

# Intelligent Systems (AI-2)

## Computer Science cpsc422, Lecture 13

Oct, 6, 2017

# How many samples? (Hoeffding's inequality)

- $p$  can be the probability of any event for random variable  $X = \{X_1, \dots, X_n\}$  described by a Bayesian network
- Suppose  $p$  is the true probability and  $s$  is the sample average from  $n$  independent samples.

$$P(|s - p| > \varepsilon) \leq 2e^{-2n\varepsilon^2}$$

- If you want an infinitely small probability of having an error greater than  $\varepsilon$ , you need infinitely many samples
- But if you settle on something less than infinitely small, let's say  $\delta$ , then you just need to set

$$2e^{-2n\varepsilon^2} < \delta$$

- So you pick
  - the error  $\varepsilon$  you can tolerate,
  - the frequency  $\delta$  with which you can tolerate it
- And solve for  $n$ , i.e., the number of samples that can ensure this performance

$$n > \frac{-\ln \frac{\delta}{2}}{2\varepsilon^2} \quad (1)$$

# Hoeffding's inequality

## ➤ Examples:

- You can tolerate an error greater than 0.1 only in 5% of your cases
- Set  $\varepsilon = 0.1$ ,  $\delta = 0.05$
- Equation (1) gives you  $n > 184$

$$n > \frac{-\ln \frac{\delta}{2}}{2\varepsilon^2} \quad (1)$$

- If you can tolerate the same error (0.1) only in 1% of the cases, then you need 265 samples
- If you want an error greater than 0.01 in no more than 5% of the cases, you need 18,445 samples

# Hoeffding's inequality

## ➤ Examples:

- You can tolerate an error greater than 0.1 only in 5% of your cases
- Set  $\epsilon = 0.1$ ,  $\delta = 0.05$
- Equation (1) gives you  $n > 184$

$$n > \frac{-\ln \frac{\delta}{2}}{2\epsilon^2} \quad (1)$$

can rewrite  
as

$$n > \frac{\ln \frac{2}{\delta}}{2\epsilon^2}$$

- If you can tolerate the same error (0.1) only in 1% of the cases, then you need 265 samples

- If you want an error greater than 0.01 in no more than 5% of the cases, you need 18,445 samples

so it should be  
clear that

↓ goes down  
↑ goes up

$\epsilon$  ↓  
 $\delta$  ↓

$n$  ↑

# Cited by 561

## Using Bayesian networks to manage uncertainty in student modeling

C Conati, A Gertner, K Vanlehn – User modeling and user-adapted ..., 2002 – Springer

When a tutoring system aims to provide students with interactive help, it needs to know what knowledge the student has and what goals the student is currently trying to achieve. That is, it must do both assessment and plan recognition. These modeling tasks involve a high level...

# Some recent (2017) citations

## IRT-based adaptive hints to scaffold learning in programming

M Ueno, Y Miyazawa – IEEE Transactions on Learning ..., 2017 – [ieeexplore.ieee.org](http://ieeexplore.ieee.org)

35 days ago – Over the past few decades, many studies conducted in the field of learning science have described that scaffolding plays an important role in human learning. To scaffold a learner efficiently, a teacher should predict how much support a learner must have

## Leveraging CPTs in a Bayesian Approach to Grade Open Ended Answers

M De Marsico, A Sterbini... – ... (ICALT), 2017 IEEE 17th ..., 2017 – [ieeexplore.ieee.org](http://ieeexplore.ieee.org)

52 days ago – Here we discuss a framework (OpenAnswer) providing support to the teacher's activity of grading answers to open ended questions. OpenAnswer implements a teacher mediated peer-evaluation approach: the marking results obtained from peer assessments

## Classification and prediction of port variables using Bayesian Networks

BM Serrano, N González-Cancelas, F Soler-Flores... – Transport Policy, 2017 – Elsevier

58 days ago – Abstract Many variables are included in planning and management of port terminals. They can be economic, social, environmental and institutional. Agent needs to know relationship between these variables to modify planning conditions. Use of Bayesian

## Learner Modeling for Integration Skills

Y Huang, J Guerra-Hollstein, J Barria-Pineda... – Proceedings of the 25th ..., 2017 – [dl.acm.org](http://dl.acm.org)

83 days ago – Abstract Complex skill mastery requires not only acquiring individual basic component skills, but also practicing integrating such basic skills. However, traditional approaches to knowledge modeling, such as Bayesian knowledge tracing, only trace

## Predicting Learner's Deductive Reasoning Skills Using a Bayesian Network

A Tato, R Nkambou, J Brisson, S Robert – International Conference on ..., 2017 – Springer

92 days ago – Abstract Logic-Muse is an Intelligent Tutoring System (ITS) that helps improve deductive reasoning skills in multiple contexts. All its three main components (The learner, the tutor and the expert models) have been developed while relying on the help of experts

## Exploring Learner Model Differences Between Students

M Eagle, A Corbett, J Stamper, BM McLaren... – ... Conference on Artificial ..., 2017 – Springer

92 days ago – Abstract Bayesian Knowledge Tracing (BKT) has been employed successfully in intelligent learning environments to individualize curriculum sequencing and help messages. Standard BKT employs four parameters, which are estimated separately for

# ILE: Challenges

Representing the instructional domain (expert model)

Understanding the student (student model)

Providing adequate help and instruction (tutoring model)

# ANDES: an ITS for Coached problem solving

- The tutor monitors the student's solution and intervenes when the student needs help.
  - Gives feedback on correctness of student solution entries
  - Provides hints when student is stuck

ANDES Physics Workbench - [P11-2-Solution.fbd]

File Edit Diagram Variable View Help

A 2000-kg car in neutral at the top of a 20-degree inclined driveway 20 m long slips its parking brake and rolls down. Assume that the driveway is frictionless.

At what speed will it hit the garage door?

Answer:

**Think about the direction of N...**  
have a complete free [body](#) diagram for the car.

[Explain further](#) [Hide](#) CPSC 422, Lecture 13

For Help, press F1

Name	Definition	X-Comp	Y-Comp
T0	car starts rolling		
T1	car hits garage door		
mc	mass of car		
Fw	magnitude of the Weight For...		

1.  $F_w = mc * g$

2.

3.

4.

5.

6.

NUM 00:02:11



# Student Model for Coached Problem Solving

## Three main functions

- **Assess from the student's actions her domain knowledge**, to decide which concepts the student needs help on (*knowledge tracing*)
- **Infer from student's actions the solution being followed**, to understand what the student is trying to do (*plan recognition*)
- **Predict what further actions should be suggested to the student**, to provide meaningful suggestions (*adaptive procedural help*)

# Andes user interface

Problem solving interface

The screenshot shows the ANDES Physics Workbench interface. The main window title is "ANDES Physics Workbench - [dt5o.fbd]". The menu bar includes "File", "Edit", "Diagram", "Variable", "View", and "Help". The toolbar contains various icons for file operations and physics tools.

**Problem description:** A 2000-kg car in neutral at the top of a 20.0 deg inclined driveway 20.0 m long slips its parking brake and rolls down. If we ignore friction and drag, what would the magnitude of the velocity of the car be when it hits the garage door?

**Diagram:** A diagram shows a car on a 20-degree inclined driveway of length 20 m. A coordinate system is defined with +X along the incline and +Y perpendicular to it. A force vector  $F_w$  is shown acting vertically downwards from the car's center of mass.

**Variables table:**

Name	Unit	Dir	X-Comp	Y-Comp
T0	car starts rolling			
T1	car hits garage door			
x	ax		Rx=20°	
mc	mass of car			
d	magnitude of the Displacement of car at time T0 to T1		Xd=200°	d_x d_y
Fw	magnitude of the Weight Force on car at time T0 to T1 due to Earth		XFw=270°	Fw_x Fw_y

**Answer input:** A text box labeled "Answer:" is empty.

**Equation editor:**

1.  $mc = 2000 \text{ kg}$
2.  $d = 20.0 \text{ m}$
3.  $Fw_y = mc * g$

**Help text:**

T: Now that you have stated all of the given information, you should start on the major principles. What quantity is the problem seeking?  
S: The magnitude of the instantaneous Velocity of car at time T1  
T: Yep. What is the first principle application that you would like to work on? Hint: this principle application will actually be one that mentions the sought quantity explicitly. Therefore it's equation may contain the sought quantity that the problem seeks.

**Annotations:** Yellow callouts point to various parts of the interface: "Read a physics problem" points to the problem text; "Draw vectors" points to the force diagram; "Type in equations" points to the equation editor; "Type in answer" points to the answer input box.

# Andes feedback and hints

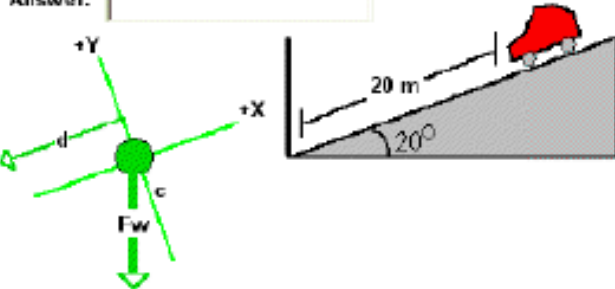
ANDES Physics Workbench - [dt5a.fbd]

File Edit Diagram Variable View Help

A 2000-kg car in neutral at the top of a 20.0 deg inclined driveway 20.0 m long slips its parking brake and rolls down.

If we ignore friction and drag, what would the magnitude of the velocity of the car be when it hits the garage door?

Answer:



Name	Definition	Dir	R...	Y-Comp
T0	car starts rolling			
T1	car hits garage door			
x	axle		Rx=20P	
mc	mass of car			
d	magnitude of the Displacement of car at time T0 to T1		Rd=200P	d_x d_y
Fw	magnitude of the Weight Force on car at time T0 to T1 due to Earth		WFw=270P	Fw_x Fw_y

Green means correct  
Red means incorrect

Dialogue & hints

T: Now that you have stated all of the given information, you should start on the major principles. What quantity is the problem seeking?  
S: The magnitude of the instantaneous Velocity of car at time T1  
T: Yep. What is the first principle application that you would like to work on? Hint: this principle application will usually be one that mentions the sought quantity explicitly. Therefore it's equation may contain the sought quantity that the problem seeks.

270 degrees 00:10:30 SCORE: 39

# Several sources of uncertainty

- Same action can belong to different solutions
- Often much of the reasoning behind the student's actions is hidden from the tutor
- Correct answers can be achieved through guessing
- Errors can be due to slips
- System's help affects learning
- In many domains, there is flexible solution step order

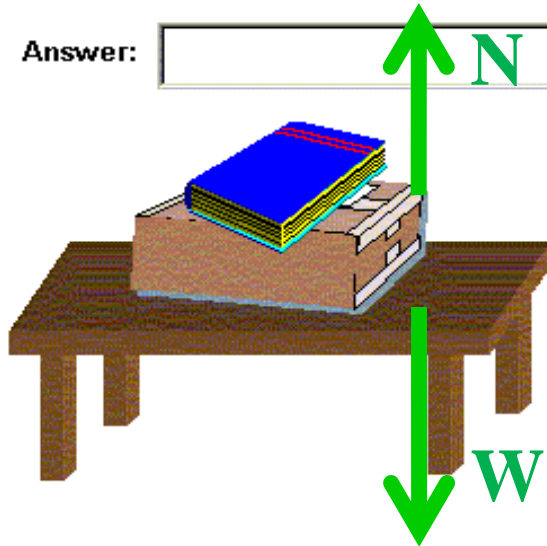
**Andes deals with this uncertainty by using Bayesian Networks**

# Example 1

A block of mass  $m = 2\text{kg}$  slides on a frictionless table pulled by a force  $F_p = 5\text{N}$ .

Find the acceleration of the block

Answer:



$$a = 5/2$$

## Correct solution

- $\Sigma F_t = \mathbf{W} + \mathbf{N} + \mathbf{F}_p = m \cdot \mathbf{a}$
- $\Sigma F_{t_x} = F_p = m \cdot a_x$
- $a = 5/2$

## Incorrect solution

- $F_p = m \cdot a$
- $a = 5/2$

If the student only types  $a = 5/2$  m/sec, what line of reasoning did she follow?

# Example 2

ANDES Physics Workbench - [P11-2-Solution.fbd]

File Edit Diagram Variable View Help

A 2000-kg car in neutral at the top of a 20-degree inclined driveway 20 m long slips its parking brake and rolls down. Assume that the driveway is frictionless.

At what speed will it hit the garage door?

Answer:

## Solution

Steps

- Find the velocity by applying the kinematics equation

$$V_{t_x}^2 = V_{0_x}^2 + 2d_x * a_x$$

- Find the acceleration of the car by applying Newton's 2<sup>nd</sup> law

$$\Sigma F_x = W_x + N_x = m * a_x$$

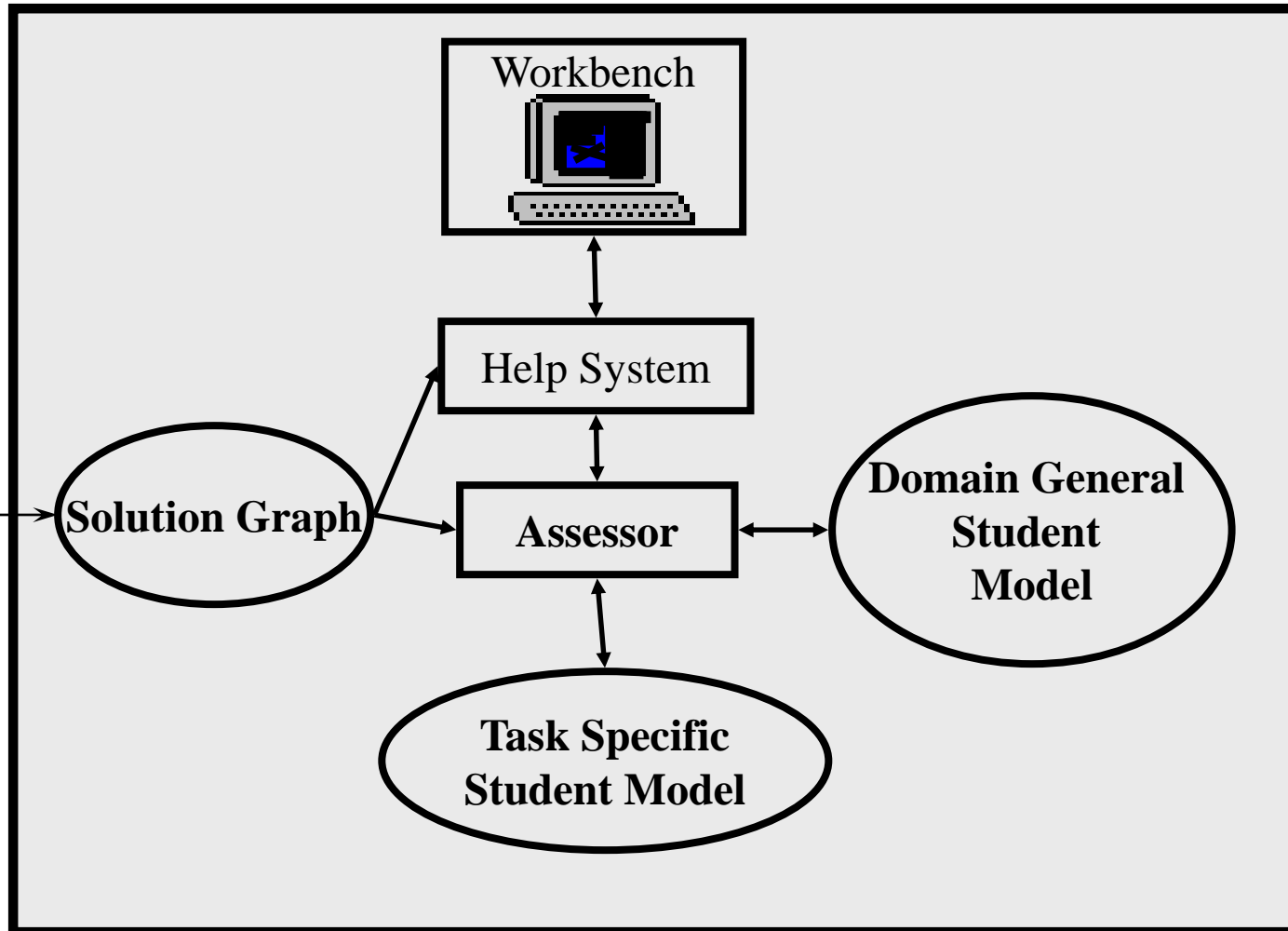
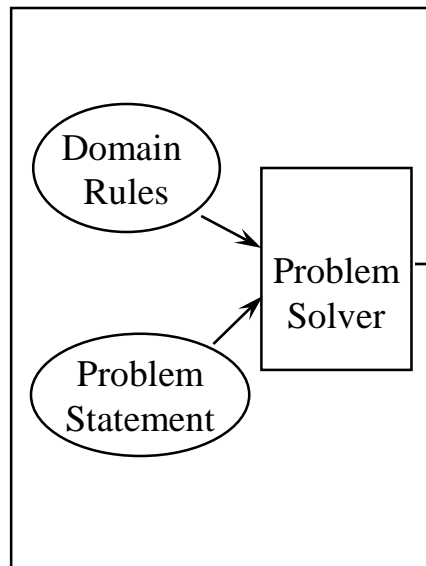
If the student draws the axes and then gets stuck, is she

- trying to write the kinematics equations to find V?
- trying to find the car acceleration by applying Newton's laws?

flexible solution step order

# Architecture

Andes



# Components of Andes' Student Model

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## ◆ Domain General

- Reflects the content of Andes' rules
- Defined once along with Andes' KB
- Maintained across problems
- Assesses the student's domain knowledge

## ◆ Task Specific

- Automatically built when a new problem is opened
- Assesses the student's task specific knowledge and problem solving behavior



# Domain General Bnet

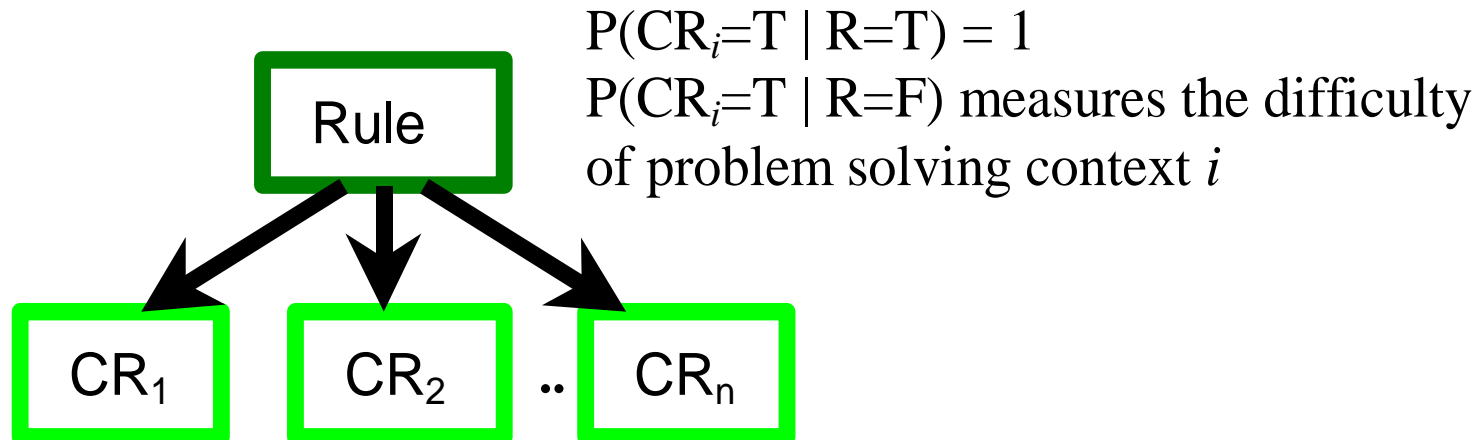
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## ◆ Rule nodes

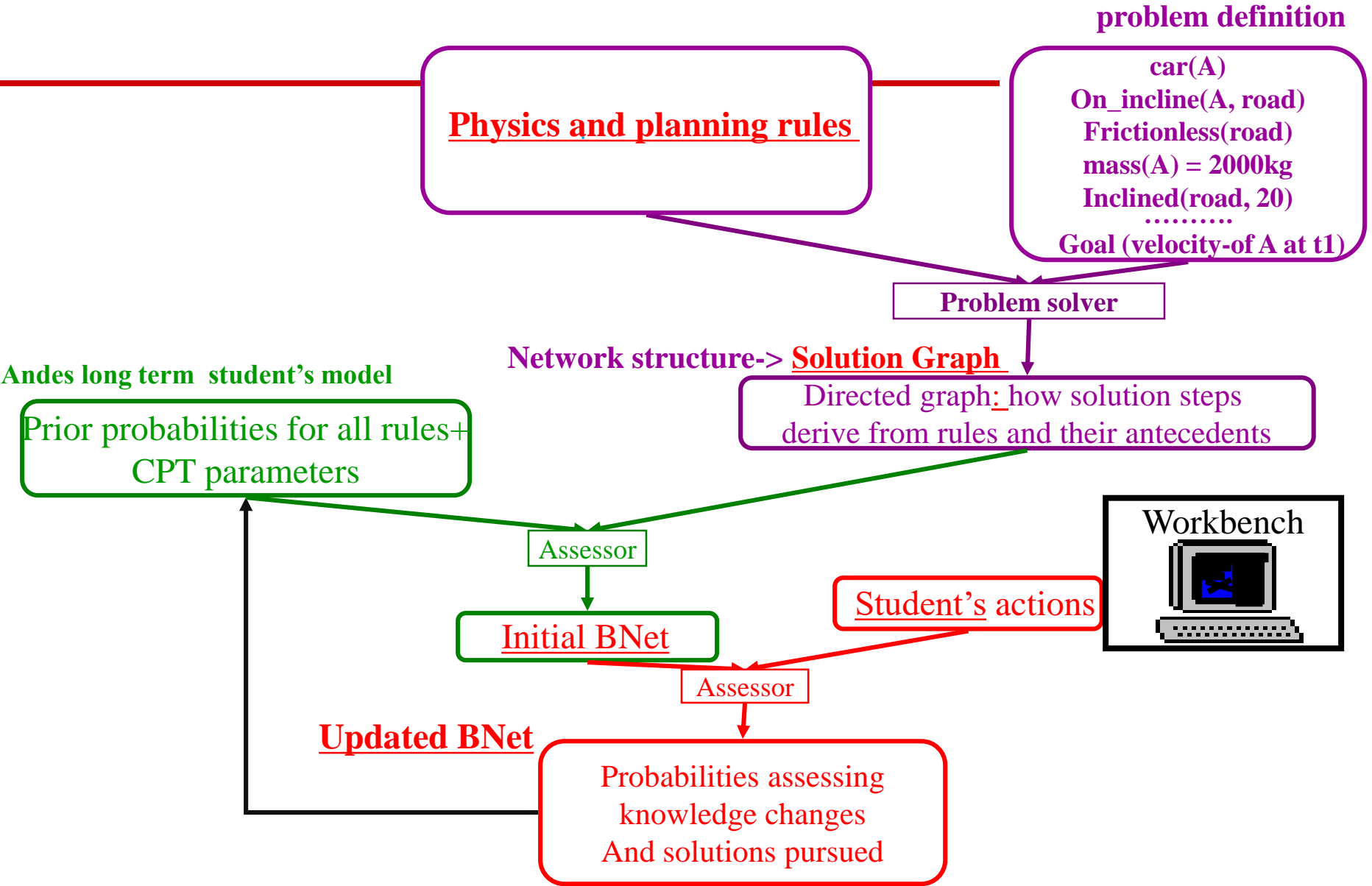
- represent knowledge of generic physics and planning rules
- $P(R = T)$ : probability that the student knows the rule (how to apply it in any context)

## ◆ Context rule nodes

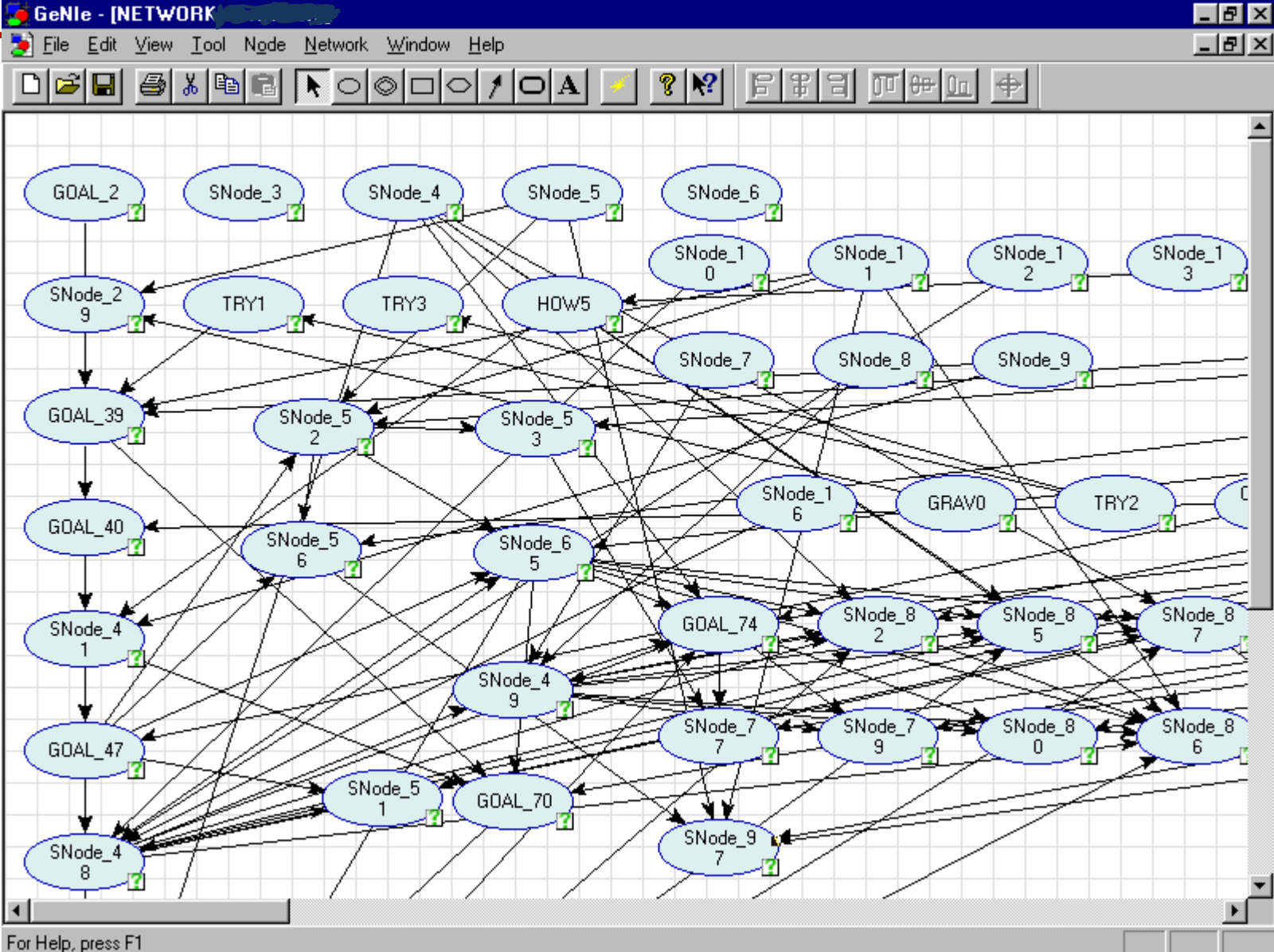
- Represent rules in specific problem solving contexts
- $P(CR = T)$ : probability that the student can use the rule in the corresponding context



# Construction of the task specific BNet



# Importance of Automatic Generation



# Andes rules: encode a solution approach

## R-try-Newton-2law

*If* the problem's goal is to find a force  
*then* set the goal to try Newton's second Law to solve the problem

## R-goal-choose-body

*If* there is a goal to try Newton's second law to solve a problem  
*then* set the goal to select a body to which to apply the law

## R-body-by-force

*If* there is a goal to select a body to apply Newton's second law  
*and* the problem goal is to find a force on an object  
*then* select as body the object to which the force is applied

## R-normal-exists

*If* there is a goal to find all forces on a body  
*and* And the body rests on a surface  
*then* there is a Normal Force exerted on the body by the surface

(a)

(b)

Involving goals

(c)

(d)

Encoding qualitative physics principles



# Andes problem solver generate a solution graph

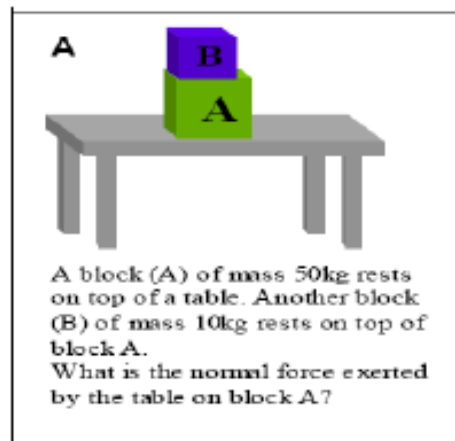
There is a block A, which has a magnitude of 50kg

1. Encode the problem to Andes problem solver as:

```
(SCALAR (KIND MASS) (BODY BLOCK-A) (MAGNITUDE 50) (UNITS KG))
```

2. Encode the problem goal to Andes problem solver as

```
(GOAL-PROBLEM (IS FIND-NORMAL-FORCE) (APPLIED-TO BLOCK-A)  
(APPLIED-BY TABLE) (TIME 1 2))
```



Find the normal force on block A applied by table

3. Find the sub-goals and apply rules until to solve the sought quantity

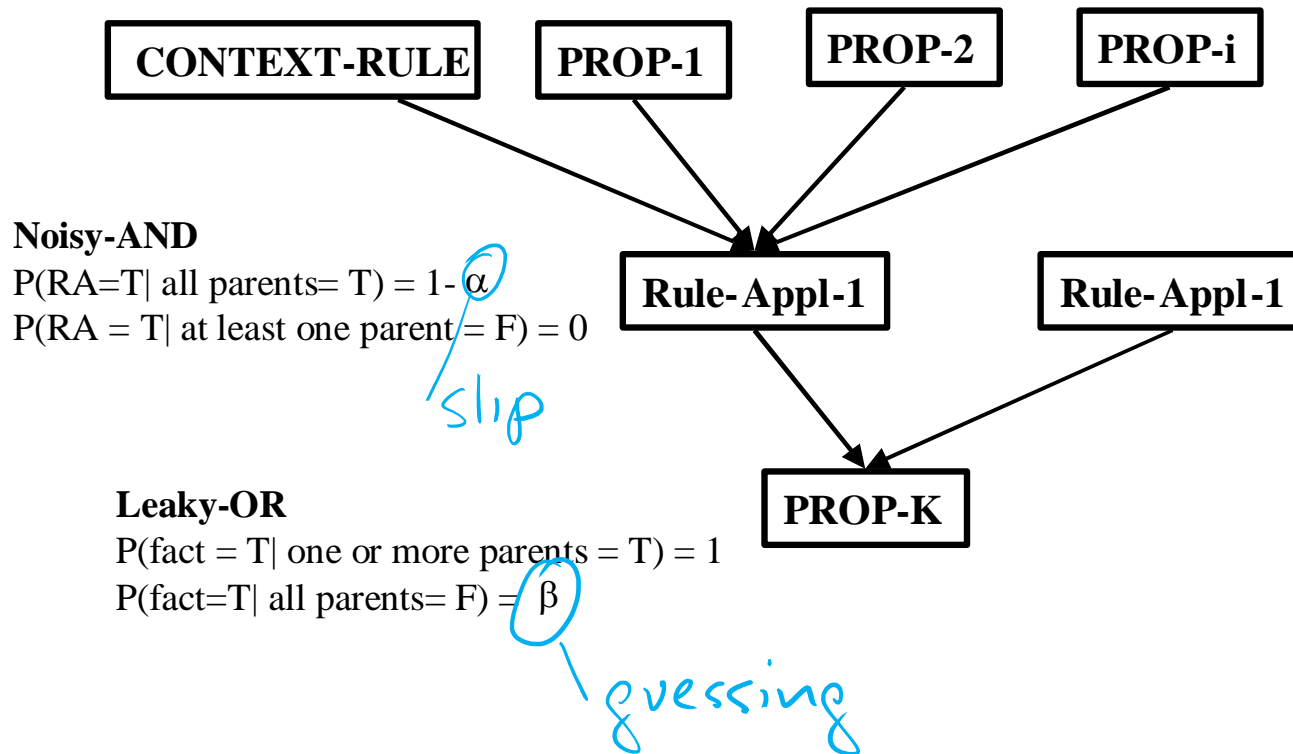
1. choose a body/bodies to which to apply the law,

2. identify all the forces on the body,

3. write the component equations for  $\Sigma F_i = m \cdot a$ .

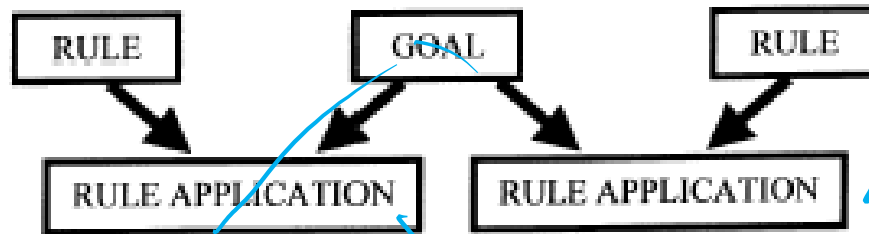


# Conditional Probabilities in the Task Specific BNet



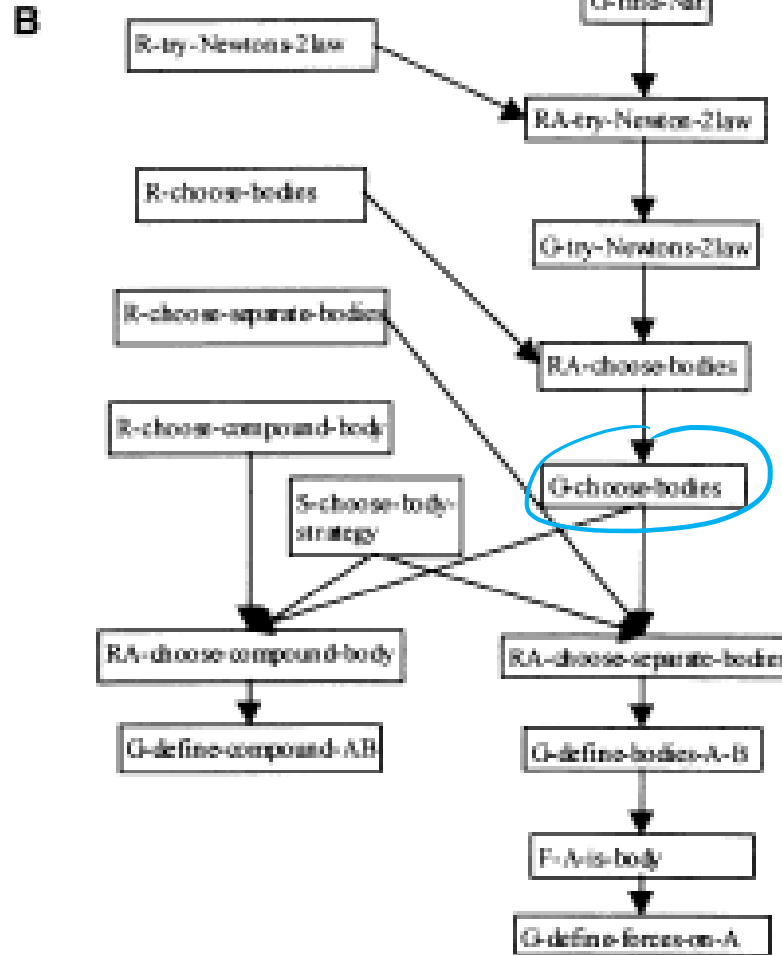
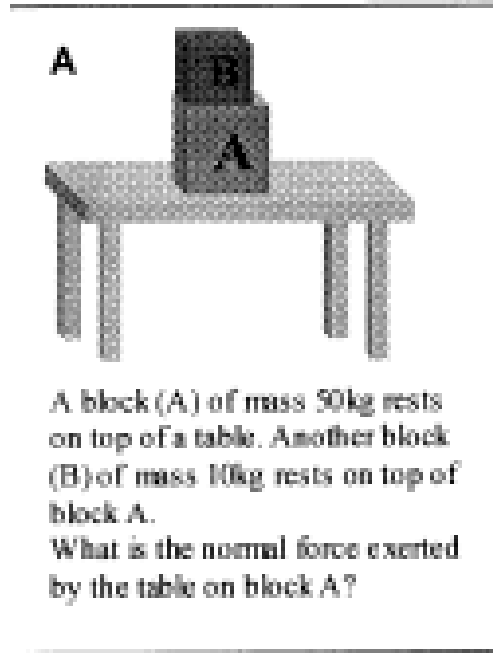
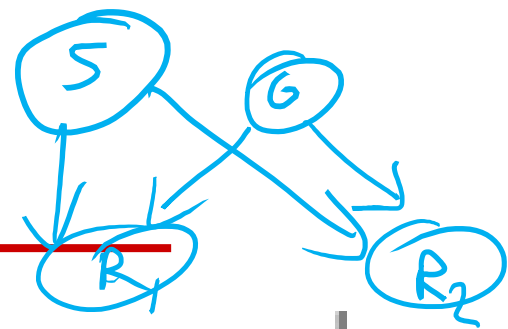
# Strategy Nodes

- ◆ If a given goal is involved in generating two alternative solutions, evidence that a student is following one solution should decrease the probability of the other solution
- ◆ This does not happen with the basic Andes' Bnet. Actually, evidence of a solution would increase the probability of any other alternative solution that shares a goal with it



*change structure of  
BNet  
to avoid  
undesired  
evidence  
propagation*

# Example



$S \quad \checkmark \quad \checkmark$

$P(R_1 | S)$

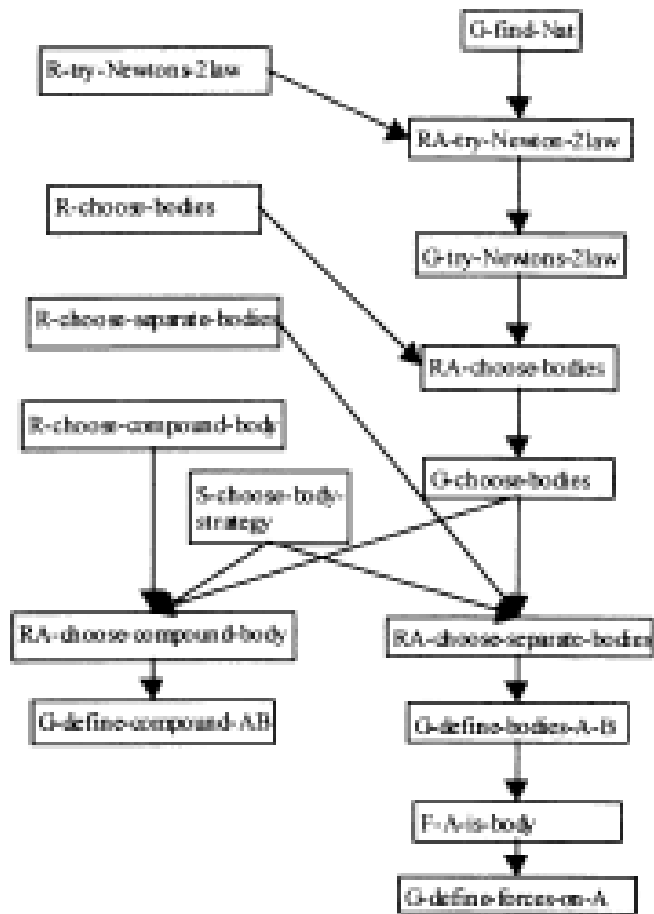
	T	F
$\checkmark_1$	1	0
$\checkmark_2$	0	1

$P(R_2 | S)$

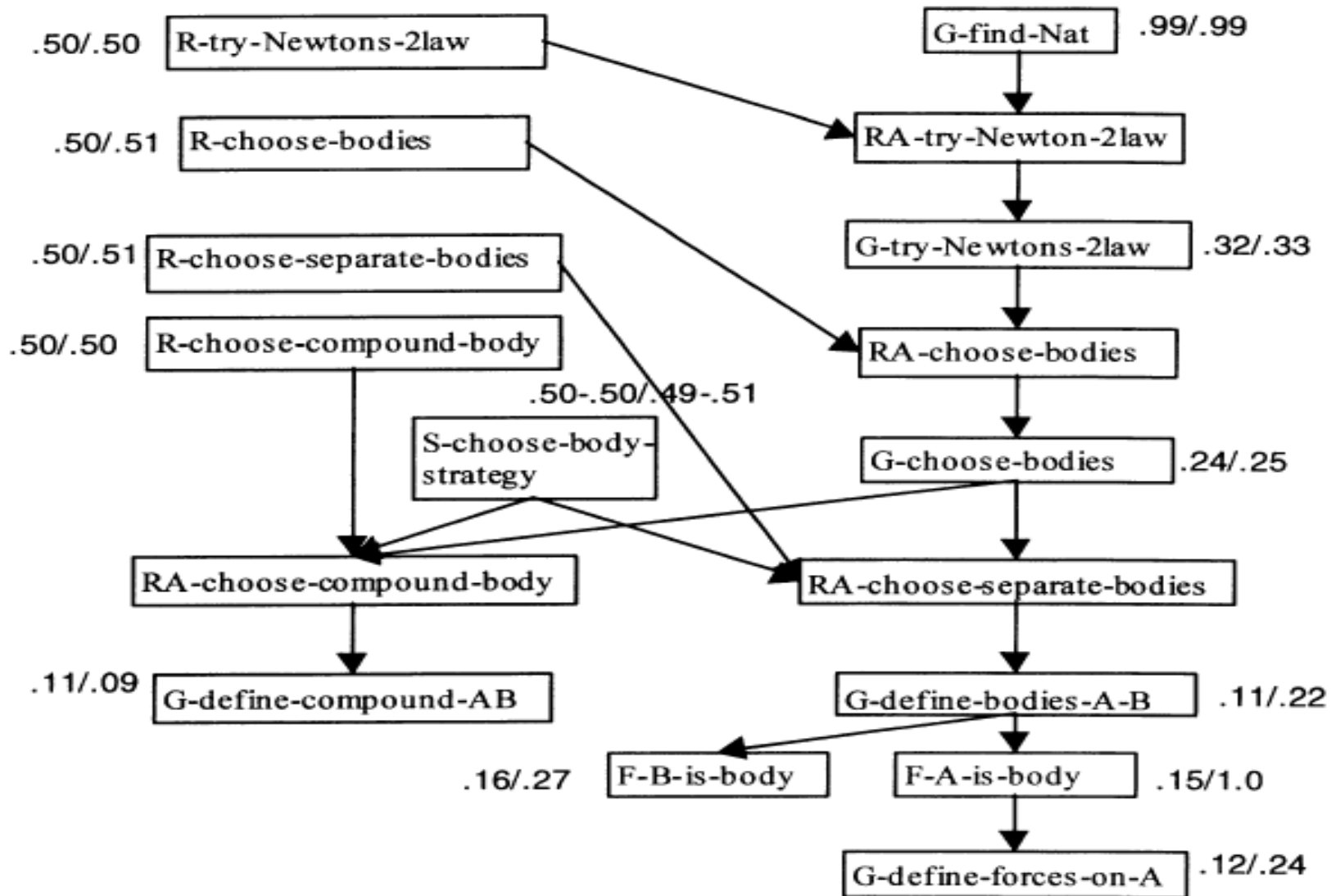
	T	F
$\checkmark_1$	0	1
$\checkmark_2$	1	0

two solutions





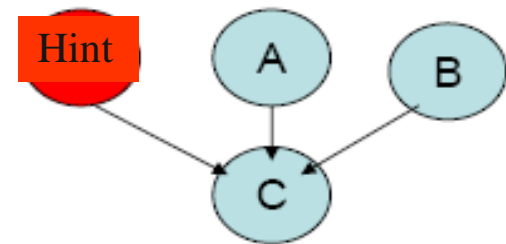
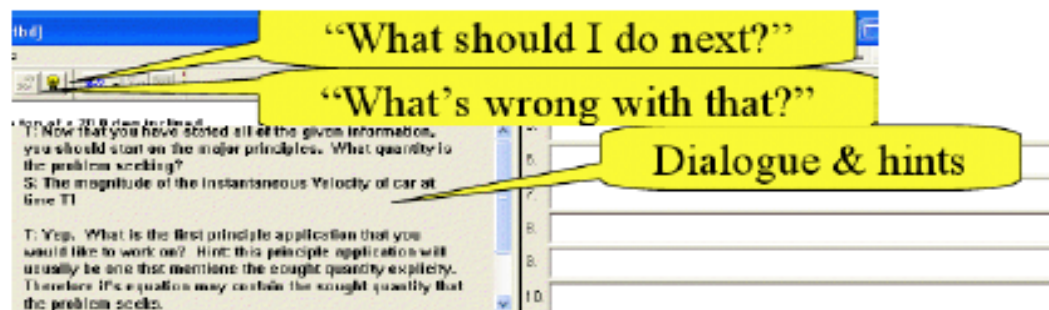
# The network before and after observing F-A-is-a-body.



# Andes problem solving Coach— handle Errors

- Two type errors:
  - Errors of omission :missing actions
  - errors of commission: disbelieve a certain correct fact or not clear what a correct action is
- Omission errors : rarely clamps nodes to F because Andes does not require explicit actions ordering
- Errors of commission:
  - Implies to disbelieve a certain correct fact, clamps nodes to F
  - otherwise not (more common)

# Andes problem solving Coach— handle hint issue



- Andes hints affect actions not domain knowledge
  - Hints just reminds knowledge not teaches it;
  - Hints increases the chance of guessing the next action.
- Hint node is added as a parent node of the proposition node

## Andes problem solving Coach— generate help (plan recognition)

Use Bayesian network to figure out what is the goal trying to achieve (plan recognition) and where to get stuck (action prediction) before generate help.

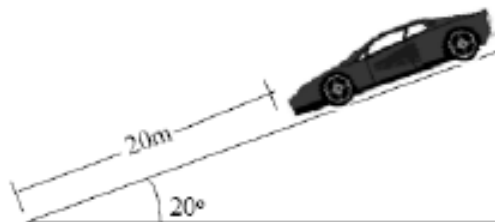
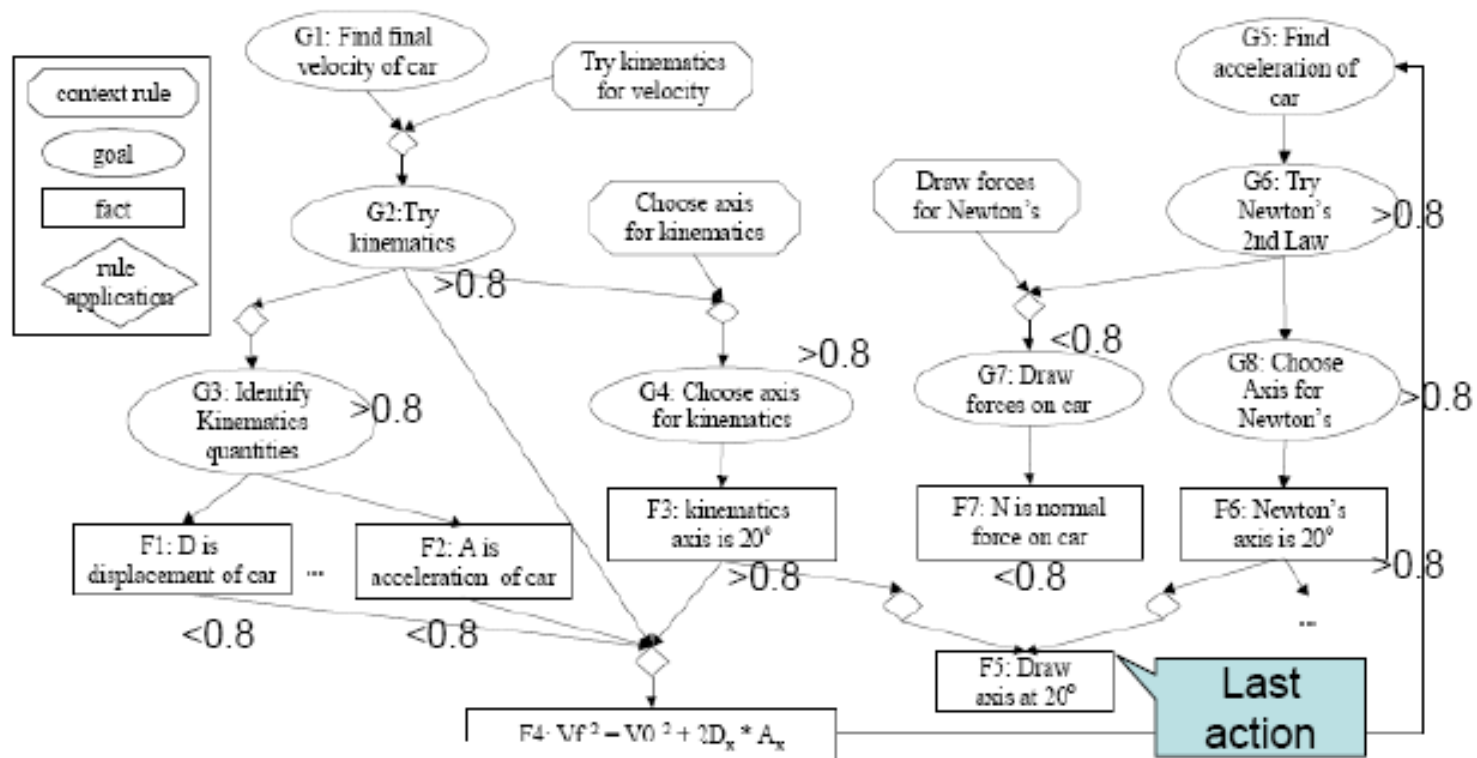
How ?



Search solution graph in depth-first way. The depth-first traversal stops when it reaches a low probability below threshold(0.8)

The result of this traversal is a set of paths through the solution graph beginning with the most recent action, and stopping with a node whose probability is below 0.8

Reference: procedural help in Andes: generating hints using Bayesian network student model



- F5-F3-G4-G2-G3-F1
- F5-F3-G4-G2-G3-F2
- F5-F6-G8-G6-G7

joint probability computing for each path

Choose the highest value path

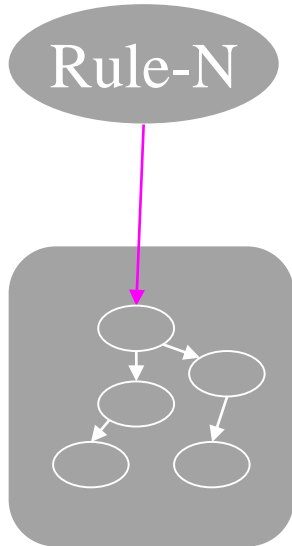
A 2000kg car at the top of a 20° inclined driveway 20m long slips its parking brake and rolls down. Assume that the driveway is frictionless. At what speed will it hit the garage door?

Reference: procedural help in Andes: generating hints using Bayesian network student model

# Andes Dynamic Bayesian Network

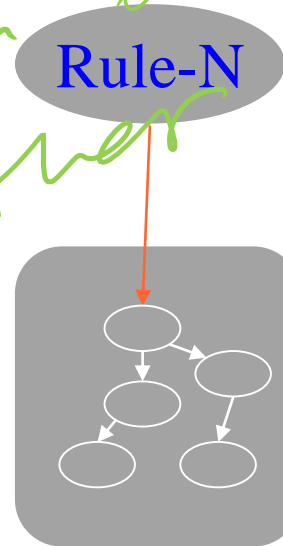
$P(\text{Rule-N} | \text{what student did in problem } i)$

$P(\text{Rule-N} | \text{what student did in problem } j)$



Network  
for problem<sub>i</sub>

*From another problem*



Network  
for problem<sub>j</sub>

What is the granularity of a time-slice in Andes?

# Evaluation

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- ◆ Andes tutor for physics is currently in use at the US Naval Academy
- ◆ Informal studies have shown positive effect on learning
- ◆ Continuously updated through students' feedback



# Outline

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- ◆ ILE, background.
- ◆ Probabilistic student modeling for coached problem solving.
- ◆ Probabilistic student modeling to support learning from examples.

# ILE - a step beyond

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- ◆ Most ILE targets problem solving and domain specific knowledge
- ◆ Andes' SE-Coach - a framework to
  - support learning from examples
  - coach self-explanation(SE)
    - » generate explanations to oneself to clarify an example solution

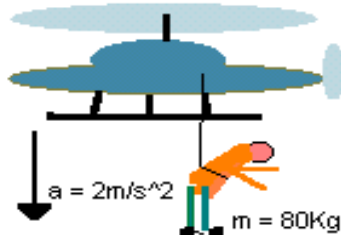
# Sample physics example

Problem Statement

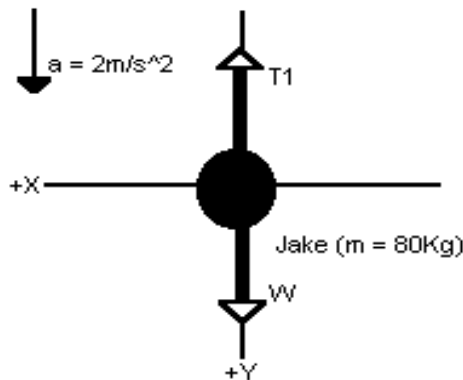
Situation Diagram

Free Body Diagram

EXAMPLE 1: Boy rescued by a helicopter  
Jake, an 80Kg undergrad, is rescued from a burning building by a helicopter.  
He hangs at the end of a rope dangling beneath the helicopter.  
If the helicopter accelerates, straight downward with respect to the ground, with an acceleration  $a = 2\text{m/s}^2$ ,  
FIND:  
The tension  $T$  exerted by the rope.



FREE BODY DIAGRAM:



SOLUTION

Because we want to find a force, we apply Newton's 2nd law to solve this problem.

We choose Jake as the body to which to apply Newton's 2nd law.

The helicopter's rope exerts a tension force  $T$  on Jake.

The tension force  $T$  is directed upwards.

The other force acting on Jake is his weight  $W$ .

The weight  $W$  is directed downwards.

To apply Newton's 2nd law to Jake, we choose a coordinate system with the  $Y$  axis directed downward.

The  $Y$  component of Jake's weight  $W$  is  
 $W_y = W$ .

The  $Y$  component of the tension  $T$  on Jake is  
 $T_y = -T$ .

The net force acting on Jake along the  $Y$  axis is  
 $\text{Net-force}_y = W_y + T_y$ .

Therefore, substituting  
 $W_y = W$ , and  $T_y = -T$   
into the net force equation, we obtain  
 $\text{Net-force}_y = W - T$ .

If we apply Newton's 2nd Law to Jake, along the  $Y$  axis, we obtain:

$$\text{Net-force}_y = m \cdot a_y$$

The  $Y$  component of Jake's acceleration  $a$  is  
 $a_y = a$ .

Therefore, if we substitute  $a_y$  and  
 $\text{Net-force}_y = W - T$   
into

$$\text{Net-force}_y = m \cdot a_y$$

we obtain:

$$W - T = m \cdot a = (80 \cdot 2) \text{ Newtons.}$$

Solving the preceding equation for  $T$  gives:

Worked out solution

# Why examples and self-explanation?

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- ◆ Students who self-explain learn more
- ◆ Many students do not self-explain
  - Fail to detect their lack of understanding
  - Unable to use knowledge to self-explain
- ◆ Human tutors can guide self-explanation

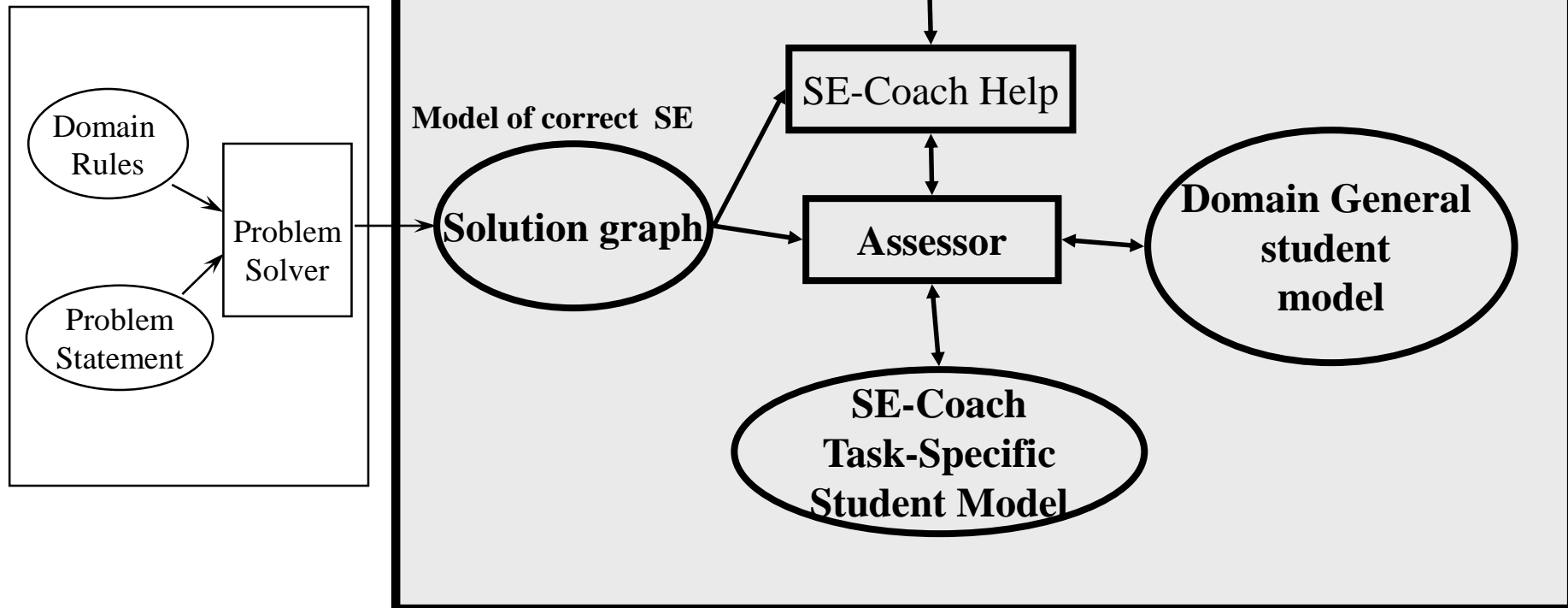
# SE-Coach: individualized support to SE

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- ◆ Monitor students as they study examples
- ◆ Guide self-explanation to improve students' understanding
- ◆ Challenge: only prompt self-explanations that improve students' understanding

# SE-Coach Architecture

Andes



# The SE-Coach Workbench

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- ◆ Masking interface
  - Helps students focus attention and SE-Coach monitor it
- ◆ Prompts for relevant self-explanations
  - Justify solution steps in terms of domain principles
  - Explain role of a step in the underlying solution plan
- ◆ Menu based tools to generate self-explanations

# The Workbench - Masking Interface

- ◆ Helps students focus attention and SE-Coach monitor it

The screenshot displays the ANDES Physics Workbench interface. The window title is "ANDES Physics Workbench - [Se1.apx]". The menu bar includes "File", "View", and "Help".

**EXAMPLE 1: Boy rescued by a helicopter**

The problem area contains several gray rectangular boxes representing masked text. Below the text is a **FREE BODY DIAGRAM:**

The free body diagram shows a central black circle representing "Jake (m = 80Kg)". A coordinate system is shown with a horizontal arrow pointing right labeled "+X" and a vertical arrow pointing down labeled "+Y".

- An upward-pointing arrow is labeled  $T_1$ .
- A downward-pointing arrow is labeled  $W$ .
- To the left of the circle, a downward-pointing arrow is labeled  $a = 2\text{m/s}^2$ .

**SOLUTION**

The solution area contains a "Self-Explain" button and several lines of masked text. The visible text reads: "We choose Jake as the body to which to apply Newton's 2nd law."

**Explaining role of this step in the solution**

The explanation pane contains a large gray rectangular area for text. At the bottom of this pane are two buttons: "Submit" and "Done".

Below the explanation pane, there is a small text box with the following instructions: "Click on the [+] to expand a step. Double click on a step to submit it."



# Prompts to Self-Explain

- ◆ Stimulate self-questioning on relevant explanations

**SOLUTION**

We choose Jake as the body to which to apply Newton's 2nd law.

Self-Explain:

- This choice is correct because...
- The role of this choice in the solution plan is to...

Explaining role of this step in

**SOLUTION**

The helicopter's rope exerts a tension force  $T$  on Jake.

Self-Explain:

- This fact is true because...
- The role of this fact in the solution plan is to...

Explaining role of this step in

# Justify Solution Steps: Rule Browser

**SOLUTION**

We choose Jake as the body to which to apply Newton's 2nd law.

The Y component of the tension T on Jake is  $T_y = -T$ .

**RULE BROWSER**

Explaining why this choice is correct

Search for a rule that justifies this choice

- [-] **Choosing a Body**
  - ✓ USING-FORCE
  - [-] USING\_VELOCITY
  - X USING\_ACCELERATION**
  - [-] COMPOUND\_BODY\_WITH\_SURFACE
  - [-] COMPOUND\_BODY\_TIED\_TOGETHER
- [-] **Compound Body Properties**
  - [-] MASS\_OF\_COMPOUND\_BODY
  - [-] FORCE\_ON\_COMPOUND\_BODY
- [+] **Describing Forces**
- [-] **Newton's Laws**
  - [+] **Newton's Second Law**
  - [+] **Action Reaction Law**
- [-] **Choosing Axes**
  - [-] HOW\_TO\_CHOOSE\_AXES
- [+] **Finding Vector Components**
- [+] **Kinematics**

Template

Click on the [+] to expand a Rule Category  
Double Click on a Rule to submit it

# Justify Solution Steps: Rule Templates

- ◆ Help students generate principle definitions

The image displays a software interface for justifying solution steps using rule templates. It is divided into several main sections:

- SOLUTION:** A text area where students enter their reasoning. Visible text includes: "We choose Jake as the body to which to apply Newton's 2nd law.", "The net force ac...", "Net-force", "The helicopter's rope exerts a tension force T on Jake.", and "The weight W is directed downwards."
- RULE BROWSER:** A pane for searching and selecting rules. It contains the text "Explaining why this choice is correct" and "Search for a rule that justifies this choice". A tree view shows categories: "Choosing a Body" (with a checked "USING-FORCE" rule), "Compound Body Properties", "Describing Forces", "Weight", and "Tension" (with a checked "TENSION\_EXISTS" rule). Below the tree, "TENSION\_FORCE\_DIRECTION" is also visible.
- Template for: USING-FORCE:** A dialog box with a dropdown menu for "IF we want to find" and a text area for "THEN we can choose that object as the body". It has "Back", "Submit", and "Cancel" buttons.
- Template for: TENSION\_EXISTS:** A dialog box with dropdown menus for "IF an object is" (set to "tied to a string") and "AND the string". It has a text area for "THEN there is a tension force on the object" and a dropdown for "EXERTED BY" (with a list including "an object outside the compound body", "the second object", "the earth", and "the string" which is selected). It has "Back", "Submit", and "Cancel" buttons.

# Identify Goal Structure - Plan Browser

- ◆ Encodes abstract solution plan

The image shows a software interface with two main panels. The left panel, titled "SOLUTION", contains a list of horizontal bars representing steps in a solution plan. The text "The helicopter's rope exerts a tension force T on Jake." is visible between two bars. The right panel, titled "PLAN BROWSER", displays a hierarchical tree structure for "Plan for Newton's 2nd Law". The tree includes steps like "Apply Newton's Second Law", "Choose body", "Describe body's properties", "Identify all forces on the body" (highlighted with a green checkmark), "Write component equations", and "Find quantities algebraically". A "Done" button is located at the bottom right of the plan browser. Below the button, there is a note: "Click on the [+] to expand a step Double Click on a step to submit it".

**SOLUTION**

The helicopter's rope exerts a tension force T on Jake.

**PLAN BROWSER**

Explaining the role of this fact in the solution plan

Plan for Newton's 2nd Law

- [-] Apply Newton's Second Law
  - **Choose body**
  - [-] **Describe body's properties**
    - Describe body's acceleration
    - Describe body's mass
  - ✓ **Identify all forces on the body**
  - [-] **Write component equations**
    - ✗ Choose coordinate axes
    - Find vector components
    - Write equations for Newton's 2nd law
  - [-] **Find quantities algebraically**
    - Find remaining unknowns
    - Solve for desired quantities

Done

Click on the [+] to expand a step  
Double Click on a step to submit it

# SE-Coach Hints

SOLUTION

We choose Jake as the body to which to apply Newton's 2nd law.

Self-Explain with the Plan Window

The screenshot shows a software interface with a 'SOLUTION' window on the left and a 'Plan' window on the right. The 'SOLUTION' window contains a text box with the text 'We choose Jake as the body to which to apply Newton's 2nd law.' This text box is highlighted in light purple. Below it are several other horizontal bars, also highlighted in light purple. The 'Plan' window is partially visible on the right side of the interface.

SOLUTION

The helicopter's rope exerts a tension force  $T$  on Jake.

Self-Explain with the Rule Browser

The screenshot shows a software interface with a 'SOLUTION' window on the left and a 'Rule Browser' window on the right. The 'SOLUTION' window contains a text box with the text 'The helicopter's rope exerts a tension force  $T$  on Jake.' This text box is highlighted in light purple. Below it are several other horizontal bars, also highlighted in light purple. The 'Rule Browser' window is partially visible on the right side of the interface.

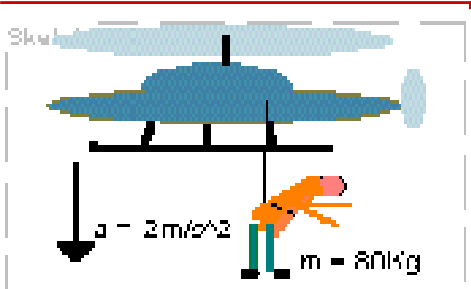
# Probabilistic Student Model

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Based on a Bayesian network to deal with various sources of uncertainty involved in the modeling task

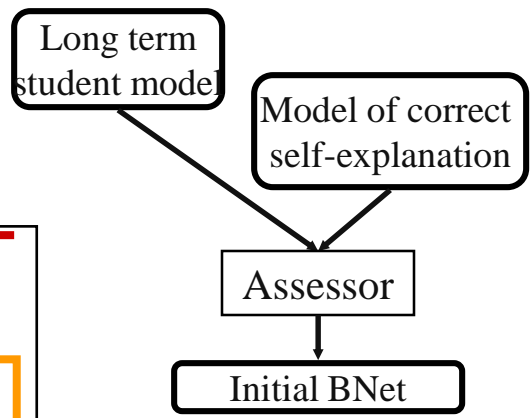
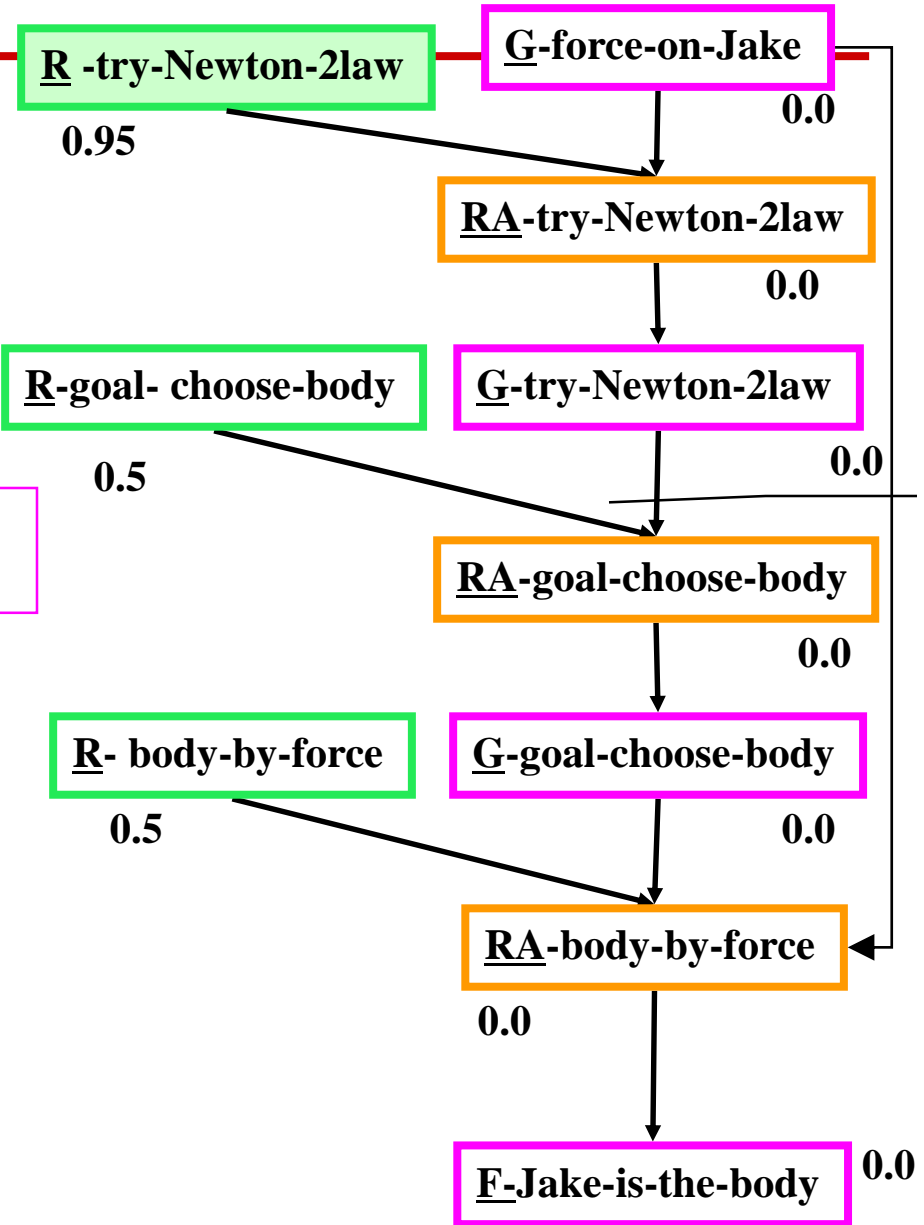
- ◆ Detecting spontaneous self-explanation from
  - Reading time
  - Student's knowledge
- ◆ Some students study examples by reasoning forward.
- ◆ Assessing learning from using the interface menu-based tools

# From SE model to initial Bnet



Find the force exerted on Jake by the rope.

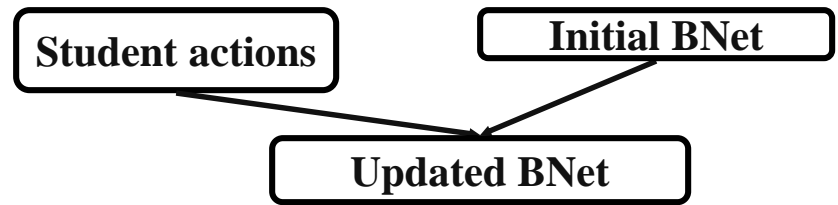
To solve this problem, we choose Jake as the body.



**Noisy-AND**  
 $P(\text{RA} | \text{parents}) = 1 - \alpha$   
 $P(\text{RA} | \exists \neg \text{parent}) = 0$

- R Rule
- F/G Fact/Goal
- RA Rule Application

# Student Actions



◆ Read nodes: duration of attention to example parts

**read-PROP** → **RULE-APPL** → **PROP**

*PCP/Re, RA*

		Knows RULE	Knows Goal/Fact	READ		
		T	T	LOW	OK	LONG
				$p_1 = 1 - \alpha$	$p_2 = 1 - \alpha$	$p_3 > \max\{p_2, 0.9\}$
		otherwise		0	0	0

	READ	LOW	OK	LONG
RULE-APPL	T	1.0	1.0	1.0
	F	$p_1 < 0.5$	$p_2 > 0.9$	$p_3 > p_2$

*← it does not matter if I read or not*

◆ SE nodes: actions with Plan Browser and Templates

<b>RULE</b>		<i>T</i>	<i>F</i>
	<i>T</i>	0.95	0.2
	<i>F</i>	0.05	0.8

*guessing*

```

    graph TD
      RGOAL[R-GOAL] --> pbGOAL[pb-GOAL]
      RRULE[R-RULE] --> tempRULE[temp-RULE]
  
```



# After Filling Template and Closing

read  
*Find force on Jake*

ok

R -try-Newton-2law

0.95

G-force-on-Jake

0.95

RA-try-Newton-2law

0.91

pb-choose-body

1.0

R-goal-choose-body

0.82

G-try-Newton-2law

0.91

RA-goal-choose-body

0.79

temp-body-by-force

1.0

R- body-by-force

0.5 / 0.8

G-goal-choose-body

0.79

RA-body-by-force

0.77

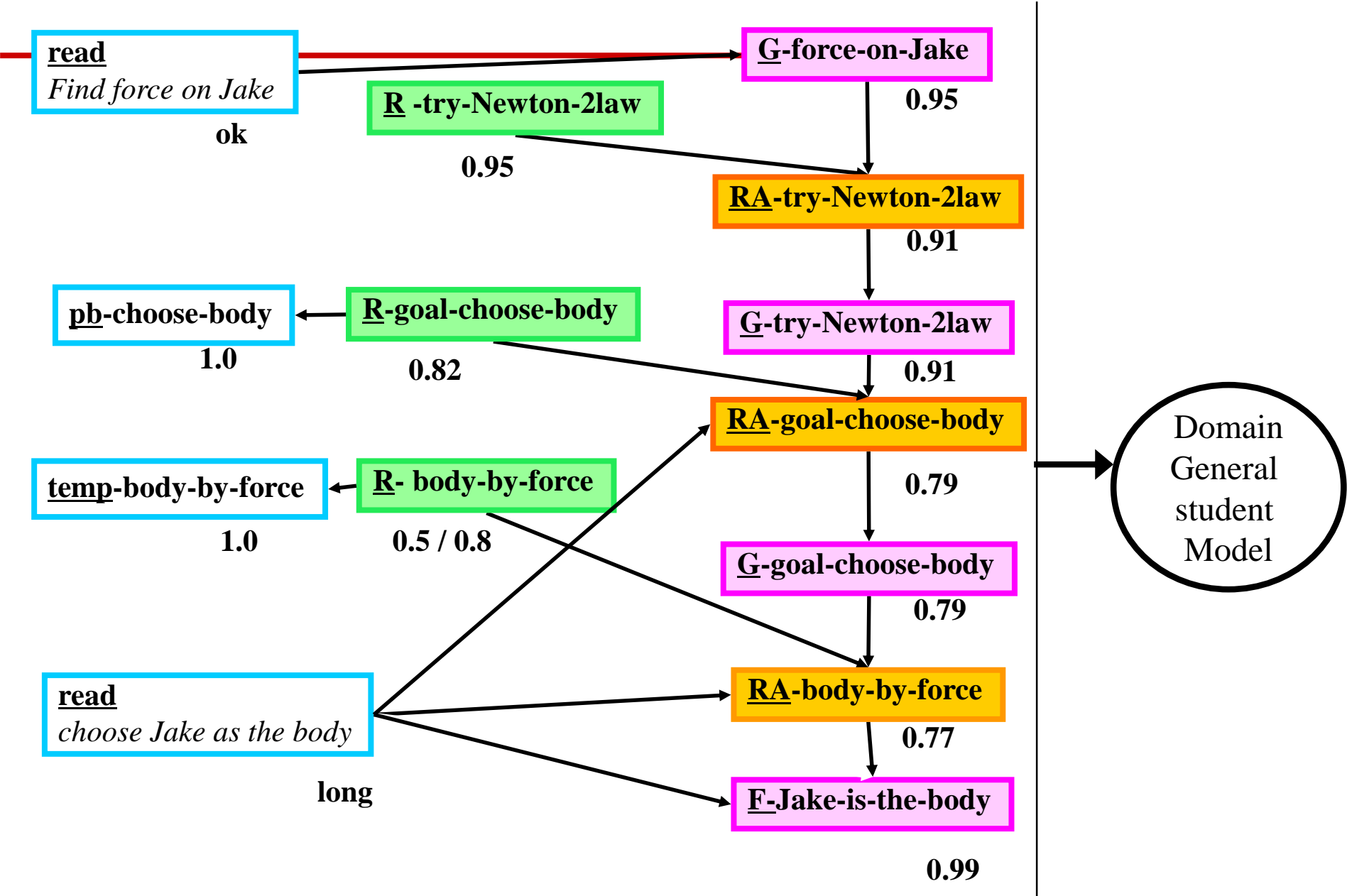
read  
*choose Jake as the body*

long

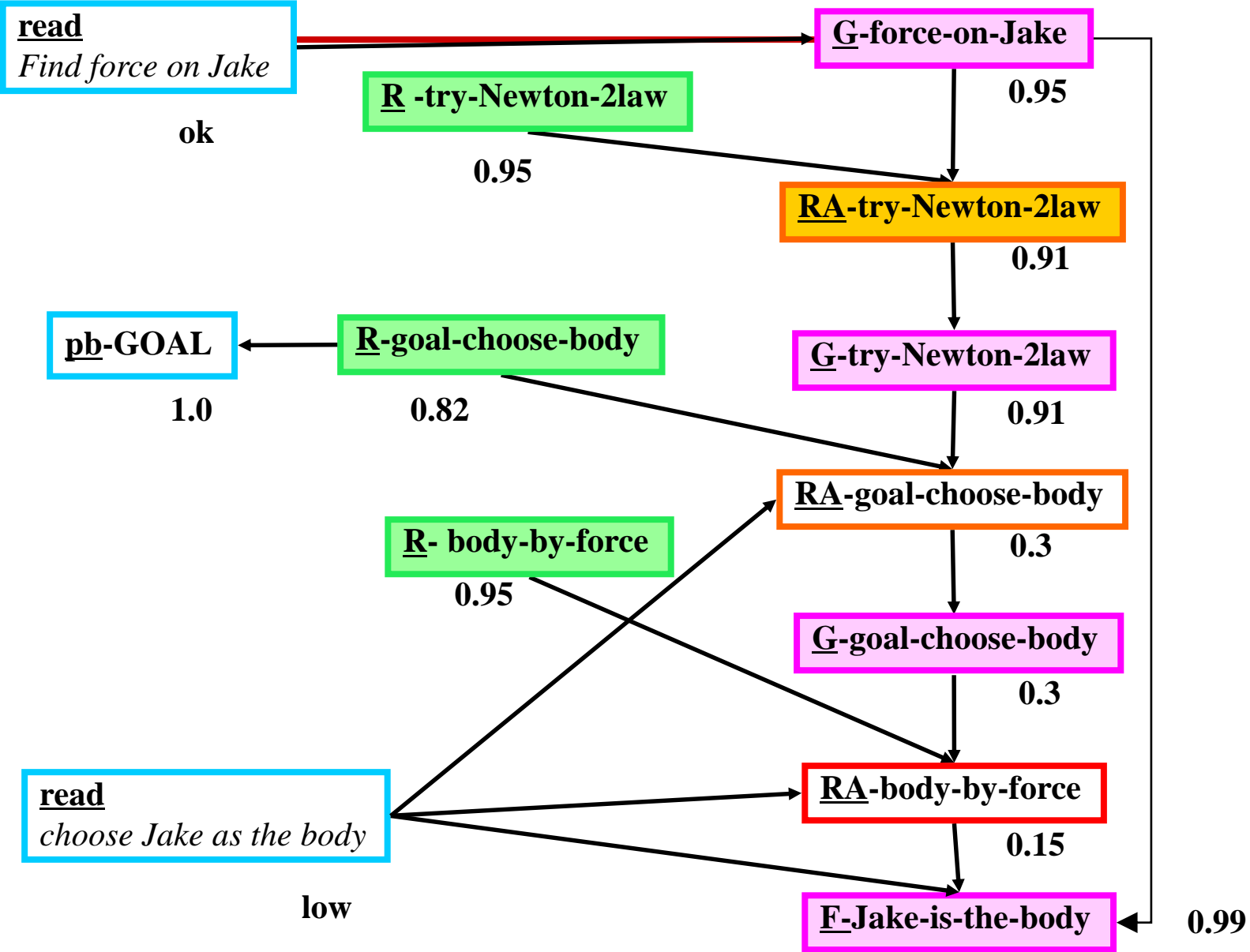
F-Jake-is-the-body

0.99

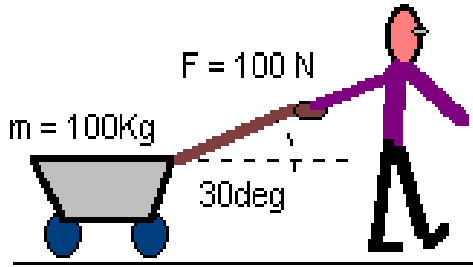
Domain  
General  
student  
Model



# After Reading and Plan Browser Selection



# Transfer to a new example



Find the force  $N$  exerted on the wagon by the ground.

We choose the wagon as the body.

**read**  
*Find force on wagon*

long

**G-force-on-wagon**

**R-try-Newton-2law**

0.95

0.95

**RA-try-Newton-2law**

0.91

**R-goal-choose-body**

0.82

**G-try-Newton-2law**

0.91

**RA-goal-choose-body**

0.79

**R-body-by-force**

0.82

**G-goal-choose-body**

0.79

**read**  
*choose Jake as the body*

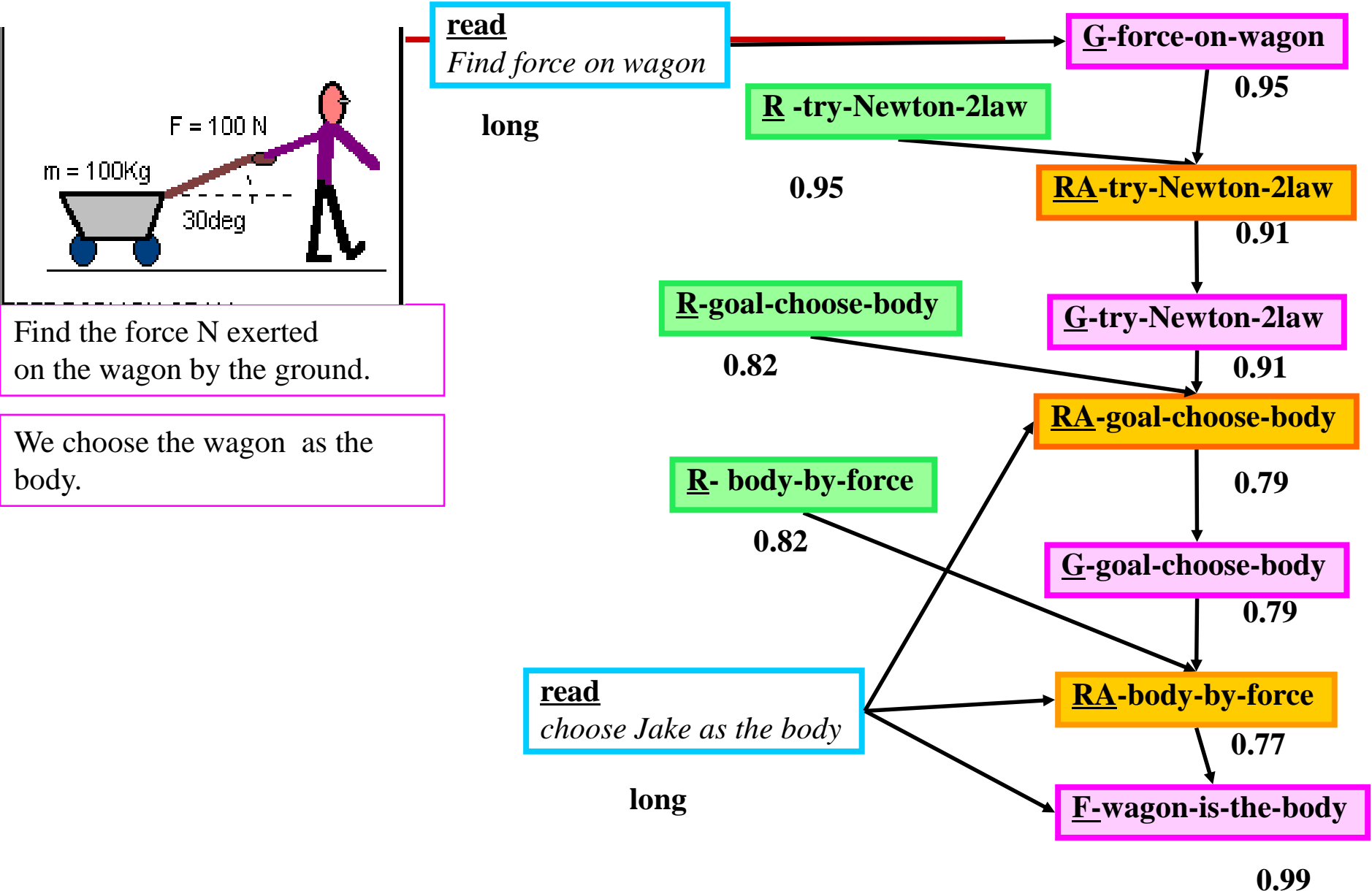
long

**RA-body-by-force**

0.77

**F-wagon-is-the-body**

0.99



# Empirical Evaluation

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- ◆ Subjects - 56 students taking Introductory Physics
- ◆ Pretest - 4 problems on Newton's second law
- ◆ Treatment
  - Experimental (29): studied examples with complete SE-Coach
  - Control (27): studied examples with Masking interface and Plan Window, no feedback nor coaching
- ◆ Posttest - 4 problems analogous to pretest

# Evaluation of the SE-Coach

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- ◆ Interface easy to use and generally successful at stimulating SE.
- ◆ Overall effectiveness seems to depend on learning stage
  - The SE-Coach was more effective for the subjects that had just started learning the examples topic (late-start subjects).
- ◆ Student model: guides interventions that positively correlate with learning ( $p < 0.05$ )

Prompt Type	Max.	Generated	Followed
<b>Use Rule Browser/Templ.</b>	<b>43</b>	<b>22.6</b>	<b>38.6%</b>
<b>Use Plan Browser</b>	<b>34</b>	<b>22.4</b>	<b>42%</b>
<b>Read More Carefully</b>	<b>43</b>	<b>7</b>	<b>34%</b>

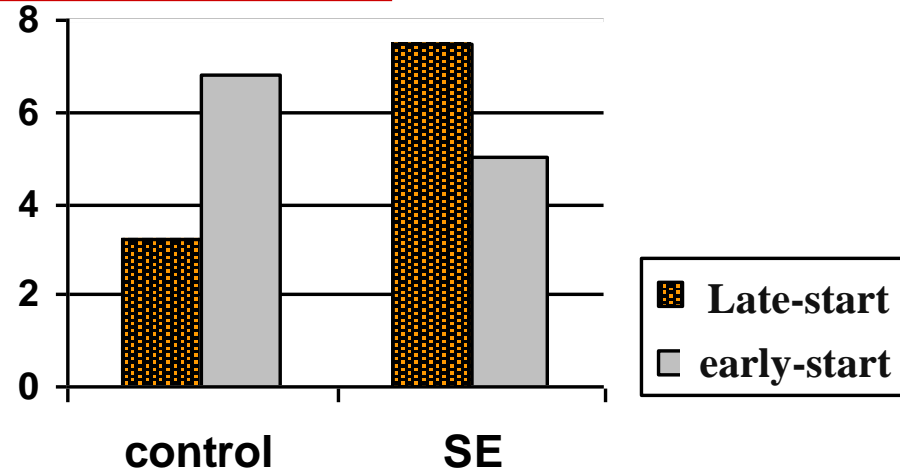
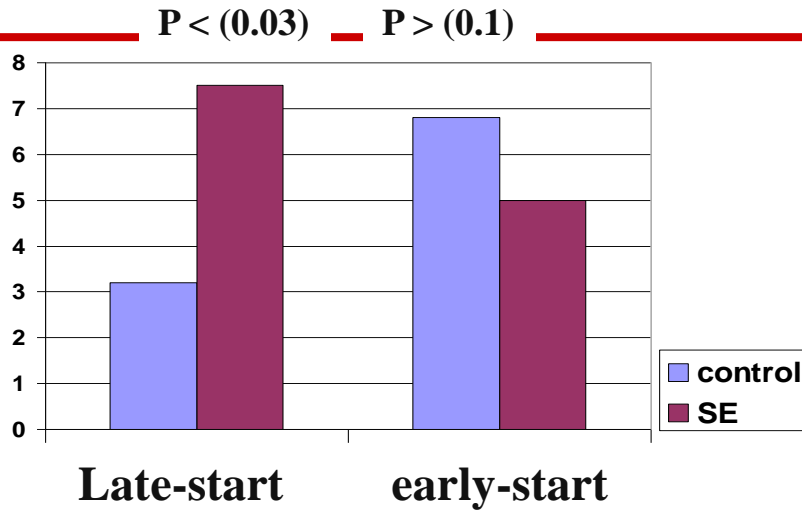
# Results: Hints to self-explain

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Prompt Type	Max	Generated	Followed
<b>Use Rule Browser/Templ.</b>	<b>43</b>	<b>22.6</b>	<b>38.6%</b>
<b>Use Plan Browser</b>	<b>34</b>	<b>22.4</b>	<b>42%</b>
<b>Read More Carefully</b>	<b>43</b>	<b>7</b>	<b>34%</b>

- ◆ All hints positively correlated with posttest ( $p < 0.05$ )

# Results: Learning



- ◆ Late-start subjects in SE condition more motivated to learn from Workbench tools?
  - Significantly more ( $p = 0.01$ ) attempts before abandoning template explanation
  - Larger correlation ( $r = 0.3$  vs.  $r = 0.03$ ) between learned rules and posttest
- ◆ Early-start subjects control spontaneously self-explained?
  - Mean and St.Dev. # of line accesses correlate with posttest ( $p < 0.08$ )
  - Pitt-USNA classes started semester earlier  $\Rightarrow$  More recall to self-explain spontaneously

# Conclusions

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Probabilistic student modeling for

- ◆ Coached problem solving

- On-line knowledge tracing, plan recognition and action prediction to improve the effectiveness of the tutor's interventions

- ◆ Learning from examples

- Assessment of the understanding of written instructional material
- Takes into account student's attention patterns



# Andes Bnet inference

- Andes' networks include anywhere between 100 and 1000 nodes
- Update needs to happen in real time
  - Starts each time a student performs a new action
  - Needs to be done when the student asks for help
- Exact when feasible
- Otherwise Approximate

# Several questions about...

Why Bnets and not MDPs or POMDPs?

Actions of the agent and action of the student ...

What would be a state?.....

reason for not modelling it as a planning problem  
because there would be a **large number of  
states** due to fact that Andes stresses that  
the order of solving the problem is not strict

# Inference

Can the model be extended to **Reinforcement learning model** based on the observations of user behaviors in the practice questions?

Is the paper using Approximate Inference at all? It may be implied somewhere but I can't find a concrete example.

*Yes exact inference in some cases was taking seconds... too much for an interactive system*

## Selecting the problem

As a first/second year physics tutor for many years, I've seen a lot of students becoming completely lost when the problem incorporate more than 2 or more physics theories/concepts. In the paper, it says Andes will choose a problem with an appropriate complexity that involves only a few rules that the student has not yet mastered, how exactly does Andes generate such problem and how does it know what is the appropriate complexity for the student?

# Student modeling...

At what point will the Andes Student model determine that a Student has **mastered** a rule?

How does this model handle with **different difficulty levels** of questions with same rule applied to decide the **mastery** of this rule? For example, two questions might use the same rule but one of them is extremely tricky and students may fail to do this one while it cannot say they do not master the rule.

Was the approach able to predict the effect of outside knowledge affecting students answers? In the case of a student having **sufficient knowledge in calculus and linear equations the majority of Newtonian** mechanics is simplistic, but would not provide diagramming skills.

No

What happens if a student interacts with the system and the network learns about the student but then the student completely changes his behaviour in some way ...Will it take a long time for the system to re-adapt to this?

Yes... probably the same for a human ;-)

# Student modeling...

What happens if a rule of some sort is created by the teacher (e.g. these two are mutually exclusive strategies to solve a problem), realizes it's incorrect after some students .....

It seems as if the probability of knowing a rule is based on the student's reading ability. However since the AI tutor is using time as the only reference, how will it take into account if the student had opened the application and did not immediately start reading?

## Self explaining

**Error due to input mistake:** there is a prob for that

**Error due to language mistake:** ESL student might ...

Not covered by Andes

# Problem Solving Interface

Can the students view information the system has on them, such as how likely the system thinks they are likely to self-explain, or what topics they are likely to not yet have mastered?

No but this is an interesting possibility

How do students actually use the “hint” feature? The hint is encoded so that the probability of mastery is not raised as much when a hint is given but perhaps students use the hint to confirm their solutions as opposed to solely for when they have not mastered the rule. Is there evidence that the “hint” feature is encoded in the way that is actually used by students?

?? Given that mutual exclusivity is a big issue with Newtonian physics, how does the system handle this when presenting problems to students and generating the probability distribution?

# Bnet structure

Many of the nodes are described to have binary domains. Although the paper provides reasoning for this choice, is it common practice to do this for Bayesian networks due to the increase in complexity with having to maintain bigger probability tables if more domain values are available?

No I would say you try to model your domain as close as possible

## Domain-general part

- Is there a problem with making general rule nodes observable with perhaps a simple question about a definition?

No, could be an interesting extension

- How are Context-rule nodes corresponding to a template for student's self-explanation created and how does their input get translated into Bayesian Network probabilities required for building their student model?

This is encoded in the Bayesian network by linking the SE node for a template filling action with the Context-rule node corresponding to that template's content.

- Dependencies among rules

Not captured in Andes

# Task / Probabilities

- ..... It would be very useful if particular **dominant strategies** could be identified – e.g. if a problem can be solved in multiple ways, but those who solved it in one particular way were more or less likely to solve a separate problem.

Not sure this analysis was ever done. But it would be interesting and possible for similar systems

- On page 387, then definition of a **slip** is presented. Would something still be considered a slip if all preconditions were known and two rules were mastered, but one was chosen instead of the other? (i.e. is there an idea of a “best” action to take, or are all the correct actions really just as good as each other?). **No**
- The approach to implement Leaky-OR relationship to address the case where the student might be guessing is really interesting. What are other potential or actual usage for this in the industry? to make them seem more random and human like?

I would say yes.

- How are alpha and beta determined in ‘slipping’ and ‘guessing’ (i.e., Leaky-OR and Noisy-AND)?

Slide 65

Conditional/ Prior Probability Where do prior probabilities come from? Default to 0.5? Are there better starting values? [Learn probabilities from more data on the student \(Educational Data Mining\)](#)



# Task / Probabilities

**series of correct guesses?** Wouldn't the model have no way to know/recover from that?

What about humans?

## Reading latency

How did they end up tackling the problem of deciding what is happening during the student latency time period?

## Student modeling for example studying

It is discussed that reading latency is used to evaluate the probability of self-explanation without requiring self-explanation explicitly, and an equation modeling this was provided. How is this probability value scaled compared to explicit self-explanation?

## Student learning in practice

“Has this tutoring system had an impact on student learning in practice?”

# Adaptation to new tasks/domains

How difficult would it be to add more physics problems to Andes system?

Could this model be applied to **different learning domains** such as language learning, literature analysis or history?

What are the limitations of expanding this system to other problem domains?

How difficult is it to extend the system? For example, by adding new rules and problem types.

other applications exists for the Andes? Is it possible to use it in **a literature class environment**? Since there are multiple interpretation of a book/paragraph/essay/paper, how would Andes handle such high level of variety in the student's response? strictly model for student in **mathematics and theorem** related courses?

The ITS, Andes, studied in this paper is using in the subject of physics. Physics involves a lot of problem solving and formula applying, and it is a good field to apply ITS to improve self-learning. However, this tutoring model may not be good for other subject such as **Philosophy and Business** where the answer can be various due to different point of view. These could cause a even higher uncertainty and hard to make a educated guess.

Slide 67

What about **chemistry**, assess comprehension in the **arts**?

# Future Directions

**NLP:** There has been huge advancement in natural language processing since the year this paper was accepted in 2002. How would expressing self-explanations work if we were to replace the interface discussed in this paper with current available natural language processing technology? Still not “easy” ... Very specific, simple proposal...

Lehman, B., Mills, C., D’Mello, S., & Graesser, A. (2012). Automatic Evaluation of Learner Self-Explanations and Erroneous Responses for Dialogue-Based ITSs. In S. A. Cerri, & B. Clancey (Eds.), *Proceedings of 11th International Conference on Intelligent Tutoring Systems (ITS 2012)* (pp. 544–553). Berlin: Springer-Verlag.

**NLP:** What parts of the system can be changed with better natural language processing? ...

**Eye tracking:** With today’s eye tracking technologies, can we train a separate model which is able to classify whether student is confused or satisfied on a particular problem from student’s eye movement? Then, we can integrate this feature as a prior probability to student’s actions in the bayesian network, as it may provide accurate information for the student model to infer student’s action and generate help. **Yes**

Slide 68

Does taking into account other student’s tendencies and patterns help create a better algorithm for future students?

**It could**

# TODO for Mon

- **Start Reading Textbook Chp. 8.5**
- Keep working on assignment-2 (due on Fri, Oct 20)