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 can 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 components 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

can the environment change while the agent is deliberating

Agent Communication

ability to send and receive messages

sensors (receiver)

required for the receiving of messages

perception

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