

CmpE 593 Multiagent Systems

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Distributed Problem Solving

Based largely on
Service-Oriented Computing: Semantics, Processes, Agents
– Munindar P. Singh and Michael N. Huhns, Wiley, 2004

Planning and Control Needed

How to maintain global coherence without explicit global control? Important aspects include how to

- Determine shared goals
- Determine common tasks across services
- Avoid unnecessary conflicts
- Pool knowledge and evidence

Coordination

A property of interaction among a set of agents performing some activity in a shared state. The degree of coordination is the extent to which they

- Avoid extraneous activity
 - reduce resource contention
 - avoid livelock
- Avoid deadlock
- Maintain safety conditions

Cooperation is coordination among nonantagonistic agents. Typically,

- Each agent must maintain a model of the other agents
- Each agent must develop a model of future interactions

Goals for Multiagent Control

Develop techniques for

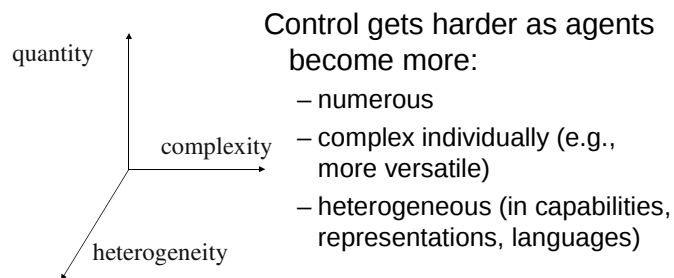
- Locating and allocating capabilities and resources that are dispersed in the environment
- Predicting, avoiding, or resolving contentions over capabilities and resources
- Mediating among more agents, with more heterogeneity and more complex interactions
- Maintaining stability, coherence, and effectiveness

Control Challenges

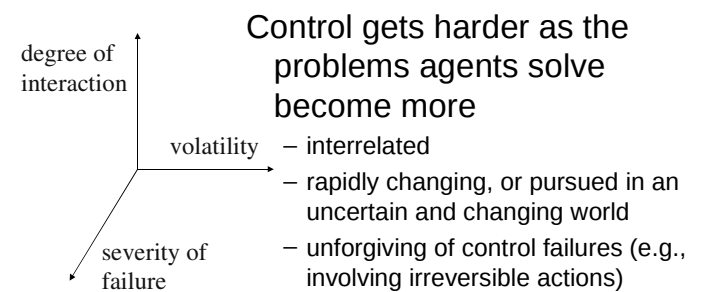
The difficulty of control depends on some major characteristics of the overall system, including:

- agents comprising the system
- problems being solved by the agents individually and/or collectively
- critical solution characteristics

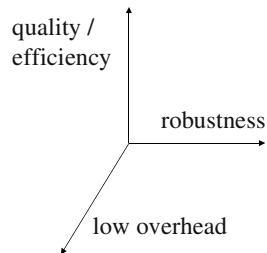
Control Challenges: Agents



Control Challenges: Problems



Control Challenges: Solutions



Control gets harder as solutions to agent problems are required to be more

- efficient
- robust to changing circumstances
- cheaper or faster to develop individually and in concert

Technologies for Agent Control

- Broker-based
- Matchmaker-based
- Market-based; auctions
- BDI and commitment based
- Decision theoretic
- Workflow (procedural) based
- Standard operating procedures
- Learning / adaptive
- Coordinated planning
- Conventions / protocols
- Stochastic or physics-based
- Organizations: teams and coalitions
- Constraint satisfaction/ optimization

Engineering Coordination

- Agents must coordinate their activities to carry out tasks
 - To improve their interest: Bid correctly in an auction
 - To satisfy group goals: Pass the ball to the available player in a soccer game
- AND/OR graph for representing goals
 - Representation of dependencies among goals
 - Resources to solve the primitive goals

Engineering Coordination

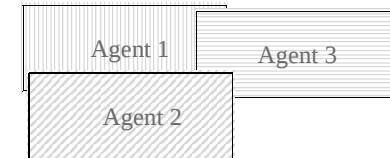
- Define the AND/OR tree
 - Requires understanding the dependencies among goals
- Assign regions of the tree to agents
- Control decisions about which areas to explore, giving priorities to some agents when appropriate
- Traverse the graph
- Allow reporting of successful traversal

Task Decomposition

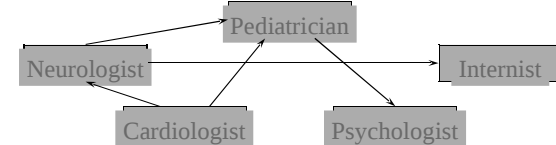
- By the system designer
 - Must be available during implementation
 - Static
- By the agents
 - Using hierarchical planning
- Using AND/OR tree if the task decomposition is inherent
- Spatially if the layout of information sources is significant
- Functionally if expertise distribution of agents is significant

Task Decomposition Examples

- Spatial decomposition: service is info source or decision point:



- Functional decomposition: service offers specialized expertise:



Task Distribution Criteria

- Avoid overloading critical resources
- Engage services on tasks where expertise matches
- Make an agent with a wide view assign tasks to other agents
- Assign overlapping responsibilities to agents to achieve coherence
- Assign highly interdependent tasks to agents in spatial or semantic proximity. This minimizes communication and synchronization costs
- Reassign tasks if necessary for completing urgent tasks

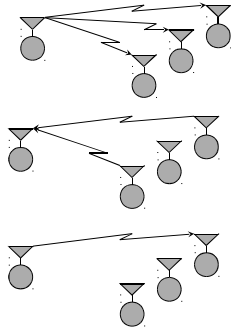
Task Distribution

- Market Mechanism
 - Task matched to agents by generalized agreement
- Negotiation
 - Task assignments are negotiated among agents
- Multiagent Planning
 - Planning agents decide the task distribution
- Organizational Structure
 - Based on roles already available in the organization

The Contract Net Protocol

An important generic protocol

- Manager announces tasks via a (possibly selective) multicast
- Agents evaluate the announcement. Some submit bids
- Manager awards a contract to the most appropriate agent
- Manager and contractor communicate privately as necessary



Task Announcement Message

- *Eligibility specification*: criteria that a node must meet to be eligible to submit a bid
- *Task abstraction*: a brief description of the task to be executed
- *Bid specification*: a description of the expected format of the bid
- *Expiration time*: a statement of the time interval during which the task announcement is valid

Bid and Award Messages

- A bid consists of a *node abstraction*—a brief specification of the agent's capabilities that are relevant to the task
- An award consists of a *task specification*—the complete specification of the task

Applicability of Contract Net

The Contract Net is

- a high-level communication protocol
- a way of distributing tasks
- a means of self-organization for a group of agents

Best used when

- the application has a well-defined hierarchy of tasks
- the problem has a coarse-grained decomposition
- the subtasks minimally interact with each other, but cooperate when they do

Distributed Planning (1)

- **Centralized Planning for Distributed Plans**
 - Given goal description, operators, initial state
 - Generate a partial order plan (with minimal overlappings)
 - Decompose the plan
 - Add synchronization points
 - Allocate agents to subplans
 - Execute plan

Distributed Planning (2)

- **Distributed Planning for Centralized Plans**
- **Distributed Planning for Distributed Plans**
 - Plan Merging
 - Iterative Plan Formation

Organizations

- Organizations are larger-scale than single agent, goal-oriented, and with knowledge and memory beyond individual
- Organizations help overcome the limitations of agents in
 - reasoning
 - capabilities
 - perception
 - lifetime and persistence
- Concretely, organizations consist of agents acting coherently
- Coherence is how well a system behaves as a unit. It requires some form of organization structure
- Roles to define templates for acting

Hierarchy

- Agents arranged in a tree structure
- Accommodates parallel tasks
- Agents at the top have a broader view; results of lower levels propagated up
- Problems:
 - Possible single points of failure
 - Rigid communication
- Contract Net Protocol
- Commonly found
- Deciding on the depth and width of the hierarchy is difficult

Holarchy

- Hierarchical and nested structure
- Mostly mimicking biological organizations
- Holons maintain autonomy
- Problems:
 - Not easily applicable
 - Performance expectation not clear

Coalition

- Individual goals
- Short term
- Gathering to increase overall reward
- Coalition formation
 - Selecting the group of agents for the coalition so that the reward will be maximized
 - Consider the associated cost
- Problems
 - Self-interested agents
 - Trust

Team

- Group level goals
- Address larger tasks
- Task distribution important
- Flexible communication
- Can be heterogeneous
- Adopt additional tasks to help others

Teamwork

- When a team carries out some complex activity
- Negotiating what to do
 - Monitoring actions jointly
 - Supporting each other
 - Repairing plans