Center for

LifeLong Learning & Design

University of Colorado at Boulder

Wisdom is not the product of schooling but the lifelong attempt to acquire it.
- Albert Einstein

Knowledge in Learning and Human Learning

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Chapter 21 in Russell / Norvig Book

Gerhard Fischer

AI Course, Fall 1996, Lecture October 23

Overview

- in the book: learning is **machine learning** = subfield of AI concerned with programs that learn from experience

- we (as a research center) have been interested in computational media and environments in support of **human learning**

- chapter 18: learning from observations
    - improve behavior by analysis of own behavior

- chapter 19: learning in neural networks — Guest Lecture by **Michael Mozer**
    - train complex networks of simple computing elements

- chapter 20: reinforcement learning — Guest Lecture by **Satinder Singh**
    - learn from success and failure, reward and punishment

- chapter 21: knowledge in learning
    - take advantage of prior knowledge

What Does Learning Mean?

- **definition**: "learning is a goal-directed process of a system that improves the knowledge or the knowledge representation of the system by exploring experience and prior knowledge"

- acquisition of new declarative knowledge

- development of motor and cognitive skills through instruction and practice

- organization of new knowledge into general effective representation

- discovery of new facts and theories through observation and experimentation

Learning / Problem Solving as Change in Representation

Simon:

- "all mathematics exhibits in its conclusions only what is already implicit in its premises"

informational equivalence: a transformation from on representation to another causes no loss of information; they can be constructed from each other.

computational equivalence: the same information and the same inferences are achieved with the same amount of effort

examples:

- Tic-Tac Toe
- Roman Numerals versus Arabic Numerals
- Turing Tar Pit

Objectives of Machine Learning

- **applied learning systems — a practical necessity?**
  - to overcome the tedious work of programming
  - the ultimate form of knowledge acquisition in knowledge-based systems
  - example: "do not put appliances with the door against the wall!"

- **machine learning as a science**
  - understand human learning well enough to reproduce aspects of that learning behavior in computer systems
  - computer enforces a commitment to fine-structure process-level detail
  - insights into the principles underlying human learning abilities has the potential to lead to more effective educational techniques —example: student models in intelligent tutoring systems
  - exploration of alternative learning mechanism complementing human learning methods

- **knowledge acquisition versus skill refinement**
  - knowledge acquisition (example: learning physics) — learning new symbolic information coupled with the ability to apply that information in an effective manner
  - skill refinement (example: riding a bicycle, playing the piano) — occurs at a subconscious level by virtue of repeated practice

Basic Learning Mechanisms

- **improve the knowledge of the system**
  - active = asking informative questions
  - passive = incorporate new information into the knowledge representation of the system

- **translate one representation into another**
  - truth preserving
    - * improve efficiency (speed-up learning) and effectiveness
      - examples: explanation-based learning, knowledge compilation, construction of macro-operators, reinforcement learning
    - * improve comprehensibility of represented knowledge
      - examples: extract logical representations out of neural networks, decompilation

  - non-truth preserving:
    - * "if something is a swan, then its color is white" (non-monotonic reasoning)
    - * examples: inductive learning of concepts from examples, concept formation, abductive reasoning, learning by analogy, knowledge revision

Knowledge in Learning

- **inductive learning:**
  - function-learning characterization in chapter 18
  - logical formulation of the learning problem

- **Hypothesis ∧ Descriptions ⟹ Classifications (entailment constraint)**
  - examples = descriptions and classifications
  - object of inductive learning in the logical setting: to find a hypothesis that explains the classifications of the examples, given their descriptions
  - descriptions = conjunction of all example descriptions
  - classifications = conjunction of all example classifications

- **modern approach (??):** to design agents that already know something and are trying to learn some more

Explanation-Based Learning (EBL)

Hypothesis $\land$ **Descriptions** $\Rightarrow$ **Classifications**

Background $\Rightarrow$ **Hypothesis**

the background knowledge is sufficient to explain the hypothesis — the agent does not learn anything factually new from the instance

EBL
- extracts general rules from single examples by explaining the examples and generalizing the explanation
- a method for converting first-principles theories into useful, special-purpose knowledge

Whitehead (1911): *"Civilization advances by extending the number of important operations that we can do without thinking about them"*

example: general principle of painless cooking

Analogical Reasoning and Cased-Based Reasoning

analogical reasoning: instead of using examples as foci for generalization, one can use them directly to solve new problems

cased-based reasoning: learning takes place
- remember cases and add them to the memory
- generalize from the cases by noticing similarities between cases
- better indexing schemes (making cases relevant to the task at hand)

Relevance-Based Learning (RBL)

Hypothesis $\wedge$ **Descriptions** $\implies$ **Classifications**

Background $\wedge$ **Descriptions** $\wedge$ **Classifications** $\implies$ **Hypothesis**

RBL:
- uses prior knowledge in the form of determinations to identify the relevant attributes
- generates a reduced hypothesis space

example: Brazilians speak Portuguese, but are not all called Fernando

Knowledge-Based Inductive Learning (KBIL)

Background $\wedge$ **Hypothesis** $\wedge$ **Descriptions** $\Rightarrow$ **Classifications**

KBIL:
- finds inductive hypotheses that explain set of observations with the help of background knowledge

example: a particular antibiotic is effective for a particular type of infection

Human Learning: Current Theories

- learning is a process of **knowledge construction**, not of knowledge recording or absorption

- learning is **knowledge-dependent**; people use their existing knowledge to construct new knowledge

- learning is highly **tuned to the situation** in which it takes place

- learning needs to account for **distributed cognition** requiring to combine knowledge in the head with knowledge in the world

- learning is affected as much by **motivational issues** as by cognitive issues

Situated Learning and Transfer

- transfer occurs rather seldom (empirically verified)
    - Number Scrabble and Tic-Tac-Toe
    - Duncker radiation problem and fortress problem

- theories for interpretation: induction, analogical thinking, schema theory, knowledge transfer, ...

- question: how can we design learning environments so that knowledge application/transfer increases

Issues in Human Learning

- learning
    - is not only done is schools
    - learning can take place without being taught

- reflection in action and learning on demand
  Norman — *"Real Learning: The way we learn is trying something, doing it and getting stuck. In order to learn, we really have to be stuck, and when we're stuck we are ready for the critical piece of information. The same piece of information that made no impact at a lecture makes a dramatic impact when we're ready for it."*

- lifelong learning

- collaborative learning

- organizational learning

- distributed cognition (learning on demand versus using on demand)

LifeLong Learning

- **more than "adult education" — tries to cover and unify all phases:** intuitive learner (home), scholastic learner (school and university), skilled domain worker (workplace)

- **integration of working and learning:** learning is a new form of labor

- **engagement in self-directed, authentic problems:** constructionism

- **learning on demand:** coverage is impossible and obsolescence cannot be avoided

- **collaboration:** the individual human mind is limited
  ---> organizational and collaborative learning

Collaborative Learning

- **human mind is limited**
  - there is only so much we can remember and learn

  - human beings have a bounded rationality ---> satisfycing instead of optimizing

  - talented people require approximately a decade to reach top professional proficiency

  - when a domain reaches a point where the knowledge for skillful professional practice cannot be acquired in a decade:
    * specialization will increase
    * practitioners will make increasing use external reference aids
    * collaboration is a necessity rather than a luxury

- **"symmetry of ignorance"** — requires communication, mutual learning, and mutual understanding

- knowledge is **distributed** between the head and the world — requires integration with external artifacts and work practices (Bobrow article)

Distributed Cognition and Learning Webs

- **envisioned by Ivan Illich in 1971:**
  - reference services to educational objects

  - skill exchanges

  - peer matching

  - reference services to educators-at-large

- **support of learning webs with computational environments:**
  - domain-orientation

  - making information relevant to the task at hand

  - partial understanding of the task at hand