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Note: Researchers at Carnegie Mellon University (CMU) and Worcester Polytechnic Institute (WPI) conducted the following research collaboratively. This document is the WPI version. Ken Koedinger at CMU is submitting the same final report for the CMU version of the final report.

Final Report

Grant Number: N000140310221

Principal Investigator: Neil T. Heffernan

Institution: Computer Science Department,
Worcester Polytechnic Institute, Worcester, MA 01609

Grant Title: Affordable Cognitive Modeling Authoring Tools using HCI
Methods: Worcester Polytechnic Institute Portion

Award Period: Dec 1st , 2002- Nov 17th , 2005

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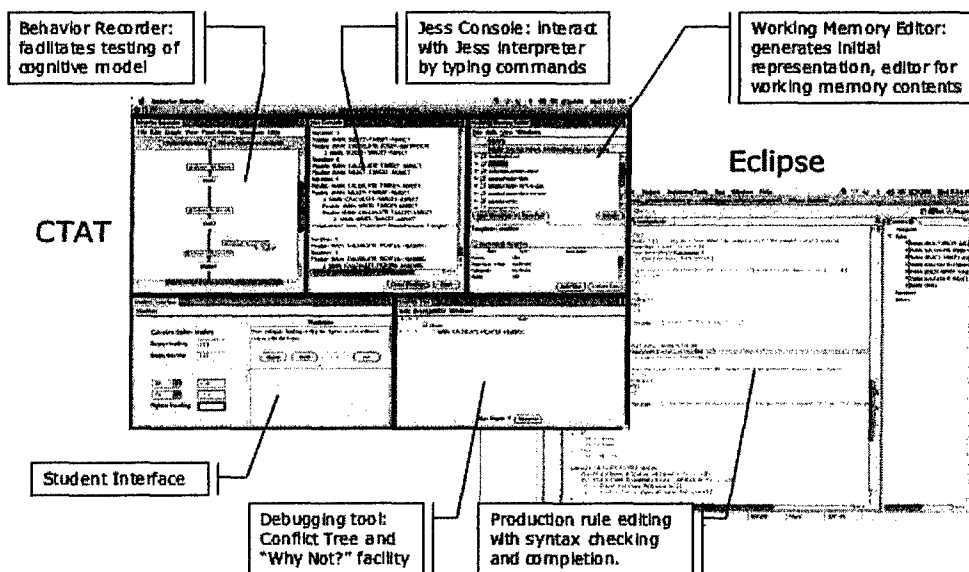
Objective:

To investigate ways to increase the affordability of human behavioral modeling through development of better software tools to support this task and the gathering of objective evidence that the tools do make modeling more affordable.

Approach:

We proposed to develop a suite of Cognitive Tutor Authoring Tools (CTAT) to make modeling both *easier and faster* for experienced modelers and *possible* for potential modelers who are not experts in cognitive psychology or artificial intelligence programming. Our concrete goal was to reduce modeling time by a factor of three and to experimentally demonstrate this reduction. We also proposed to push the state of the art in “programming by demonstration” by having our tools induce cognitive rules from demonstrated solutions.

The approach we used was to build a suite of tools, called the Cognitive Tutor Authoring Tools (CTAT), which allow non-programmers to “demonstrate” the behavior they want the system to model. A central tool called the Behavior Recorder records the demonstrated problem steps in a “Behavior Graph,” which may capture multiple paths through a problem scenario, as well as incorrect behavior that needs to be modeled. Behavior Graphs are used in two ways. First, they are used to build what we call “example-tracing tutors,” which are less general than cognitive rule-based tutors but much faster to develop. The second use of these demonstrations is as a guide to help behavioral rule-based modelers do their task. The cognitive modeler uses the Behavior Graphs as test cases to test his/her rules. The CTAT tools are shown below and described in greater detail in Koedinger, Alevan, Heffernan, McLaren, & Hockenberry, 2004; Alevan, Sewall, McLaren, & Koedinger, in press; Alevan, McLaren, Sewall, & Koedinger, in press.



We used these tools to build our own tutors as well as hosting weeklong summer workshops in 2003, 2004, and 2005 in which we freely distributed the tools to researchers and trained them in their use. Over 100 researchers have attended these training and dissemination workshops and several other academic groups are now using the tools. We have also made our tools freely

available from a website (<http://ctat.pact.cs.cmu.edu/>). We estimate that there are currently between 100 and 200 users of CTAT.

Accomplishments:

We were able to show that our tools can be used to build many different rule-based cognitive models, such as a Warrior Simulator at Fort Benning (Livak & Heffernan, 2004), a Logic Tutor for internal use at CMU, and a Genetics tutor.

In preliminary controlled experiments involving basic Cognitive Tutor development tasks, we found efficiency gains due to CTAT of 1.4 to 2 times faster (Aleven, McLaren, Sewall & Koedinger, 2006). We also demonstrated across 4 different behavioral modeling projects that our tools created example-tracing tutors that drastically reduced modeling costs (Koedinger, Aleven, Heffernan, McLaren, & Hockenberry, 2004, Heffernan, Turner, Lourenco, Macasek, Nuzzo-Jones, Koedinger, 2006). Not only did we reduce the time dramatically (averaging a reduction of over a factor 5), we also reduced the experience level modelers needed.

Finally, we pushed the state of the art in data mining and machine learning support to help rule-writers (McLaren et al 2005; Harrer et al, 2005; McLaren et al, 2004b; McLaren et al, 2004a; Jarvis, Nuzzo-Jones, & Heffernan, 2004; Matsuda, Cohen, and Koedinger, 2005a; 2005b; 2005c).

Conclusions

We have made excellent progress toward creating and demonstrating affordable behavior modeling through development and evaluation research on the Cognitive Tutor Authoring Tools. The central approach has been to use human-computer interaction, data mining, and machine learning techniques to create software components, smart interfaces and underlying intelligence, that speed the process of behavior modeling. Critical to our success has been creating a large user community that provides both realistic user tests and vote-with-your-feet evidence that CTAT is effectively reducing behavior-modeling costs. The 200 users of CTAT represent the largest number of users of any technology in the AHBM program. We have also provided reasonable evidence of affordability improvements.

Significance

Cognitive models are used successfully throughout the Armed Forces as well as in educational and training software. However, cognitive models have traditionally been very expensive to build. This small project has produced valuable knowledge about methods that can be used to make modeling more cost effective. This project has also created a specific set of tools (CTAT) that embodies some of this knowledge, and that set of tools has led to the cost-effective creation of many new cognitive models. These models in turn lead to more knowledge as exhibited by the many peer-reviewed papers produced under this grant or related to this grant.

Publications

- Aleven, V., McLaren, B. M., Sewall, J., and Koedinger, K. R. (in press). The Cognitive Tutor Authoring Tools (CTAT): Preliminary Evaluation of Efficiency Gains; Accepted for presentation at the 8th International Conference on Intelligent Tutoring Systems, Jhongli, Taiwan, June 26-30, 2006.
- Aleven, V., Sewall, J., McLaren, B. M., & Koedinger, K. R. (in press). Rapid authoring of intelligent tutors for real-world and experimental use. Accepted for presentation at the The 6th IEEE International Conference on Advanced Learning Technologies (ICALT 2006).
- Harrer, A., McLaren, B. M., Walker, E., Bollen, L., and Sewall, J. (2005) Collaboration and Cognitive Tutoring: Integration, Empirical Results, and Future Directions. In the Proceedings of the 12th

- International Conference on Artificial Intelligence and Education (AIED-05), Amsterdam, the Netherlands, July 2005.
- Heffernan N.T., Turner T.E., Lourenco A.L.N., Macasek M.A., Nuzzo-Jones G., Koedinger K.R., The ASSISTment Builder: Towards an Analysis of Cost Effectiveness of ITS creation, Accepted by FLAIRS2006 sponsored of American Association of Artificial Intelligence, Florida, USA (2006).
- Jarvis, M., Nuzzo-Jones, G. & Heffernan, N. T. (2004) Applying Machine Learning Techniques to Rule Generation in Intelligent Tutoring Systems. In J.C. Lester, R.M. Vicari, & F. Parguacu (Eds.) *Proceedings of the 7th International Conference on Intelligent Tutoring Systems*. Berlin: Springer-Verlag., p. 541-553.
- Koedinger, K. R., Alevan, V., & Heffernan, N. T. (2003) Toward a Rapid Development Environment for Cognitive Tutors. 12th Annual Conference on Behavior Representation in Modeling and Simulation. Simulation Interoperability Standards Organization.
- Koedinger, K. R., Alevan, V., Heffernan, T., McLaren, B. & Hockenberry, M. (2004) Opening the Door to Non-Programmers: Authoring Intelligent Tutor Behavior by Demonstration. In J.C. Lester, R.M. Vicari, & F. Parguacu (Eds.) *Proceedings of the 7th International Conference on Intelligent Tutoring Systems*, 162-174. Berlin: Springer-Verlag.
- Livak, T., Heffernan, N. T., Moyer, D. (2004) Using Cognitive Models for Computer Generated Forces and Human Tutoring. 13th Annual Conference on (BRIMS) Behavior Representation in Modeling and Simulation. Simulation Interoperability Standards Organization. Arlington, VA. Summer 2004
- Matsuda, N., Cohen, W. W., & Koedinger, K. R. (2005). Building Cognitive Tutors with Programming by Demonstration. In S. Kramer & B. Pfahringer (Eds.), Technical report: TUM-I0510 (*Proceedings of the International Conference on Inductive Logic Programming*) (pp. 41-46): Institut für Informatik, Technische Universität München.
- Matsuda, N., Cohen, W. W., & Koedinger, K. R. (2005). Applying Programming by Demonstration in an Intelligent Authoring Tool for Cognitive Tutors. In AAI Workshop on Human Comprehensible Machine Learning (Technical Report WS-05-04) (pp. 1-8). Menlo Park, CA: AAI association.
- Matsuda, N., Cohen, W. W., & Koedinger, K. R. (2005). An Intelligent Authoring System with Programming by Demonstration. In *Proceedings of the Japan National Conference on Information and Systems in Education* (pp.33-34). Kanazawa, Japan.
- McLaren, B. M., Bollen, L., Walker, E., Harrer, A., and Sewall, J. (2005). Cognitive Tutoring of Collaboration: Developmental and Empirical Steps Toward Realization, In the *Proceedings of the Conference on Computer Supported Collaborative Learning (CSCL-05)*, Taipei, Taiwan in May/June 2005.
- McLaren, B. M., Koedinger, K. R., Schneider, M., Harrer, A., and Bollen, L. (2004a). Bootstrapping Novice Data: Semi-Automated Tutor Authoring Using Student Log Files; In the *Proceedings of the Workshop on Analyzing Student-Tutor Interaction Logs to Improve Educational Outcomes*, Seventh International Conference on Intelligent Tutoring Systems (ITS-2004), August 2004.
- McLaren, B. M., Koedinger, K. R., Schneider, M., Harrer, A., and Bollen, L. (2004b) Toward Cognitive Tutoring in a Collaborative, Web-Based Environment; *Proceedings of the Workshop of AHCW 04*, Munich, Germany, July 2004.
- Nuzzo-Jones, G., Walonoski, J.A., Heffernan, N.T., Livak, T. (2005). The eXtensible Tutor Architecture: A New Foundation for ITS. In Looi, McCalla, Bredeweg, & Breuker (Eds.) *Proceedings of the 12th Artificial Intelligence In Education*, 555-562. Amsterdam: ISO Press. p. 902-904.
- Razzaq, L., Feng, M., Nuzzo-Jones, G., Heffernan, N.T., Koedinger, K. R., Junker, B., Ritter, S., Knight, A., Aniszczyk, C., Choksey, S., Livak, T., Mercado, E., Turner, T.E., Upalekar, R., Walonoski, J.A., Macasek, M.A., Rasmussen, K.P. (2005). The Assistment Project: Blending Assessment and Assisting. In C.K. Looi, G. McCalla, B. Bredeweg, & J. Breuker (Eds.) *Proceedings of the 12th Artificial Intelligence In Education*, 555-562. Amsterdam: ISO Press.
- Razzaq L., Heffernan, N.T. (in press) Scaffolding vs. Hints in the Assistment System, 8th Annual International Conference on Intelligent Tutoring Systems. Taiwan
- Turner, T.E., Macasek, M.A., Nuzzo-Jones, G., Heffernan, N.T., Koedinger, K. (2005). The Assistment Builder: A Rapid Development Tool for ITS. In Looi, McCalla, Bredeweg, & Breuker (Eds.) *Proceedings of the 12th Artificial Intelligence In Education*, Amsterdam: ISO Press. p. 929-931.

Patents

WPI's Heffernan and CMU's Koedinger filed for a U.S. Pat. No. 60/699,624 related to the WPI version of pseudo-tutor construction.

Awards:

This grant funding helped lead to many other successful projects that used the results of this ONR grant.

- Heffernan was awarded an NSF CAREER award half way through this grant¹.
- Koedinger was awarded a \$25 million NSF Science of Learning Center grant that is now supporting the use, and further development, of the authoring tools this grant produced.
- Heffernan and Koedinger were awarded \$1.4 millions dollars to use the techniques developed during the grant to cost-effectively create a complex new cognitive model, and tutoring systems used by thousands of students inside of 2 year. ²
- Heffernan and colleagues at WPI were awarded a grant to further the learning sciences³
- Heffernan and colleagues at Sonalysts were funded to demonstrate application of these techniques to help Fort Benning enable "Warrior Tutoring" inside of their simulations at Fort Benning.
- Koedinger received a 2-year grant from the Grable foundation to support the further development of the CTAT tool suite. Grant title: Authoring Cognitive Tutors, Number: 11655-1-1030164, Start: 4/12/04, End: 5/31/06

¹ "Learning about Learning" NSF CAREER award to Heffernan. \$600,000.

² "Using Web-Based Cognitive Assessment Systems for Predicting Student Performance on State Exams" US Dept of Education: Institute of Education Sciences . \$1.4 million.

³ Title: "Fellowships in CS to support the learning sciences and security". US Dept of Ed: Graduate Assistance in Areas of National Need (GAANN). \$804,940. PI: Ward, Heffernan, Agu and Heineman