ADAPTIVE LEARNING ENVIRONMENTS:
Student Modelling
Why model students?

Customisation (or personalisation) to learners.
- major research theme in ALEs for past decade or so, and in other education policy changes
- this is a big part of the “adaptivity” in “adaptive learning environments”

Back earlier discussion of “why build an ALE?”
- issues of efficiency in learning,
- accommodate student styles

Goals re: learning about learning, e.g. how and why DO students make mistakes
Goals of Student Modelling

Find out what the student knows, believes, can do
- Look for evidence that user fails to exploit some knowledge
- Look for inconsistent beliefs, differences between student and domain models

If teacher believes students has different beliefs or skills:
1. make a list (bug catalogue) and match to it
2. reason about what student would have to believe in order to exhibit behaviour indicating this

*Component of an ITS that represents student's current state of knowledge = STUDENT MODEL*
*Process of inferring the Student Model = DIAGNOSIS*
Models and Adaptivity

WHICH students to model?
- students studying a domain, with non-expert, “buggy” versions of domain model?
- a “profile” (e.g. Low vs. High domain experience, male vs. female students, “competitive” vs cooperative...)
- default settings for different profiles, different problem set, dialogue strategies, etc.
- individual student sitting in front of the computer?
Models and Adaptivity

WHAT to include in your models?
- How or what do we “diagnose” regarding issues with student knowledge?
- What about diagnosing affect? Motivation?
- Student “profiles” or strategies?
- Something else?

How to UPDATE model as the students/their knowledge changes?

...And what do you DO with the working model when you have it?
Example: BUGGY project

Understand student modelling with simple example
- Student procedures for addition/subtraction
- Correct and “buggy” sub-procedures.

_Buggy procedure=like bug in a program_

BUGGY (Brown and Burton, late 1970’s)
Used corpus of student work to identify arithmetic bugs
Created a game for student teachers to learn about better arithmetic teaching
- Help look for, identify sub-procedure errors
- Target these errors in feedback
Diagnosing Models: BUGGY

1. BUGGY selects a faulty algorithm
   
   BUGGY: Welcome to Buggy. I have chosen a bug. Here is an example of the bug.

   17
   +______5
   13

   Now you give me problems to determine the bug.

2. the user sets some problems

   User: 18 43
   + 6 + 79

3. BUGGY gives the answers (by faulty algorithm)

   BUGGY: 15 23

4. user diagnoses the problem

   User: Got the bug!
BUGGY contd.

BUGGY: Please describe the bug.
User: Student adds the number to be carried into the last column worked in.

5. BUGGY sets test, user predicts answers

BUGGY: Here are some problems to test your theory about the bug. What is:

\[
\begin{align*}
21 \\
+ 39 \\
\end{align*}
\]

User: 51

BUGGY: That’s not the bug I have. Using my bug:

\[
\begin{align*}
21 \\
+ 39 \\
\end{align*}
\]

15

Try giving me some more examples.
BUGGY contd.

User:  
51  
99  
68  
+ 1707  
+ 99  
+ 9 

BUGGY:  
21  
36  
23  

User: Got the bug!

BUGGY: Please describe the bug you think I have.

User: The student is adding all the digits together.

BUGGY: Here are some problems to test your theory about the bug. What is:

33 1091 8 28 90

+ 99 + 60 + 34 + 70 + 6

User:  
24 17 15 17 15

BUGGY: Very good. My description of the bug is:
The student always sums up all the digits with no regard to columns.
Modelling for (error) diagnosis

Sub-procedures linked into a procedural network of sub-goals for a single skill (i.e. Addition)
Any skill constituent (i.e. sub-skill) that could be mis-learned needs separate representation
Can run the network on a set of problems

Goal of a diagnostic model is to have an abstracted representation of the student’s skill at a point in time
- Exact composition of correct, buggy procedures that individual uses for subtraction
- Running the network (i.e. the model) should mimic student’s actual behaviour
PARTIAL procedural network for addition (From Brown & Burton, 1978)

Links between nodes “call” procedures, sub-procedures
BUGGY: Drawbacks

**Misconception** represented as a single node:
- can contain any code as its executable part
- single out bugs, but can only explain misconception by means of demonstration or canned text attached to node

**Representation** supposes that:
- *user is merely executing some kind of algorithm*, in a context-free way
- *basic misconceptions represented in same way as basic components of the skill*
- depends on decomposition of skill to level where *single bug is a separate procedure*

Only procedural knowledge?

*System builder has to do all representational work*
Andes: more bugs

Also includes “buggy” knowledge in representations

Has “solution model” of a problem, and tracks student progress in relation to it (a model-tracing tutor)

See Woolf ch 3 p 79 for partial solution graph, too small to show here

Time for hints is when students straying from a correct path (likely to be multiple paths)

Understanding what students know: Two pronged approach
- Current state of problem solving (for individual problem)
PLUS
- “longer term” assessment of overall physics knowledge
A typical ANDES problem and diagram, reproduced from Woolf (2009), p. 78

FIGURE 3.13

The car problem. A 2000 kg car at the top of a 20° inclined driveway 20 m long slips its parking brake and rolls down. Assume that the driveway is frictionless. At what speed will the car hit the garage door (Gertner et al., 1998)?
Andes “solution graph” for car problem, reproduced from Woolf (2009), p. 79
Updating Andes’ model

Uses Bayesian networks (probabilistic representation)
• One problem= network representing one complete solution space (100-200 nodes)
• Nodes equate to student actions, states (and performing action in program can turn nodes on/off)
• “General knowledge” estimates updated at end of each problem based on state of network → initialise model for next problem

To do an action that relies on student knowledge or mental state (e.g. TUTORIAL ACTIONS), other system modules can query network about relevant nodes and their probabilities.
Student Modelling: Language Examples
Example: difficulties in spelling

A child types

e.g. “neiz”

“wen”

What did they intend?
Identifying and Correcting Errors

e.g. “neiz” -> knees/niece

“wen” -> when/went/we/win

“fiknusiz” ->
Identifying and Correcting Errors

e.g. “neiz” $\rightarrow$ knees/niece

“wen” $\rightarrow$ when/went/we/win

“fiknusiz” $\rightarrow$ thicknesses
Possible Inferences

Work back from the misspelling to the correction

k w i c  quick

r i d  red, rid, ride, write, rite, read

f a t  fate

Letter as its name? i for i_e  a for a_e
**Phoncode (Pain, 1985)**

Based on phoneme-grapheme grammar: consider what phonemes error was intended to represent, then see if any word matches

```
'n'  'ei'  'z'

/n/  /i/  /z/  No  kEEp  Zoo
/ng/ /IE/ /zh/ siNG  EAr  pleaSure
/m/ /al/ /s/  jaM  hIGH  Sit
    /l/  /sh/  
    /eE/ /bIt/
    /el/  /buSH/

/knees /n/
/niece /n/  /i/  /i/  /z/  /s/
```
Using language: Autotutor

Student modelling all about **semantic matching**, regular expressions and similar

**Inferring** student concept knowledge through their natural-language (text) input
- For each **main question**, compare input to pre-generated list of expectations and misconceptions via **latent semantic analysis (LSA)**

*Expectations* = anticipated “good answers”, productive procedural steps

**LSA compares conceptual similarity** of two pieces of text

See D’Mello & Graesser, 2012, section 3 for gory linguistic details.
Screenshot from Autotutor problem about operating systems interacting with a word processor (Image from D’Mello & Graesser, 2012)
Semantics for DOING

Multiple rounds of tutorial dialogue for a main question, doing analyses on each round of input. System [dialogue] actions aim to identify (i.e. diagnose) and target “missing” expectations related to main question. Trying to reach a threshold LSA value: This means that student is using same concepts and propositions in an “expected” answer. Don’t worry about the details of this.

More bugs: Parts of student input may match stored misconceptions. This then triggers system to take certain tutorial actions (e.g. offer hint or explicit correction).
Using Language: ARTCHECK

Correct article usage problem for English language learners:
Some native languages do not include an article category, e.g. Finnish - definiteness and indefiniteness expressed in quite different ways (also Basque, Chinese, Russian)
Aims to help such learners use articles appropriately

Rules which determine correct article usage:
- how do you know whether you are talking about a specific object, or any old object?
- how do we choose the correct article to indicate the indefinite or definite property of the noun in an utterance?

Indefinite a/an, eg John is a teacher
            zero, eg Do you take milk in coffee?
Definite the, eg He is the only teacher I like
ArtCheck Tutor (Sentence, 1993)

Applying knowledge to user input, to detect when the incorrect article is used

Example errors:

*I have visited __ Tower of London
*We discussed our plans over the breakfast

There may be patterns in the errors

* John is teacher.
* Sandy is pig.
* I am doctor.
  John is a good man.

Use rules as basis for generating explanations, customised to learner, to help them learn correct user
Determining correct usage

Rules indicate whether article before noun should be:

- the **definite article** *the*
- the **indefinite article** *a/an*
- no article at all, *(the zero article)*

Some are **fixed rules**: *the definite article should be used when the noun is modified by a superlative adjective,*

  eg *the largest dog*

Other depend on context of use: *the indefinite article should be used to introduce new information.*

The sources of information used by the system:

- the **lexicon,** the **parser,** the **morphological analyser,** and a **discourse history module.**
# Examples of rules

<table>
<thead>
<tr>
<th>Article Usage Rules</th>
<th>Example</th>
<th>Information needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>The definite article can be used where the noun is modified by a relative clause</td>
<td><em>The man who I saw.</em></td>
<td>Syntactic</td>
</tr>
<tr>
<td>The zero article can be used before plural count nouns</td>
<td><em>Do you like eggs?</em></td>
<td>Morphological</td>
</tr>
<tr>
<td>The zero article can be used with proper nouns</td>
<td><em>My dog is called Marcus</em></td>
<td>Lexical</td>
</tr>
<tr>
<td>The indefinite article is used in some expressions of frequency</td>
<td><em>I go running twice a day</em></td>
<td>Idiomatic</td>
</tr>
</tbody>
</table>
Providing feedback

Uses *rule induction* to learn rules from positive and negative training instances of the error:

* John is teacher. \(Positive\ \text{instance}\)
* Sandy is pig. \(“\)
* I am doctor. \(“\)

John is a good man. \(Negative\ \text{instance}\)

Produce new rules, based on the expert ones, in this case:

Rule 11: *Use the article a/an where a singular count noun is used as the complement of the verb to be.*

Identify incorrect (mal-rule) proposed to account for data:

*Where there is a singular, unmodified, common, count noun preceded by a singular form of the verb be, use the zero article.*

And explain this to the student:

*“You seem to use no article instead of a or an before a singular count noun and after the verb to be”*
**Learning from errors**

One goal is for user of the system to learn from any errors made. To do this it must:

- be able to understand the observed errors,
- be able to communicate effectively with the user
- provide a good explanation for that error.

Explanation in Artcheck is tailored to the learner in three ways:

1. *relating to the learner’s level of ability,*
2. *learning style,* and
3. the *type of error* observed.

In addition, the learner is given some control over the information received.
Example dialogue

Student: I am doctor

AC: identify error: doctor in I am doctor is incorrect.

AC: correct error: It should be: a doctor.

AC: ask student for feedback

Select: m more q quit explanation

Student: m

AC: state rule The rule is: RULE 11

Use a or an before singular count nouns which come after the verb to be.

AC: ask student for feedback

Select: m more q quit explanation

Student: m

AC: explain mal-rule:

I have noticed that you seem to use no article instead of a or an before a singular count and after the verb to be in the singular
Dialogue, continued

AC: ask student for feedback

Select: m more q quit explanation

Student: m

AC: exemplify mal-rule

You also said: *** Sandy is pig *** John is teacher

which are similar errors.

Try one of these again: Sandy is **** pig

Choose the correct article:

1 a
2 an
3 the
4 no article

Student: 1

AC: Well done. That is the correct answer.

Continue? (y/n) n
Evaluation of ArtCheck

Can understand many types of sentence structures.
Cannot understand questions and imperatives.
- grammar could easily be extended
Sometimes wrongly predict appropriate article usage:
- less common idiomatic usages.
- distant or complex referring expressions, where semantic information required
Lot of data required for mal-rule to be generated.

Feedback during external evaluation generally positive:
• students confirmed this was an area of difficulty
• were enthusiastic about experimenting with system
• found the system easy and helpful to use.
Most showed some improvement after using ArtCheck for a short period of time.
Verbal and written feedback generally very positive.
Open Learner Modelling:
LeActiveMath
http://www.leactivemath.org/
Open Learner Modelling

Should only the system access the model? Should students see them? What about teachers? Why would we do that anyway?

- Help learners and teachers to reflect on their own knowledge, misconceptions and learning processes

- Give an alternative for diagnosis by enabling students (or even peers and teachers) to intervene in the diagnosis process and influence the system judgments

A challenge: how best to collect, analyse and externalise data from learner interactions and how to represent this for most effective support of reflection
OLM in LeActiveMath

Externalisation of the Learner Model
- Organise and display LM beliefs about the learner's knowledge, skills, competencies, affective and motivational states.

Interaction with the learner based on:
- performance on system (e.g. you scored 70%)
- and on value judgements (e.g. you did well)

OLM “suggestions” to the Tutorial Component
- Belief revision may highlight need for learner to do an exercise, study an example, etc.

A dedicated Graphical User Interface
Architecture

- Domain Knowledge Subsystem
- Extended Learner Model Subsystem
- Interface Subsystem
- OLM Interface
- Learner Model
- Open Learner Model
- Situation Model
- Learner History
- Tutorial Subsystem
Learner Model Content

Domain Knowledge (e.g. derivation rules, function, chain rule)

Competencies (e.g. reasoning mathematically, handling mathematical symbols and formalisms)

Meta-cognition (e.g. student believes that they understand chain rule)

Affect and Motivation (e.g. frustrated, interested, puts effort)

Conceptual and performance errors (incorrect derivative for negative power function, expanding brackets incorrectly)
Learner model structure

Dimensions are piled up in layers
Bottom layer is the subject domain, as a *ground* dimension
Beliefs are placed in the upper layers only
Beliefs are about higher layers *applied* to lower layers

Example: a belief on learner *awareness* of her *motivation* at following a *proof* of the *chain rule for derivatives*
Open Learner Model: Specification

Belief and Evidence
Link the model to the direct actions and activities that the user may recall (i.e. as stored in the Learner History)

Interactive diagnosis
Dialogue moves as language for learner and OLM to use to communicate and argue about beliefs and performance

Deployed by graphical widgets with NLG support
# Inference/Diagnosis: Dialogue Moves

**Learner’s Moves**

<table>
<thead>
<tr>
<th>SHOW ME:</th>
<th>Show me what you think I know about differentiation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Show me how competent you think I am in terms of learning</td>
</tr>
<tr>
<td>I DISAGREE:</td>
<td>I don’t think I know the chain rule (but you seem to think I can)</td>
</tr>
<tr>
<td>I AGREE:</td>
<td>Yes, I am very confident about my understanding of differentiation</td>
</tr>
<tr>
<td>I DISCONFIRM:</td>
<td>I cannot accept that I understand the chain rule quite well</td>
</tr>
<tr>
<td>I’M BAFFLED:</td>
<td>I do not understand how you reach your conclusion</td>
</tr>
<tr>
<td>LET’S MOVE ON:</td>
<td>I never want to revisit this topic</td>
</tr>
</tbody>
</table>

**OLM’s Moves**

<table>
<thead>
<tr>
<th>PERHAPS:</th>
<th>Perhaps you are quite confident about using the chain rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>HERE IS:</td>
<td>Here is the evidence I have about what you can differentiate</td>
</tr>
<tr>
<td>CAN I CONFIRM:</td>
<td>So we agree that you understand the chain rule well</td>
</tr>
<tr>
<td>UNRAVELLING:</td>
<td>I believe you are quite good at mathematical modelling because you told me so yesterday and your performance is as good as yesterday</td>
</tr>
<tr>
<td>FINISH TOPIC:</td>
<td>So we agree to differ about your competence at mathematical modelling - we move on but will revisit some time soon</td>
</tr>
</tbody>
</table>
OLM and NLP

Templates used for transcription of dialogue between OLM and learner

Templates for every dialogue moves

Reference to LM and OLM elements mapped into the templates (i.e. Belief descriptor, TAP nodes)

Value judgement mapped to every LM belief (i.e. Level, Performance)

Internationalisation easily supported

OLM Welcome my dear toto. What brings you here today?
toto I don't know what to do now.
OLM Perhaps you should explore [derivative, , think, , , ].
toto Yes, why not.
toto Show me what you think I know about [derivative, , think, , , ].
OLM I think your are Level I about [derivative, , think, , , ].
toto I don't understand why you think Level I.
OLM Here is the evidence for me to think you are Level I.
toto I don't understand why you think Level I.
OLM Here is the evidence for me to think you are Level I.
toto I don't understand why you think WARRANT_2.
OLM Because you did this easy exercise with a 0.0 performance.
toto I disagree with WARRANT_2.
OLM In this case, what is your own judgement about the situation?
toto Let's change the topic of discussion, please.
OLM Fine, but we will have to come back to this issue later.
If want more on this...

Common types of student modelling not discussed here:
  - Constraint-based modelling
  - Plan recognition
  - Expert-system model

see Woolf (2009) Chapter 3, required reading

A totally different idea of the roles models can play: Lifelong learner modelling (see reading list)