Background

Counterfactual: Outcome would have been observed had the treatment been different, namely the unobserved outcome.

Graphical Model

<table>
<thead>
<tr>
<th>Level</th>
<th>Symbol</th>
<th>Typical Activity</th>
<th>Typical Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Anomeration</td>
<td>P(θ</td>
<td>x)</td>
<td>Seeing</td>
</tr>
<tr>
<td>2. Intervention</td>
<td>P(θ</td>
<td>x, a)</td>
<td>Doing</td>
</tr>
<tr>
<td>3. Counterfactuals</td>
<td>P(y</td>
<td>θ, x)</td>
<td>Imagining, Retrospection</td>
</tr>
</tbody>
</table>

Prior Work

- Hidden Markov Model (HMM) to analyze the student trajectory throughout an educational game.
- Bayesian knowledge tracing (BKT): a two state HMM where the probability of forgetting a concept is zero.
- Intelligent Tutoring System (ITS)

Limitation

- No control for the confounders.
- No account for modeling the feedback to students.
- No account for the loss-to-follow up.

Observational Study in Education

What happens if there is a treatment-confounder feedback:

- Traditional methods such as regression would fail.
- Problem can be solved efficiently using Inverse Probability of Treatment Weighting (IPTW).
- Weight elements by the inverse of the probability of treatment received.
- Results in pseudo-population, where confounders and treatments are not connected.

Results

Experimental Setup: All treatments and confounders X_1, X_2, X_3, L_1, L_2 and L_3 are Bernoulli random variables. The outcome (O) is normally distributed.

- No unmeasured confounders
- With unmeasured confounders

Prior Study

- Treatment-Confounder Feedback

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>True Regression Estimate</th>
<th>IPTW Coefficient</th>
<th>True Regression Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.1</td>
<td>0.21</td>
<td>2.1</td>
</tr>
<tr>
<td>X_1</td>
<td>2.42</td>
<td>4.12</td>
<td>2.31</td>
</tr>
<tr>
<td>X_2</td>
<td>2.95</td>
<td>4.02</td>
<td>2.47</td>
</tr>
<tr>
<td>X_3</td>
<td>5.93</td>
<td>6.16</td>
<td>5.93</td>
</tr>
</tbody>
</table>

Conclusion

- A single intervention is not sufficient and does not provide enough feedback to students.
- Model the education system as time varying treatment-confounder feedback.
- Measure and account for sufficient set of confounders to close as many backdoor paths as possible.
- Can be done with simple means:
  - Include questions on potential confounders in diagnostic test.
  - Instruct TA’s to inquire during office hours.