Intelligent Tutoring Systems for Enhancing Warfighter Performance: A Practical Introduction

I/ITSEC 2013 Tutorial

Presented by: Sowmya Ramachandran
Stottler Henke Associates, Inc.
Stottler@StottlerHenke.com
650-931-2716

Stottler Henke
Smarter Software Solutions

Learning Objectives

Tutorial attendees will have a high level understanding of:

1. **What Intelligent Tutoring Systems (ITS) are**
2. **How Intelligent Tutoring Systems can be used to support training programs**
3. **How ITSs work**
4. **The tools and resources that are available for developing ITSs**
5. **The factors to consider when examining if an ITS is an option for a training program**

Agenda

1. **Overview of ITSs**
2. **Case studies of ITSs in operational use**
    1. **Tactical Action Officer ITS**
    2. **PUMP Algebra Tutor (PAT)**
3. **ITS architecture and components**
4. **ITS Benefits and costs**
5. **ITS Development resources**
    1. **General ITS architectures and frameworks**
        1. Generalized Intelligent Framework for Tutoring (GIFT)
        2. FlexiTrainer
    2. **ITS authoring tools**
    3. **Data analysis tools**
6. **Summary and conclusions**
    1. **Is an ITS right for you?**

Intelligent Tutoring Systems: The Early Years

Originally an endeavor to create an intelligence that could tutor the way humans do

- **Many studies analyzed human tutoring sessions**
- **Early research was focused on developing cognitive models of reasoning and learning**
- **Traditional ITSs maintain detailed cognitive model of domain knowledge**
- **Models were augmented with knowledge of misconceptions and typical errors**

A Key Objective of Intelligent Tutoring

The objective was to infer student reasoning by mapping their actions to the system's cognitive models

- **What do they know?**
- **Where are they getting stuck? How to help them?**
- **What misconceptions do they hold?**

Evolution of Domain Models

- **Implication**
  - **The AI tutor was actually an expert problem-solver in the domain**
- **This level of modeling is not feasible for many training tasks**
- **Therefore, more feasible approaches designed**
  1. **Constraint based**
  2. **Pseudotutor**

The Inner-Loop/Outer-Loop Model

- **The instruction provided by an ITS can be modeled as two instructional loops**
  - **Inner and Outer**

- **The Inner loop is concerned with teaching in the context of a single problem or experience**
  - **assessing performance**
  - **following their reasoning**
  - **figuring out why they are stuck or making errors**
  - **providing appropriate help**

The Outer Loop

- **Concerned with the sequencing of experiences**
  - **What sort of an experience should come next?**
    - Should the learners watch a video?
    - Read some text?
    - Watch a demonstration?
    - Work on another problem?
  - **Should we give them a different type of a problem**
    - e.g. writing an essay vs. answering multiple-choice
  - **What should the experience relate to?**
  - **Should it be similar to the previous one? Should we give them something new to try?**
  - **How challenging should be the next experience?**
  - **Should we make problems harder?**

ITS: A Broader View

- **Today, the definition of intelligent tutoring has been broadened**
  - **Any training system that uses information about student performance to tailor its content to a degree (inner-loop and outer loop adaptations)**
  - **Not necessarily based on a cognitive model**
- **But the objectives still are**
  - **To understand state of knowledge and understanding at a deep enough level, and**
  - **To find an effective combination of instructional interventions to help students learn**

Assessment

Key Phrase: to understand state of knowledge and understanding at a deep enough level

That is, ASSESSMENT

- **Assess not the end product, but the process of reasoning.**
  - **Learners typically solve problems step-by-step; therefore a tutor can pinpoint where they have difficulties**
  - **Ask learners to provide reasons and justifications for their inputs.**
  - **Conduct interactive dialogs with learners to elicit their reasoning (AutoTutor)**
  - **Assess problem-solving strategy**

Instruction

- **To reiterate, the emphasis is on process not just the product**
  - **Teach the steps**
  - **Teach the strategies**
  - **Provide process-based feedback, explanations, and hints**
  - **Provide multiple perspectives**
  - **Provide a lot of process-based practice**

Intelligent Tutoring and Adaptive Learning

- **Intelligent Tutors enable adaptive learning**
- **But adaptive learning is a very nebulous term**
- **When you see the term adaptive learning ask yourself**
  - **What are the dimensions of adaptation? I.e. Inner loop adaptation? Outer loop adaptation? Both?**
  - **For each, what are the dimensions of variability or choices over which adaptation occurs**
  - **Is the emphasis on product or on process?**

Adaptation: A Matter of Degrees

- **Adaptive Trainer 1**
  - **Has a network of learning objectives arranged in some order of difficulty**
  - **Has problems associated with learning objectives**
  - **Uses student performance assessment to determine if the learner should continue to work on problems related on one set of objectives or move on to a more advanced set**

Is this adaptive? - Yes

More, or Less

- **Adaptive Training 2**
  - **Network of LOs etc., same as before**
  - **But this one has problems at various levels of challenges, includes a variety of problem types, remedial learning material, problem demonstrations**
  - **It also follows a learner's reasoning step-by-step as they solve a problem and provides hints targeted at particular items of knowledge/misconception traced**

Is this system adaptive? – Of course

More, or Less?

- **Which is better?**
  - **Hard to tell because not all dimensions of adaptation have been studied in a controlled manner**
- **But we do know**
  - **Some traditional ITSs have been shown 1-sigma improvement**[1]

[1]Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995). Cognitive tutors: Lessons learned. *The journal of the learning sciences*, *4*(2), 167-207.

Evidence of Effectiveness of ITSs

- **Tutoring systems developed based on a cognitive analysis of the skills involved in troubleshooting tasks have shown to be very effective**
  - **E.g. Sherlock that taught Air Force people in avionics skills**
  - **This tutor focused on the process of reasoning**
- **Multiple studies have the found the following reading tutors to be significantly more effective than an "adaptive" computer-based trainer**
  - **ReadInsight, STAR, Gradient**
  - **Multiple-strategies**
  - **Process-based scaffolds and feedback**
  - **Mastery-based adaptation**

- **Auto-Tutor**
  - **Validation studies show a 0.8 sigma learning gain**
  - **Process-based emphasizing elicitation of student input on their reasoning about a problem**
  - **Mimics one-on-one human tutoring**

Other Notable Evaluation Results

AF: Sherlock, diagnose electronics, 6 month post test results:

- **Experts: 83%, ITS Group: 74%, Control Group: 58%**

LISP Programming Language ITS: 45% higher on final exam

Database programming tutor: improved 1 standard deviation

US Naval Academy: Andes Physics Tutor: improved 0.92 sd

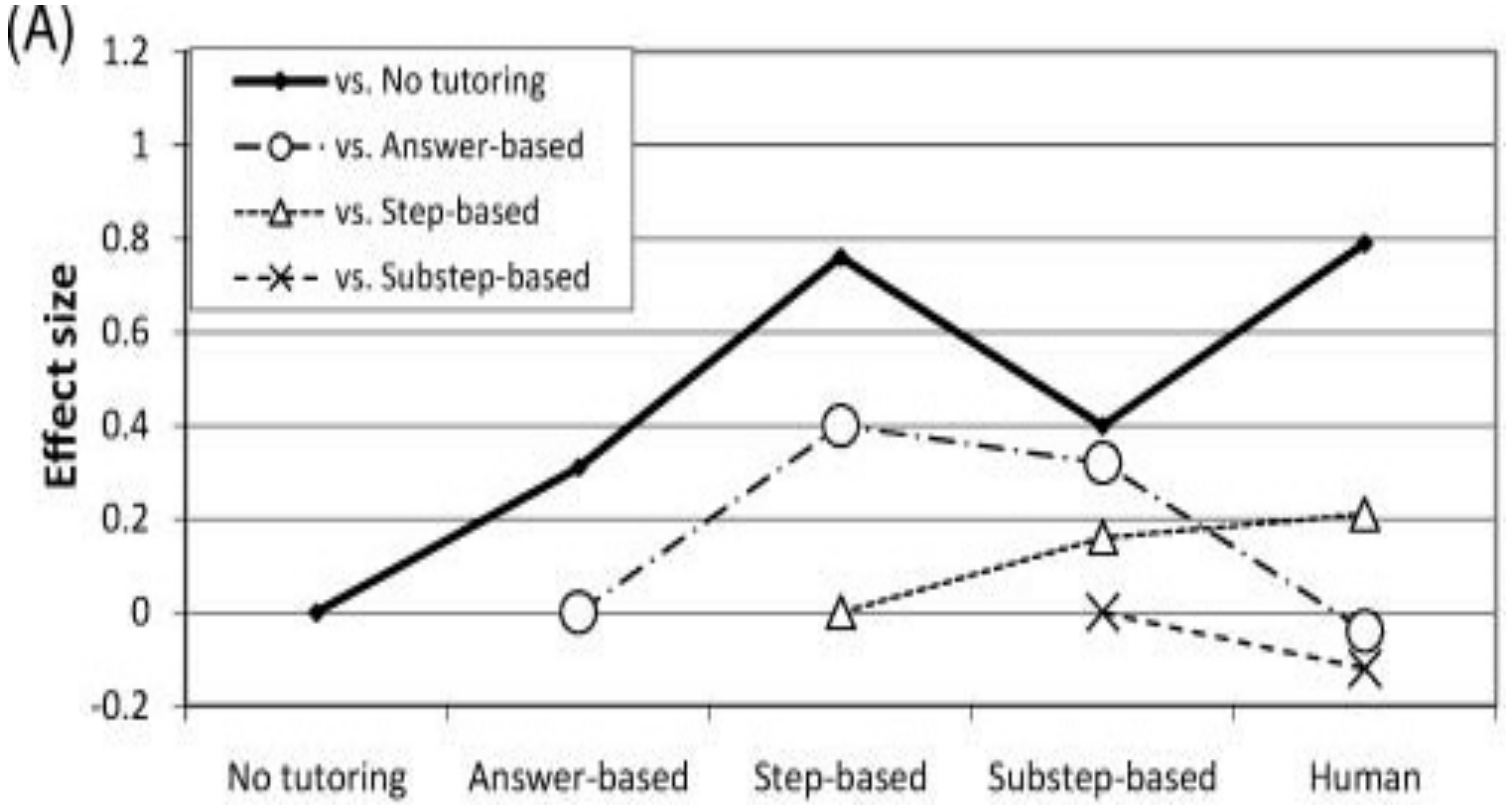
CMU LISTEN Reading Tutor:

- **Statistically significant improvement versus reading alone**

US Navy SWOS: TAO ITS: Student Survey Results:

- **Classroom aid: 75% Extremely Fav., 17% Fav., 8% Neutral**
- **Standalone Training Tool: 83% Ex. Favorable, 17% Favorable**

Comparison of Tutoring Approaches



VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist*, *46*(4), 197-221, 2011, APA. Reprinted with permission.

ITS CASE STUDIES

ITS Case Studies

- **Tactical Action Officer ITS**
  - **Simulator-based ITS for training Tactical Action Officers in tactical and communication skills**
- **PUMP Algebra Tutor**
  - **Developed by Carnegie Mellon University**
  - **Teaches high school Algebra**

The TAO ITS Story

- **SWOS was using the PORTS desktop simulator to train its new TAOs**
- **One instructor could train two students at time, each working with their own simulation**
- **Too demanding on instructor resources**
  - **A typical class includes 40 TAO trainees**
  - **A 1:2 ratio made it a challenge to train such a large cohort**
- **Enter ITSs**
  - **The ITS performs a large share of what instructors used to do**
- **Now there is 1 trainer per 40 students**

TAO ITS Training Task

- **Objective: To prepare Tactical Action Officers in the task of commanding their teams of watchstanders**
- **Two main skill sets**
  - **Tactical Decision-Making**
  - **Communication**
- **The ITS uses virtual agents to play the role of watchstanders**
- **The trainee communicates with the virtual team via speech**

TAO ITS Characteristics

- **Designed according to cognitive learning principles**
  - **Learning by doing (Simulation-based)**
  - **Process focused**
  - **Faded scaffolding**
- **But no cognitive model of the domain**
  - **Domain knowledge is represented as a collection of cases or training scenarios**
  - **The ITS also has a hierarchical model of the knowledge, skills, and abilities (KSAs)**
  - **Scenarios are linked to appropriate KSAs**
  - **Finite-state machines are used to assess performance**

Parameters of Adaptation

- **Outer Loop**
  - **LOs organized in a prerequisite network**
  - **Graded challenge levels**
  - **Shared responsibility with the instructor**
    - The tutor only suggests the next activity. The instructor selects the next activity (overriding the ITS if need be)
- **Inner Loop**
  - **Step-by-step assessment of performance**
  - **3-level hinting system**
    - General to specific
  - **Hinting is withdrawn as learner gains expertise**
  - **After-action review: Process-focused feedback on performance**

TAO ITS: Development Resources

- **The following authoring tools were use to create this ITS**
  - **FlexiTrainer**
  - **Simbionic**

- **The ITS is accompanied by**
  - **Scenario Authoring Tool**
  - **Exercise Authoring Tool**

TAO ITS Demo

A sample simulation exercise showing

- **speech-based interactions**
- **simulated agents**
- **hint sequences**
- **feedback**
- **after-action review**

TAO ITS: Operational Use

- **The ITS is in operational use at SWOS**
- **It is used in a classroom setting**
  - **Instructor supervised**
  - **Instructors assign scenarios**
  - **But students work with the ITS independently**
  - **An Instructor Console application lets instructors keep an eye on the student progress**

TAO ITS Evaluation

- **A survey was conducted to study trainee reaction to the ITS**
- **Though some improvements were recommended, overall the reaction was favorable**

TRAINING VALUE	Strongly Disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5	Comment
1. Practicing with PORTS-ITS will increase my confidence in supervising watch standing.	4.0; 54 responses, one system down; 10 missing pages					
2. I can see how PORTS-ITS will help me learn the principles.	4.2; 54 responses, one system down; 10 missing pages					
3. If lab time were scheduled to practice with PORTS-ITS, I would attend the lab voluntarily.	4.0; 53 responses, one system down; 10 missing pages					

PUMP Algebra Tutor (PAT)

For high-school Algebra

- **True blue ITS**
  - **Based on a cognitive model of the domain**
  - **Uses cognitive modeling to generate word problems, assess solutions, and provide feedback**
- **Emphasizes not just algorithms but also the use of multiple strategies, common sense reasoning etc.**
- **Process-focused**

PUMP Algebra Tutor (PAT)

Outer Loop

- **Multiple versions of the tutor**
- **Some select next activity based on student data**
- **Others let teachers decide**

Inner Loop

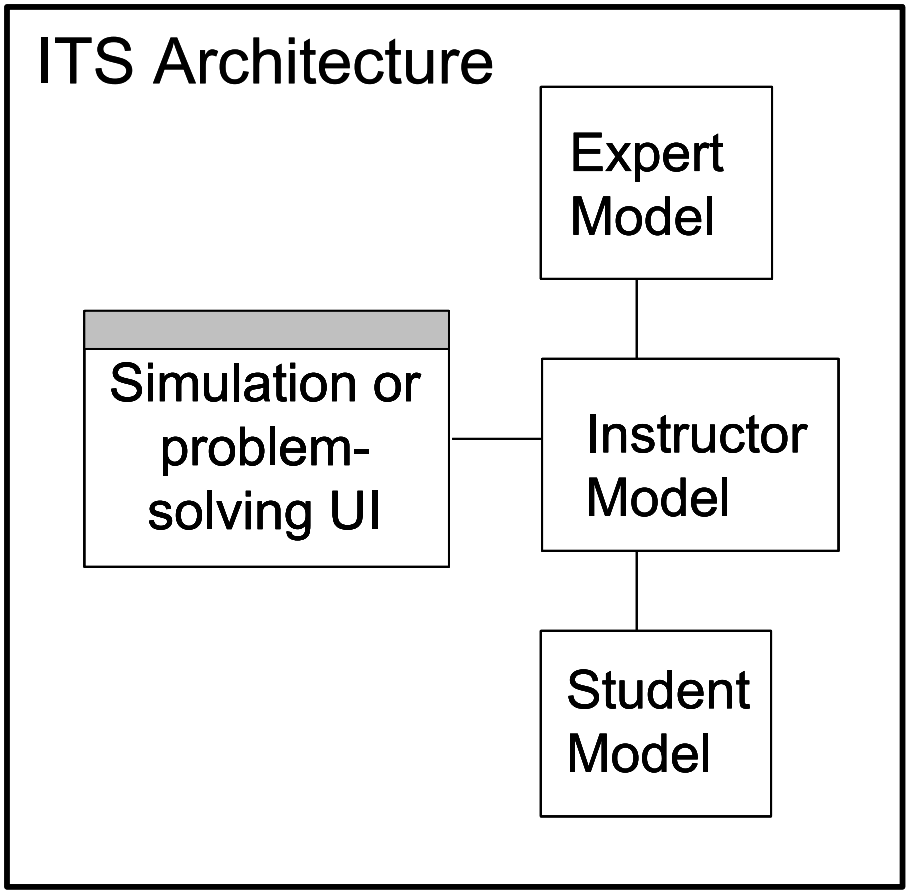
- **Interface for step-by-step problem-solving**
- **Error feedback at a step level**
- **Multiple levels of hinting**
  - modeling of misconceptions and typical errors
- **Interface and feedback support multiple problem-solving strategies**

Evaluation of PAT

- **A descendent of PAT has been fielded extensively**
- **Many validations have been conducted with somewhat mixed results**
- **The most recent large scale study was conducted by Rand Corporation**
  - **73 high-schools and 74 middle schools**
  - **18,000+ students participated**
  - **Found no statistically significant effect the first year of implementation**
  - **Significant effect was found during year 2. Students showed an improvement of 8 percentage points on average**

ITS COMPONENTS

High-Level Architecture

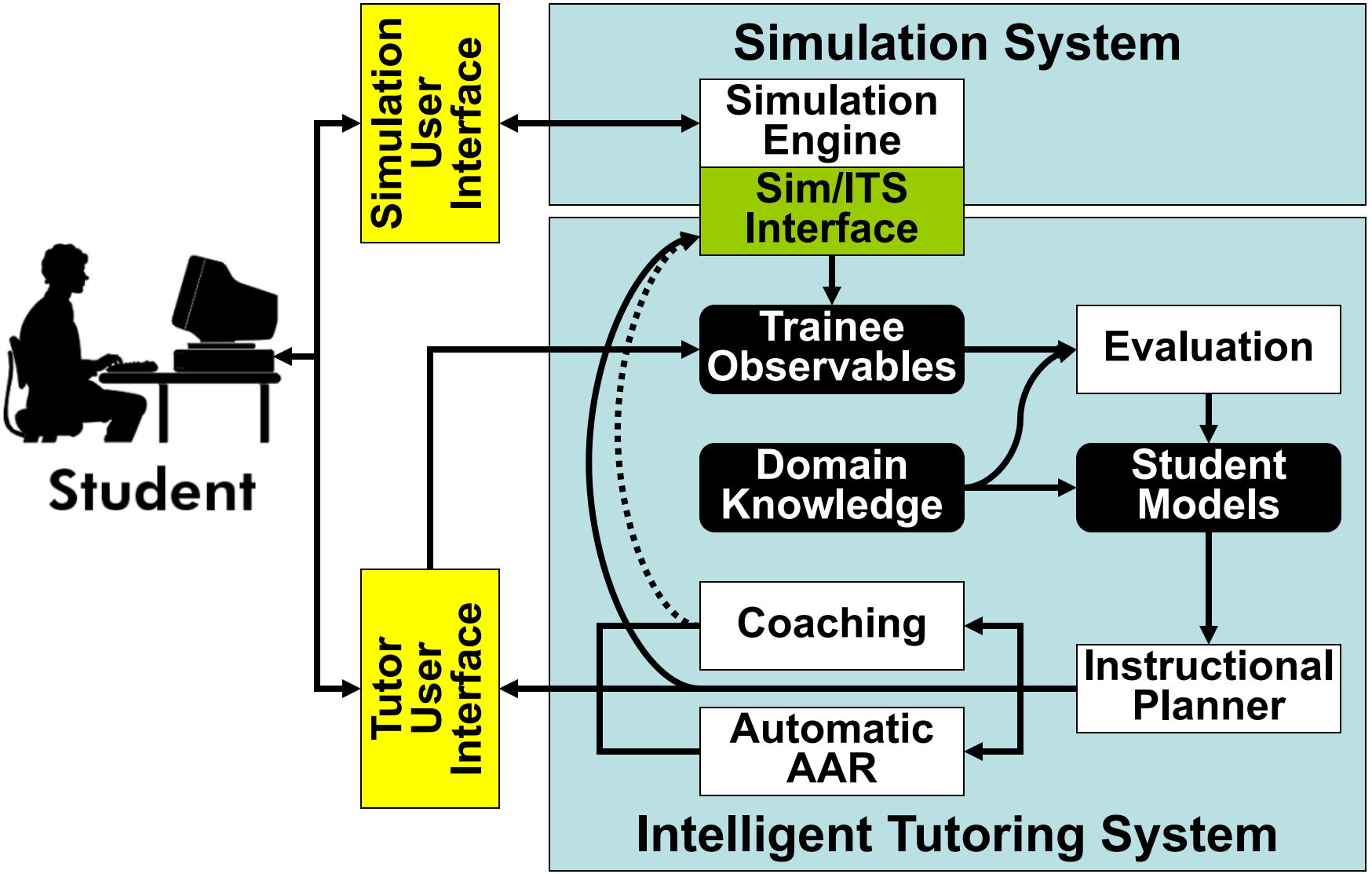


What they are teaching

How to teach

Who they are teaching

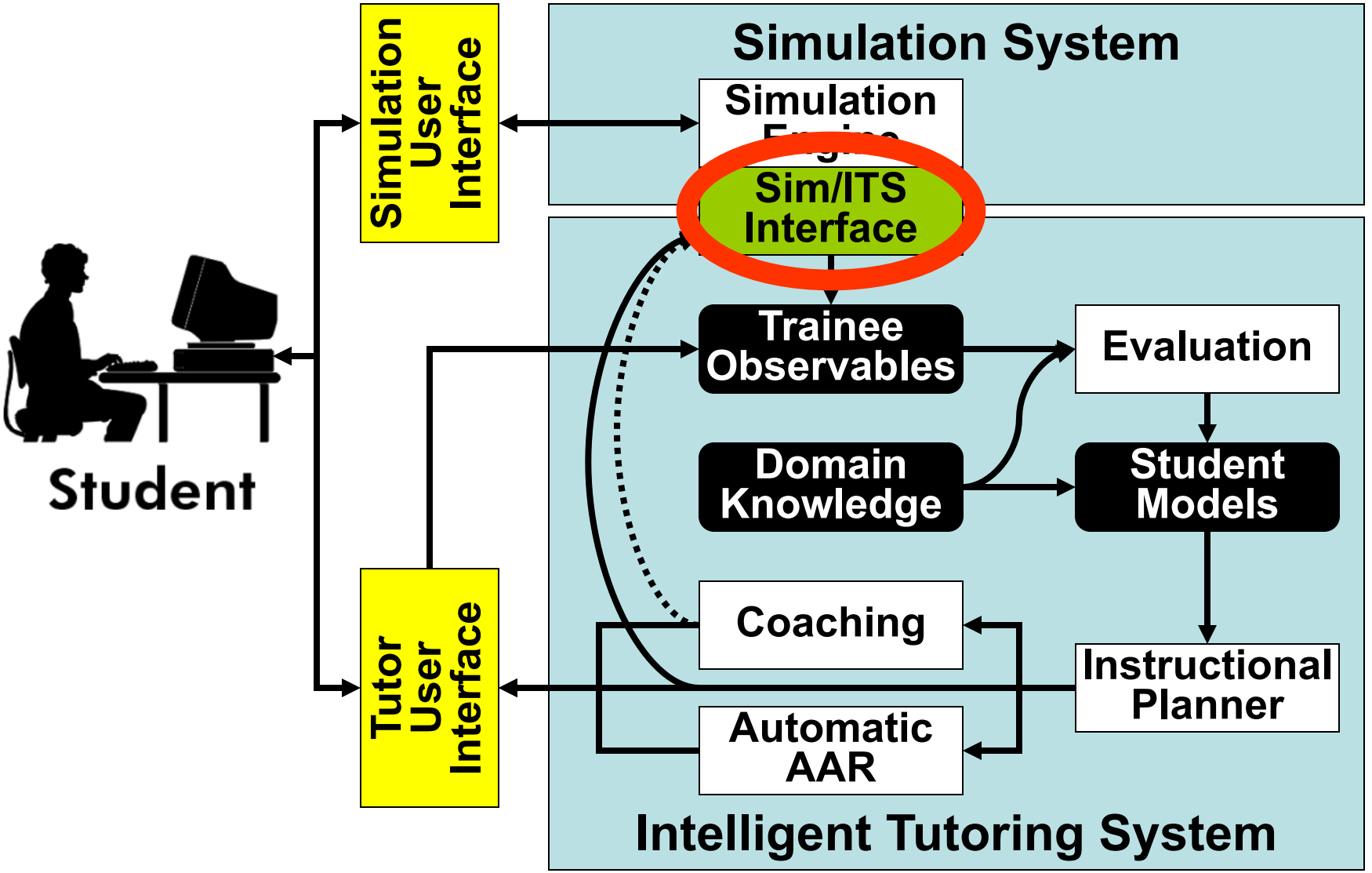
Architecture: A Closer Look



ITS Components

- **Evaluation Module (Expert Model)**
- **Simulation Interface (Problem-Solving UI)**
- **Student Model**
- **Auto AAR/Debriefing Module (Expert Model)**
- **Instructional Planner (Instructor Model)**
- **Coaching Module (Expert Model)**
- **Domain Knowledge (Expert Model)**
- **User Interface (Problem-Solving UI)**

Simulation User Interface



Simulation Interface

Simulation data input to the ITS

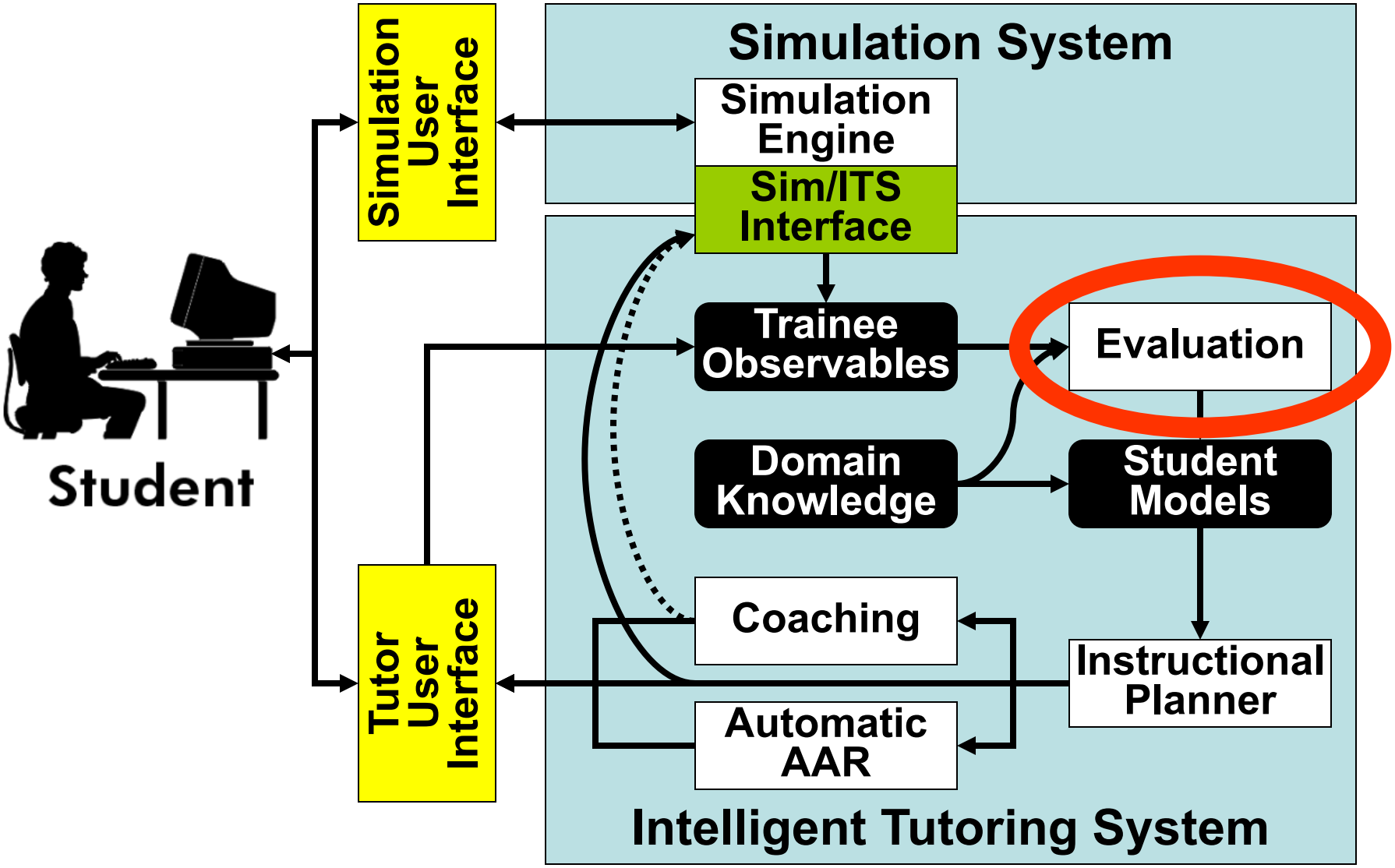
- **Distributed Interactive Simulation (DIS)**
- **DIS with embedded data**
- **High Level Architecture (HLA)**
- **HLA with extensions**
- **Log files**
- **Custom interface**

Optional: ITS outputs to the simulation

Simulation Interoperability Standards Organization (SISO) Draft ITS/Simulation Interoperability Standard (I/SIS)

- **SISO-REF-011-2005: Intelligent Tutoring System Interoperability (ITSI) Study Group Final Report**
- **http://www.sisostds.org/ProductsPublications/ReferenceDocuments.aspx**

Performance Assessment/Evaluation



Evaluation – Cognitive Modeling

Traditional ITS approach

- **Model the decision-making to be taught using production rules**
- **Construct computable model of expert knowledge**
- **Compare student's actions to those of the model**
- **Use comparison and inference trace to diagnose**

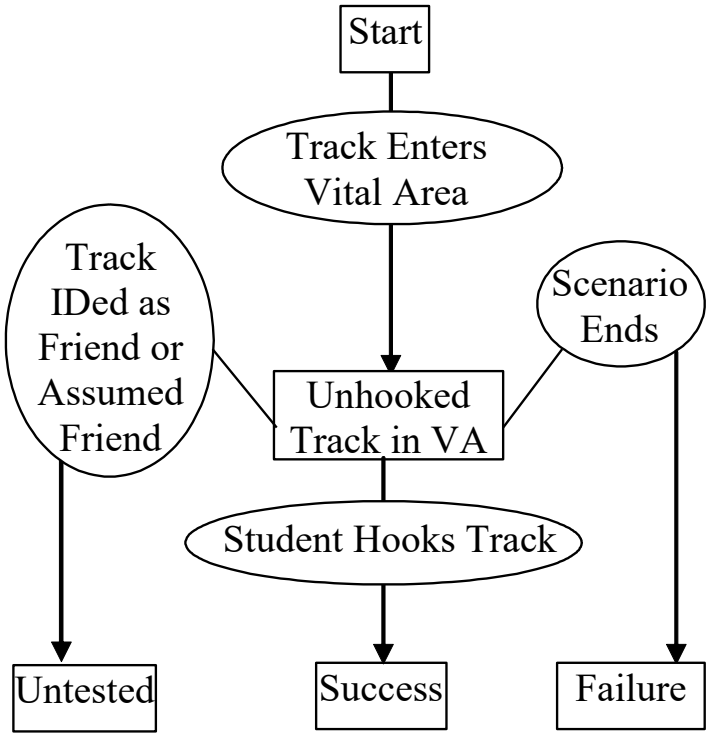
Concerns

- **Assumes computable model can be constructed**
- **Really need human if have an expert model?**

Evaluation – Finite State Machines

Often useful for real-time tactical decisions

- **Network of states**
- **Transitions between states**
- **Finite State Machine (FSM) is in one state at a time.**
- **Each state may have software that executes**
- **Each transition has a condition**
- **When true, transition from one state to another**
- **FSMs have 1 initial state**
- **Part looks for a situation type**
- **Remainder evaluates student response to that situation**
- **Many operate in parallel**



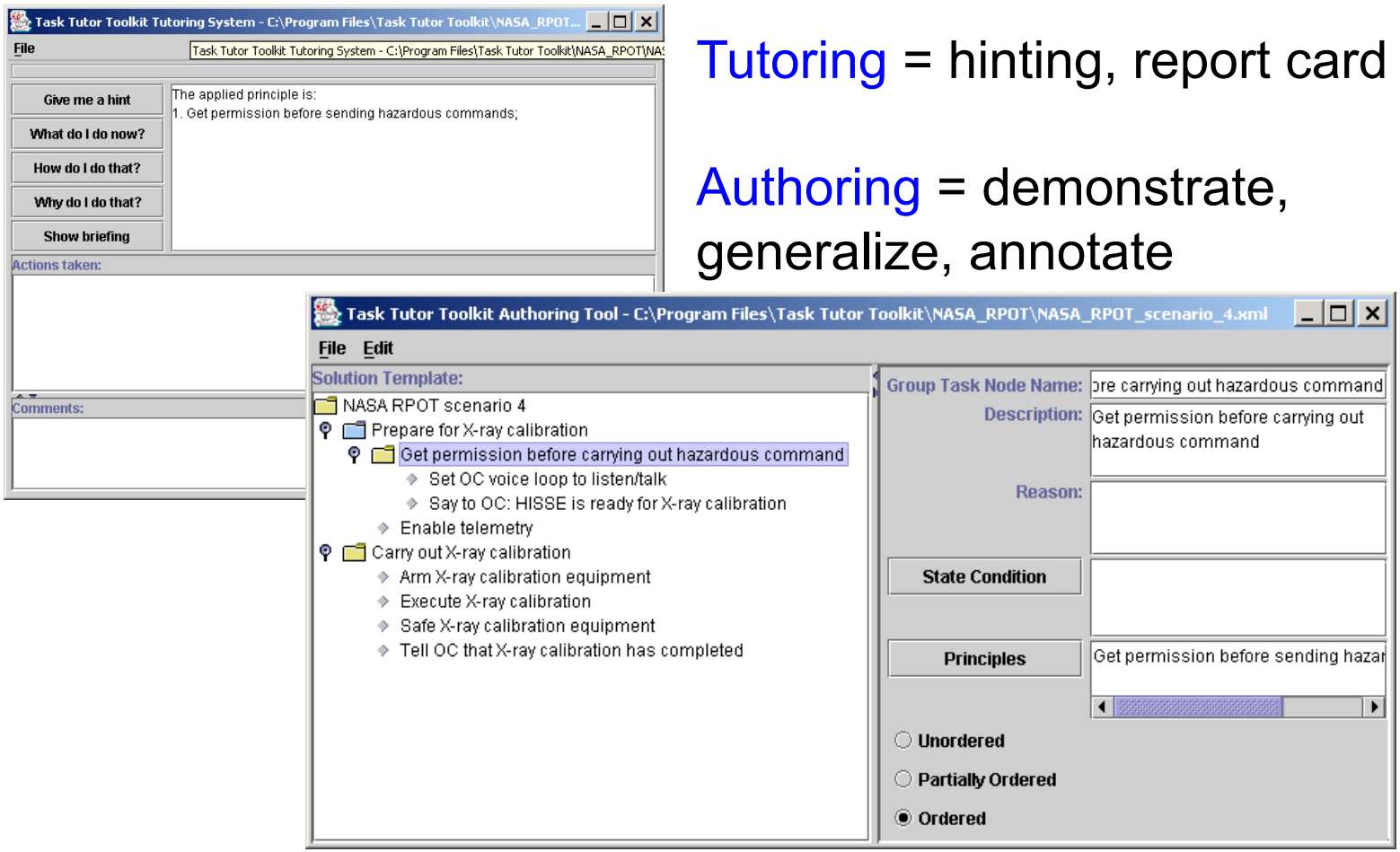
Evaluation – Procedure Templates Task Tutor Toolkit

Purpose Enable rapid development of tutoring scenarios for technical training that provide step-by-step coaching and performance assessment.

Approach Solution template encodes the correct sequences of actions for each scenario, with some variation allowed.

Authoring tool enables rapid development by demonstrating, generalizing, and annotating solution templates.

T³ Tutoring and Authoring Applications



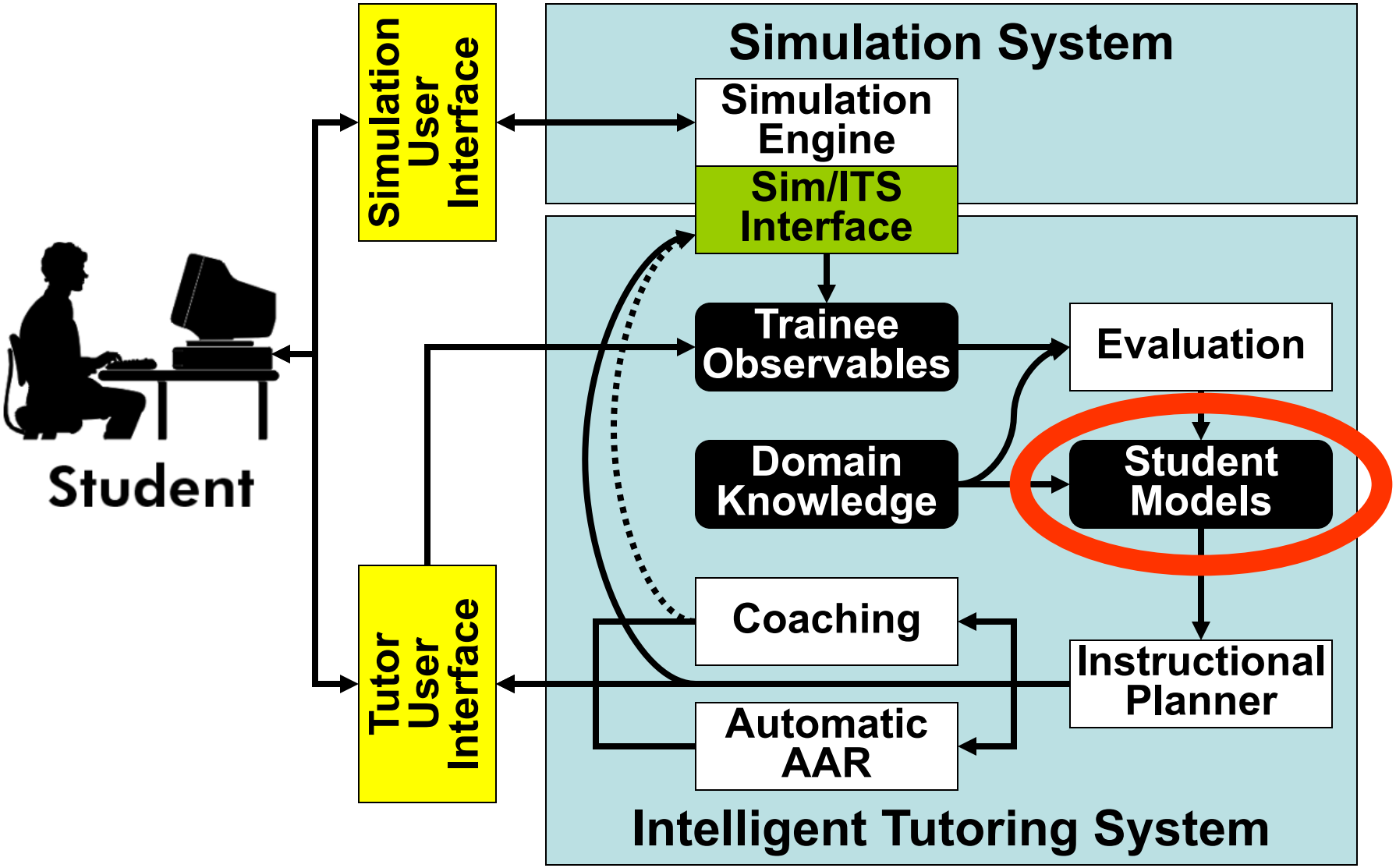
Tutoring = hinting, report card

Authoring = demonstrate, generalize, annotate

Dialog-Based Assessment

- **Socratic Dialogs, Conversational Tutors (e.g. Autotutor)**
  - **Extended dialog, built around tutor questions**
  - **Tutor gets chance to build insight into student**
    - Not just their actions, but their *reasons* for action
  - **Student gets chance to originate/own/explore critiques of own actions**
    - Not just told, but led to *conclude for self*
  - **Can go beyond overt simulation outcomes**
    - Questions can address hypotheticals

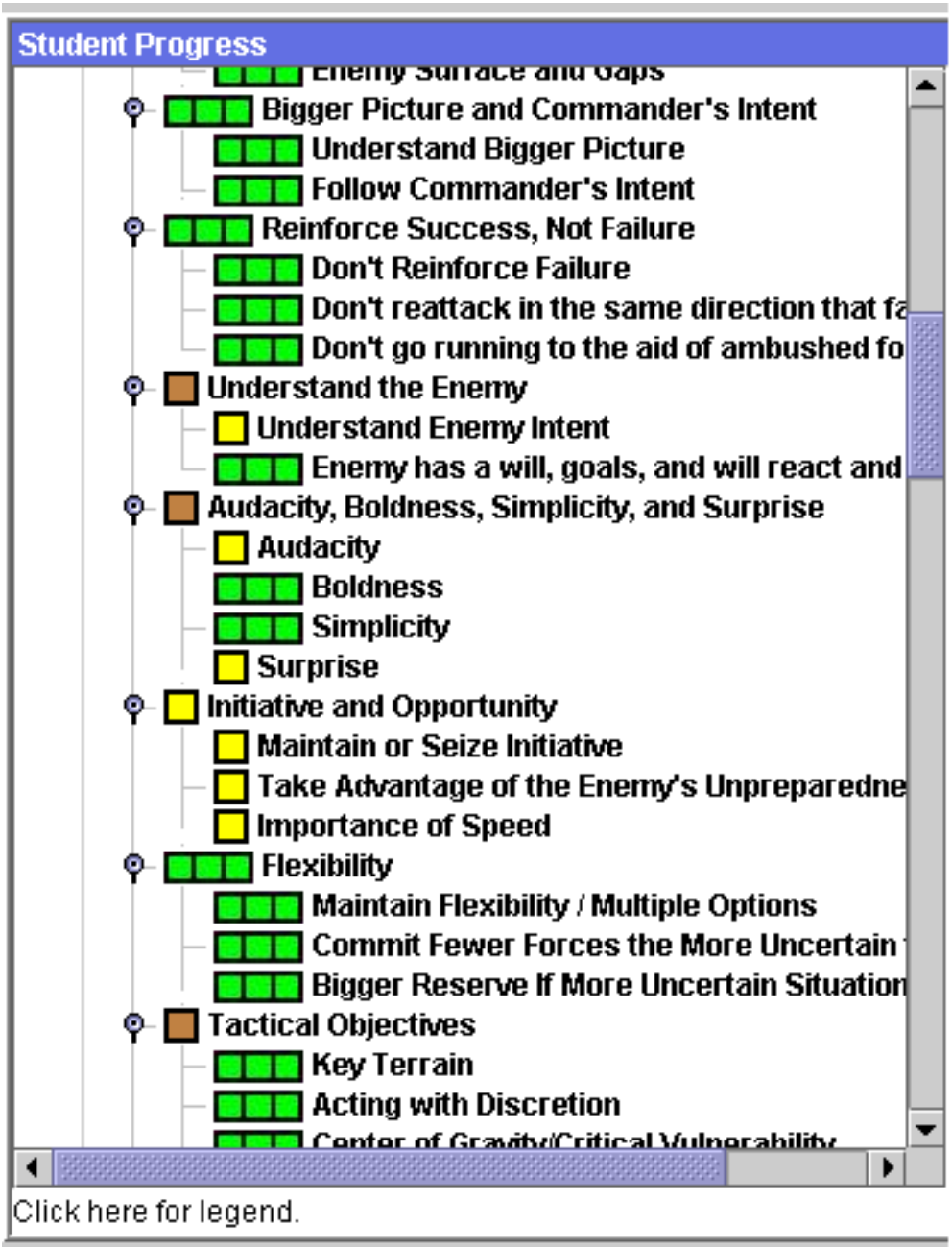
Student Modeling



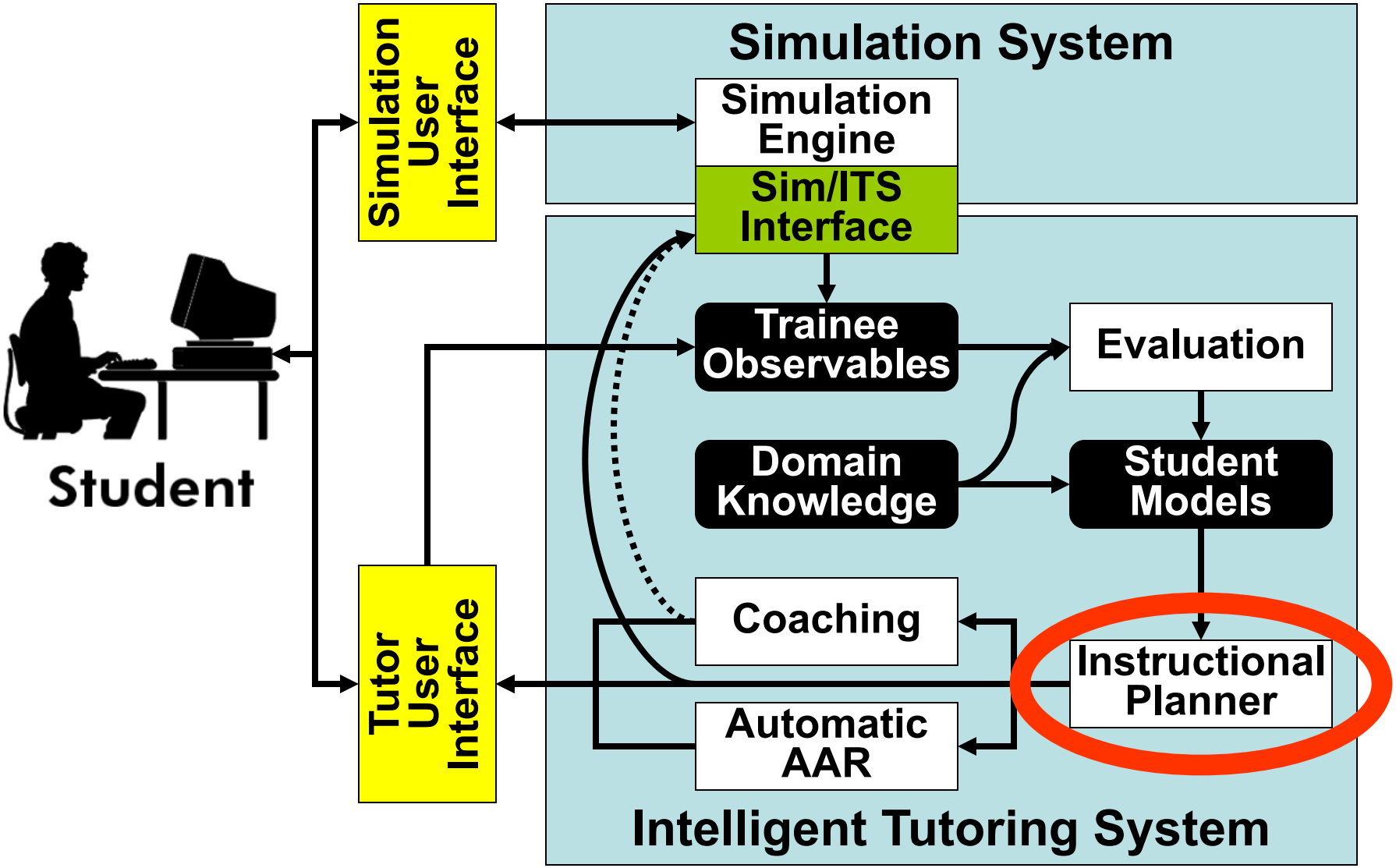
Student Model

- **Mastery estimate of skills and knowledge**
  - **Student's ability to APPLY them as appropriate**
  - **Inferred from actions in all simulated scenarios**
  - **"Principle" hierarchy (many dimensional)**
  - **Parallels domain knowledge model**
- **Each principle mastery estimate based on number of relevant, recent successes/failures**
- **Uses:**
  - **Feeds into all instructional decisions by ITS**
  - **Can present as feedback to student**
  - **Can report to instructor/supervisor/commander**

Student Model Example:



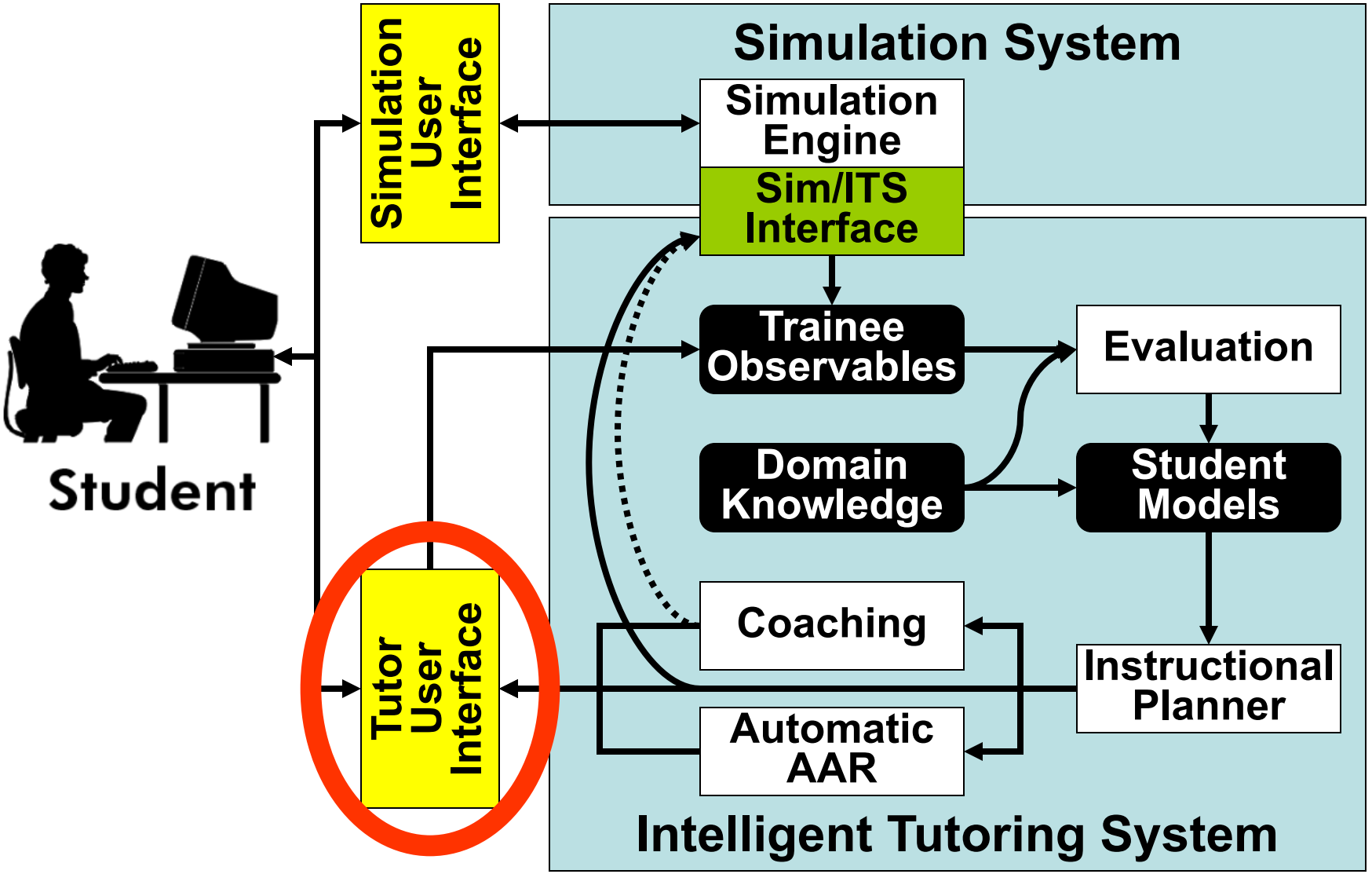
Instructional Planner



Instructional Planner

- **Formulates instructional plan from student model**
- **Decides next instructional event**
  - **Next scenario**
  - **Hint**
  - **Positive/negative feedback, when**
  - **Remedial exercises**
  - **Direct instruction**
  - **IMI**
  - **Demonstrations**

Tutor User Interface



User Interface

Session management & information conduit…

- **Logon, briefing, hints, feedback, questions, etc.**

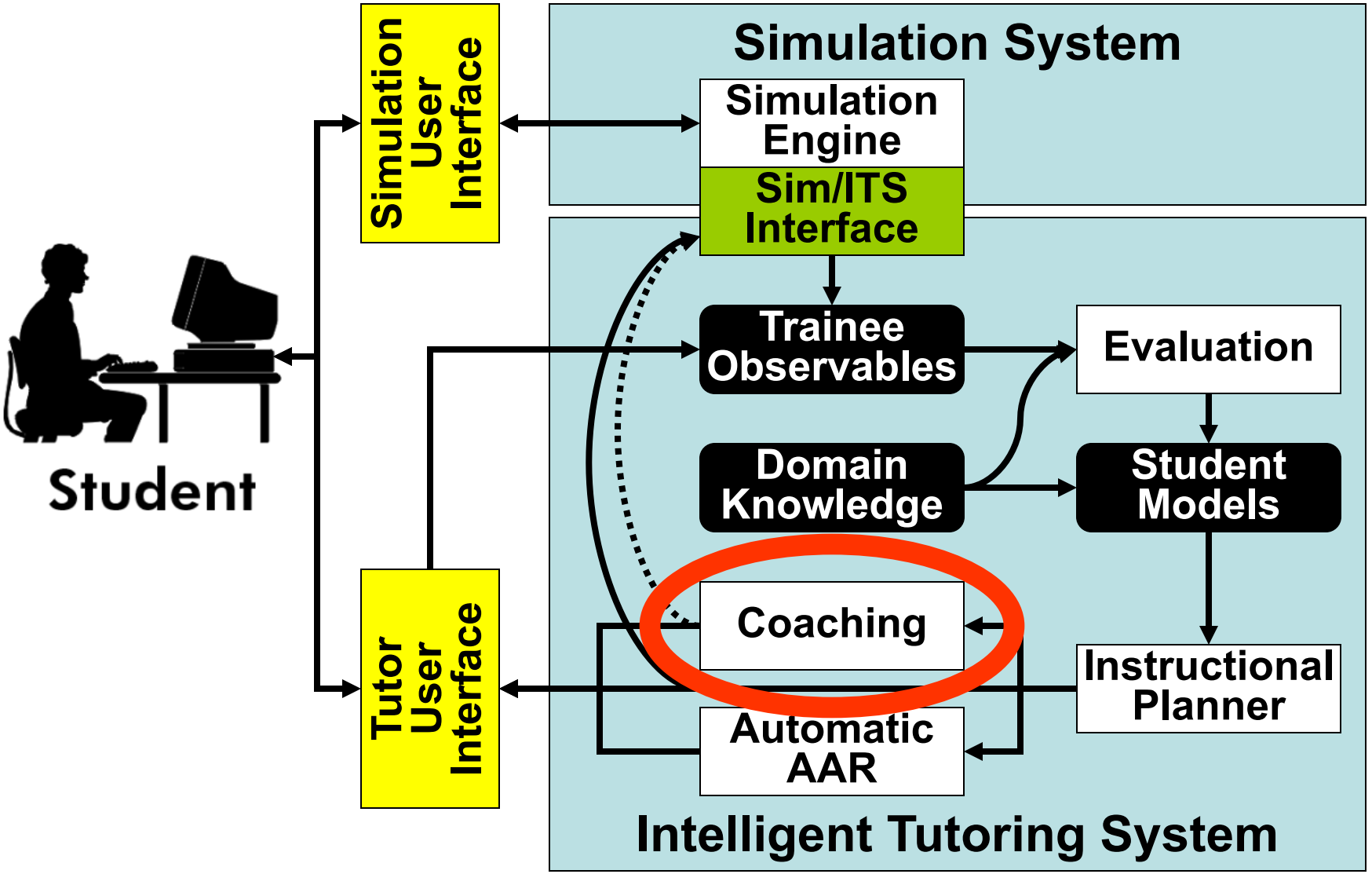
Variety of control schemes

- **Student control**
- **Off-line instructor control**
- **Live instructor control (coordination required)**
- **ITS control**
- **Dynamic mix (requires careful usability design)**

Possibly integrated into simulation

- **ITS window**
- **Simulation window**
- **Simulation “character”**

Automated Coaching



Process-based coaching and feedback

- **The assessment should have uncovered the areas of challenge for the learner**
- **The ITS provides process-based feedback**
  - **Not just “This is incorrect”**
  - **But “this is incorrect because…”**
- **Alternately, the tutor can coach**
  - **“let’s break this down…”**
  - **“let’s talk about how you are thinking about this…”**

Coaching

Real-time simulation interface for evaluation

Immediately notify student of mistakes

Process feedback is better for beginners

Proactively hint when student likely to fail

- **Based on student model & principles about to fail**
- **Least specific hint which allows correct decision**

Reactively respond to student questions

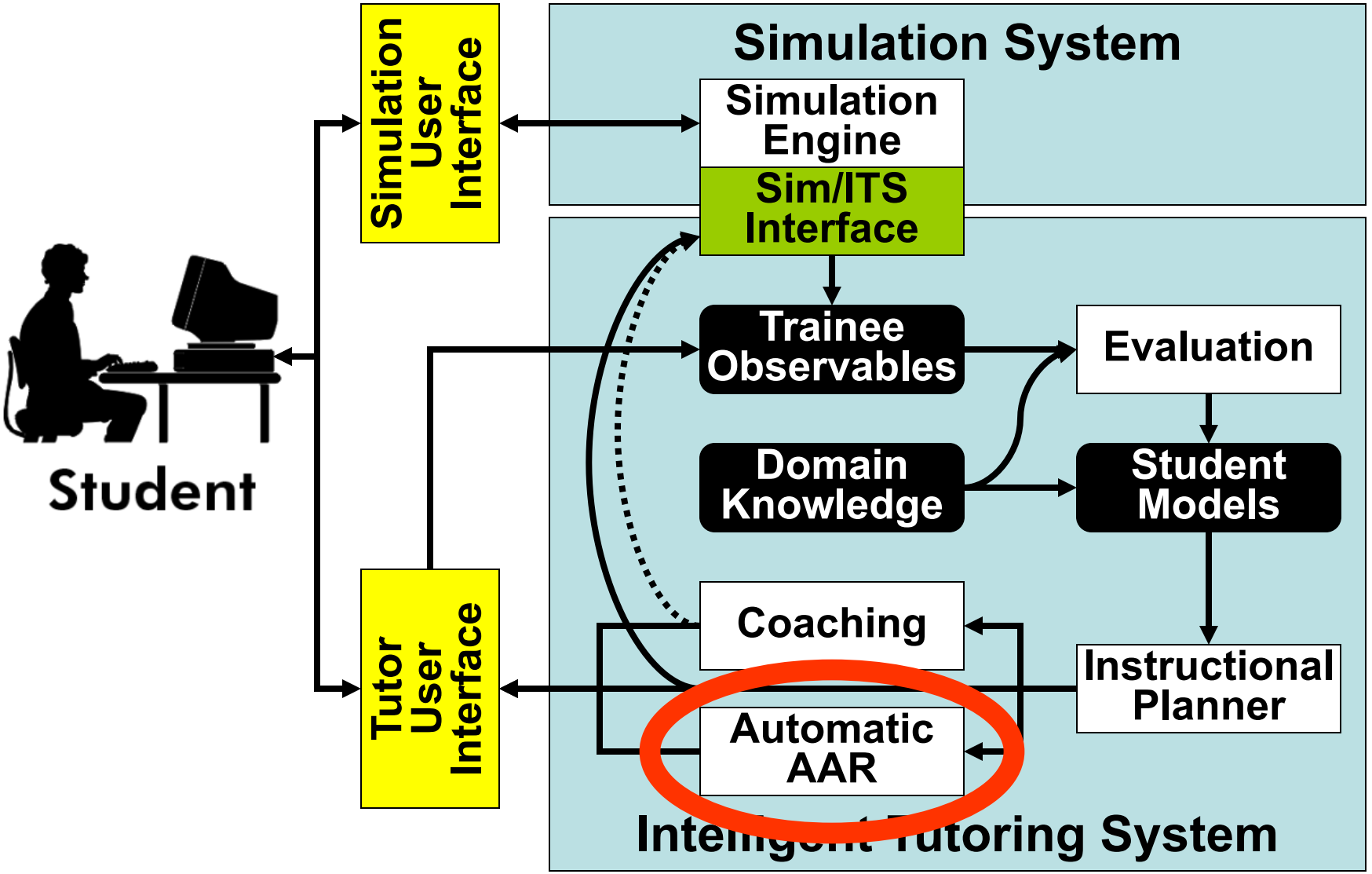
Less commonly notify student of correct actions

- **Most appropriate for beginners**

Aim to avoid disruption

- **Small text/audio comments, highlight element, etc.**

Automatic After Action Review



Automatic AAR/Debriefing

Report card format

- **Sorted by Correct/Incorrect**
- **Sorted by priority**
- **Sorted by principle and principle category**
- **Sorted by chronology (log)**
- **Generally allow access to multimedia descriptions**

Interactive format

Narrative format

Socratic AAR

Interactive format for AAR

Extended dialog, built around tutor questions

Tutor gets chance to build insight into student

- **Not just their actions, but their *reasons* for action**

Student gets chance to originate/own/explore critiques of own actions

- **Not just told, but led to *conclude for self***

Can go beyond overt simulation outcomes

- **Questions can address hypotheticals**

ITS RESOURCES

ITS Development Frameworks

Generalized Intelligent Tutoring Framework(GIFT)

- An architecture developed by ARL-HRED as a open-source, reusable ITS architecture
- Service-Oriented Architecture
- Modular design provides a framework for interoperability and reuse

FlexiTrainer

- Similar to GIFT, developed by Stottler Henke
- Agent-based architecture
- Modular design supports interoperability and reuse

GIFT

- **A reusable, service-oriented framework**
- **Objectives**
  - **Establish a common ontology for domain and performance assessment knowledge**
  - **Establish a set of reusable, domain independent ITS modules**
  - **Establish a test bed environment for systematic comparison of various ITS functionality**
- **GIFT defines a standardized architecture**
  - **A set of tutoring components**
  - **A definition of the interface between them**
  - **Any module that implements the proper interface can plug into the architecture and interact with components developed by others**
- **www.gifttutoring.org**

FlexiTrainer

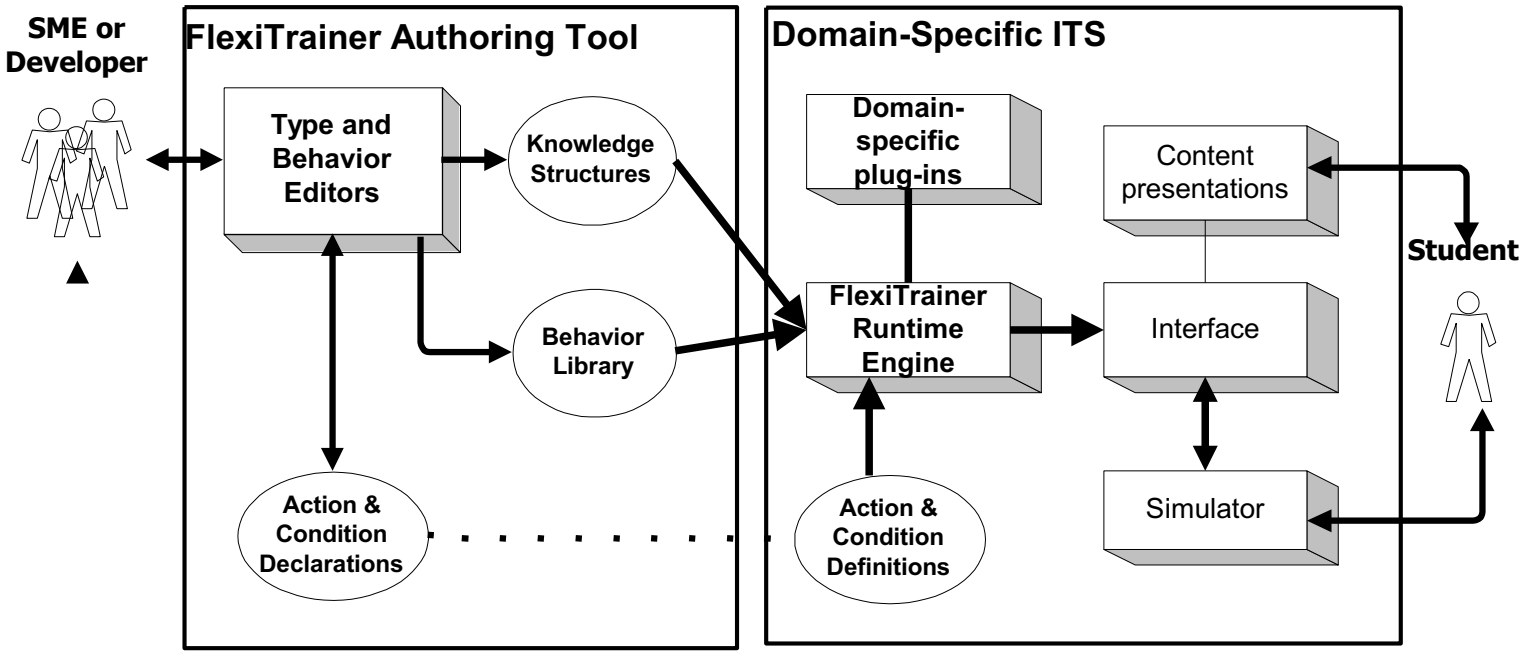
Framework and tools for building intelligent tutoring systems

Flexible and extensible

Provides:

- **Runtime engine**
  - Goal-driven agents for assessment and coaching
  - Instructional planner
  - Student model
- **Course authoring tool**

FlexiTrainer: Overview



A Framework for Supporting Reuse

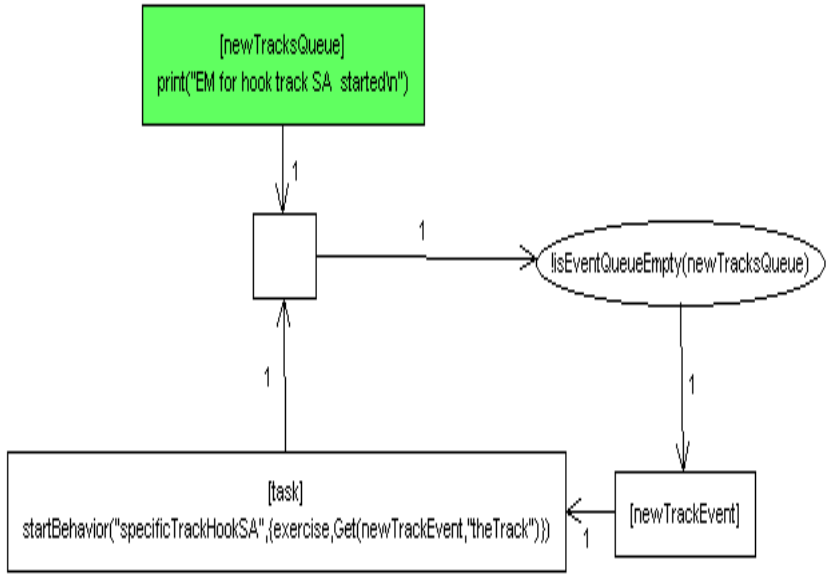
- **Extensible Framework**
  - **Interfacing with a variety of third-party simulations**
    - Well-defined interface between the runtime engine and simulations to pass data
- **Extensible instructional strategies**
  - **Instructional strategies modeled as agents**
  - **Rules control the selection of agents that best meet current instructional goals**
  - **New strategies created by adding agents and adding/modifying rules**
  - **Agents communicate by publishing and consuming events and messages.**
- **Extensible performance assessment and student modeling**
  - **In fact, every ITS role is represented by a collection of agents**
  - **This includes performance assessment, instructional planning, and student modeling**

Visual Behavior Authoring

Agent behaviors are represented as Behavior Transition Networks (BTNs)

- **BTNs are a generalization of Finite-State Machines**

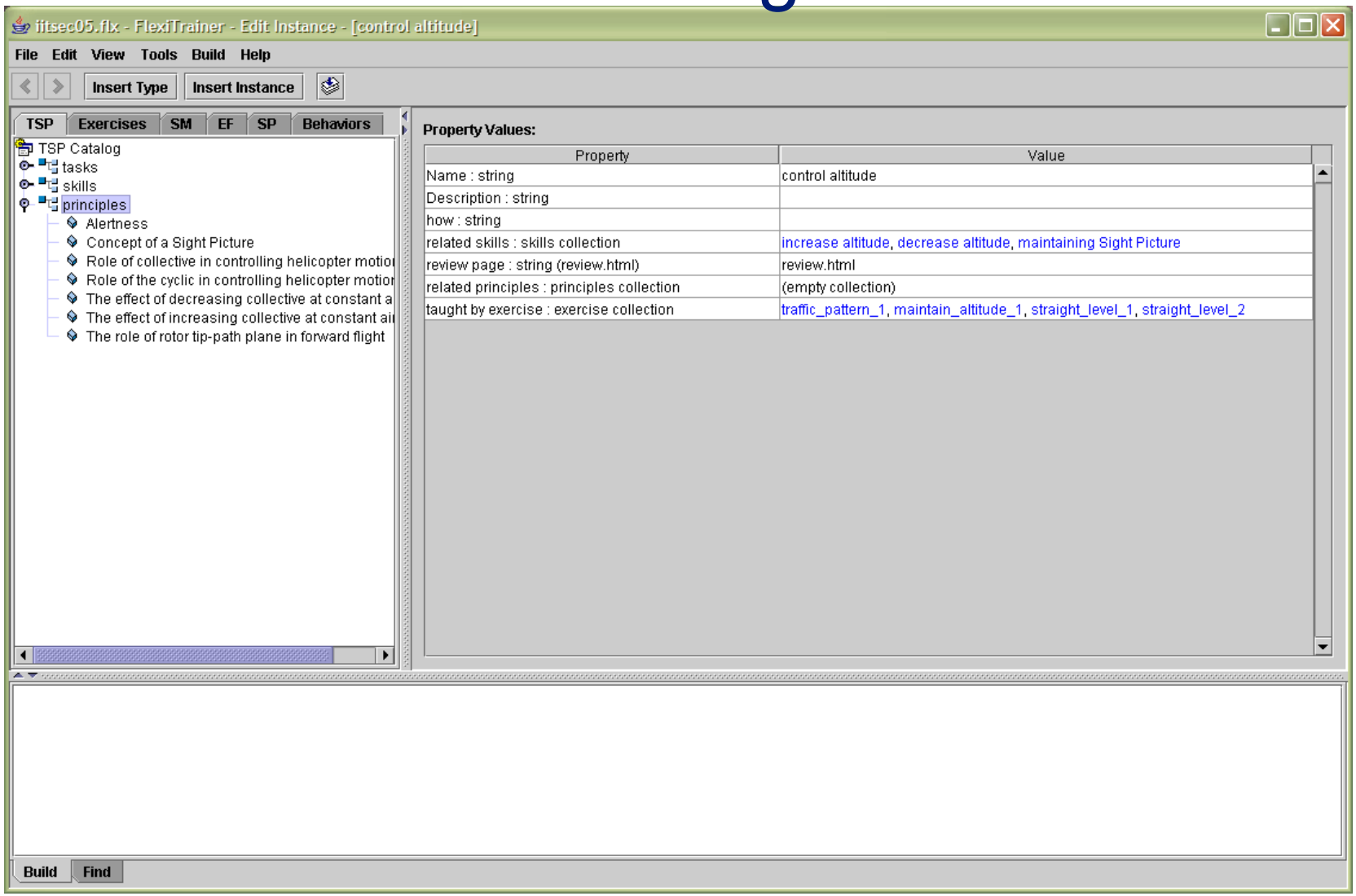
Behaviors are authored visually using Stottler Henke's SimBionic tool



Ontology Editors

- **FlexiTrainer provides editors for specifying**
  - **types of domain objects, their instances, and relationships between objects**
  - **domain principles and relationships between them**
  - **hierarchy of simulation and tutoring events**

FlexiTrainer Authoring Tool



Other ITS Authoring Tools

Entire system (simulation & ITS, combined)
RIDES/VIVIDS, SIMQUEST, SimCore

Academic ITS authoring tools (Tom Murray's book)

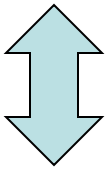
Sim. development tools (many); IMI Dev. Tools (several)

Examples:

- **Cognitive Tutor Authoring Tools (CTAT)**
- **REDEEM**
- **SimBionic / SimVentive**
- **Task Tutor Toolkit**
- **FlexiTrainer**

Is an ITS right for you?

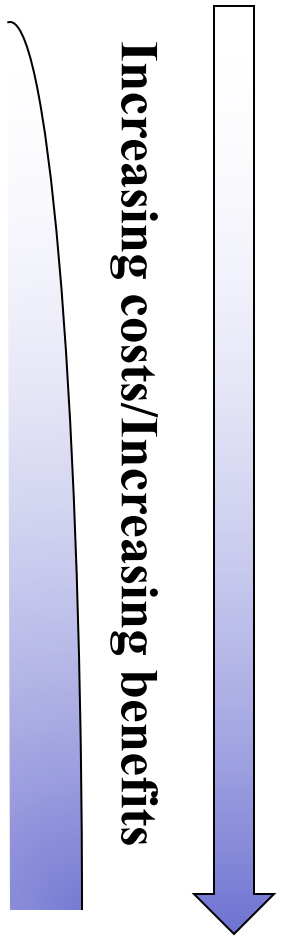
- **Adaptive learning systems can span the spectrum from**
  - **Simple mastery-based adaptive sequencing**



  - **Traditional ITS based on cognitive modeling**

ITS: Cost-Benefit Trade-off

Level1	CBT with mastery-based adaption
Level 2	Process-based assessment (step-by-step problem-solving interface, simple means of asking for explanation of their actions) Combined with process-based hints and feedback And mastery learning
Level 3	Modeling misconceptions and typical mistakes
Level 4	Including an expanded variety of learning and assessment experiences at different challenge levels
Level 5	Develop an ITS based on a cognitive model of the domain
Level 6	Dialog-based interactions for assessment and coaching



ITS Future Directions

Mainstream DOD acquisition upswing

More emphasis on supported, commercial authoring tools

- **Second generation**
- **Easy to author**

Game-based

Natural Dialogue (verbal and/or chat)

Emotional modeling, emotional agents

Convergence between Learning Analytics and intelligent tutoring

Convergence between new forms of online learning (MOOCs, “learning in the wild”) with intelligent tutoring

References (1)

Domeshek, E., E. Holman, S. Luperfoy, "Discussion Control in an Automated Socratic Tutor", *I/ITSEC 2004,* Dec. 2004.

Mitrovic, A., Martin, B., & Mayo, M. (2002). Using evaluation to shape ITS design: Results and experiences with SQL-Tutor. *User Modeling and User-Adapted Interaction*, *12*(2-3), 243-279.

Mostow, J., Aist, G., Burkhead, P., Corbett, A., Cuneo, A., Eitelman, S. et al. (2003). Evaluation of an automated Reading Tutor that listens: Comparison to human tutoring and classroom instruction. *Journal of Educational Computing Research*, *29*(1), 61-117.

Murray, T., *Authoring Tools for Advanced Technology Learning Environments*, Kluwer Academic Publishers, 2003.

Nichols, P., Pokorny, R., Jones, G., Gott, S. P., & Alley, W. E. Evaluation of an avionics troubleshooting tutoring system (Special Report). *Brooks AFB, TX: Air Force Human Resources Laboratory*.

Pane, J. F., McCaffrey, D. F., Slaughter, M. E., Steele, J. L., & Ikemoto, G. S. (2010). An experiment to evaluate the efficacy of cognitive tutor geometry. *Journal of Research on Educational Effectiveness*, *3*(3), 254-281.

References (2)

Ramachandran, S., E. Remolina, D. Fu, "FlexiTrainer: A Visual Authoring Framework for Case-based Intelligent Tutoring Systems", Proceedings of the Seventh International Conference on Intelligent Tutoring (ITS 2004).

Ramachandran, S., & Atkinson, R. (2008). An Evaluation of Intelligent Reading Tutors. *Proceedings from Intelligent Tutoring Systems*.

Ramos, C., Frasson, C., Ramchandran, S., "Special Issue on Real World Applications of Intelligent Tutoring Systems", IEEE Transactions on Learning Technologies, Vol. 2, April-June, 2009.

Stottler, R., Panichas, S., Treadwell, M., Davis, A., Designing and Implementing Intelligent Tutoring Instruction for Tactical Action Officers, *I/ITSEC 2007*. Dec., 2007.

VanLehn, K., Lynch, C., Taylor, L., Weinstein, A., Shelby, R., Schulze, K. et al. (2002). Minimally invasive tutoring of complex physics problem solving. *Intelligent Tutoring Systems,* 367-376.

Woolf, B., *Building Intelligent Tutors*, Morgan Kauffmann, 2009.