Knowledge Tracing - Continued

Machine Learning for Behavioral Data

April 1, 2025

Today's Topic

Week	Lecture/Lab
1	Introduction
2	Data Exploration
3	Regression
4	Classification
5	Model Evaluation
6	Time Series Prediction
7	**Time Series Prediction**
8	Time Series Prediction

Supervised learning on time series:

- **Probabilistic graphical models**
- **GLMMs**
- **Neural networks: LSTM, GRU, etc.**

Getting ready for today's lecture…

- **If not done yet**: clone the repository containing the Jupyter notebook and data for today's lecture into your Noto workspace
- SpeakUp room for today's lecture:

https://go.epfl.ch/speakup-mlbd2025

Agenda

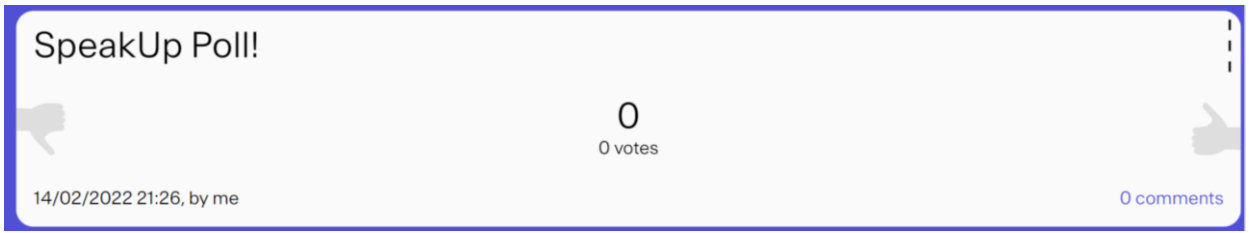
- Short quiz about the past…
- Learning Curves
- Alternative approaches to knowledge tracing
- Daylight Saving quiz!

Win Swiss chocolate!

Short quiz about the past…

BKT does account for students guessing the correct answer.

a) True
b) False

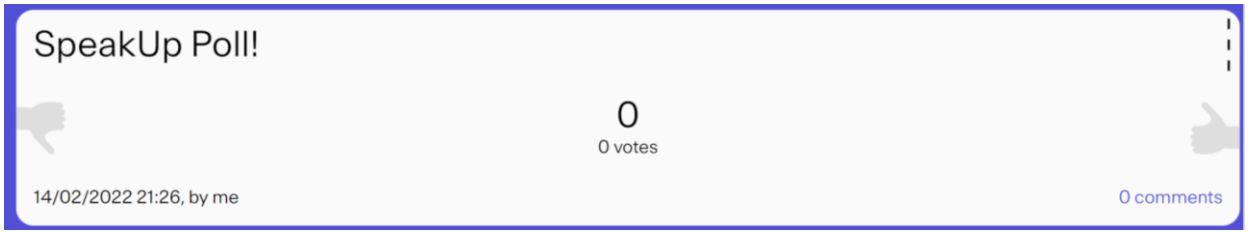


Short quiz about the past…

Mixed-effect models are useful when the samples in the data set are uncorrelated.

a) True

b) False



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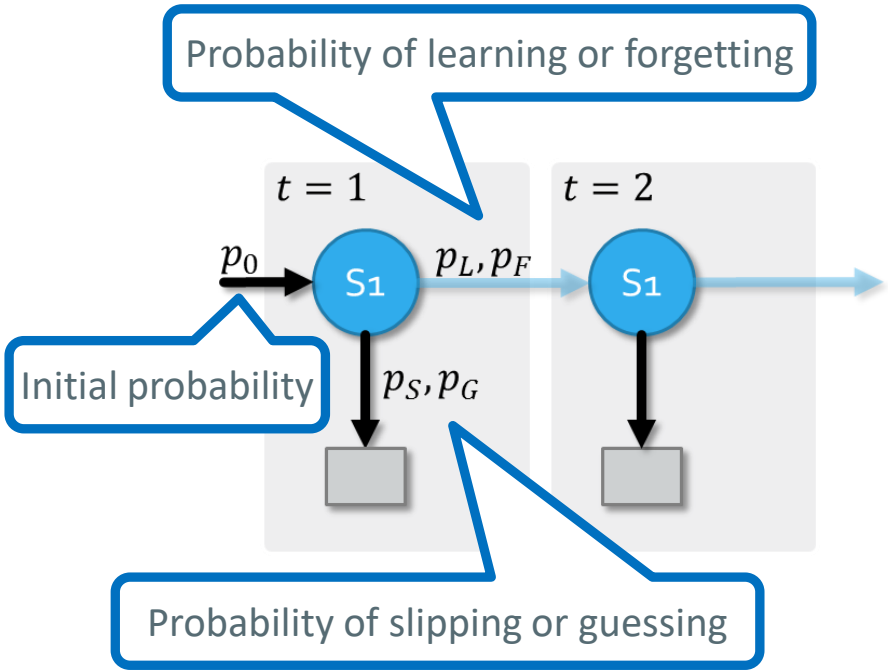
Last Week: Bayesian Knowledge Tracing



- Predict $p(o_{i_{s1},t} | o_0, \ldots, o_{t-1})$, the probability that the student will solve task i_{s1} correctly at time step t
- Predict $p(s_{1,t} | o_0, \ldots, o_{t-1})$, the probability that the student has mastered skill s_1 at time step t

Assumptions behind BKT

- Knowledge can be divided into different skills
- Definition of skills is accurate/detailed enough
- Each task corresponds to a single skill (original)
- There is **no** connection between the skills
- Mastery can be achieved through practice
- There is no forgetting: $p_F = 0$ (original)

Today

- **Learning Curves**
- Alternative Models for Knowledge Tracing
  - AFM
  - PFA

Today's Use Case

- ASSISTments is a free tool for assigning and assessing math problems and homework
- All math problems (tasks/items) are associated to a specific skill/knowledge component
- 4,151 middle-school students
- 525,534 observations

Tracing Knowledge – why is it useful?

- Is the student learning?
  - Measure what the student *knows* at a specific time t
  - More specifically: knowledge of the student about relevant knowledge components (skills)

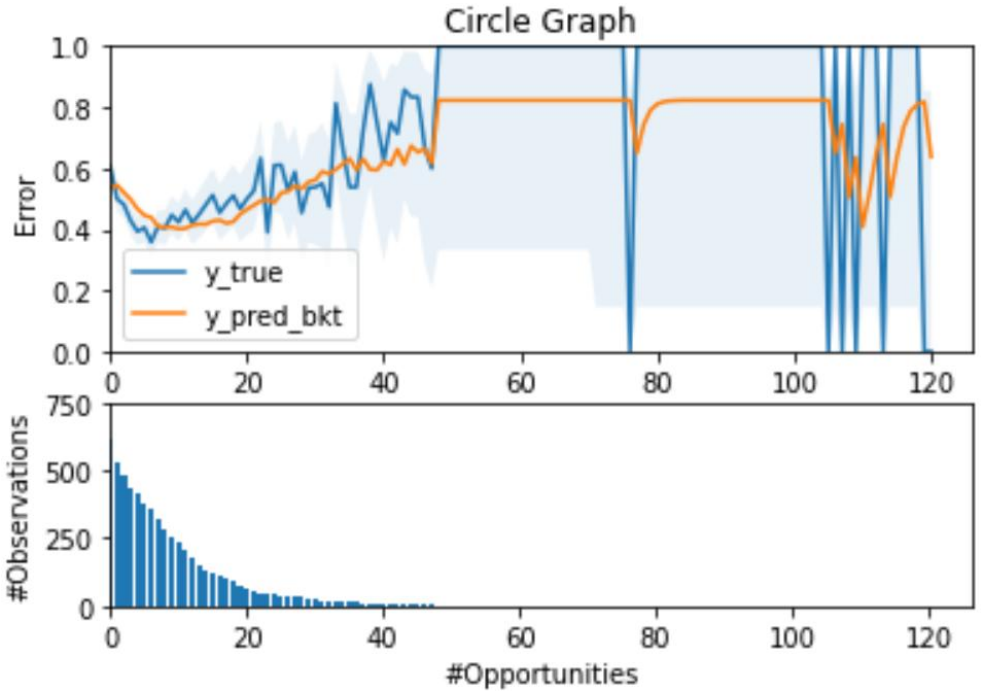
➡ Choose the next appropriate activity

➡ Know which activities support learning

Building a learning curve for skill s

Student	Opportunity	y_true	y_pred
0	0	0	0.3
0	1	0	0.5
0	2	1	0.7
0	3	1	0.9
1	0	0	0.3
1	1	1	0.5
2	0	0	0.3
2	1	1	0.5
2	2	1	0.7
3	0	1	0.3
3	1	0	0.7
3	2	1	0.5
3	3	1	0.9

What could this curve indicate?



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Your Turn – Learning Curves

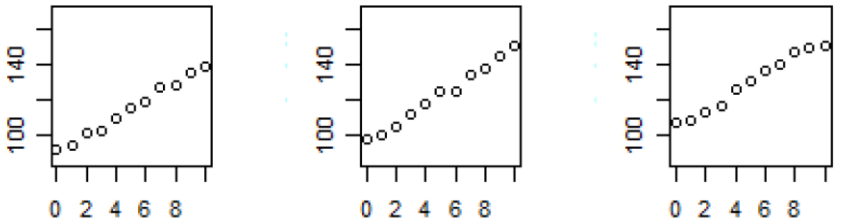
- In the student notebook, you have:
  - BKT model trained on all skills and students
  - List of available skills
  - Function for plotting learning curves and student numbers for a specific skill
- Your task:
  - Pick 1-2 skills, generate the learning curves for them, and interpret them
  - Send us your plots and interpretations

Today

- Learning Curves
- **Alternative Models for Knowledge Tracing**
  - AFM
  - PFA

Generalized Linear Mixed Effects Models revisited

- Example: strength gain by weight training
  - Each person has individual starting strength



$$y_n = \beta_0 + u_n + \beta_1 x_{n,1}$$

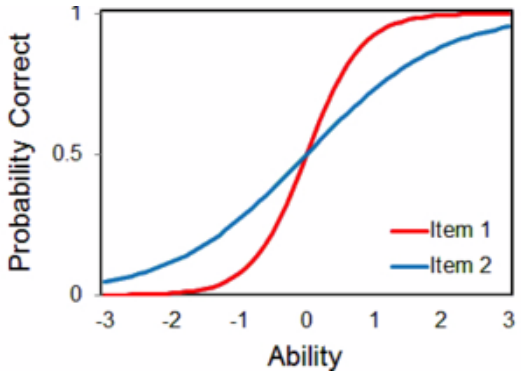
"Fixed" Effects

"Random" Effect

Rasch Model

$$\log\left(\frac{p_{i,n}}{1-p_{i,n}}\right) = \theta_n - b_i$$

Probability that student n will solve item i correctly.



θ_n: student ability

b_i: difficulty of item i

Additive Factors Model (AFM)

$$p_{n,i} = \frac{1}{1 + e^{-\pi_{n,i}}}$$

Probability that student n will solve task i correctly.

Additive Factors Model (AFM)

$$p_{n,i} = \frac{1}{1 + e^{-\pi_{n,i}}}$$

$$\pi_{n,i} = \theta_n + \sum_k q_{i,k} \cdot (\beta_k + \gamma_k \cdot T_{n,k})$$

[Cen et al., ITS 2006; Cen et al., ITS 2008]

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Student proficiency

[Cen et al., ITS 2006; Cen et al., ITS 2008]

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Student proficiency

$q_{ik} = 1$, if item *i* uses skill *k*

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Student proficiency

Difficulty of skill *k*

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Student proficiency

$q_{ik} = 1$, if item *i* uses skill *k*

Difficulty of skill *k*

Learning rate at skill *k*

Number of practice opportunities student *n* had at skill *k*

[Cen et al., ITS 2006; Cen et al., ITS 2008]

AFM - Assumptions

- Students may initially know more or less
- Students learn at the same rate
- Some skills are more likely to initially be known
- Some skills are easier to learn than others
- Students learn with each practice opportunity
- Each item belongs to one or more skills

Performance Factors Analysis (PFA)

$$\pi_{n,i} = \theta_n + \sum_k q_{i,k} \cdot (\beta_k + \gamma_k \cdot T_{n,k})$$

[Pavlik et al., AIED 2009]

Performance Factors Analysis (PFA)

$$\pi_{n,i} = \theta_n + \sum_k q_{i,k} \cdot (\beta_k + \gamma_k \cdot s_{n,k} + \rho_k \cdot f_{n,k})$$

Number of prior **successes** student *n* had at skill *k*

Number of prior **failures** student *n* had at skill *k*

[Pavlik et al., AIED 2009]

PFA - Assumptions

- Students may initially know more or less
- Students learn at the same rate
- Some skills are more likely to initially be known
- Some skills are easier to learn than others
- Students learning rate differs for correct and wrong practice opportunities
- Each item belongs to one or more skills

AFM/PFA in action…

- Jupyter Notebook

  Cheat sheet for mixed effect models:
  https://go.epfl.ch/mlbd-mixed-effects

Your Turn: Comparing Models

- We have evaluated AFM, PFA, and BKT on a subset of six skills. Your task:
  - Visualize the overall RMSE and AUC of the models such that it can easily be compared
  - Discuss the obtained results

Summary

- Learning Curves
- Alternative Models for Knowledge Tracing:
  - AFM
  - PFA

Daylight Saving Quiz – Join us on Kahoot!

www.kahoot.it

Enter the game pin!

Win some Swiss chocolate!