KidLearn
machine learning applied to the personalization of didactic sequences

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Topics

1. **How to select the best examples to teach at each time step?**

2. **How to generate good examples for teaching?**
   *Algorithmic and Human Teaching of Sequential Decision Tasks*, Maya Cakmak and Manuel Lopes. AAAI Conf. on Artificial Intelligence (AAAI), 2012
Both steps may incur problems that do not allow students to acquire the competences aimed by the educational system.

Building an ITS requires a difficult pedagogical study.
Objectifs of ITS

- Reduce the conception time of an automated tutoring system
- Provide more personalized teaching
- Adapt to more uncommon situations not accounted for at design time
- Reduce the time to acquire the different competences
- Improve motivation and engagement of learners
Intelligent Tutoring Systems

- A computer system that aims to provide immediate and customized instruction or feedback to learners, usually without intervention from a human teacher.

- Components of an ITS
  - Cognitive Model
  - Learner Model
  - Tutoring Model
  - Interface Model
Cognitive Model

- A set of Knowledge Units (KU)
- A set of activities with different parameters ($a_i$)
- Q-Table with the relation between activities and the required competence level
- For a given exercise, the required competence level is:

$$q_i(a) = \sqrt[n]{\prod_{j=1}^{n} q_i(a_j)}$$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
<th>$KU_1$</th>
<th>$KU_2$</th>
<th>$KU_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_1$</td>
<td>1</td>
<td>$q_{1,1,1}$</td>
<td>...</td>
<td>$q_{n,1,1}$</td>
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<tr>
<td>$a_1$</td>
<td>2</td>
<td>$q_{1,1,2}$</td>
<td>...</td>
<td>$q_{n,1,2}$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$a_m$</td>
<td>1</td>
<td>$q_{1,m,1}$</td>
<td>...</td>
<td>$q_{n,m,1}$</td>
</tr>
<tr>
<td>$a_m$</td>
<td>2</td>
<td>$q_{1,m,2}$</td>
<td>...</td>
<td>$q_{n,m,2}$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$a_m$</td>
<td>$k_m$</td>
<td>$q_{1,m,k_m}$</td>
<td>...</td>
<td>$q_{n,m,k_m}$</td>
</tr>
</tbody>
</table>

Knowledge Units: Sum, Subtract, Count, ...

The activities can be very different: interactive exercises, animations/videos, ...
What is the best activity?

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ETA</th>
<th>ETB</th>
</tr>
</thead>
<tbody>
<tr>
<td>KU1</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>KU2</td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
</tr>
<tr>
<td>KU3</td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
</tbody>
</table>

ETA and ETB are parameterizable exercises that can be used to allow students to acquire KU1-KU3.

Parameters: data for exercises, difficulty level, modality of presentation, type of interaction, …

Predefined sequence

Optimal sequence for specific students
Intrinsic Motivation

- **Maximum of motivation**: when the difficulty level is just slightly above the competence level
Cognitive/Student Model

- Q-Table with the relation between activities and the required competence level

- For a given exercise, the required competence level is:

\[ q_i(a) = \sqrt[n]{\prod_{j=1}^{n} q_i(a_j)} \]

- If exercise correct:

\[ r = q_i(a) - c_i^L \]

- Update competence level (c_i^L):

\[ c_i^L = c_i^L + \alpha r \]

- Expected learning progress per parameter:

\[ w_i(a_i) \leftarrow \beta w_i(a_i) + \eta r \]

- Exercises are chosen proportionally to \( w_i \).
Multi-Armed Bandits

How to play to optimize the received reward

- Many algorithms that can simultaneously explore to estimate the return of each machine, and exploit to collect the maximum reward.

- RILRIT propose the activity more adapted to the student
**Algorithm 2 Right Activity at Right Time (RiARiT)**

**Require:** Set of $n_c$ competences $C$

**Require:** Set of exercise parameters $A = \{A_1, \ldots, A_{n_a}\}$

**Require:** Set of $n_a$ experts $w_i$

1: Initialize $c^L = 0, \ldots, m$

2: Initialize experts: $w_i(j) = \frac{1}{\#(A_i)}$

3: **while** learning **do**

4: \{Generate exercise\}

5: \textbf{for} $i = 1 \ldots n_a$ \textbf{do}

6: $\tilde{w}_i = \sum_j w_i(j)$

7: $p_i = \tilde{w}_i \xi_q + \gamma \xi_u$

8: Sample $a_i$ proportional to $p_i$

9: \textbf{end for}

10: Propose exercise $a = \{a_1, \ldots, a_{n_a}\}$

11: Get Student Answer

12: $C^L, r \leftarrow$ Update competence level

13: \{Update greedy expert\}

14: \textbf{for} $i = 1 \ldots n_a$ \textbf{do}

15: $w_i(a_i) \leftarrow \beta w_i(a_i) + \eta r$

16: \textbf{end for}

17: \textbf{end while}
How to define the cognitive model

Table 4

<table>
<thead>
<tr>
<th>Exercise Type</th>
<th>KnowMoney</th>
<th>IntSum</th>
<th>IntDec</th>
<th>DecSum</th>
<th>DecDec</th>
<th>Memory</th>
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<tbody>
<tr>
<td>1</td>
<td>0.7</td>
<td>0.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
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<td>0.7</td>
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<td>0.3</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
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<tr>
<td>3</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
<td>0</td>
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</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0.7</td>
<td>0.6</td>
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<td>0.3</td>
<td>0.7</td>
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<tr>
<td>5</td>
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<td>0.7</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>6</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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</table>

<table>
<thead>
<tr>
<th>Price Present.</th>
<th>KnowMoney</th>
<th>IntSum</th>
<th>IntDec</th>
<th>DecSum</th>
<th>DecDec</th>
<th>Memory</th>
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<tbody>
<tr>
<td>S</td>
<td>0.9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>W</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>S&amp;W</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.2</td>
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</table>

<table>
<thead>
<tr>
<th>Cents Not.</th>
<th>KnowMoney</th>
<th>IntSum</th>
<th>IntDec</th>
<th>DecSum</th>
<th>DecDec</th>
<th>Memory</th>
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<tbody>
<tr>
<td>x. x €</td>
<td>0.8</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>x € x</td>
<td>0.9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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</table>

<table>
<thead>
<tr>
<th>Money Type</th>
<th>KnowMoney</th>
<th>IntSum</th>
<th>IntDec</th>
<th>DecSum</th>
<th>DecDec</th>
<th>Memory</th>
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</thead>
<tbody>
<tr>
<td>Real Token</td>
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<td>-</td>
<td>-</td>
<td>0.9</td>
<td>0.9</td>
<td>1</td>
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<tr>
<td>Token</td>
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<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
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</tbody>
</table>
Pedagogycal Restrictions

Fig. 14. Pre-requisites graph
How to use

1. **List of competences** to be acquired

2. Definition of the **activity types** and their **parameterization**

3. Definition of **Pedagogical Constraints** and **Cues**
   - Restrictions on the parameters automatically selected.
   - List of errors and the aid to be given

4. **Creation of the Cognitive Model**
   - Relation between the parameter of the activities and the minimum required competences’ level

5. After each activity, **estimate student’s competence**. **Propose new activity** based on the competence level.

6. Individual report: detailed results, level of knowledge acquisition, personal difficulties/strengths

The activities can be very different: interactive exercises, animations/videos, …

**Other Possible Optimizations**
- Bootstrap optimization based on pre-knowledge about the student
- Create student profiles to share information among students
- Use biometric information: attention, concentration, …
Money Game

Two experiments

- With simulated students
- With real students (CE1) level in the Bordeaux region
Competences

- Know the money
- Sum/Subtract and decompose integers
- Sum/Subtract and decompose fractional numbers
- Optimal decomposition
- Memory
Parameters

- **P1**: Price complexity
  
  \[ \text{ND} = \{0 ; 1 ; 2 ; 5\} ; \quad \text{ND}^* = \{1 ; 2 ; 5\} : \text{Valeurs à lecture directe.} \]
  
  \[ \text{NC} = \{3 ; 4 ; 6 ; 7 ; 8 ; 9\} : \text{Valeurs à composer.} \]

<table>
<thead>
<tr>
<th>Niveaux</th>
<th>Niveau 1</th>
<th>Niveau 2</th>
<th>Niveau 3</th>
<th>Niveau 4</th>
<th>Niveau 5</th>
<th>Niveau 6</th>
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</thead>
<tbody>
<tr>
<td>Décomposition</td>
<td>(a \in \text{ND}^*, b \in \text{ND}, c = d = 0)</td>
<td>(a \in \text{ND}^*, b \in \text{NC}, c = d = 0)</td>
<td>(a \in \text{NC}, b \in \text{NC}, c = d = 0)</td>
<td>(a \in \text{ND}, b \in \text{NC}, c \in \text{ND}^*, d \in \text{ND})</td>
<td>(a \in \text{NC}, b \in \text{NC}, c \in \text{NC}, d \in \text{NC})</td>
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<tr>
<td>exemple</td>
<td>10</td>
<td>18</td>
<td>39</td>
<td>10.25</td>
<td>39.15</td>
<td>98.97</td>
</tr>
</tbody>
</table>

- **P2**: Real and monopoly money
- **P3**: Two different representation of decimals
- **P4**: Price written or spoken
Virtual Students

- «Q»
  - Modeled by specific levels of competence per KC
  - Probability of answering right depends on the difference between competence level and required competence

- «P»
  - Modeled by specific comprehension levels of each parameter
  - Probability of answering right depends on the difference between competence level and required competence, and the level of understanding of each parameter
RiLRiT propose more difficult exercises earlier on, but keeps proposing simpler exercises longer. This shows an adaptation to the difficulties of particular students.
Number of errors

PredSeq

RiLRiT

Q

P

1 error
2 errors
3 errors
4 errors
5 errors
6 errors
7 errors
8 errors
9 errors
10 and +
Competences’ Level

Q

Not significantly different in population Q.

P

Big difference in population P.
Difference between real and estimated level

- RilRit estimates better the level of students
User Studies

- Experiments:
  - 5 different schools, 130 students (CE1)
  - Use of the computers of schools
  - 35 minutes per student
    => each student does a different number of exercises

- Observations:
  - Bad informatic infrastructure in most schools
  - 66 students with reliable data
  - Good participation and engament by the students and the teachers
Results

Level

The most difficult exercises are proposed sooner

Maximum level succeeded

More student get and solve most difficult exercises
Conclusions

- In general the optimized sequences are better adapted to each particular student
- Faster learning
- Better estimation of students level
- Easier to develop and distribute than a hand-made sequence, and robust to design errors

- In general students are very motivated to play these games, good reception by the teachers.

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