Cognitive Modeling
Intelligent Tutor Systems

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last change: 17. Dezember 2014
Applications of Cognitive Modeling

- Cognitive modeling is concerned with the simulation of cognitive processes.
- In all applications where the state of mind of an (individual) user needs to be taken into account, cognitive modeling techniques are necessary.
- Examples:
  - Preferences which guide decisions (e.g. to buy something, to visit something)
  - Degree of expertise when dealing with a software system or a content domain (adaptive user models, HCI)
  - Interactive learning environments (E-learning)

Intelligent Tutor Systems (ITS) as an application domain for cognitive modeling.
Intelligent Tutor Systems

Expert Knowledge and Skills about his/her domain

Didactic/pedagogical principles

Knowledge about typical misconceptions and how to resolve them

Model about the learning history, state of knowledge, previous errors of the individual pupil
Learning

- Change of behavior caused by experience
  - Declarative: Extension of knowledge
  - Procedural: Skill acquisition

- Improvement by restructuring or incorporation of new knowledge/skills
  - Faster or more accurate performance (power law of learning)
  - New behavior
Types of Learning

- **Rote Learning**
  The capital of France is Paris.
  5 times 7 is 35.
  A dog is a mammal.

- **Concept Learning**
  Dog, Ancestor (recursive), Preparation to an exam such that I pass

- **Skill and Strategy Acquisition**
  Making a proof by induction, preparing a travel

- Concept learning and skill acquisition is learning from examples, that is, inductive learning! (see lecture machine learning)
Paradigms for Learning

- **Behaviorism**
  - “Brain” as Black Box
  - Teaching: Connecting the stimulus with the “correct” response
  - Positive (or negative) Feedback
  - “Drill and Test”

- **Cognitivism**
  - Information processing paradigm
  - Teaching: support for problem solving, learning by doing

- **Constructivism**
  - Learners build personal interpretations of the world based on individual experiences and interactions.
  - Teaching: Align and design experiences for the learner so that authentic, relevant contexts can be experienced.
Excursus: History of Psychology

- 19th century, early work psycho-physics (Helmholtz, Weber, Fechner)
  Relation between physical entity and subjective evaluation (brightness, loudness, heaviness)
- Wilhelm Wundt, 1874, *Principles of Physiological Psychology* (structuralism)
- William James (1842-1910) (functionalism, e.g., by introspection)
- James M. Cattell (1860-1944), measurement of human abilities, intelligence tests, factor analytical model of intelligence
- Gestalt Psychology (early 20th century): description of phenomena in perception (Gestalt laws, Berlin school), problem solving (Köhler) and language (Bühler, Würzburg school)
- Behaviorism (early 20th century), shift from German dominated to American dominated research: basic learning processes, no introspection, relation between stimulus and response
- 1950ies: Cognitive Revolution, focus on mental processes, information processing theories, experimental research (Chomsky-Skinner Debate, Language cannot be learned by reinforcement of behavior)
Excursus: Gestalt Laws

- Originally only descriptions of stimuli, now used in the context of computer vision algorithms (i.e., from description to process model)
- Gestalt laws of grouping: Proximity, Similarity, Closure, Good Gestalt (Pragnanz); Reification
Learning with the Computer

- Independence of time/place
- Individual speed of learning, individual interests
- Individual strategies of learning (?)
- Relieve of teachers (costs, availability, quality assurance)
- Learning dangerous activities (e.g. flight simulator)
- Learning in the context of realistic models
- Problems: social component of learning (model learning), restricted human-computer communication, trade-off of effort and utility, quality of systems
Didactic Principles

- Motivation: intrinsical vs. extrinsical
- Encouragement of creativity: give experience of perception with all sense, allow new ideas
- Differenciation: working with homogenous groups students
- Structuring: clear topic, separate in clear parts, systematic introduction of concepts and rules
- Illustration and exemplification
- Exercise and success control: allow for success (without making things trivial), relevance
Dimensions of Tutor Systems

- Tutor strategies
  - Explaining
  - Observing and Helping
  - Mentoring and Coaching

- Content: facts and context free rules; problem solving, complex situations, ...

- Goals: remembering, applying, understanding, discovering, ...
Types of Systems

- Presentation and Browsing
- Drill and Test
- Tutor Systems
- Intelligent Tutor Systems
- Simulations
Presentation and Browsing

- Restricted interaction, fixed branching
- Hypertext and Hypermedia
- Cheaper than books, full text search

Most modern e-learning systems are of this type.
Drill and Test

- Only tests, with statistics (percent correct answers etc.)
- Vocable trainer, medicine exams, driving licence
- Wer wird Millionär?
- Types of Questions
  - Closed: Multiple Choice, Rank order, cloze (Lückentext)
  - Open: input of numbers, text
Tutor Systems

- Teaching of new contents/skills, Question Answering by the system
- Simple tutor systems do *not* have an internal student model!
- Computer-aided instruction: module and questions, depending on the answers repetition with variations or progress
- Frame-oriented CAI: discrimination between error types and branching (variations) in dependence of the recognized type (predecessor to student model in ITS)
Simulation

- Technical or social simulation
- Can be based on causal mental models/qualitative reasoning
- Student actions are executed in the simulation model, this is the only form of feedback
- Dynamical, high degree of interaction
- E.g. simulation systems for complex problem solving (Dörner)
- E.g. SOPHIE (early system of the 70ies): debugging of electronical circuits
- E.g. LOGO (Papert, late 60ies), Scratch (MIT), Robot Carol (CMU)
- Lego mindstorms
ITS Overview

- Simple tutor systems know nothing about what they teach and whom they teach
- 70ies: with the beginning of AI research, extension of tutor systems with internal knowledge modules
- Paradigm: cognitivism
- System has its own inference component
- Because of internal models: generation of interaction sequences, exercises; system is able to answer questions
Knowledge models:

- **domain model**
  - e.g. SCHOLAR (geography of south america), allows mixed initiative dialogs

- **learner model**
  - e.g. GUIDON (tutor extension of the expert system MYCIN), allows diagnosis of didactical relevant states of the student
different data sources (dialog history, behavior of the student, goal-directed intervention)
Components of ITSs

![Diagram showing components of ITSs](http://home2.pacific.net.sg/~auddrick/its.html)

**Figure 6.2 Anatomy of an Intelligent Tutoring System**
Components of ITSs

- GUI: robust and intuitive
- Didactic component: lecture modules, plan of sessions, pedagogical knowledge, pedagogical strategies
- Student model: model of the knowledge of the student, base for planning further didactical procedure
- Domain model: expert knowledge and skill, often executable, inference component allows to answer student questions
Applications of ITSs

- Medicin (GUIDON): problem based learning with generated feedback
- Mathematics (e.g. Geometry Tutor based on ACT): learning algebra or proofs in geometry with step-by-step application and generated feedback
- Programming (e.g. Lisp Tutor based on ACT)
- many more (in the 1980ies)
Pros and Cons of ITSs

- **Pro:** Highly flexible and adaptive
- **Main Problem:** Very high effort, esp. for domain model and for some types of student models
- **Restricted language for the student-tutor dialogues**
- **No inter-human student-teacher relationship**
Domain Model

- Source of Knowledge and standard for evaluation of student inputs
  - must be communicable (simple, *symbolic* repres.)
  - simple processing (no complex numerical calculations such as Bayes), no complex control structures (best is linear, no nesting of loops etc)
- Relation to previous knowledge of students
- Maybe knowledge on different competence levels
- Knowledge representation with: semantic nets, frames, rules, constraints, qualitative or quantitative simulation
- Diagnostic knowledge models: decision trees, heuristic diagnosis, case-based diagnosis
- Agent models for distributed knowledge, ...
Student Model

- What does the student know? (know that)
- What can the student do? (know how)
- What did the student do until now? (history)
- What type is the student?
- Input/Generation:
  - explicit: stereotype selection
  - implicit interrupting: interruption, explicit enquiry
  - implicit automatically: monitoring
Types of Student Models

- Stereotypes
- Error Libraries
- Overlay Models
- Extended Overlay Models
- Constructive Models
Stereotypes

- Facts, attributes and preferences which are interrelated
- Example intermediate student knows all simple knowledge units and some medium-level knowledge units
Error Libraries

- Collection of typical errors and misconceptions of students
- Select an item from the library during a tutoring situation
- Simple and flexible, but high costs in assessment
Overlay Model

- Domain model is extended by annotations: which knowledge unit is known by a student
- simple but not flexible
- implicit assumption: errors are due to **incomplete** knowledge
- Extended Overlay Model: additionally taking into account errors and misconceptions; can be generated from knowledge elements or from error library (very good but very expensive)
Dynamically Constructed Model

- Use machine learning to generate models about student knowledge
- Highly flexible but difficult to obtain
Applications

- WHY, SOPHY: no student model
- Geography Tutor SCHOLAR: overlay model initiative dialog
- BUGGY (and others): error libraries
- LISP-Tutor: extended overlay (correct and erroneous production rules)
Scholar

- (Slides from Frank Puppe, ITS lecture)
- Jaime Carbonell (ph.d. 1970; first ITS)
- Domain: Geography of South America
- Knowledge model: semantic net (frames)
- Tutor model: overlay (with deleted or changed edges)
- didactics: mixed initiative dialog, selection of topics by “degree of interestingness”, history of dialog, random
- GUI: restricted natural language (understanding: patterns and keywords; generation: sentence and phrase patterns, instantiated from knowledge base)
<table>
<thead>
<tr>
<th>Scholar</th>
<th>Approx what is the area for Brazil?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student</td>
<td>2 500 000 square miles</td>
</tr>
<tr>
<td>Scholar</td>
<td>Wrong. Please indicate if the following statement is correct: the area of Paraguay is approx 47 432 square miles.</td>
</tr>
<tr>
<td>Student</td>
<td>What is the area of Brazil?</td>
</tr>
<tr>
<td>Scholar</td>
<td>The area of Brazil is approx 3 600 000 square miles. Now answer the question you didn't answer before.</td>
</tr>
<tr>
<td>Student</td>
<td>False</td>
</tr>
<tr>
<td>Scholar</td>
<td>Rephrase your statement. I can't understand it.</td>
</tr>
<tr>
<td>Student</td>
<td>Incorrect</td>
</tr>
<tr>
<td>Scholar</td>
<td>Very good. The area of Paraguay is approx. 157 000 square miles. The language in Brazil is French. Right or Wrong?</td>
</tr>
<tr>
<td>Student</td>
<td>Wrong</td>
</tr>
<tr>
<td>Scholar</td>
<td>You are correct. The language of Brazil is Portuguese. Is it true that the capital in Brazil is Brazilia?</td>
</tr>
<tr>
<td>Student</td>
<td>Yes</td>
</tr>
<tr>
<td>---------</td>
<td>-----</td>
</tr>
<tr>
<td>Scholar</td>
<td>That's fine. Approx what is the population in Brazil?</td>
</tr>
<tr>
<td>Student</td>
<td>60 000 000</td>
</tr>
<tr>
<td>Scholar</td>
<td>Approx true, but a more exact value is 70 000 000. What is Brazil?</td>
</tr>
<tr>
<td>Student</td>
<td>Tell me about Peru.</td>
</tr>
<tr>
<td>Scholar</td>
<td>Wait a minute. I am checking my files. Let's proceed now. Peru is country. It is in South America. The population is approx. 7 000 000 people. The capital is Lima. Now answer the question you didn’t answer before.</td>
</tr>
<tr>
<td>Student</td>
<td>Q/A</td>
</tr>
<tr>
<td>Scholar</td>
<td>Do you want to change the general model of the interaction to Q/A? Please answer Y or N.</td>
</tr>
<tr>
<td>Student</td>
<td>Y</td>
</tr>
<tr>
<td>Scholar</td>
<td>OK. Mr. Jones. Let's go ahead.</td>
</tr>
<tr>
<td>Student</td>
<td>Please tell me more about Peru.</td>
</tr>
</tbody>
</table>
Problems with Student Models

- How good can a student model be?
  - inconsistencies in behavior due to motivation, concentration, “luck”
  - Combinations of errors can produce unexpected (maybe even correct) behavior
- Clustering students in learning psychological stereotypes (cognitive styles; motivational styles) is controversial
- Privacy and data security
Didactical Module

- Which paradigm? which kind of learning? (reception, transfer, problem solving, ...) which competences? (cognitive, organizational, communicative ...)
- Initiative: system, learner, mixed
- Presentation: sequence, degree of guidance
- Tasks: number, time, complexity
- Feedback: eager or by request, hints, explanations, examples
Dealing with Student Errors

- **What kind of error?**
  - Profound error in content/in learning progress?
  - Error rates; repetition of same error?
  - Error recognized with certainty?
  - Reaction: ignore, protocol, hint, insist on correction

- **Typically realized by set of rules**
Explanations and Evaluations

- Explanations by the student (socratical dialog): open or closed form inputs; evaluation by tutor system, relation to explanations of domain model
- Explanations of the system: pre-formulated or generated, general or situational, automatically or by request, degree of details
- Evaluation: generated or static, situational or dependent on result
GUI

- Robust, efficient, easy to learn and use
- Interaction language: commands, restricted natural, natural
- Interface to model: icons, menus, graphics
- Flexible navigation (event based vs guided)
- Taking account of context, learning history
References to ITS