Chapter Overview

Introduction
   What is an Expert System?

Terminology
   Knowledge, Data, Information

Representation and Processing
   of Knowledge

Methods in Computing
   Algorithms, Rules, Semantic Nets, ...

Search in Artificial Intelligence
   Basic Search Methods

Knowledge and Expertise
   Experts and their Knowledge

Knowledge-Based Systems
   Definition and Historical Development
   Types of Knowledge
   Features of Knowledge-Based Systems
   Development of Knowledge-Based Systems

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Artificial Intelligence

Myths, hype, and the truth ...

Old adages
   “It’s an AI problem if it hasn’t been solved yet.”
   “AI is like computers in movies (e.g. HAL).”
   “AI is Advanced Informatics.”

AI Applications

The truth (maybe).

Natural Language
   parsers (games, data base front ends)

Programming
   objects, expert systems, agents

Robotics
   autonomous vehicles, sensors, planning

Vision
   object recognition, feature detection

Knowledge
   representation, acquisition, processing
What is an Expert System?¹

**Basic concepts**

- designer / user supplies facts and information
- user asks queries and receives expert advice
- limited to a problem domain (*knowledge domain*)

**Components**

- user interface
- knowledge base
- inference mechanism

*Synonyms:* knowledge-based system, knowledge-based expert system


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**Knowledge:**

definition:¹ Information and understanding about a subject which a person has in his or her mind or which is shared by all human beings

similar terms:² learning, lore, scholarship, wisdom, instruction, book-learning, enlightenment, expertise, intelligence, light, theory, science, principles, philosophy, awareness, insight, education, substance, store of learning, know-how

important aspects: possibly complex structure (relations between items)

¹[Sinclair, 1987]
²[Laird, 1982]

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**Data:**

definition:¹ Information, usually in the form of facts or statistics that you can analyse, or that you use to do further calculations

similar terms:² evidence, reports, details, results, notes, documents, abstracts, testimony, matters of direct observation, facts, raw materials, memorandums, statistics, figures, measurements, conclusions, information, circumstances, experiments

important aspects: rigid, simple structure (tables)

¹[Sinclair, 1987]
²[Laird, 1982]

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**Information:**

definition:¹

1. knowledge acquired through experience or study
2. knowledge of specific and timely events or situations; news
3. the act of informing or the condition of being informed
4. an office, agency, etc. providing information
5. a charge or complaint made before justice of the peace
6. the results derived from the processing of data according to programmed instructions
7. another word for data

similar terms:² derived knowledge, acquired facts, evidence, knowledge, reports, details, results

¹[Hanks, 1979]
²[Laird, 1982]
notes, documents, testimony, facts, figures, statistics, measurements, conclusions, deductions, plans, field or laboratory notes, learning, erudition; news, report, notice, message

important aspects:
rather vague usage in common language,
precise definition in information theory

**Structured Knowledge**

information items and their relationships

**information items**
objects, concepts, features, attributes

**relationships**
hierarchical, membership, component,
similarity, location, ...

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**Knowledge Representation**

formalisms to describe information items and their relationships

**adequate**
arere essential aspects captured?

**comprehensible**
is the represented knowledge understandable?

**transferable**
can the knowledge be communicated?

**uniform**
is identical information consolidated?

**composite**
can components be grouped into ensembles?

**efficient**
usage of space
execution time for basic operations

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**Knowledge Processing**

knowledge representation formalism plus inference mechanism

**algorithms**
knowledge as data structures, procedural processing

**rules**
rule-based representation, forward/backward chaining

**semantic nets**
network representation, activity propagation or specific reasoning methods

**schemata**
frames, scripts as enhanced data structures; specific reasoning methods

**objects**
the essential aspects of all of these formalisms can be translated into propositional or predicate logic
**Algorithms**

structured sequence of steps to solve a problem

**natural**
relatively easy to formulate and understand

**formal basis**
Turing machines, computability

**evaluation**
good fit with the way computers work

**Advantages**
- modularity
  procedures, modules
- uniformity
  all knowledge is represented in the same
  format can also be a limitation
- naturalness
  similar to the way many programmers think
  not necessarily for all applications
- popularity

**Rules**
knowledge expressed in If ... Then format

**natural**
relatively easy to formulate and understand

**formal basis**
modus ponens as inference rule

**nonmonotonic**
assertions may be retracted to avoid
contradictions

**uncertainty**
can be incorporated into the inference process

**Advantages**
- modularity
  rules are separate units of knowledge
  can be added, modified, removed
  independently (with limitations)
- uniformity
  all knowledge is represented in the same

most popular method to program computers

**Problems**
- formal verification tedious to impossible
- not suitable for the representation of
  knowledge
- complex systems become difficult to handle
- re-use is limited in practice
- no satisfactory algorithms for “easy” problems

**Problems**
- cyclic rules lead to infinite chaining
- introduction of contradictions
- modification of rules
Semantic Nets

- **nodes**
  - represent objects or concepts

- **arcs**
  - represent relationships between concepts

- **semantic relationships**
  - constructed to provide an understanding of the represented information

- **inheritance**
  - propagation of attributes in hierarchies

**Advantages**
- visual representation
- explicit relationships between concepts
- flexible

**Problems**
- logical inadequacy

Schemata

- based on structures for representing knowledge
- examples: frames, scripts

- **nodes** can have internal structure
  - a set of attribute-value pairs (slots, fillers)

- **stereotypes**
  - a frame represents a typical object or situation
  - contains related knowledge about a situation

**Advantages**
- very flexible
- useful for representing commonsense knowledge
- well suited for causal knowledge
- organized representation of knowledge
- can incorporate hierarchies and inheritance
- rule-based and procedural components can be integrated

- differentiates between generic and specific knowledge

**Problems**
- semantics and interpretation of slots
- handling of atypical and new situations
- modifications may have unforeseen consequences in other frames
- heuristic knowledge may be specified more easily via rules
Objects

encapsulation of related information and manipulation methods

object
data and methods corresponding to an entity in the real world

classes define general properties of objects
instances specific individual objects

messages are used to exchange information between objects

Abstraction
suppression of lower-level information not relevant for the current task

Encapsulation (information hiding)
implementation details are hidden, only interface information is visible

Inheritance
common characteristics are derived from ancestors

Polymorphism
appropriate instances of classes and operators can be selected at runtime

Advantages
• very flexible
• suitable for large systems
• support reuse

Problems
• handling of new and atypical situations
• quite complex
• formal verification

Extreme Positions

about knowledge and its representation

formalistic assumption
knowledge can be represented by finite structures composed of discrete atomic symbols in accordance with a finite number of syntactic relations

relativistic assumption
knowledge can only be described in a meaningful way with respect to a framework incorporating non-quantitative aspects like experience, belief, expectation, feelings, ... as a consequence, knowledge cannot be described in absolute terms

Physical Symbol Systems Hypothesis
A Physical Symbol System consists of symbols and structures that have to be realized physically; it has the necessary and sufficient

conditions for an intelligent system

3[Newell and Simon, 1976]
Search

in Artificial Intelligence

**search of a problem space**
for a solution to a problem
*not: search through data structures*

**basic idea:**
find a path from the initial description of a problem to a description of the solved problem

**problem space** is created incrementally,
not predefined and already in existence

**problem-solving method**
powerful technique for many different areas

Problem Space

**Representation**

**Network**
graph with nodes as states and arcs as possible steps
unique representations of states, multiple incoming arcs

**Tree**
multiple representations of states

Search

different ways to search

**random search**
next step is selected randomly from the possible ones
non-systematic; can’t guarantee complete coverage of the search space; paths may be selected multiple times; may take infinite time

**blind search**
systematic approach; no knowledge about closeness to the solution; complete coverage; ineffective if closeness to solutions can be measured

**directed search** (also: informed search)
systematic approach; paths leading towards the solution are preferred

Search Methods

used in AI problems

**depth-first**
blind, systematic
expands each path to the end, backtracking when a dead end is encountered

**breadth-first**
blind, systematic
all nodes at one level are expanded finds the shortest path

**beam search**
directed, heuristic variation of breadth-first
only a limited number of nodes are expanded all successor nodes are evaluated, the best ones are selected for expansion

**hill-climbing**
directed variation of depth-first successor node with the greatest progress towards the goal is selected
problems: local maxima, plateaus, ridges

**uniform-cost** (lowest path-cost)
directed search
node with the shortest path so far is selected
finds the shortest path
**problem:** significant portion of the search tree
must be expanded

**best-first** (greedy)
directed, heuristic search algorithm
requires estimate of the distance to the
solution
selects the node with the smallest estimate
**problem:** does not take into account the
length of already expanded parts of the paths

**A***(A-Star)
combination of best-first and uniform-cost
requires estimate of the distance to the
solution
uses estimate and previous path length to
calculate the cost

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**Knowledge and Expertise**

representation of expert knowledge

**general knowledge**
central topic of many initial AI approaches
not sufficient for most practical applications

**specific knowledge**
different for each domain
 corresponds to much of the knowledge of a
human expert

**heuristics**
informal knowledge (rules of thumb,
experience)
cause-and-effect relationships
often shortcuts to a satisfactory solution
not always optimal or even correct

**salient features**
important aspects of the problem

**Heuristics**

finding an acceptable solution

**combinatorial explosion**
too many possible paths

**evaluation**
It is difficult to decide which path is better
complex algorithmic evaluation function

**approximation**
the algorithmic evaluation function is
unknown
Knowledge-Based Systems

Definition

**computer-based system**
implemented on a computer system

**domain knowledge**
must be available in the system

**reasoning mechanism**
to draw conclusions based on the domain knowledge

**problem solving**
must be able to find an equivalent solution to
that of a human expert

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Fundamental Concepts

of knowledge-based systems

**separation** of knowledge and its usage

**specificity**
highly specific domain knowledge

**heuristic nature**
solutions are often derived by heuristics
rather than algorithms

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Types of Knowledge

skills of experts

**associational knowledge**
heuristic ability to associate inputs with outputs
“black-box knowledge”

**motor skills**
usually learned by repetition
may be difficult for computers / robots

**theoretical knowledge**
formal knowledge about a domain
requires understanding of the underlying concepts

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Features

of knowledge-based systems

**Requirements**

- performance: level of competency equal or higher than an expert
- response time: at least as fast as a human expert; critical for real-time expert systems
- reliability: crashes or malfunctions may be dangerous
- understandability: steps of reasoning must be explained on request
Advantages

- availability of expertise
- explicit representation of knowledge
- ease of modification
- consistency of answers
- accessibility
- incomplete / inexact data
- comprehensibility

Disadvantages

- incorrect answers
- limited knowledge
- lack of commonsense
- brittleness

Development

of knowledge-based systems

knowledge acquisition
   extract knowledge from a human expert

knowledge representation
   suitable for use by computers

maintenance
   update of the knowledge base

Chapter Review

Computing Methods
   algorithms, rules, semantic nets, ...

Search Methods
   random, blind, directed search
   depth-/breadth first, uniform-cost, best first,
   A*

Knowledge-Based Systems
   separation of knowledge and its use
   availability of expertise
   performance and reliability
   limited domain knowledge