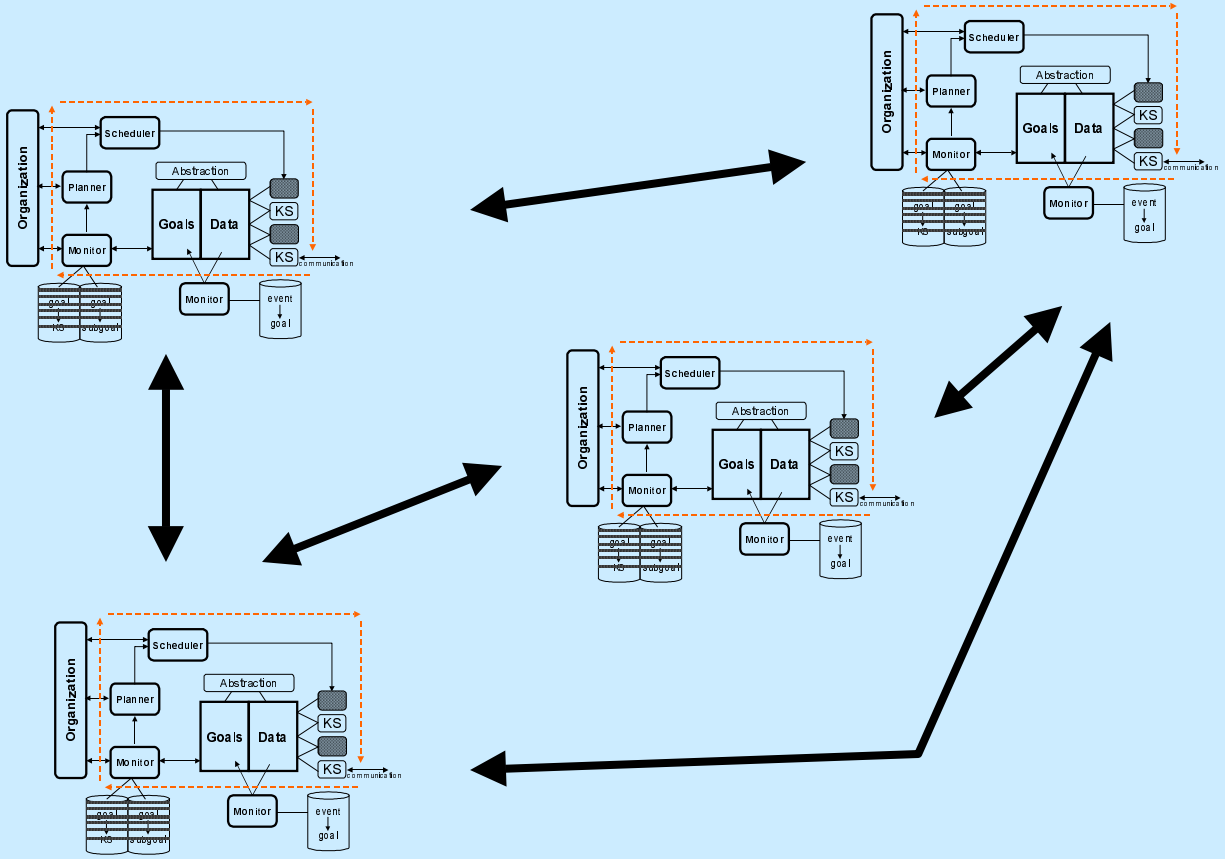
2. **Moreover, $R_{A_1A_2}$ means that $E(G_{2e}) = P(G_{2e}|G_{2c}) * U(G_{2e})$ and $E(G_{2c}) = P(G_{2c}|G_{2e}) * U(G_{2c})$. Without knowledge of each other, neither agent knows the other's probabilities or utilities. Thus i) each agent A_i can do no better than guessing that A_j's choice is random, and ii) the expected utility of achieving each goal implicated in $R_{A_1A_2}$ isn't known.**

3. ***Organization is the collective knowledge of biases in these probabilities, i.e., structured collective choice.***
   (needn't be long-term ala Lesser...)

Implementing Organization as Time & Roles
(Durfee, Lesser and Corkill)



Implementing Organization as Time & Roles



Division of Activity Types...

& Coordination….

….but no adaptation

Organizational Adaptation

Principle: Effective Global Control is based on Global Knowledge

Process (Diagnosis/Repair):

- **Measure & monitor (global) organizational performance**
- **Detect undesirable organizational performance**
- **Diagnose causes ***
- **Use causal model to refine organizational model ***
- **Implement new organization (e.g., by *revising roles*[#])**

→ **"Organization Self-Design"**

[#] **Note direct dependence on the organization model**

Adaptive Organizations

(Ishida, Gasser, Yokoo)

Problem:

How to design an organizational MAS in which agents and organization *mutually construct each other*, and which demonstrates practical utility for optimization.

Theoretical Import:

Computational account of mechanisms for adaptive organization
Computational account of mutual construction process

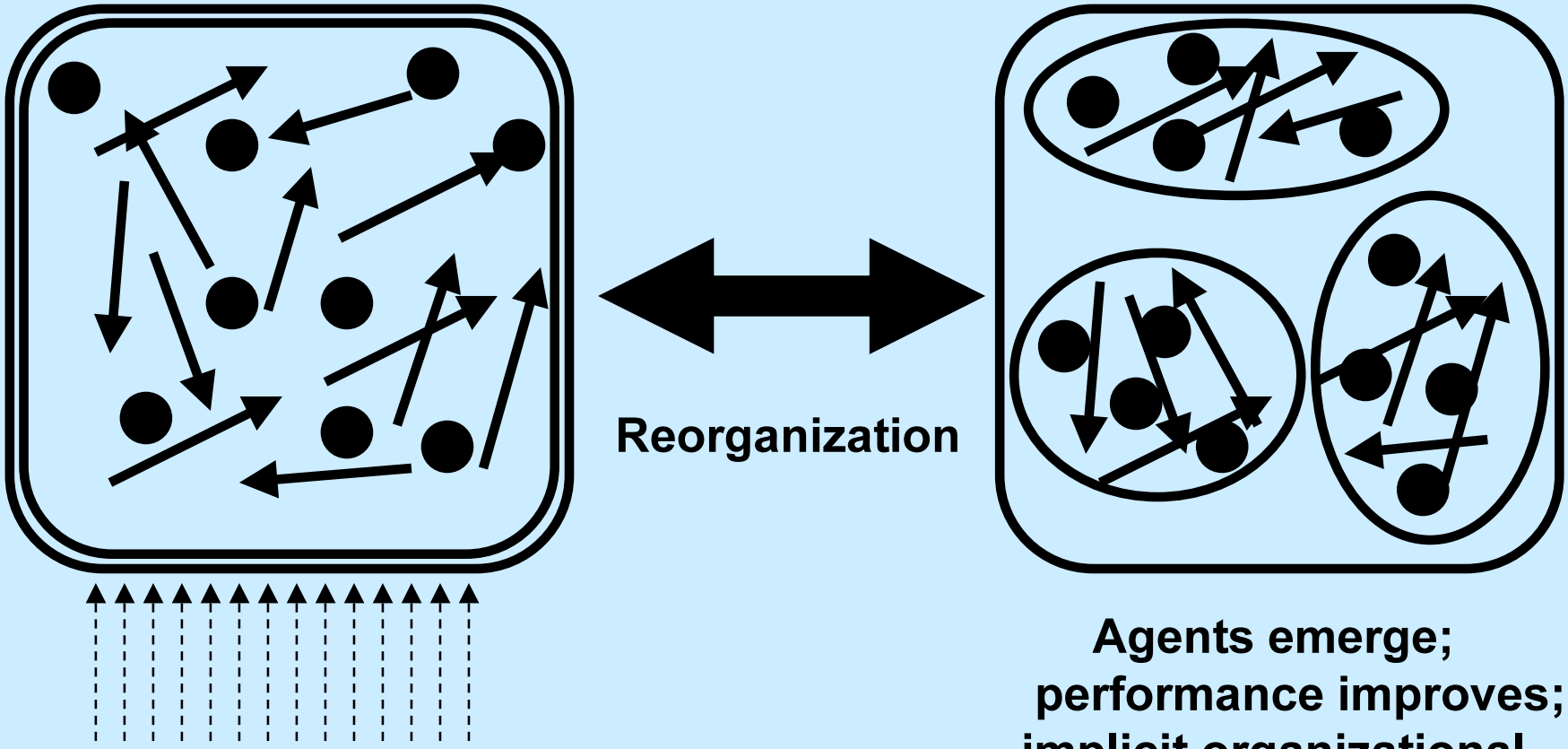
Practical Import:

Dynamic optimization of resource use and knowledge distribution

Progress:

Architecture and simulations completed (1991; 2001); Proof of concept demonstrations; limits explored;

Organizational Adaptability from Emergent Agents (Detailed case)



Organization Self-Design

The study of how multiple agents develop an efficient problem solving organization.

Problem solving organization:

The result of problem decomposition and load balanceing

Load BalancingTechniques

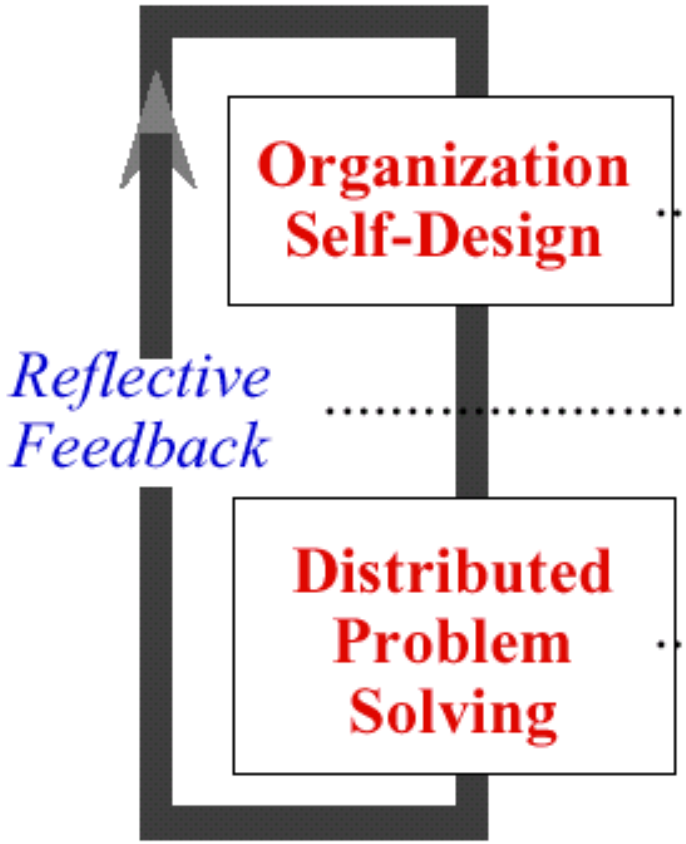
1) Goal Assignment

To distribute multiple subgoals into multiple agents and balance their load.

2) Knowledge Assignment

To distribute problem solving skills by assigning relevant knowledge to multiple agents.

Organizational Problem Solving



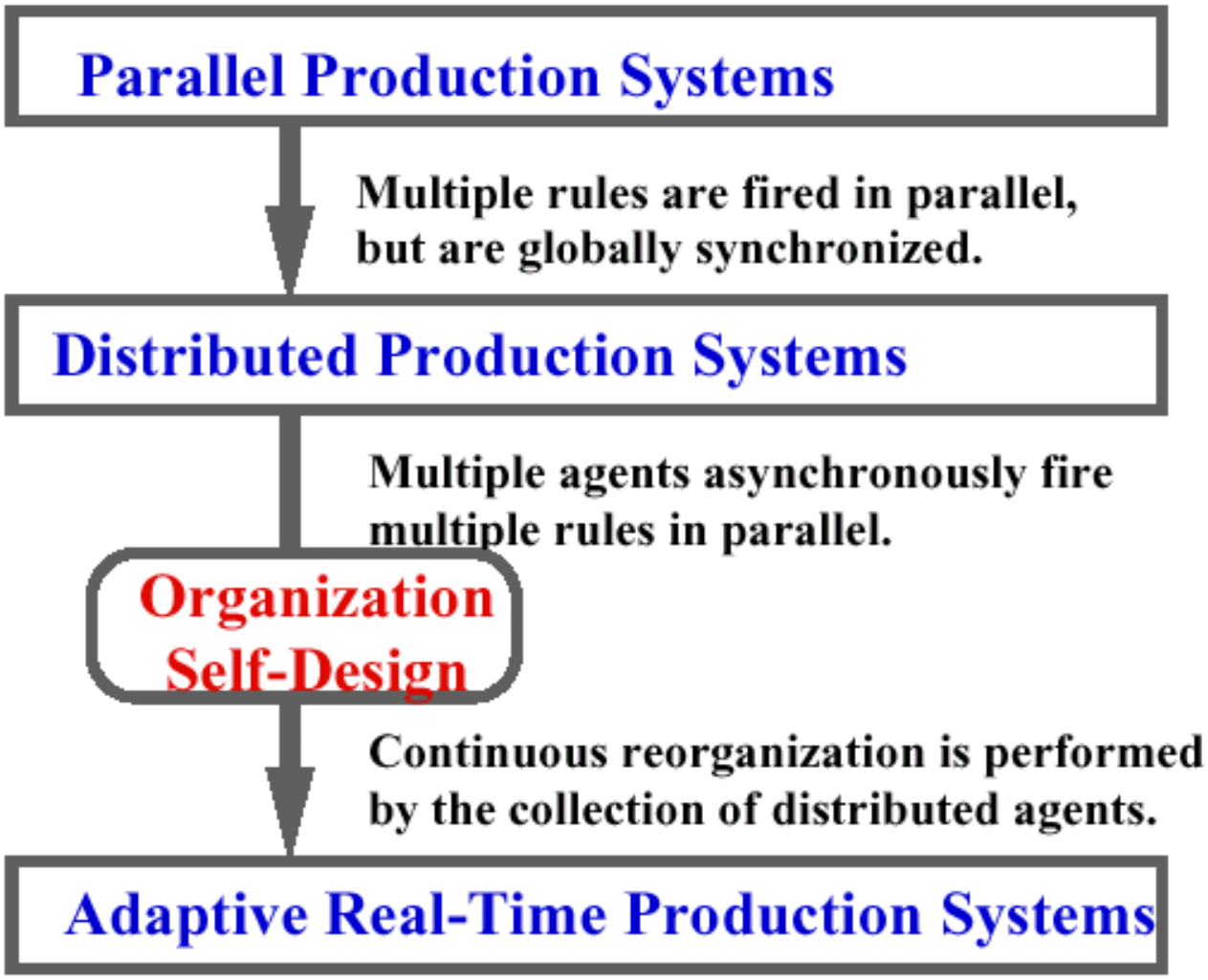
Knowledge and goals are reallocated to the agents.

The agents are triggered to reorganize themselves.

Conflicts significantly decrease the organizational performance.

This feedback enables the agents to maintain their efficiency even though the environment changes dynamically.

Organizational Production System (Overview)

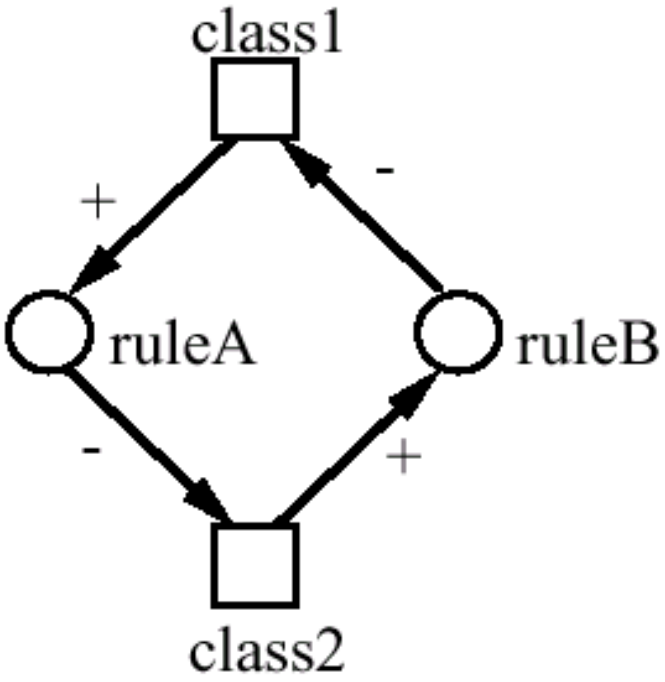


Interrelationships between Rules

1. **Data dependency relationships**
2. **Interference relationships**

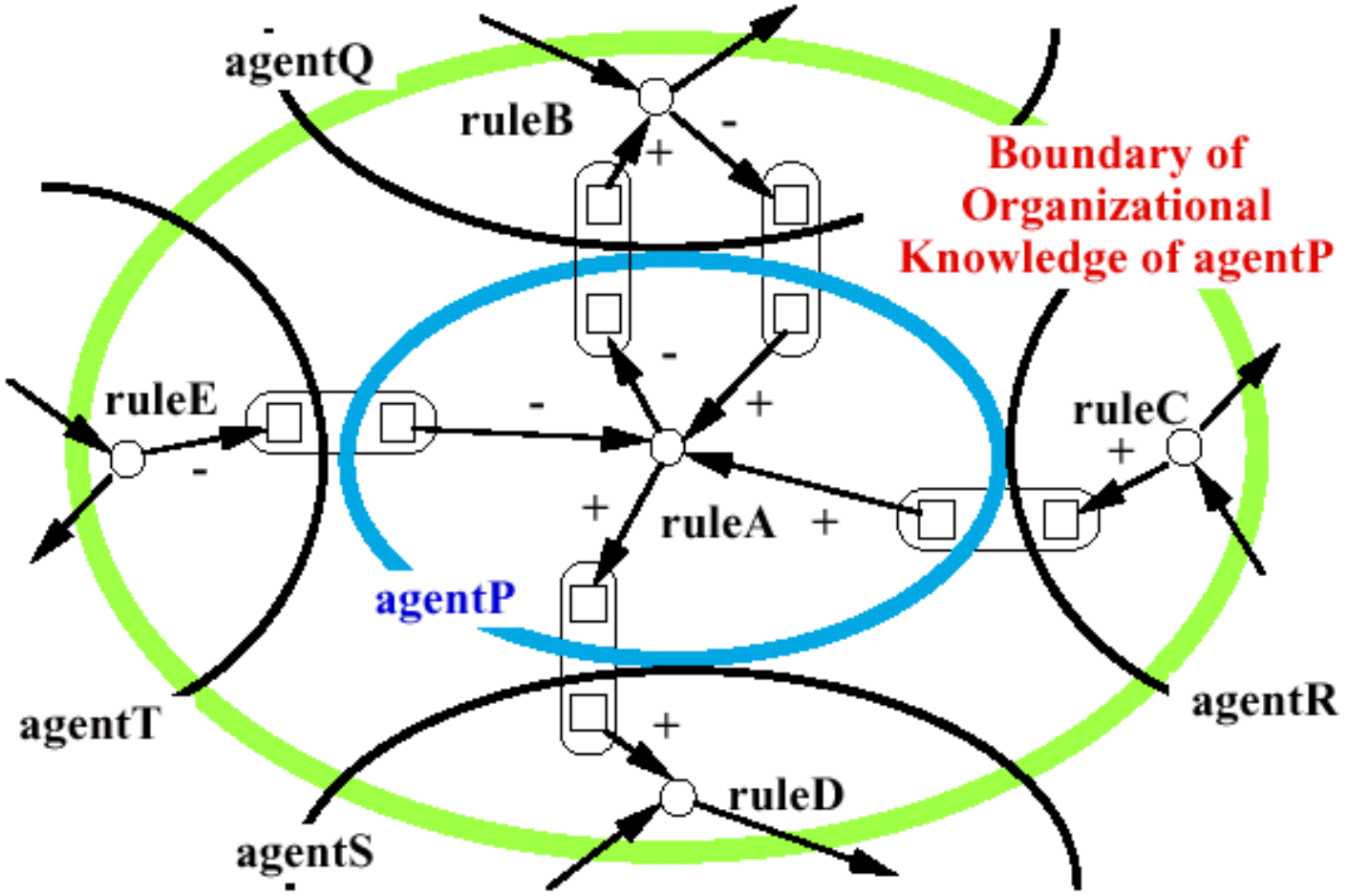
```
(p  ruleA
    (class1 ...)
    -->
    (remove  class2))

(p  ruleB
    (class2 ...)
    -->
    (remove  class1))
```



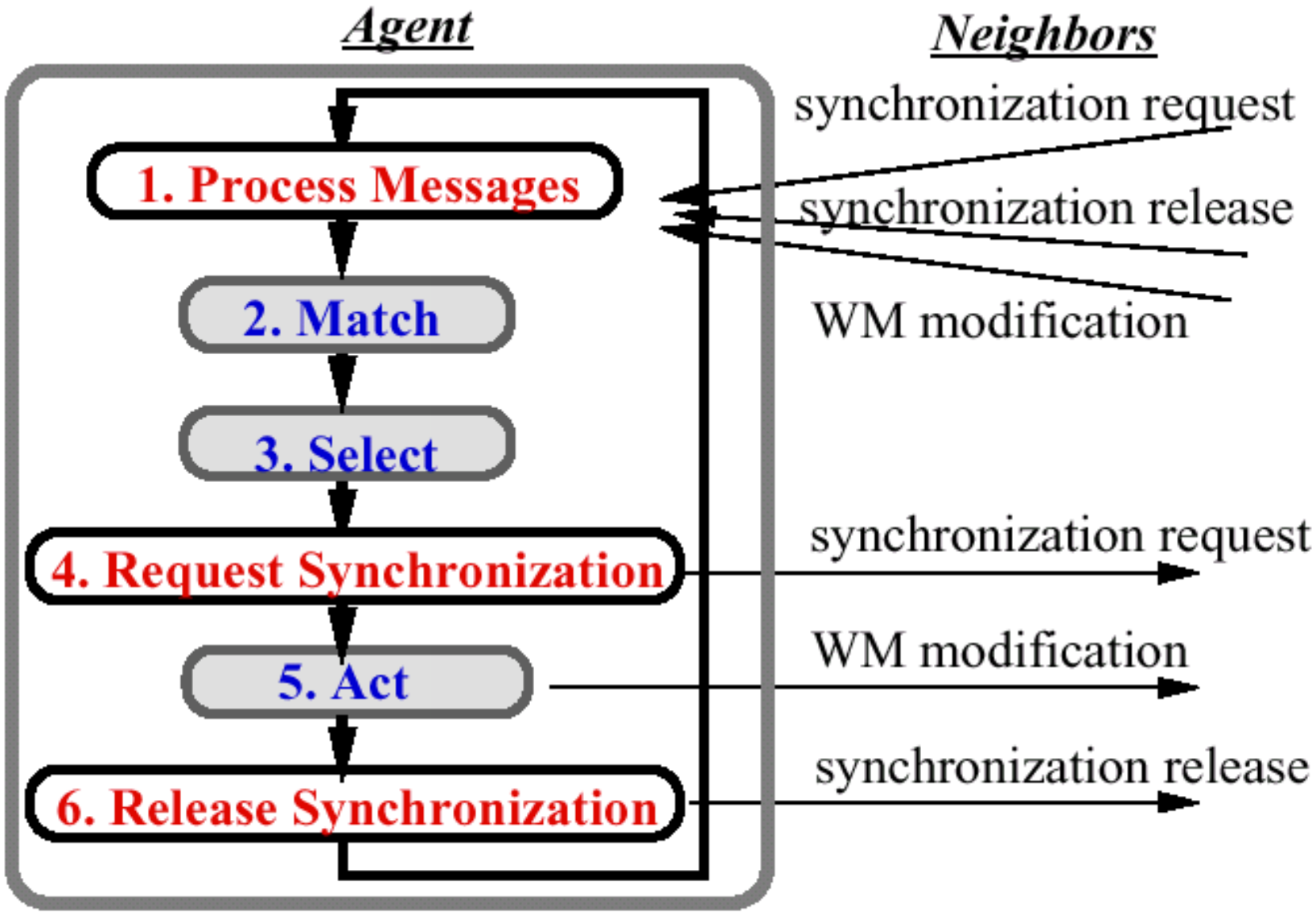
Production Rule **Data-Dependency Graph**

Organizational Knowledge

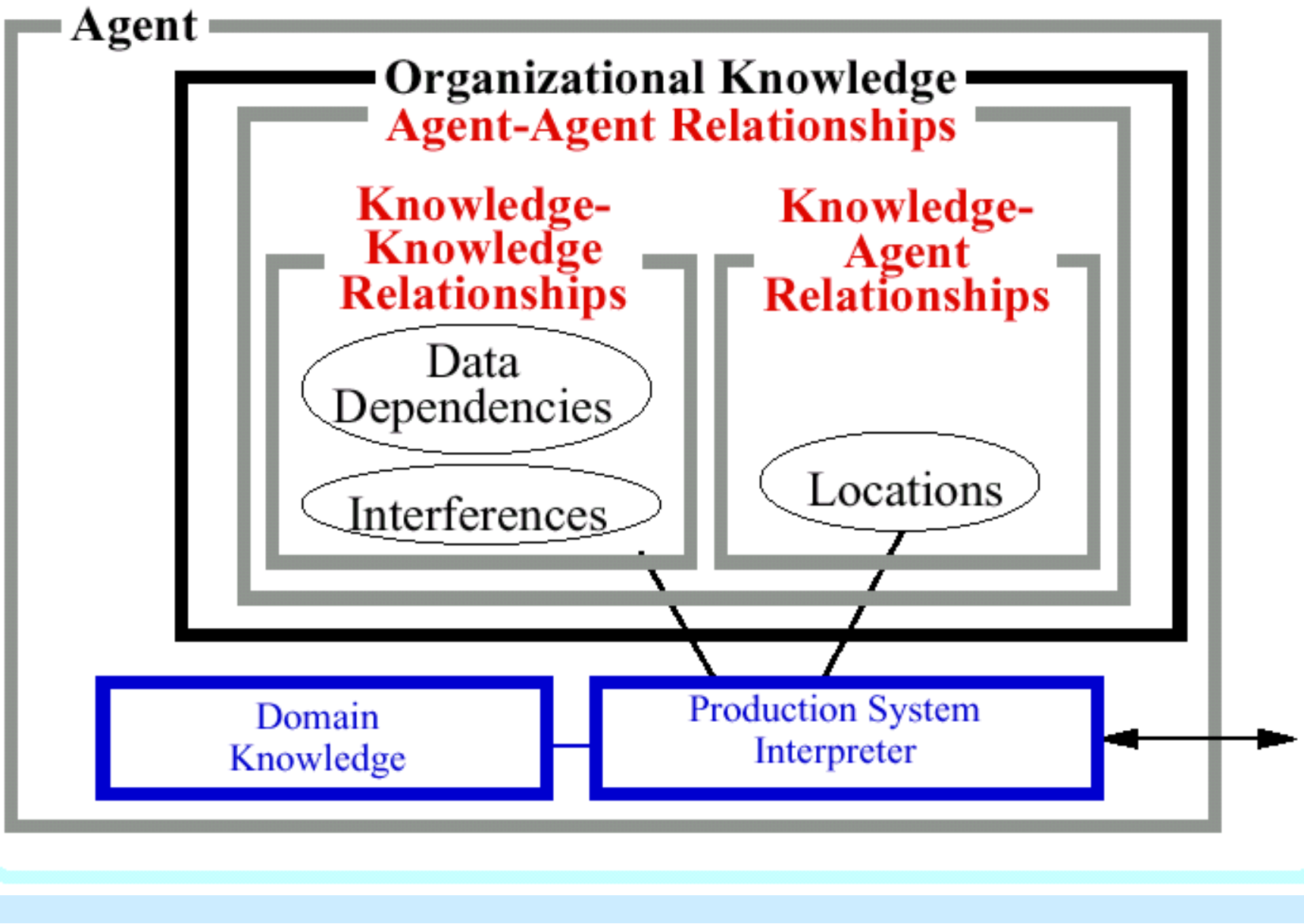


Complete organizational knowledge is not necessary for each agent

Problem Solving Cycle



Distributed Production System Agent

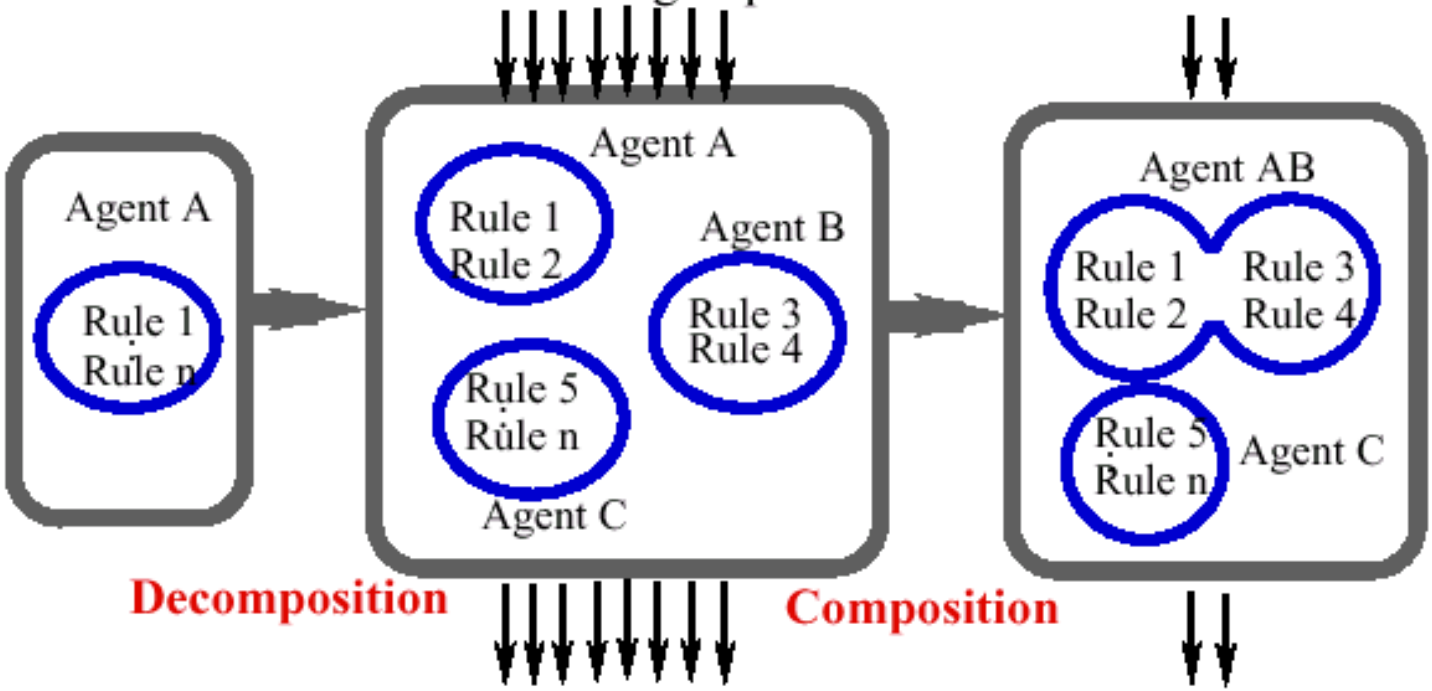


Organizational Production System

Assumption A particular organization shares a collection of parallel processors with other organizations.

Goals To satisfy real-time constraints

To efficiently utilize processor resources



Reorganization Primitives

The behavior of the organization is continuously observed

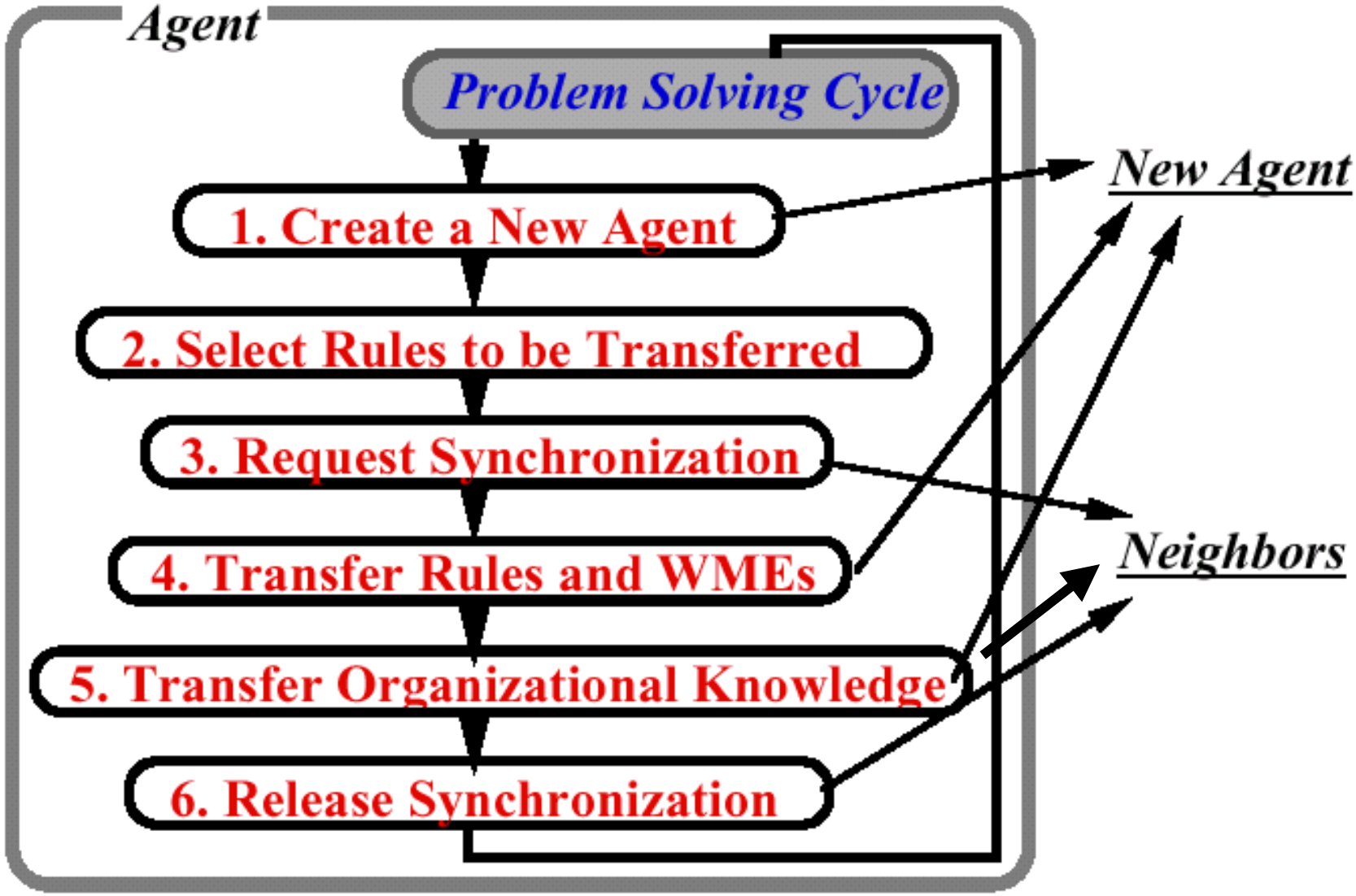
Decomposition

When: The organization cannot meet deadlines.
Effect: Initiate the dividing of heavily-loaded agents.
Until: Parallelism increases, and response-times are shortened.

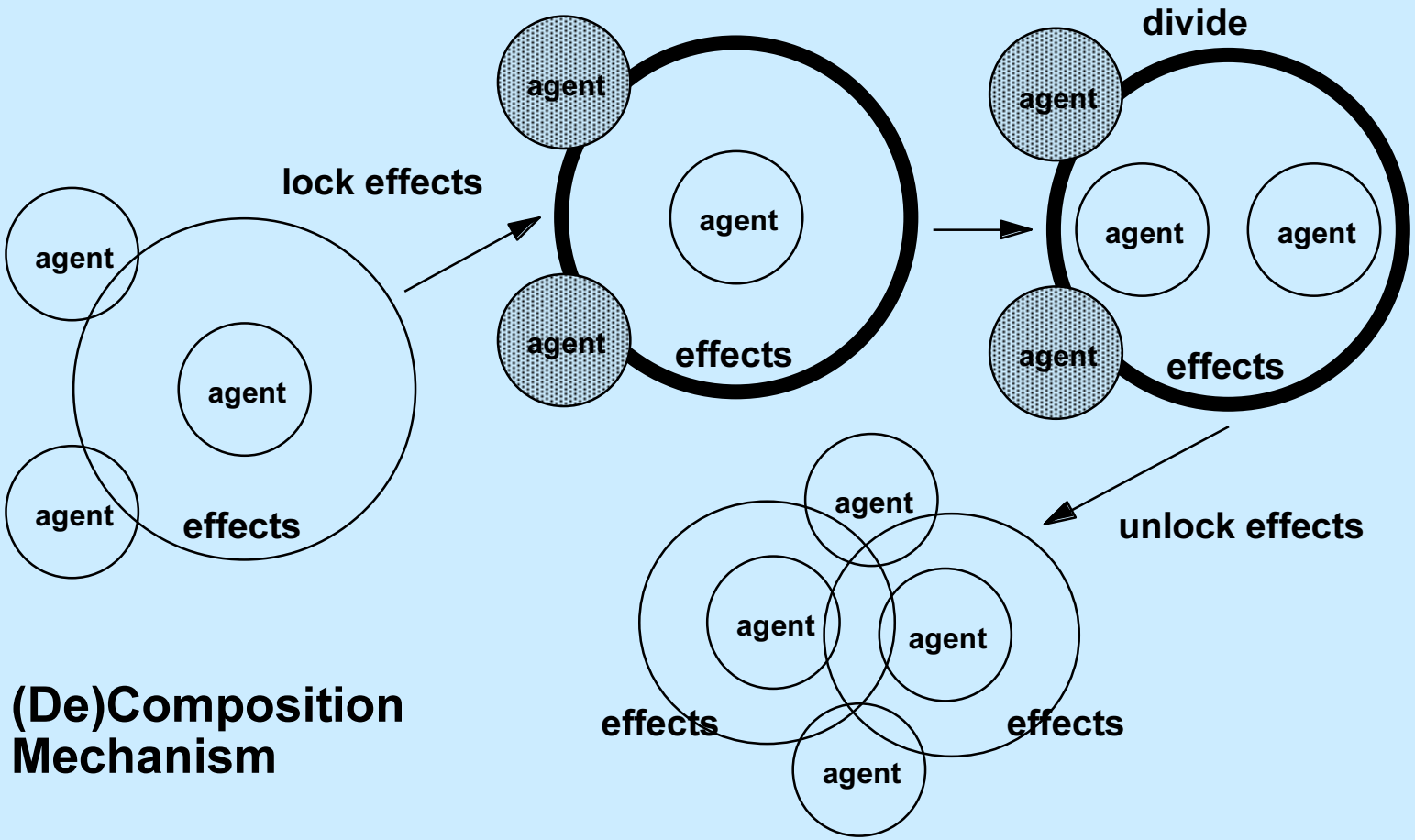
Composition

When: The organization-wide load is light.
Effect: Initiate the combination of lightly-loaded agents.
Until: The organization's load increases.

Decomposition Process

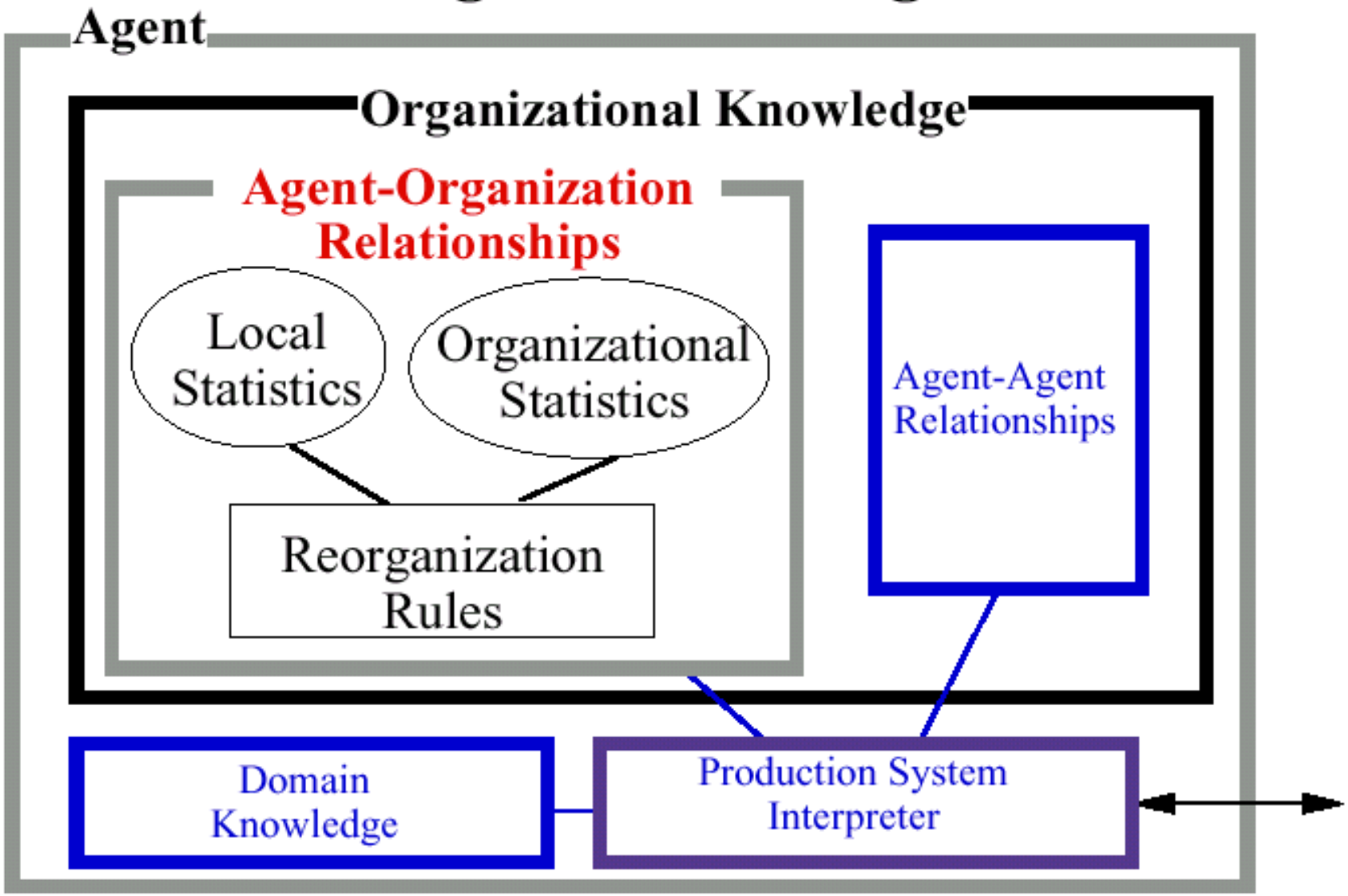


Reorganization Process



(De)Composition Mechanism

Organizational Agent



Simulation

Problem

Waltz Labeling Problem: **36 rules , 80 rule firings**

Problem Solving

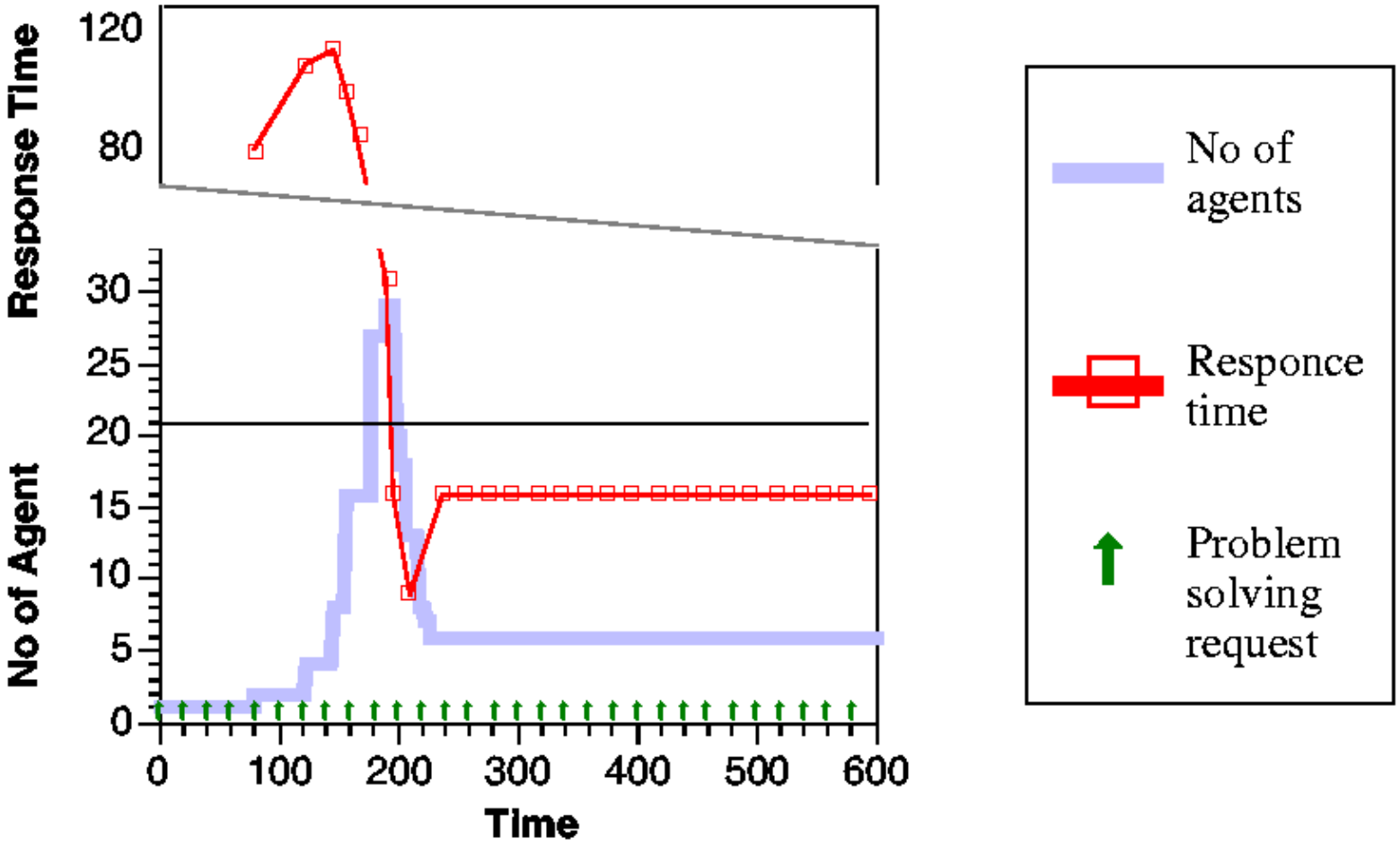
Initial State: **One agent with complete knowledge**
Request Processing: **First-come First-served**
Load Estimation: **Firing-ratio = Rule firings / Cycles**

Reorganization Parameters

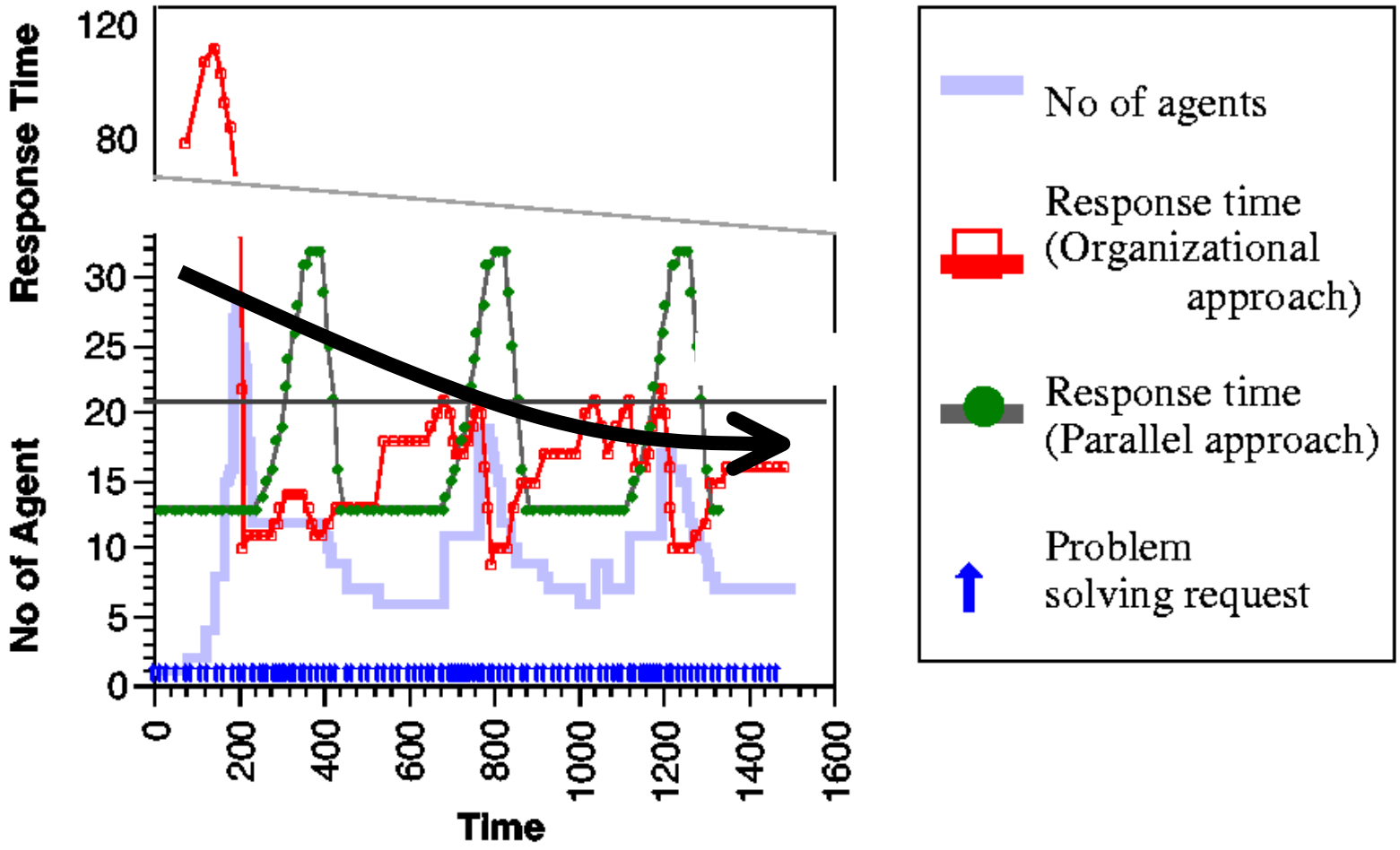
Decomposition:
- *When:* **Time limit = 20 cycles**
- *Who:* **Firing-ratio > 80%**
- *How:* **Rules are arbitrarily divided**

Composition:
- *When:* **Organization-wide firing-ratio < 60%**
- *Who:* **Firing-ratio < 30%**

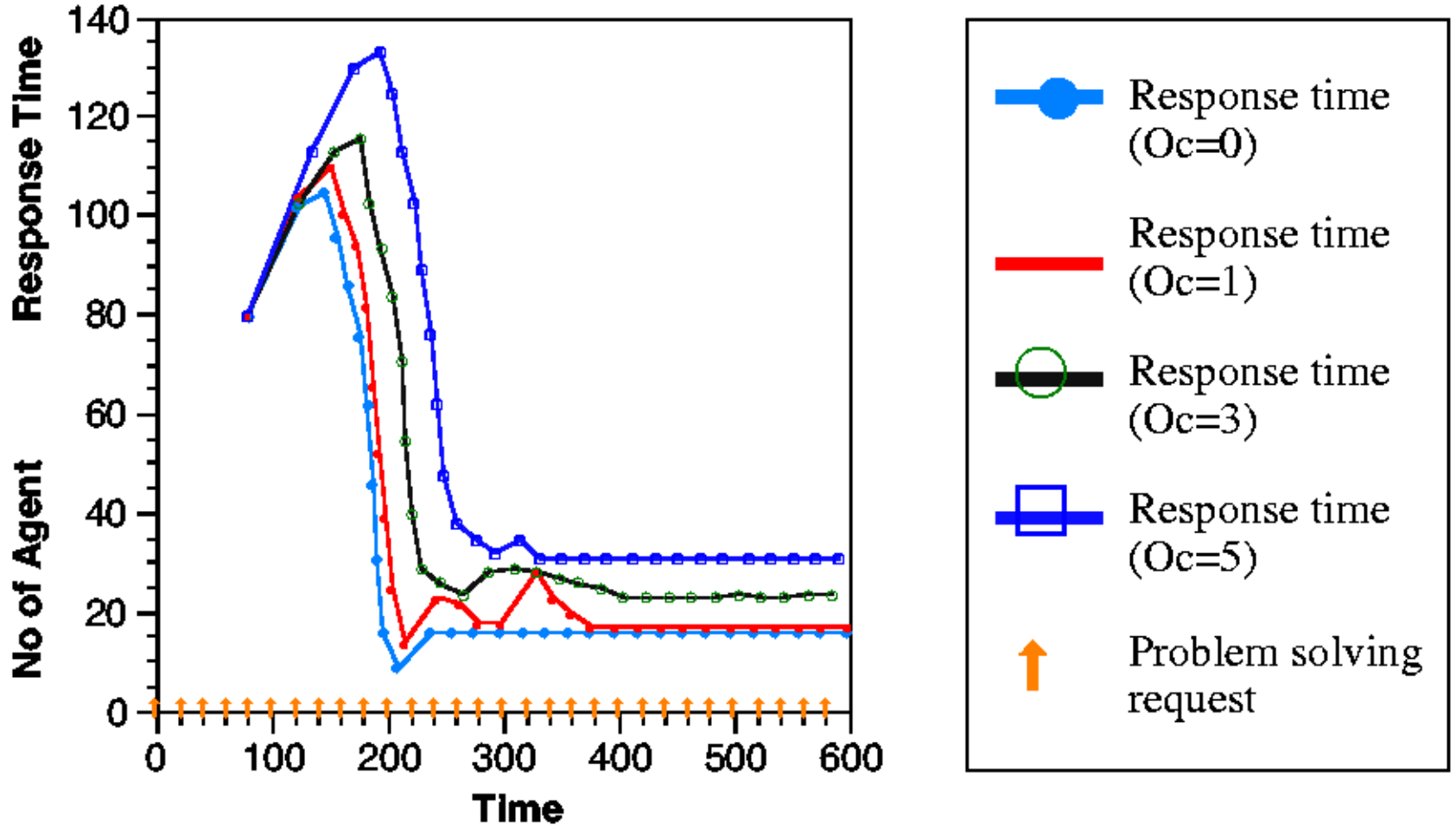
Simulation Results (Constant Intervals)



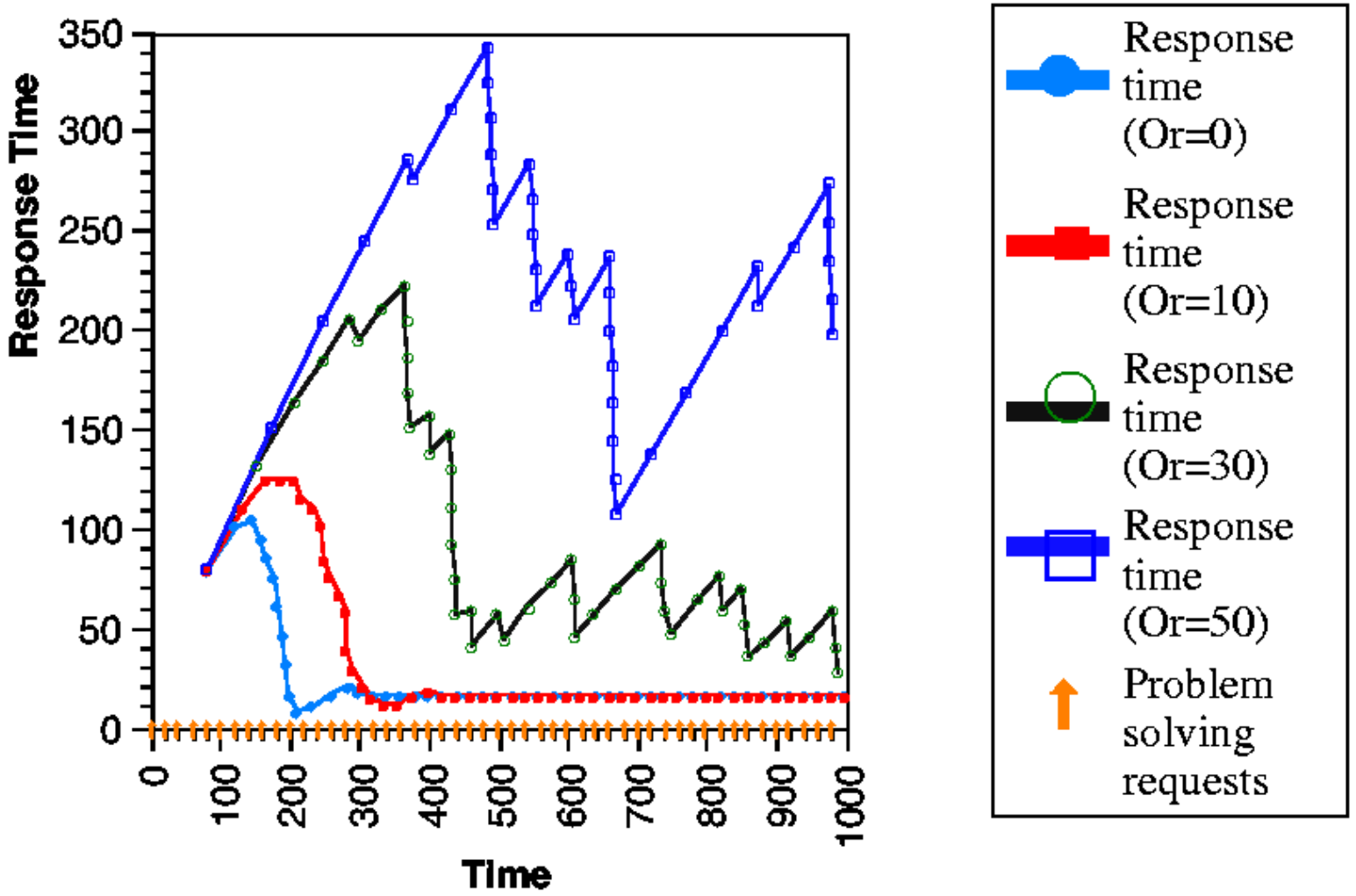
Simulation Results (Dynamic Intervals)



Simulation Results (with Communication Overhead)



Simulation Results (with Reorganization Overhead)



Evaluation Results

Real-Time Problem Solving

The effect of reorganization lags behind
the change in problem load.
Time limits must be set shorter than actual deadlines.

Efficient Resource Utilization

Organizational Approach: **9 processors (average)**
Conventional Approach: **17 processors (permanent)**

Adaptiveness of the Organization

The society of agents can gradually adapt to
the situation through repeated reorganization.

Fontana/Buss's Algorithmic Chemistry

Biology moved from a science of types to a science of dynamics in the 19th century

Biological dynamics are exemplified by the "Modern Synthesis": Darwinian Evolution (replication and selection/fitness) and Mendelian genetics (inheritance). *These presuppose the elements they purport to explain: complex structures*

Biology needs a *theory of organization*, and one that is not based on replication (since replication presumes a replicant)

Can we have evolutionary dynamics & organization, without replication?

Fontana/Buss's Algorithmic Chemistry

Consider reaction A + B => A + B + C

Such a reaction is *non-copying,* I.e. it is not replication

Next, consider autocatalytic cycles:

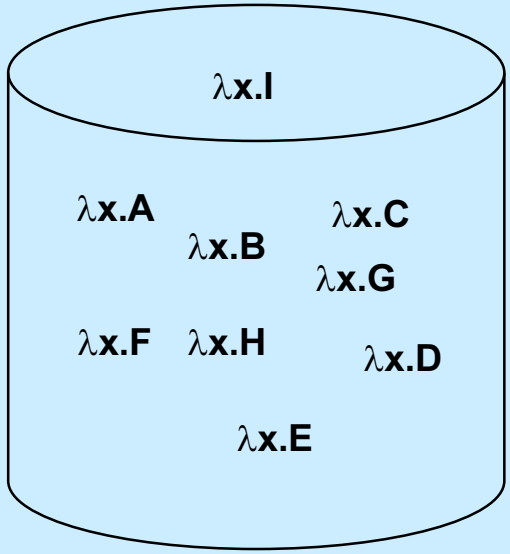
A + B => A + B + C
C + D => A + B + D

Fontana/Buss's Algorithmic Chemistry

Lambda calculus flow reactor mimics chemistry:

λx.A and B(B)

- **Seed reactor with lambda expressions**
- **Randomly pick two expressions *I* and *J***
- **Apply *I* to *J* producing *I*, *J*, and *K***
- **Put all three back in the flow reactor**
- **Randomly remove one expression**
- **Repeat**



Results: With copy operations, general convergence to steady state of identity operations. (Level 0)

Fontana/Buss's Algorithmic Chemistry

Results:

With no copy operations, emergence of sustained autocatalytic cycles, characterized by:

- **Stable kinetics**
- **Algebra of relationships among elements (grammar)**

  (Level 1)

Organization is defined as *system with stable kinetics and stable algebra of relationships*.

Such organizations are
a) very robust to perturbation, and
b) propagatable from small segments (distributed, scalable)

Fontana/Buss's Algorithmic Chemistry

Results: when two Level 1 organizations are combined,

- **They coexist and persist**
- **They sometimes develop cross-catalytic reactions or "glue"**
- **The "glue" is not self-sustaining and cannot exist on its own.**

Taken as a whole, this approach to organization is

- **decentralized**
- **scalable**
- **of inherently distributed structure**
- **non-technological in the sense of not being targetable**

Note: No locality, hence no local-global segmentation

Conclusion

MAS/DAI is developing new concepts and theories of organization, new ways of studying organizations phenomenologically, and new ways of exploiting organizations as technologies.

Organizational MAS systems have been around for at least twenty years, and computational organization models have existed since at least the early 1960s, so there is a wealth of experience.

Interest in MAS organizations is growing as more researchers recognize the need to move from agent-centric orientations to social and organizational orientations.

End