# 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

**cooperation** 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 clearning, 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

mutal or individual benefits

**cooperation**

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 agents 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

**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