Seminar: Tutorielle Systeme

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Kursseite: http://www.dfki.de/~horacek/tutor.html

Beschreibung: In dieser Veranstaltung werden intelligente tutorielle Systeme in Bezug auf die Verwendung natürlichsprachlicher Interaktion behandelt (Analyse, Generierung, Dialog, tutorielle Strategien, …)

Vorträge wahlweise in Deutsch oder Englisch (Englisch präferiert), Folien englisch

Gemeinsame Veranstaltung mit Computerlinguistik und EduTech

Leistungspunkte je nach anwendbarer Studienordnung (siehe Kursseite)

What is an intelligent tutoring system (ITS)?

What is an intelligent tutoring system (ITS)?

a digitalized teacher

Properties of intelligent tutoring systems

Tutoring task

Categories of human tutoring:

Classroom, one-to-one tutoring

Features of intelligent tutors

Not just a collection of instances of tutor reactions

Abstraction into descriptions of tutorial settings

Mechanisms that mimic aspects of human tutoring

Reasonable handling of unexpected student reactions

Features met by some tutoring systems:

Mixed initiative, interactive learning, instructional modeling, self-improving

Distinctions to Computer Aided Instructions

Computer Aided Instruction

Progam designer specifies input and output in terms of terminal behaviors

Material to be learned, problem to be solved, feedback to answer

The teacher constructs all branching in the program ahead of time

”Intelligent” tutoring

”Intelligent means that the system uses inference mechanisms to provide coaching, explanation, or other information to the student performing a task. Further, it implies that this information is tuned to the context of the student's ongoing work and/or a model of the student's evolving knowledge.”

Alan Lesgold

Why building and using intelligent tutoring systems?

Benefits of tutoring

Teaching is necessary to acquire knowledge and skills

Constructivist teaching – learning unique for each individual

Students may make mistakes, query processes, monitor their own progress

Inquiry and social discussion

essential for critical thinking, problem solving and reasoning

Motivation for ITS

Overcoming the bottleneck of human tutors

Availability of expertise and teaching material

But: operationalization of tutoring capabilities increasingly difficult

GUIDON – the first intelligent tutoring system

Domain of tutoring

Teaching medical knowledge

Classification and problem solving

Size of the system

400 domain rules

200 tutoring rules

Main achievement as an ITS

Explicit separation of domain knowledge and pedagogical knowledge

A SUCCESS STORY - MS. LINDQUIST

Patented system, used in hundreds of US schools

What the system is dedicated to

Algebra Word Problem

Method

based on a videotaped analysis and research on an expert tutor

Some statements by Neal Heffernan (principle author)

I have spent 4 years working on nothing but studying how to teach students to write algebra expressions given a word problem. This task is very important since a student can't make any use of all the algebra symbolic manipulation skills unless she can translate real world problems into the language of algebra.

I have studied how to make tutoring software that will help students learn this skill.

I have studied what make these problems so hard

A tutoring session with Ms. Lindquist (algebra tutor)

T1: Hello. (After presenting a 'bike-trip' problem).
Please write an expression for the total time the trip took. (symbolize)

S1: Help! (The tutor breaks down the problem into steps)

T2: Let me ask an easier question. Please compute the time actually on the bikes if instead the speed was 20 miles per hour, the time of the break was 2 hours, and the distance ridden was 100 miles?

S2: 7

T3: Correct. What math did you do to get that 7?

S3: 2+5 (Student does not completely articulate)

T4: Okay. But how did you get the 5? (similar to T3)

S4: 100/20

T5: Correct. Now lets try this again, what math did you do to get the 7?
(same question as T3 but inserting the phrase 'lets try this again'

S5: 2+100/20 (correct articulation)

T6: Correct. Now write your answer of '2+100/20' using the variables given in the problem. (generalize like T4 from previous example)

S6: b+m/s

T7: Correct.

Some tutoring skill incorporated in Ms. Lindquist

Teaching technqiues – implementing human strategies

Partitioning/simplifying the problem
Elaborating instantiations
Combining and abstracting partial solutions

Communicative behavior

Encouraging attitude
Accepting partially correct answers
Emphasizing discourse coherence

Innovations

Feedback not based on explicit buggy rules
Chains of hints as progressively more explicit messages

IMPORTANCE OF NATURAL LANGUAGE

Empirical investigations

Natural language communication makes tutoring effective

[Moore 2000]

Presenting reasoning structures in natural language increases subjects' performance

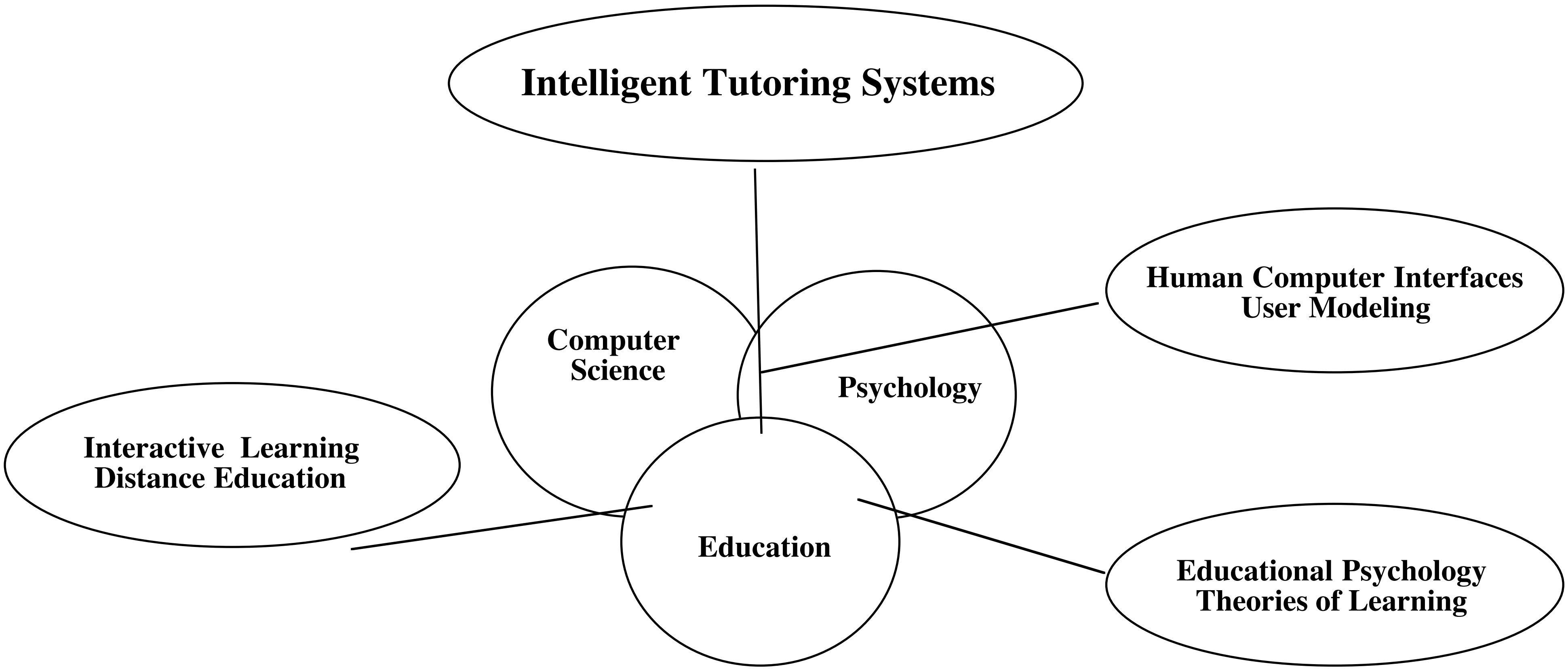
[Di Eugenio et al. 2002]

Natural language evaluative arguments convey object preferences more effectively

[Carenini, Moore 2001]

Preference of natural language variant shown to be *statistically significant*

Building an ITS is an interdisciplinary activity



Important issues related to the development of ITS

1970s	1980s	1990s
Problem generation	**Model tracing**	**Learner control**
Simple student modeling	More buggy-based systems	Individual vs. collaborative
Knowlegde representation	Case-based reasoning	Situated learning vs. information processing
Socratic tutoring	Discovery worlds	Virtual reality
Skills and strategic knowledge	Progression of mental models	
Reactive learning environment	Simulation	
Buggy library	Natural language processing	
Expert systems and tutors	Authoring systems	
Overlay models/ genetic graphs		

Components of an ITS

Domain module

Student module

Tutoring module

Communication module

Knowledge relevant for an ITS (1)

Domain knowledge

Model of expert knowledge

Topics, subtopics, definitions or processes

Skills needed to generate algebra equations, administer medications, …

Student knowledge

Describes how tutor reasons about a student's presumed knowledge

Represents each student's mastery of the domain

(acquired skills, time spent on problems, hints requested, possible misconceptions, correct answers, preferred learning style)

Knowledge relevant for an ITS (2)

Tutoring knowledge

Teaching strategies: methods for providing remediation, examples, …

Reasoning about the use of materials, feedback, and testing

(empirical observations, learning theories, technology-enabled)

Communication knowledge

Methods for communication – graphical interface, animated agents, dialog

Communication motivates and supports students

Ensures that a tutor follows a student's reasoning

Categories of domains

***Well-structured* to *ill-structured* domains**

***Problem solving domains* (e.g., mathematics problems; Newtonian mechanics)**
live at the simple and most well-structured end of the axes.
Some simple diagnostic cases with explicit correct answers also exist here
(e.g., identifying a fault in an electrical board).

***Analytic and unverifiable domains* (e.g., ethics and law)**
in which no absolute measurement or right/wrong answers exist
live in the middle of these two axises.
New regions of physics (e.g., astrophysics) also live here
as empirical verification is untenable.

***Design domains* (e.g., architecture and music composition)**
live at the most complex and ill-structured end of the axes.
In these domains novelty and creativity are the goals, not problem solution.

Student models (1)

Task to be accomplished

Observes student behavior and creates a qualitative representation of
cognitive and affective knowledge

Partially accounts for student performance
(time on problems, observed errors), as well as
the student's emotional state and
reasons about how to adjust feedback to
each student's specific learning needs

Continuously updates the model through the course of the interaction

Student models (2)

Purpose

Supply data to the other tutor modules, particularly the *teaching module*,

which adapts the tutor's responses to student behavior.

Influences choice of problems presented, feedback adaptation, reaction category

Factors include spatial capabilities, gender, media preferences, …

Motivation

Customized feedback pivotal for producing efficient student learning

Instruction tailored to the student's preferred learning approach increases

student *interest* in learning and supports

the *amount* of learning accomplished

Model concepts

Domain model

Experts knowledge (facts, procedures, …), student model part too

Overlay model

Overlay/ proper subset of the domain model (mastery level, missing knowledge)

Problems to represent misconceptions, bug libraries notoriously incomplete

Bandwith

Describes amount and quality of student input available to the student model

Detailed analysis and comparison to expert solutions

Open model

Student can inspect the user model and make corrections/changes

Has the potential as an aid to reflective learning

Cognitive science techniques

Model-tracing tutors

Model of the domain used to interpret student actions and solution paths

Cognitive representation of tasks, mostly a result of careful task analysis

Tutor traces a student's implicit execution of the encoded rules

Assumes that all problem solving steps can be identified and explicitly coded

Assumes that student performs the same reasoning as encoded in the rules

Constraint-based tutors

Pedagogically significant states expressed as constraints

Constraints represent the application of a piece of declarative knowledge

Detect and correct student errors which appear as violated constraints

Constraints represent states the student should satisfy, not the paths involved

Applied in intractable domains, domains that cannot be fully articulated

Model tracing

Method

Problem solving/student behavior modeled by a production system

Rules model “curriculum chunks” of cognitive skills

Production system encompasses space of suitable problem solving ways

(reasoning in physics and mathematics, logical inferencing)

Advantages

Enables monitoring the acquisition of chunks of knowledge (tracing)

Enables feedback on very precise level (individual production rules)

Adaptable to student behavior

Problems

Letting the student explore the consequences of misconceptions

Finding out about failure is associated with big learning gains

Only applicable to modeling procedural skill acquisition

Constraint-based tutoring

Method

Problem solutions checked against a set of constraints

Constraints model domain properties

(syntactic, semantic constraints)

Applicable to "ill-structured" domains where model tracing is infeasible

Advantages

Enables monitoring the acquisition of domain properties

Enables feedback on very precise level (constraint violation)

Caters for variations in solution specifications

Problems

Only applicable to complete solution specifications

Little support for incremental development

No reference to proper problem solving process

Teaching strategies

Didactic strategy

Student's problem solving accompanied by piece-wise explanations

Student in some sense navigates in a normative problem-solving space

Socratic strategy

Student's problem solving is guided and supported by hints

Aims at enabling a student's knowledge construction

Socratic teaching generally considered superior:

Long term benefits achieved, harder for students (takes more time)

Support knowledge transfer (applying skills to related tasks and domains)

Means of communication

Formal

Comparably easy to control

Interpretation of errors may not be so simple

Applicable to limited set of domains

Menu-based/pseudo natural language

Also easy to control

Offers prefabricated choices rather than opportunities for free specifications

Natural language

Notoriously difficult to analyze

Some success, but severe problems with shallow, robust methods

Increased learning gain through exercising the precise use of expressions

Increased difficulties with combined natural language/formula expressions

Categories of reactions/feedback

Accept/reject

Basic form of (rudimentary) feedback

Encouragement

Addresses the student's emotional state; important, but not overdoing

Corrections

Some sort of a combined (and more informative) accept/reject

Hinting

Most important contribution to direct the student, rich variety of hints

Prompting

A specific form of hinting, best achievable with speech

Summary

Description of intermediate/final state of problem solving

Communication of tutors – a classification

Mixed-initiative dialog

Only few NL tutors support full mixed initiative dialog

Single-initiative dialog

Limited discourse context considered

Directed dialog

Tutor controls the dialog, prompts students for explicit information, …

Finessed dialog

Dialog simulated through menu-based input, logical forms, …

The geometry tutor

Capabilities

Supports students in the solution of geometry problems

Exhibits careful and detailed natural language analysis

Natural language reference to, e.g., angles in triangles may be tricky

Motivation

Students are encouraged to write self-explanations

Cognitive science studies demonstrate that this increases learning effects

Promoting self-explanations requires the system to

- **understand them**
- **facilitate their elaboration through adequate feedback**

Two excerpts of sessions with the geometry tutor

S1: Angles are equal.
T1: Are any two angles congruent? What tells you that there are two congruent angles?
S2: Angles in a triangle are equal.
T2: That is a bit imprecise. Are ALL angles in ALL triangles congruent?
S3: Angles in an isosceles triangle are equal.
T3: Correct, except to: are all three angles in an isosceles triangle congruent?
S4: Base angles in an isosceles triangle are equal. (correct)

…

S5: They are 180
T5: Could ou be more specific? Who are *they*? And what tells you they are 180?
S6: The angles are 180
T6: You are heading in the right direction, but you need to state this rule more precisely. First, where does the 180 come from? Are all angles 180?
S7: The angles in a triangle are 180.
T7: You are awfully close. But is each angle measure equal to 180? Precisely what is 180?
S8: The sum of the angles in a triangle are 180. (correct)

Issues in the communication of tutors

Dialog strategies

Only few NL tutors support full mixed initiative dialog

NL analysis

Limited discourse context considered

NL generation

Tutor controls the dialog, prompts students for explicit information, …

The role of emotion in tutoring

Recognising the mood of the student

Interpreting sequences of student actions

(some even monitor facial expresssions)

Selecting/adapting system actions to boredom, frustration, enthusiams, …

Teaching environments

Use of animated agents

Examining the effects of varions forms of agents

Preventing misuse

Gaming – just clicking to get maximum feedback in minimal time

Cheating – producing absurd or off-the-topic contributions

Pedagogical agents

Properties of autonomous agents

Perceive their environment

Having an internal goal and can process information

Use artificial intelligence techniques to respond rationally in their environment

Properties of padagogical agents

***R*epresent a special class of software agents**

(goes beyond simply looking good*)*

Life-like and appear to have emotion along with

an understanding of the student's problems

providing contextualized advice and feedback throughout a learning episode

Motivation

Provide contextualized problem-solving advice

Evidence suggests that intelligent tutors with lifelike characters are

pedagogically effective and have a strong motivating effect on learners

Authoring tools

Purpose

Facilitates the design and development of tutoring systems

Motivation

Best done by domain experts with domain expertise, but no software skills

Ingredients modeled

Task and example specifications, associated with communication specifications

Modeling

Generally oriented on surface appearances (e.g., natural language text portions)

A fundamental trade-off

between depth of formal reasoning and potential for building authoring tools

Evaluating tutoring systems

Techniques

Specifying conditions to be tested

Experiments with a featured group and a control group

Computing the effect of the difference – statistically significant?

Problems

Experiments are expensive – picking most important properties

Capturing system/teaching properties to be tested

Examples

Geometry curriculum with ITS significatly better than traditional form

Linguistically adequate presentations improve performance signifcantly

ITS as a scientific field

Research community

Annual conferences since 20 years, approx. 200 participants

A dedicated journal, presence in related conferences and journals

Domains of application

Facilitating learning in groups (classroom)

Ono-to-one tutoring in physics, mathematics, programming, formal design …

Success

Significantly improved learning with ITS

Cognitive tutors for algebra and geometry in use in more than 1300 US schools

ITS technology

Relations to other areas of intelligent systems

- **Logical inference systems (Automated theorem proving, Constraint systems, …)**
  - **Optimized towards efficient problem solving**
  - **Unusable without considerable transformations and enhancements**
- **Expert systems (including explanation facilities, e.g., Digital Aristotle)**
  - **Reasoning foresees needs of afterwards considerations**
  - **Insufficient for problem scaffolding and error handling**

Consequences on ITS development

- **Tension between use of reasoning capabilities and usability of authoring tools**
- **Strongly dependent on complexity of the tutoring task and capabilities**

The DIALOG project (SFB 378)

Goal

Participating in a flexible natural language tutorial dialog

Empirically investigating dialogs in teaching mathematical proofs

Architecture – modular design

***Learning environment* – getting acquainted with some lesson material**

***Mathematical proof assistant* – checks appropriateness of student's utterances**

***Proof manager* – maintains representation of constructed proof object**

***Natural language processing* – NL expressions interleaved with formulas**

attempts the interpretation of imprecise, ambiguous and faulty utterances

***Dialog manager*– maintains state of dialog and determines system reaction**

including an embedded hinting algorithm

***Knowledge resources* – domain and pedagogical knowledge (hint taxomony)**

WIZARD-OF-OZ EXPERIMENT 1

Goal

Collecting a corpus on tutorial dialogs in the naive set domain

Testing tutorial strategies developed

Experiment phases

Preparation and pre-test on paper

Tutoring session mediated by *Wizard-of-Oz* tool

Post-test on paper and evaluation questionnaire

Tasks to prove

(1) $K((A \cup B) \cap (C \cup D)) = (K(A) \cap K(B)) \cup (K(C) \cap K(D))$

(2) $A \cap B \in P((A \cup C) \cap (B \cup C))$

(3) If $K(B) \supseteq A$, **then** $K(A) \supseteq B$

Experience gained

Socratic strategy not as effective as hoped (long-term effects unexplored)

Distracted by lengthy clarification subdialogs resolving low-level issues

WIZARD-OF-OZ EXPERIMENT 2

Goal

Collecting a corpus on tutorial dialogs about relations (a more advanced topic)
Exploring human hinting strategies in a socratic style

Experiment phases

Getting acquainted with the domain and environment on the computer
Tutoring session mediated by *Wizard-of-Oz* and editing tools
Evaluation questionnaire

Tasks to prove

(1) $(R \circ S)^{-1} = R^{-1} \circ S^{-1}$

(2) $(R \cup S) \circ T = (R \circ T) \cup (S \circ T)$ **(for relations R, S and T over a set M)**

(3) $(R \cup S) \circ T = (T^{-1} \circ S^{-1})^{-1} \cup (T^{-1} \circ R^{-1})^{-1}$

Experience gained

Mistakes of various kinds (see the categories on the next slides)
Tutor reactions addressing errors opportunistically

INTERPRETATION OF SLOPPY EXPRESSIONS

(1) $A \cup B$ **must <u>be in</u>** $\boldsymbol{P}((A \cup C) \cap (B \cup C))$**, since** $(A \cap B) \cup C \supseteq$ **of** $A \cap B$

(2) If A **is a subset of** C **and** B **a subset of** C**, then both sets <u>together</u> must also be a subset of** C

Relations ambiguous between *element* and *subset*, resp. *union* and *intersection*

(3) $K((A \cup B) \cap (C \cup D)) = (K(A \cup B) \cup K(C \cup D))$**, De Morgan Rule 2 applied to <u>both complements</u>**

(4) $A \cap B$ **on the <u>left side</u> is** $\in$ **of** $C \cup (A \cap B)$**, which is extended only by** C

Intended referents not mentioned explicitly, scopus preferences apply

Metonymic interpretations required

DOMAIN ONTOLOGY

Domain knowledge representation

- **Complete logical definitions represented in λ-*calculus***
- **Inheritance used to percolate shared information, *no* hierarchical organization**
- **Only proof-relevant knowledge expressed**

  Discrepancy to linguistic requirements

Discrepancy bridged through intermediate representation

- **Imposing hierarchical organization**
- **Linking *vague* and *general* terms to domain terms**
- **Additionally modeling *typographic* features (markers, orderings)**

ANALYSIS PHASES

Preprocessing and parsing

- **Mathematical expressions sustituted with default lexical entries**
- **Syntactic parsing and building linguistic meaning representation**

Domain and discourse interpretation (using the semantic lexicon)

Symbolic representation built and passed to the proof manager

Consulting the tutoring manager with results obtained

EXAMPLES REVISITED

(1) $A \cup B$ must <u>be in</u> $\mathcal{P}((A \cup C) \cap (B \cup C))$, since $A \cap B \in$ of $(A \cap B) \cup C$

only ELEMENT interpretation is *relevant,* SUBSET is *incorrect*

(2) If A is a subset of C and B a subset of C, then both sets <u>together</u> must also be a subset of C

only UNION interpretation is *relevant,* INTERSECTION merely *correct*

(3) $K((A \cup B) \cap (C \cup D)) = (K(A \cup B) \cup K(C \cup D))$, De Morgan Rule 2 applied to <u>both complements</u>

only separate rule application possible, not their composition, thus disambiguated

(4) $A \cap B$ on the <u>left side</u> is $\in$ of $C \cup (A \cap B)$, which is extended only by C

judged as *incorrect*, since argument types clash with ELEMENT relation

HANDLING ERRORS – CORPUS EXAMPLES

	Example formula	*Error category*
(1)	$P((A \cup C) \cap (B \cup C)) = PC \cup (A \cap B)$	**3**
(2)	$(p \cap a) \in P(a \cap b)$	**2**
(3)	$(x \in b) \notin A \quad K(A) \supseteq x$	**2**
(4)	$P((A \cap B) \cup C) = P(A \cup B) \cup P(C)$	**1**
(5)	$P(A \cap B) \supseteq (A \cap B)$	**1**
(6)	if $K(B) \supseteq A$ then $A \notin B$	**2**

3: *Structural* errors (1): Missing space between *P* and *C*, and enclosing parentheses

2: *Type* errors (2,3,6): Typographical (2), argument type (3), operator type (6)

1: *Logical* errors (4,5): Set inclusion for equality (4), membership for subset (5)

ERROR RECOGNITION

Components contributing

Formula analyzer

Defined repertoire of operators and variables, with arity and type restrictions

Proof manager

Tries to find a proof for the assertion, within the defined context

Error categories

Structural (syntactic) errors **– Formula analyzer cannot built an analysis tree**

Type (semantic) errors **– Formula analyzer reports a type mismatch**

Logical (truth-value) errors **– Proof manager disproves the assertion**

ERROR CORRECTION

Components contributing

Formula analyzer

Performs structural modifications to enable building an analysis tree

Formula modifier

Tries to apply cognitively plausible changes to the flawed formula

Formula modifications

Local and cognitively justified changes

Guided by error category and flawed portion of the formula

Searching for modifications that improve the correctness state of the formula