Motivation

Combination of skills matters for modeling learners: mastery should be asserted only when a student can fluently apply skills in combination with other skills. However, simply creating such combination skills as new independent skills may ignore the important dependencies for reliable inferences.

Proposed Framework

A data-driven framework to model skill combinations called Conjunctive Knowledge Modeling with Hierarchical Skill Combinations (CKM-HSC)

Skill combinations (Layer 2) are selected if:
- Skill combination is much more difficult than each of its individual skills.
- Skill combination difficulty is high.
- Difficult problems (items) likely require skill combinations.
- Each problem has a limited number of skill combinations.

Network structure is learned using a greedy search algorithm (we proposed a simplified version using empirical pruning with higher efficiency).

Evaluation

Multifaceted data-driven evaluation framework that includes:
- Knowledge inference quality:
  - Mastery Accuracy: Do students mostly have correct responses on the data after a student model infers mastery?
  - Mastery Effort: How many practices does a student need to reach inferred mastery for all required skills on the data?
- Parameter plausibility: Item Discriminative Index (IDI=1-guess-slip)
- Performance prediction accuracy: RMSE, AUC

These metrics extend our recent learner effort-outcome paradigm (LEOPARD) [5] and the Polygon multifaceted evaluation framework [7].

Studies

Table 1: Dataset descriptive statistics (from two programming courses at University of Pittsburgh).

<table>
<thead>
<tr>
<th>Dataset</th>
<th>#obs.</th>
<th>#items</th>
<th>#skills</th>
<th>avg #skills/item</th>
<th>#users</th>
<th>%correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQL</td>
<td>17,197</td>
<td>45</td>
<td>34</td>
<td>5 (from 1 to 10)</td>
<td>366</td>
<td>58%</td>
</tr>
<tr>
<td>Java</td>
<td>25,988</td>
<td>45</td>
<td>56</td>
<td>5 (from 1 to 11)</td>
<td>347</td>
<td>67%</td>
</tr>
</tbody>
</table>

CKM-HSC significantly increases the mastery inference accuracy, and more reasonably distributes students' efforts (requiring students to focus more on skill combinations by a drill-down analysis), compared to Knowledge Tracing models (KT-Single, WKT) and non-hierarchical counterparts. We also showed the benefit of adding external knowledge. Details are reported in [8].