Bayesian Networks in Educational Assessment

Dynamic Bayesian Networks

Roy Levy
Arizona State University
Roy.Levy@asu.edu

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Dynamic Bayesian Networks (DBNs)

- Dynamic BNs (DBNs) for modeling longitudinal data
- Bayesian network where variables are repeated, usually over time or related index
- Assessment applications: monitor learning and growth
  - Proficiency and performance on first attempt, on second attempt, etc.
- Knowledge tracing, latent Markov models, latent transition models, growth models

DBN Psychometric Models: Within-Time Component

\[ \theta_t \xrightarrow{} x_t \xrightarrow{} \text{Performance at time } t \]

DBN Psychometric Models: Transition Component

\[ \theta_{t-1} \xrightarrow{} \theta_t \xrightarrow{} \theta_{t+1} \]

Current proficiency depends on past proficiency
- Once a master, always a master
- Transition away from (to?) misconceptions

Time (in slices)
Current proficiency depends on past performance due to feedback on performance.

Example Context: Save Patch

- Complete a level, move on to the next level
- Don’t complete a level, try again (and again, and again, …)
- Constructed as a learning tool
- Assesses proficiency of various skills (converting fractions, adding fractions, etc.) and
- Assesses various misconceptions/errors (inclusion, partitioning, etc.)
- Game-playing strategies relevant too (e.g., everything in order)
- Key departures from standard assessment paradigm
  - Feedback (student knows if correctly or incorrectly completed)
  - Learning during assessment (by design!)
  - Performances not conditionally independent (you know what you did, and how it turned out, for the most part)

Dynamic Bayesian Networks (DBNs)

- Characterization of performance
  - Standard solution
  - Alternate solution
  - Incomplete solution
  - Errors (many different kinds)
  - Skipped key
  - Wrong direction
  - Reset solution
- Example: performance on Level 19
  - Assuming the examinee does not have the misconception
  - 2-class latent variable for mastery of whole numbers
  - Probabilities estimated using MCMC, input to Netica
  - Analysis of first four types of performance, attempts resulting in others ignored

Example Context: Save Patch

- Educational video game targeting rational number equivalence
  - Adding whole numbers
  - Finding appropriate denominators, fractions < 1
  - Finding appropriate denominators, fractions > 1
  - Adding fractions given correct ingredients
  - Adding fractions greater than 1
- Student lays out ropes for character to navigate across to end
  - Success on a level leads to more complicated levels
  - Advanced levels involve converting ropes (fractions), more complicated layouts, and gaming features (picking up keys, coins)
p(Observable for Level 19 | Adding Unit Fractions)

<table>
<thead>
<tr>
<th>Adding Unit Fractions</th>
<th>Standard Solution</th>
<th>Alternate Solution</th>
<th>Incomplete Solution</th>
<th>Error</th>
<th>Unknown Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possess</td>
<td>0.95</td>
<td>0.00</td>
<td>0.01</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>Not Possess</td>
<td>0.58</td>
<td>0.02</td>
<td>0.01</td>
<td>0.25</td>
<td>0.13</td>
</tr>
</tbody>
</table>

p(Possess) = 0.70

3 Time Slices

p(Possess at time 1 | Unknown Error at time 1) = 0.15

Observe an unknown error on the first attempt
Posterior Predictive Probability

\[ p(\text{Possess at time } 2 \mid \text{Unknown Error at time } 1) = .23 \]

Observe an unknown error on the first attempt

2nd Observation

Posterior Probability

\[ p(\text{Possess at time } 2 \mid \text{Unkn Err at } t_1, \text{Wrong Num Error at } t_2) = .03 \]

Observe a wrong numerator on the second attempt

Observe a wrong numerator on the second attempt

Posterior Retrodictive Probability

\[ p(\text{Possess at time } 1 \mid \text{Unkn Err at } t_1, \text{Wrong Num Error at } t_2) = .02 \]

Observe a wrong numerator on the second attempt

3rd Observation

Observe a standard solution on the third attempt
Posterior Probability

\[ p(\text{Possess at time 3} \mid \text{Unkn Err, Wrong Num Err, Stand Sol}) = .33 \]

Netica Files:
Save Patch Level 19 Simplified Dynamic.neta
Save Patch Level 19 Simplified Dynamic Expanded 3
Time Points.neta
How many additional time slices?

When to start?

Must edit the table for the first time point

See ‘Save Patch Level 19 Simplified Dynamic Expanded 3 Time Points.neta’