AN OVERVIEW OF FUNDAMENTAL CONCEPTS OF KNOWLEDGE REPRESENTATION

What is knowledge?

Generally available orientations within the everyday framework ("common sense") of action and factual contexts;
in a more strict and scientific sense notions related to *justification* and *verification* postulates.

Opposed to *opinion, belief* and *technical skill* (techne).

The question for the conditions of knowledge formation and of justified knowledge is the subject of *epistemology*.

Knowledge representation: Formal reconstruction of knowledge and its implementation.

The Knowledge Level

Newell: The Knowledge Level Hypothesis (1981)

- Knowledge Level ⇒ LOGIC !
  - Language: propositional expressions
  - Interpretation: truth
  - Entailment: truths implicit in others
- Symbol Level
  - Symbolic Structures: taxonomies, classes, clauses,. . .
  - Operations: addition, modification, searching,. . .
- . . . Register, "Logical", Circuit, Physical Levels

The Knowledge Level (2)

A *functional concept of knowledge* (independent of its physical realization and of the processes which operate on it).

Principle of Rationality: If an agent has knowledge that one of its actions will lead to one of its goals, then the agent will select this action.

Knowledge: Whatever can be ascribed to an agent such that its behavior can be computed according to the principle of rationality.

Knowledge is to be characterized entirely functionally, in terms what it does, not structurally, in terms of physical objects with particular properties and relations. This still leaves open the requirement for a physical structure for knowledge that can fill the functional role.

(Newell 1981)

How Can Knowledge Be Represented?

The Knowledge Representation Hypothesis (Brian Smith 1982)

Any computational embodied intelligent process will be comprised of structural ingredients that

a) we as external observers naturally take to represent a propositional account of the knowledge the overall process exhibits, and

b) independent of such external semantical attribution, play a formal and essential role in engendering the behavior that manifests that knowledge.

The Knowledge Representation Hypothesis

The representation constructs must be interpretable as *propositions*.

We need a *truth theory* for the representation language.

The constructs should play a *causal role* for the behavior of the system, the knowledge base of which is built up with them (*justificaton*).

Representation: Execution of sign (symbolic) acts or their results, respectively.

Knowledge representation: Formal reconstruction of knowledge and its implementation.

Aspects of KR Formalisms

1. The **cognitive** aspect, which – beginning with the metaphor of *"computational process"* – regards human intelligent action as the prototype for automatic processing. Cognitive psychology constructs models of human knowledge processing which serve as an orientation for AI.
2. The **logical** aspect, which helps with the problems of general validation of theories and results by providing a common formal basis – logical descriptions – upon which formulations can be reconstructed in a unique way. In this case, logic is regarded primarily not as a means for representation, but as a means for the analysis of representations.

Knowledge Representation Formalism

$\rightleftharpoons$ A formal language with well defined syntax and semantics

KR system: Implementation of a KR formalism (logical language, calculus) which supports the

1. Interpretation of the expressions of a KR language by consistent and (in the ideal case) complete inference algorithms;
2. Administration and updating of formally represented bodies of knowledge.

Traditional Logic

Logic as the basis of a theory of argumentation

- **"Begriff"**: concept formation
- **"Urteil"**: expressing assertions (judgment)
- **"Schluß"**: reasoning

In AI, also the first two items are important: Formalization of practical applications!

Starting with (natural) language as the basis of all "systems of distinction" $\Rightarrow$ Semantic problem: Eliminate ambiguity

Language levels: *Object* and *meta language*

Knowledge Representation and Logic

Just as talking of *programmer-less* programming violates truth in packaging, so does talking of *non-logical* analysis of knowledge. (Newell 1981)

Logic is used in knowledge representation as a

- Tool for the analysis, design and specification of modelling tasks and formalisms,
- Representation formalism itself,
- Programming language (Prolog)

Question: *Which* logic?

First Order Logic (FOL) for Knowledge Representation?

Operations can be defined formally (proof theory) and receive semantic properties (truth theory): $\boxed{\vdash \;\equiv\; \models}$

Well-defined semantics!

Problem: **Undecidability**
Even if the decision problem is made solvable by language restrictions, it is in general not solvable within realistic time.

Specialized logic-based representation formalisms:

- Description Logics, associative networks, inheritance
- Non-monotonic calculi

How is Knowledge Processing Possible?

Paradigm of knowledge-based systems:

- Intelligent action requires *large bodies of knowledge:* 70.000 $\pm$ 20.000 knowledge units per subject area (Reddy 1988).
- It is possible to *represent* the knowledge relevant for an application.
- *Processing* of represented knowledge is in a certain sense *easy* – in any case easier than to solve the problem without knowledge.

I.e., very difficult and complex problems like diagnosis, configuration, language understanding, etc. are *reduced* to the problem of knowledge representation and processing.

(Logical) Domain Modelling

- Provision of a formal, in particular logical language for knowledge representation.
- Application of these means to represent the formal structure and the — general, i.e. not related to particular individuals — facts of an application domain.
- Application of the formal language to represent concrete application situations (individuals, instances).

The construction of a knowlege base ("knowledge engineering") comprises:

- Determination of the domain (limits??)
- Determination of the domain concepts (granularity??)
- Representation of the objects and relations in the domain.

Knowledge acquisition usually requires a close cooperation with domain experts!

Formal Ontologies

Formal ontologies consist of (formal) definitions ("descriptions") of the concepts and relations in a domain:

- The **concepts** (also: classes, categories) result from predication and abstraction, represented by predicates.
- Relations between concepts result from predicator rules and are represented in a super-/sub-concept hierarchy.
- Concepts are assigned properties ("roles", attributes), represented by (binary) relations.
- Further (content-based) relations between concepts are laid down by rules ("axioms").

A formal ontology (of a domain) defines, how and about which objects, substances, aggregates, changes, events, actions, time and place specifications, etc. can be "spoken".

Inferential Knowledge

Generation of (factual) knowledge with rules;
studying the range of facts that can be explained in this way (AI) — dynamic view

Logical inference — Automatic Theorem Proving

Other forms of reasoning (logically invalid):

1. Abductive reasoning
2. Inductive reasoning
3. Case-based and analogical reasoning
4. Probabilistic reasoning
5. Qualitative and common sense reasoning

Acting Under Uncertainty

- In the real world, an agent can never be 100% sure:
  Uncertainty due to incompleteness and incorrectnes in the domain model.
- **Qualification problem**: Many domain rules incomplete because too many conditions to enumerate, or, some conditions are unknown.
- But, agent can make a **rational decision**: consider action benefits vs. certainty of success

Problem of applicability of FOL in complex domains, e.g., medical diagnosis:

- *Laziness*: Effort to list all antecedents and consequents of rules too large,
- *Theoretical Ignorance*: Incomplete domain theory,
- **Practical Ignorance**: Even if all rules were known it is often impossible to gather complete information about a particular case.

⇒ The knowledge of an agent leads in the best case to a **"degree of belief"** for the truth of assertions.

Probability

- Degree of belief in either being true or false
- summarizes uncertainty
- usually statistically determined
- not degree of truth (fuzzy set theory)
- prior or unconditional: P(Sentence)
- posterior or conditional: P(Sentence | Percepts)

⇒ Mathematical theory of probability

Bayes' rule: $P(A|B) = P(B|A)P(A)/P(B)$
i.e., *likelihood * prior / evidence*

Decision-Theoretic Agent

Utility theory

- States have utility values or preferences
- Agents prefer states with higher utility

Decision theory = probability theory + utility theory

- Maximum Expected Utility principle:
  Agent is rational if he chooses actions yielding highest expected utility, averaged over all possible action outcomes
- Weight utility of an outcome by its probability of occurring

Belief Networks (Bayes-Nets)

A Bayes-Net is a *compact representation* in order to reduce the effort in specifying and evaluating a probabilistic system:
A *directed acyclic* graph, where

- Each node represents a random variable, and
- A directed link between nodes X and Y indicates that X “directly influences” Y:
  - Each incoming link at a node originates at a random variable which *directly influences* that node, hence, each node has a conditional probability table quantifying the effects that the “parents” have on the node;
  - Each outgoing link points to a random variable which is directly influenced by the node.

Therefore, Bayes-Nets are also called *causal networks*.

Knowledge-Based Systems

Design:

- Knowledge representation
- Knowledge utilization (problem solving)
- Knowledge acquisition
- Knowledge transfer, explanation

Uses:

- Interpretation (cf. “Data Mining”)
- Diagnosis
- Planning
- Design and construction
- Instruction and training