SimStudent: Building a Cognitive Tutor by Teaching a Simulated Student

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CTAT: Cognitive Tutor Authoring Tools

- **Example-Tracing Tutor** with zero programming
  - A cognitive model specific to a particular problem
  - Some generalization by modifying a behavior graph

- **Model-Tracing Tutor** requires a cognitive model
  - Cognitive task analysis is challenging
  - Writing production rules is even more challenging
  - *Performing the task* is much easier...

Next Generation Authoring

Build a tutor GUI

Teaching a solution

Production Rules

SimStudent

- Machine learning agent
  - Learns problem-solving steps by …
  - Observes model solutions / solving problems, and …
  - Outputs a set of production rules

- Fundamental technology
  - Programming by Demonstration
  - Inductive Logic Programming

Authoring Strategies

- Authoring by demonstration
  - Learning from worked-out examples
  - Demonstrate whole solutions
  - Learning by generalizing examples (when it can’t “self-explain”)

- Authoring by tutoring
  - Learning by doing (with tutor feedback)
  - Interactively tutor with immediate feedback and hint
  - Learning by generalizing hint with taking feedback into account

Learning Production Rules in 3 parts: What-When-How

If
  
such and such constraints hold

Then
  
do actions with the GUI elements

What-When-How

Production Rule in JESS

(defrule trans-lr-lhs
  (?problem <- (problem (interface-elements ?table1 ? ? ?))
  ?table1 <- (table (columns ?column1)) ...
  ?))

When

?column1 <- (column (cells $?m1 ?cell1 $?))
?cell1 <- (cell (value ?val1 nil))
?column1 < -(column (cells $?m3 ?cell2 $?))

RHS

Topological constraints
Feature constraints
WME conditions
Constraints

Actions

3x + 2 = 14
3x = ?
Background Knowledge

- Domain concepts to "explain" demonstrations
  - Operators
  - Feature predicates

External Jess function written in Java

(defrule multi
  (cell (value ?val0))
  (test (fraction-term ?val0))
  => (bind ?val2 (denominator ?val0))
  (bind ?input (mul-term-by ?val0 ?val2))
)

Example:
Algebra domain
- 16 Feature predicates & 28 operators

<table>
<thead>
<tr>
<th>Feature Predicates for LHS conditions</th>
<th>Operators for RHS actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>HasCoefficient</td>
<td>AddTerm</td>
</tr>
<tr>
<td>HasConstantTerm</td>
<td>AddTermBy</td>
</tr>
<tr>
<td>HasHasTerm</td>
<td>Coefficient</td>
</tr>
<tr>
<td>HasHomogeneous</td>
<td>CopyTerm</td>
</tr>
<tr>
<td>IsFractionTerm</td>
<td>Denominator</td>
</tr>
<tr>
<td>IsConstant</td>
<td>ReverseCoefficient</td>
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<tr>
<td>IsDeterminate</td>
<td>SkillAdd</td>
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<tr>
<td>IsNonzero</td>
<td>SkillDivide</td>
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<td>IsMonomial</td>
<td>SkillIF</td>
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<td>SkillSubtract</td>
</tr>
<tr>
<td>IsSkillSubtract</td>
<td>VarName</td>
</tr>
</tbody>
</table>

Learning Results

- StepScore = \[ \begin{cases} 0, & \text{if } C = 0 \\ \frac{C}{C+1}, & \text{otherwise} \end{cases} \]

Authoring Time

- Authoring by tutoring took 86 minutes
- Authoring by demonstration took 238 minutes
- 2.8x speed-up!
**Example: Stoichiometry Tutor**

![Stoichiometry Tutor diagram](image)

**Approximate Time Distribution (hours):**
- Operator generation: 30
- Feature predicate generation: 40
- Debugging: 15
- Testing: 15

Learn more about SimStudents
- Project Web
  - www.cs.cmu.edu/~mazda/SimStudent
- Download & Tutorial
  - http://ctat.pact.cs.cmu.edu (linked from project web)
- Contact Noboru
  - mazda@cs.cmu.edu

**SimStudent Projects**
- Intelligent Authoring
  - Building a Cognitive Tutor as a CTAT Plug-in
- Student Modeling and Simulation
  - Controlled educational studies
  - Error formation study
  - Prerequisite conceptual knowledge study
- Teachable Peer Learner
  - Learning by teaching

Learning by Teaching SimStudent

<table>
<thead>
<tr>
<th>Problem</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3x + 1</td>
<td>x + 4</td>
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</tbody>
</table>

Curriculum Browser

**Prepare Lucky for Quiz Level 3!**

Lucky