Overview

Multi-Agent Systems

Introduction
to multi-agent systems and agent societies

Agent Communication
knowledge exchange among agents

Agent Interaction
eliminates explicit deliberation

Societies of Agents
from individual agents to more complex situations
Introduction

**environment** (physical or computational)
- agents may share a common environment
- share resources
- coordinate activities

**objectives** for multi-agent system environments
- let agents operate effectively
- let agents interact productively

**requirements** for multi-agent system environments
- computational infrastructure
- protocols for communication and interaction between agents
Why Distributed Systems

when centralized systems may be able to achieve the same more efficiently

distributed nature of the problem
  information, resources, components of the system may be geographically distributed

size of the system
  too many components
  too much content

heterogeneity
  the system consists of fundamentally different parts that don’t fit easily into one centralized location
Role of Intelligent Agents

for distributed systems

**intelligent application programs**
individual, largely independent entities that
work together on a common task

**active information resources**
autonomous gathering and consolidation of
information
updates on a regular bases, or when significant
changes have occurred

**wrappers** around conventional components
integration of legacy systems

**services** provided by the infrastructure
agents as implementation vehicles for services
Properties of Agents

in distributed systems

knowledgeable about (local) resources
    in particular knowledge and information
    resources
    intermediaries for more detailed information

cooperation for better access
    especially for non-local knowledge

management of knowledge
    better tailored towards the needs of the user
Rationale for Multi-agent Systems

when many is better than one

cooperaition for solving problems
distribution of labor
distribution of capabilities

sharing of expertise
possibly also resources

parallel work
multiple tasks can be tackled simultaneously

fault tolerance
multiple agents provide redundancy

multiple perspectives
different agents may provide different viewpoints or solutions for a problem

modularity and reuse
agents may be built from building blocks
Household Agents

Example of a potential agent system

instances of agents
vacuum, fridge, coffee maker, telephone/voice mail/chat,

tasks
washing and cleaning, preparation of food,
heating and ventilation, energy conservation,
entertainment, ...

infrastructure
sources of energy, inter-agent communication

agent capabilities
general-purpose vs. task-specific

limitations
sensory equipment, effectors, computation,
safety, efficiency, convenience, user satisfaction
Characteristics of Multi-agent Environments

**infrastructure**
- shared resources for agents
- provides communication and interaction protocols
- transportation methods for mobile agents

**design**
- usually open, based on standards
- distributed

**inhabitants**
- autonomous agents
- communication with the environment, other agents
- may be selfish or cooperative
Environment Properties

from the agent's perspective

knowable
what does the agent know about the environment

predictable
what can the agent predict about the environment

controllable
what changes can the agent make

historical
is the history relevant for the agent’s current activities

teleological
are there other entities (agents) that act purposefully

real-time (dynamic)
can the environment change while the agent is deliberating
Agent Communication

ability to send and receive messages

**sensors** (receiver)
required to receive messages

**percept**
data structure that captures sensory information

**actions and actuators** (sender)
necessary for sending messages

**purpose** of communication
help achieving the goals of the agent
coordination of actions and behavior among agents
exchange of information with agencies
(infrastructure)

**world model**
should be compatible for communicating agents
Coordination

within a society of agents

effort
avoid extraneous activity

resource contention
several agents want to utilize the same resource

livelock/deadlock
agents get entangled in their mutual requests of resources

safety
applicable policies must be maintained

agent models
agents must maintain models of other agents
models of future interactions may be helpful
Variations on Coordination

mutual or individual benefits

coopetition
  non-antagonistic agents work towards a
  common goal
  coordination of efforts
  may involve modification of plans, activities

competition
  self-interested agents have conflicts with other
  agents
  resources, better performance
  coordination of limited resources
  may involve negotiations
Coherence

behavior of the overall system as one entity

goal (often)
  global coherence without explicit global control

communication requirements
  determine shared goals
  identify common tasks
  avoid conflicts
  pool knowledge, evidence

organization
  mutually agreed-upon structure of the society

social behavior
  frequently used means to achieve system coherence

economic principles (markets)
  alternative means for system coherence
Agent Interaction

exchange of series of messages between agents

conversation
instance of agent interaction according to an interaction protocol
also relies on a communication protocol for the individual messages

one-to-one communication
messages sent to individual agents

broadcast
messages sent to groups of agents

intermediaries
no direct exchange of information
often provided by the infrastructure in the form of mail boxes, blackboards, . . .
Objectives of Interaction

among agents

self-interested agents (competition)
  each agent tries to maximize its payoff (utility function)

collaborating agents (shared goals)
  maintain globally coherent performance
  if possible, without global control (loss of autonomy)
Coordination Protocols

required to share resources

reasons for coordination
dependencies between the actions of agents
global constraints within the system
insufficient competence, resource, information
for individuals

distribution of control/data
degree of autonomy for individuals
knowledge dispersed through the society
uncertainty about actions of individual agents
system-wide coherent behavior may be difficult
to achieve
Distributed Goal Search

as a means for coordination

AND/OR graph as representation of the problem
  indicates dependencies between individual subgoals
  identifies resources as leaves of the tree

description of coordination activities
  definition of the goal graph
  assigning regions of the graph to agents
  controlling decisions about areas to explore
  graph traversal
  completeness considerations
  reporting of results
Cooperation Protocols

for collaborative agents

strategy
often divide-and-conquer to reduce the
complexity of a task

task decomposition
by the system designer, or by the agents
may be derived from the problem representation
(AND/OR graph)
functionally, spatially or temporally

task distribution
map tasks to agents
avoid bottlenecks
use overlapping responsibilities to achieve
coherence
assign interdependent tasks to agents that are close

load balancing
mechanisms to re-distribute tasks when needed
Task Distribution Mechanisms

- **markets**
  - similar to the pricing of commodities

- **contract net**
  - announce, bid, answer cycles

- **multiagent planning**
  - planning agents assign tasks to other agents

- **organizational structure**
  - individual agents are responsible for specific tasks
Contract Net

widely used protocol for task distribution

contract

mutual agreement between agents to perform at
a task for a certain price
similar to business contracts among
corporations or individuals

roles of agents
managers want a task solved contractors are
capable of solving the task
roles are not necessarily assigned in advanced,
agents usually can perform either role
**Contract Net Steps**

**manager’s perspective**
- announce a task to be performed
- receive and evaluate bids from potential contractors
- award a contract to a suitable contractor
- receive and assemble the results

**contractor’s perspective**
- receive task announcements
- evaluate capability to perform the task
- respond (decline, bid)
- perform the task if the bid is accepted
- report the results
Multi-agent Belief Maintenance

coordination of knowledge among agents

**truth maintenance systems** used as a basis
distributed across multiple, possibly
heterogeneous agents
possibly different goals, capabilities

**consistency of knowledge bases**
within individual knowledge bases, and across
them

**well-founded knowledge bases**
no sets of beliefs are mutually dependent

**complexity**
may become quite cumbersome
Societies of Agents

longevity
how long do agents “live” in a society

adaptivity
agents must be flexible in order to get along with others

social
agents must be capable and willing to communicate and interact with others

behavior
agents may perform in different roles
Foundations of social agency

sociology
organizational theory

cognitive science, psychology
mental primitives
agent models

economics

biology
societies of animals
Summary - Multi-Agent Systems

environments for multiple agents
   co-location requires agents to share resources in
   the environment
   infrastructure to facilitate interaction

interaction between agents
   co-existence: agents share an environment
   mutual awareness: agents know about each
   other
   communication: agents exchange information
   coordination: agents pursue their own goals,
   but adapt their activities
   collaboration: agents work together on tasks