Learning Agents

Overview

Learning
  important aspects

Learning in Agents
  goal, types; individual agents, multi-agent systems

Learning Agent Model
  components, representation, feedback, prior knowledge

Learning Methods
  inductive learning, neural networks, reinforcement learning, genetic algorithms

Knowledge and Learning
  explanation-based learning, relevance information
Learning

acquisition of new knowledge and skills on the agent’s own initiative

incorporation of new knowledge into the existing knowledge

performed by the system itself not only injected by the developer

performance improvement simply accumulating knowledge isn’t sufficient
Learning in Agents

improved performance through learning

learning
modify the internal knowledge

goal
improvement of future performance

types of learning
memorization, self-observation, generalization,
exploration, creation of new theories,
meta-learning

levels of learning
value-action pairs
representation of a function
general first-order logic theories
Learning Agent Model

conceptual components

learning element
responsible for making improvements

performance element
selection of external actions:
takes in percepts and decides on actions

critic
evaluation of the performance according to a
fixed standard

problem generator
suggests exploratory actions
new experiences with potential benefits
Diagram [?] p. 526
Learning Element

how to improve performance

performance element
affected components

internal representation
used for components to improved

feedback
from the environment
from a teacher

prior knowledge
about the environment / domain
**Performance Element Components**

relevant for learning

**mapping function**
from percepts and internal state to actions

**inference mechanism**
infer relevant properties of the world from percepts

**changes in the world**
information about the way the world evolves

**effects of actions**
results of possible actions the agent can take

**utility information**
desirability of world / internal states

**action-value information**
desirability of actions in particular states

**goals**
classes of desirable states
utility maximization
Representation

used in a component

deterministic
  linear weighted polynomials

logic
  propositional, first order

probabilistic
  belief networks, decision theory

learning algorithms need to be adapted to the particular representation
Feedback

about the desired outcome

**supervised learning**
- inputs and outputs of percepts can be perceived immediately

**reinforcement learning**
- an evaluation of the action (hint) becomes available
- not necessarily immediately
- no direct information about the correct action

**unsupervised learning**
- no hint about correct outputs
Inductive Learning

learning from examples

reflex agent
  direct mapping from percepts to actions

inductive inference
  given a collection of examples for a function $f$,
  return a function $h$ (hypothesis) that
  approximates $f$

bias
  preference for one hypothesis over another
  usually large number of possible consistent
  hypotheses

incremental learning
  new examples are integrated as they arrive
Decision Trees

deriving decisions from examples

goal
  take a situation described by a set of properties, and produce a yes/no decision

goal predicate
  Boolean function defining the goal

expressiveness
  propositional logic

efficiency
  more compact than truth tables in many cases
  exponential in some cases (parity, majority)
Induction for decision trees

described by the values of the attributes and the value of the goal predicate (classification)

training set
set of examples used for training

test set
set of examples used for evaluation different from the training set

algorithm
classify into positive and negative sets
select the most important attribute
split the tree, and apply the algorithm recursively to the subtrees
Performance Evaluation

for inductive learning algorithms

goals
   reproduce classification of the training set
   predict classification of unseen examples

example set size
   must be reasonably large

average prediction quality
   for different sizes of training sets and randomly selected training sets

learning curve ("happy curve")
   plots average prediction quality as a function of the size of the training set

training and test data should be kept separate, and each run of the algorithm should be independent of the others
Examples

decision tree learning

Gasoil
  design of oil platform equipment
  expert system with 2500 rules generated from
  existing designs

using a flight simulator
  program generated from examples of skilled
  human pilots
  somewhat better performance that the teachers
  (for regular tasks)
  not so good for rare, complex tasks
Neural Networks: see separate slides
Reinforcement Learning

learning from success and failure

reinforcement or punishment
feedback about the outcome of actions
no direct feedback about the correctness of an action
possibly delayed

rewards as percepts
must be recognized as special percepts, not just another sensory input
can be components of the utility, or hints
Variations in the learning task

environment
  accessible or not

prior knowledge
  internal model of the environment
  knowledge about effects of actions
  utility information

passive learner
  watches the environment without actions

active learner
  act based upon learned information
  problem generation for exploring the environment

exploration
  trade-off between immediate and future benefits
Generalization in reinforcement learning

implicit representation
  more compact form than a table for input-output values

input generalization
  apply learned information to unknown states

trade-off between the size of the hypothesis space and the time to learn a function
Examples of reinforcement learning

**game-playing**
- TD-gammon: neural network with 80 hidden units, 300,000 training games and precomputed features added to the input representation plays on par with the top three human players worldwide

**robot control**
- cart-pole balancing (inverted pendulum)
Genetic Algorithms

as a variation of reinforcement learning

**basic idea**
selection and reproduction operators are applied
to sets of individuals

**reward**
successful reproduction
agent is a species, not an individual

**fitness function**
takes an individual, returns a real number

**algorithm**
parallel search in the space of individuals for one
that maximizes the fitness function

**selection strategy**
random, probability of selection is proportional
to fitness

**reproduction**
selected individuals are randomly paired
cross-over: gene sequences are split at the same point and crossed
mutation: each gene can be altered with small probability
Knowledge and Learning

learning with prior knowledge

learning methods
- take advantage of prior knowledge about the environment

learning level
- general first-order logic theories
- as opposed to function learning

description
- conjunction of all example specifications

classification
- conjunction of all example evaluations

hypothesis
- newly generated theory

entailment constraint
- together with descriptions, the hypothesis must entail classifications
essential step toward truly autonomous intelligent agents
Explanation-Based Learning

potentially known information is made explicit

usage
known theories are converted into directly applicable knowledge ("aha-effect")

entailment constraint
background entails hypothesis, which together with the example descriptions entails classificaitns
Example: Gary Larson sketch where Thad the caveman shows his mates how to use a stick to grill a lizard
Relevance-Based Learning

points out relevant features

functional dependencies
    generalization that derives the value of one
    predicate from another one

learning method
    deductive
    does not create any new knowledge

main effect
    limitation of the hypothesis space
    allows deductive generalizations from single
    examples
Examples: inference from nationality to spoken language
Inductive Logic Programming

learning based on predicate logic

learning methods
- discovery of new predicates and new knowledge
- extensions of decision trees to predicate logic

main effects
- reduction of the hypothesis space to include only theories that are consistent with prior knowledge
- smaller hypotheses by using prior knowledge to formulate new rules
Example: Learning of family relationships

generating the definition of Grandparent becomes much easier if Parent is available
too complex for decision-tree learning
Learning in Multi-Agent Systems

as opposed to learning in individual agents

principal categories

differentiating features

learning coordination

learning with other agents
Principal Categories

of learning in multi-agent systems

centralized learning
one agent performs all relevant activities
no interaction required
may include multiple agents with the same
learning goals

decentralized learning
several agents are engaged in the same learning
process
requires interaction and collaboration between
agents
Differentiating Features

for multi-agent learning approaches

degree of decentralization
  distributed, parallelized

interaction-specific features
  level, persistence, frequency, patterns, variability
  of interaction

involvement-specific features
  relevance of involvement
  roles played by agents

goal-specific features
  type of improvement intended by learning
  compatibility of learning goals across different
  agents

learning method
  rote learning, learning by instruction, example,
  practice, analogy, discovery

learning feedback
supervised learning
reinforcement learning
unsupervised learning
Credit Assignment

Whose fault was it?

inter-agent credit assignment
several agents are involved in a learning activity
that results in a performance change
who is responsible for the change?

intra-agent credit assignment
which of the internal components of an agent
involved in learning is responsible for a
performance change?

general question
what action carried out by which agent
contributed to what extent to the performance
change?

related question
what knowledge, what inferences, and what
decisions led to an action
Learning and Activity Coordination

improving the performance of the overall system

**reinforcement learning**
- agents try to maximize the amount of reinforcement they receive from the environment or from an instructor

**isolated reinforcement learning**
- individual agents use reinforcement learning to achieve their own goals
- no communication or collaboration about the learning processes or results

**collaborative reinforcement learning**
- agents communicate to decide on individual and group actions
- agents have some insight into each others learning processes, and share some results
Learning with Other Agents

organizational roles
- assignments of roles in teams in order to learn more effectively

environmental conditions
- adaptation to changes in the environment
- mutual exchange of pertinent information
- especially for buyer and seller agents in electronic marketplaces

team competitions
- improvements in playing against competitors
- learning from more experienced agents
Explanation-Based Learning

to improve cooperative problem solving

inefficiencies in coordinated behavior
  identification of underlying causes
  rectification of decisions or actions

learning analysis
  problem-solving traces are collected and analyzed
  explanations are generated for relevant decisions

agent models
  the explanations should be generated with the model of the agent in mind
Learning and Communication

learn more and less by exchanging information

reduced communication
learning may lead to less conversations among agents
instead of asking, agents learn themselves

reduced learning
communication can reduce the need for learning
instead of learning, agents ask other agents

balancing learning and communication
may depend on bottlenecks in computational power or bandwidth
Summary - Learning Agents

**Learning** in agents
- acquisition and generation of new knowledge
- performance improvement as goal

**Learning Agent Model**
- components, representation, feedback, prior knowledge

**Learning Methods**
- inductive learning, neural networks,
- reinforcement learning, genetic algorithms

**Knowledge and Learning**
- explanation-based learning, relevance
- information
- inductive logic programming, machine learning

**Learning in Multi-Agent Systems**
- de-centralized, interaction, integration of results