Item Response Theory for NLP

EACL2024 Tutorial, 21st March 2024

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https://eacl2024irt.github.io/

In this session

Motivation

Introducing IRT

IRT Models with Artificial Crowds

IRT for Leaderboards

The py-irt Package

Motivation

Differences between Examples

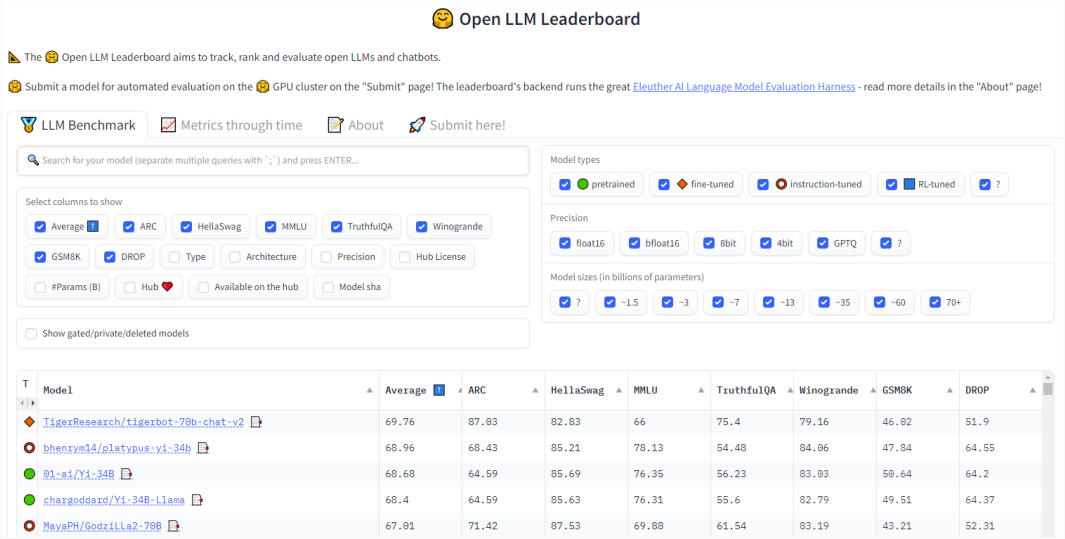
Natural language inference (NLI)

Premise	Hypothesis	Label	Difficulty
A little girl eating a sucker	A child eating candy	Entailment	*easy*
People were watching the tournament in the stadium	The people are sitting outside on the grass	Contradiction	*hard*
Two girls on a bridge dancing with the city skyline in the background	The girls are sisters.	Neutral	*easy*

Sentiment analysis (SA)

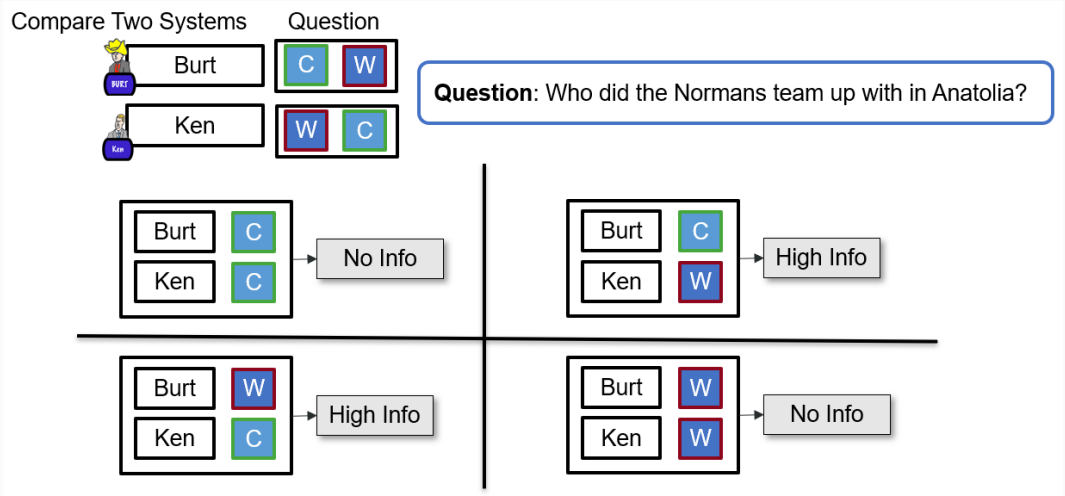
Phrase	Label	Difficulty
The stupidest, most insulting movie of 2002's first quarter.	Negative	*easy*
Still, it gets the job done - a sleepy afternoon rental.	Negative	*hard*
An endlessly fascinating, landmark movie that is as bold as anything the cinema has seen in years.	Positive	*easy*
Perhaps no picture ever made has more literally showed that the road to hell is paved with good intentions.	Positive	*hard*

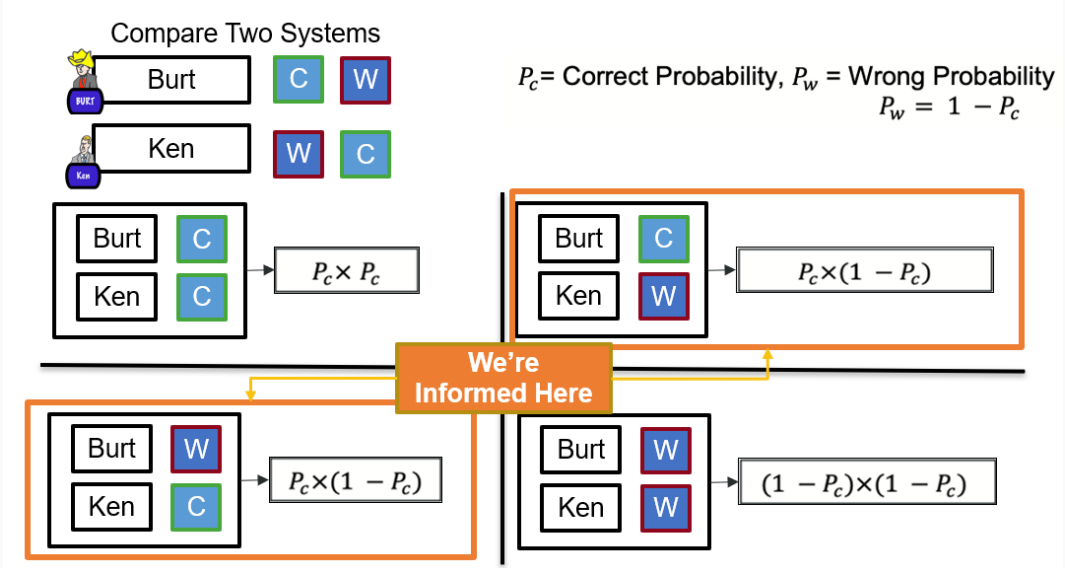
Leaderboards



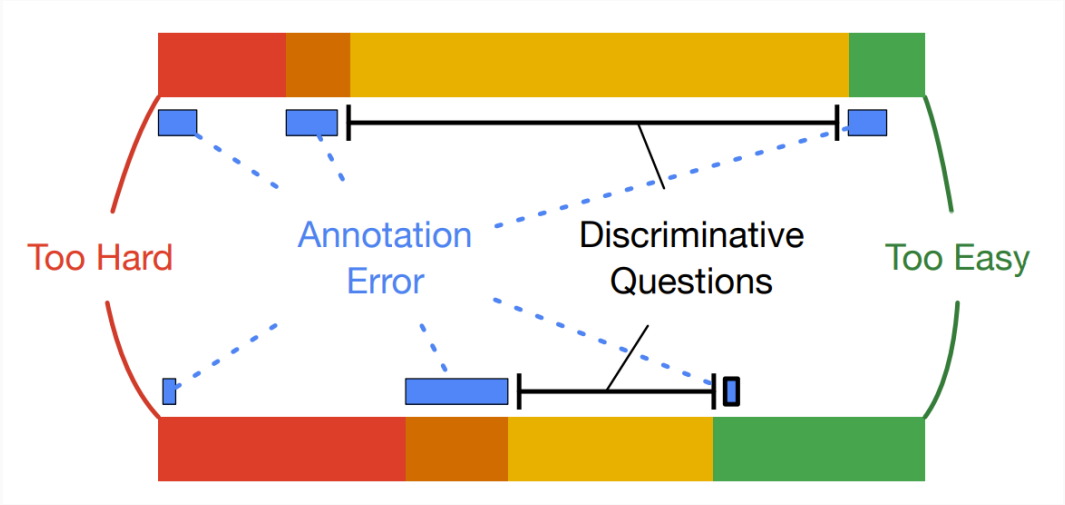
https://huggingface.co/spaces/HuggingFaceH4/open_llm_leaderboard

Differences in Questions




Compare Two Systems
Burt
C
W
Ken
W
C
P_c= Correct Probability, P_w = Wrong Probability
$P_w = 1 - P_c$
Burt
C
Ken
C
$P_c \times P_c$
Burt
C
Ken
W
$P_c \times (1 - P_c)$
We're Informed Here
Burt
W
Ken
C
$P_c \times (1 - P_c)$
Burt
W
Ken
W
$(1 - P_c) \times (1 - P_c)$

Differences in Questions



Boyd-Graber J, Börschinger B. What Question Answering can Learn from Trivia Nerds. ACL 2020.

Introducing IRT

Psychometrics

Psychometrics: study of quantitative measurement practices

- Building instruments for measurement
- Development of theoretical approaches to measurement

Item Response Theory (IRT): measure latent traits of test-takers and test questions (“items’ ’)

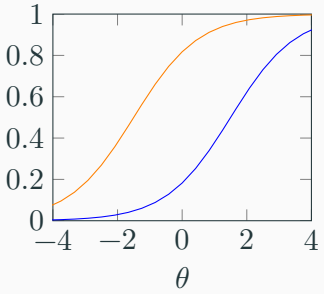
IRT: 1 Parameter Logistic Model (1PL)

Also known as *Rasch model*

$$p(y_{ij} = 1 | b_i, \theta_j) = \frac{1}{1 + e^{-(\theta_j - b_i)}}$$

θ_j: latent ability

b_i: difficulty



Parameter Estimation

$$p(y_{ij} = 1|b_i, \theta_j) = \frac{1}{1 + e^{-a_i(\theta_j - b_i)}}$$
$$p(y_{ij} = 0|b_i, \theta_j) = 1 - p(y_{ij} = 1|b_i, \theta_j)$$

$$L = \prod_{j=1}^{J} \prod_{i=1}^{I} p(Y_{ij} = y_{ij}|b_i, \theta_j)$$
$$q(\Theta, B) = \prod_j \pi_j^{\theta}(\theta_j) \prod_i \pi_i^{b}(b_i)$$

Natesan, Prathiba, et al. "Bayesian prior choice in IRT estimation using MCMC and variational Bayes.'' Frontiers in psychology 2016

Evaluating DNN Performance with IRT

Premise	Hypothesis	Label	Difficulty
A little girl eating a sucker	A child eating candy	Entailment	-2.74
People were watching the tournament in the stadium	The people are sitting outside on the grass	Contradiction	0.51
Two girls on a bridge dancing with the city skyline in the background	The girls are sisters.	Neutral	-1.92
Nine men wearing tuxedos sing	Nine women wearing dresses sing	Contradiction	0.08

Phrase	Label	Difficulty
The stupidest, most insulting movie of 2002's first quarter.	Negative	-2.46
Still, it gets the job done - a sleepy afternoon rental.	Negative	1.78
An endlessly fascinating, landmark movie that is as bold as anything the cinema has seen in years.	Positive	-2.27
Perhaps no picture ever made has more literally showed that the road to hell is paved with good intentions.	Positive	2.05

IRT for NLP: Human Annotations

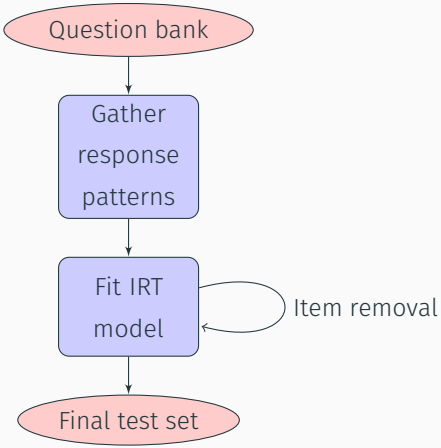
Item Set	Theta Score	Percentile	Test Acc.
5GS			
Entailment	-0.133	44.83%	96.5%
Contradiction	1.539	93.82%	87.9%
Neutral	0.423	66.28%	88%
4GS			
Contradiction	1.777	96.25%	78.9%
Neutral	0.441	67%	83%

Human Bottleneck

- Gathering human response patterns is expensive
- Can we use ensembles of models to gather response patterns?
- Even if we can, should we?

IRT Models with Artificial Crowds

Building IRT Test Sets



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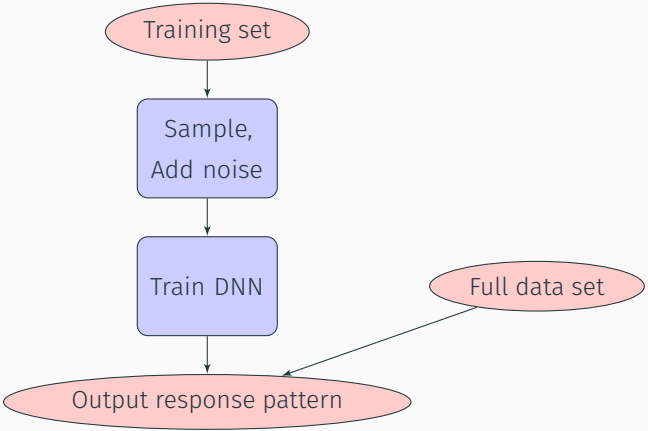
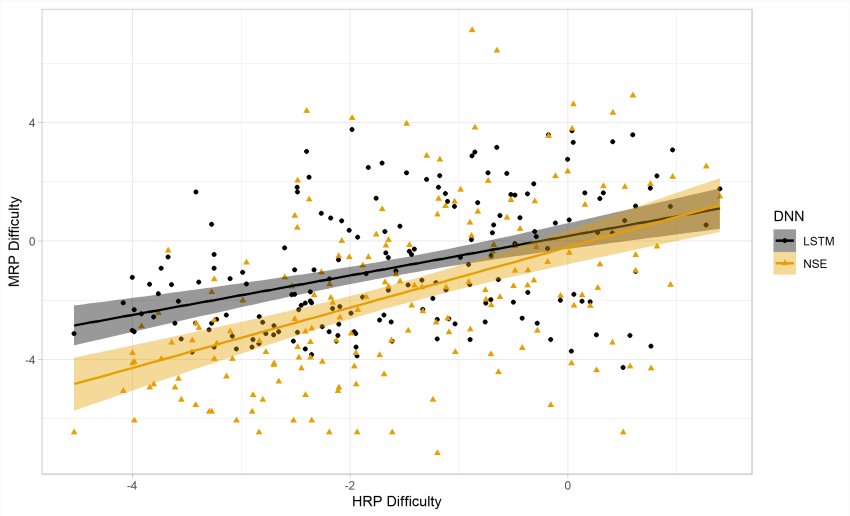
Artificial Crowd Construction



Experiments

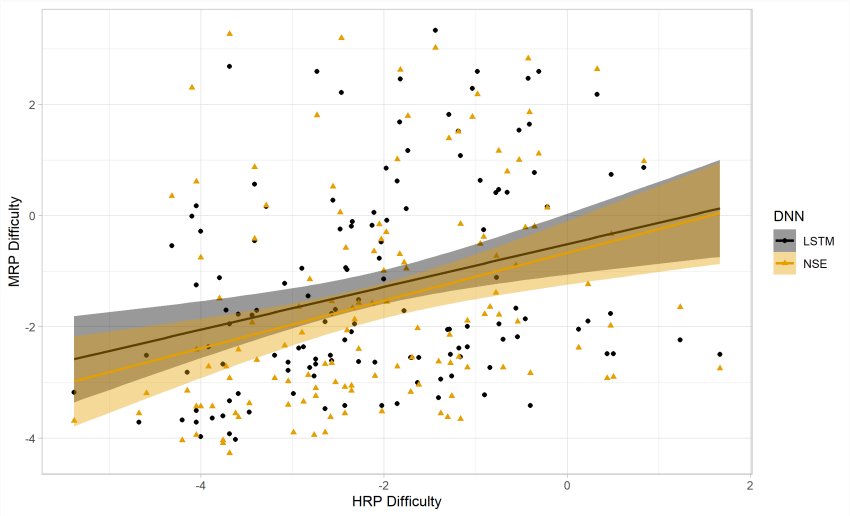
- Parameter comparison between models fit with human and machine response patterns
- Downstream use-case: training set filtering
- Qualitative evaluation: how do they look?

Human-Machine Correlation



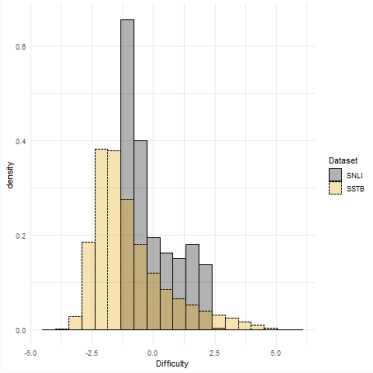
- Spearman ρ (NLI): 0.409 (LSTM) and 0.496 (NSE).

Human-Machine Correlation



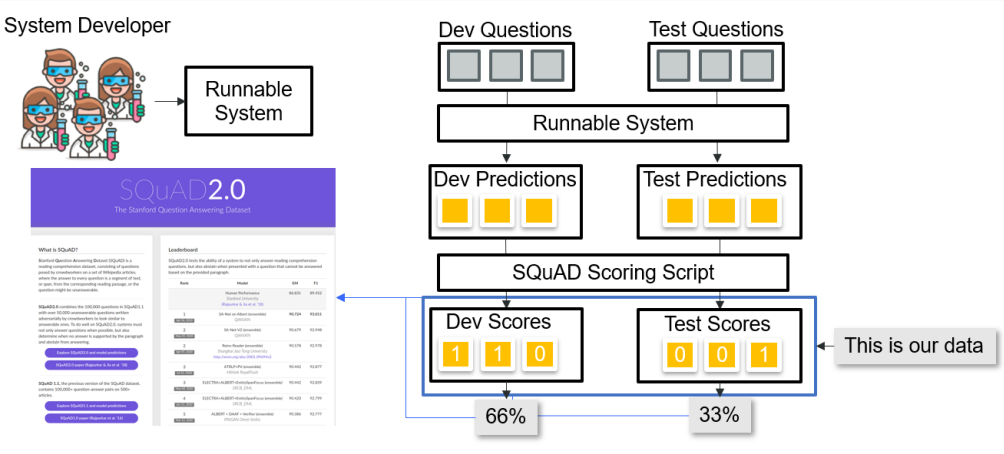
- Spearman ρ (SA): 0.332 (LSTM) and 0.392 (NSE).

Difficulty Distribution



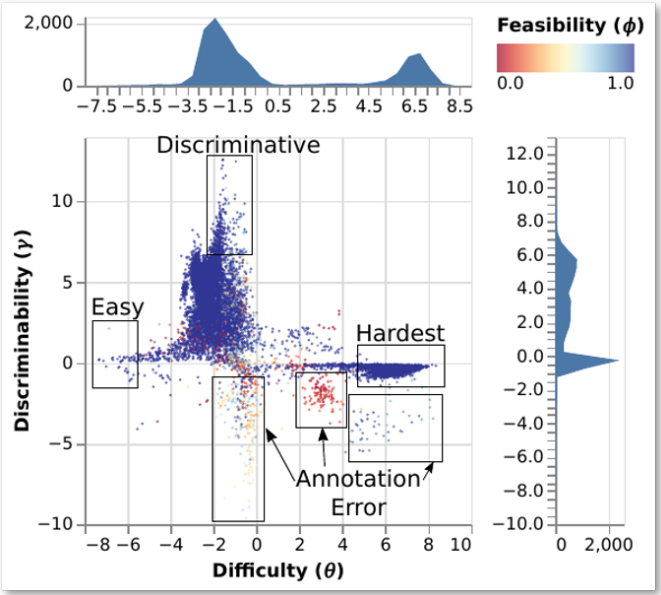
IRT for Leaderboards

IRT for Leaderboards (SQuAD)

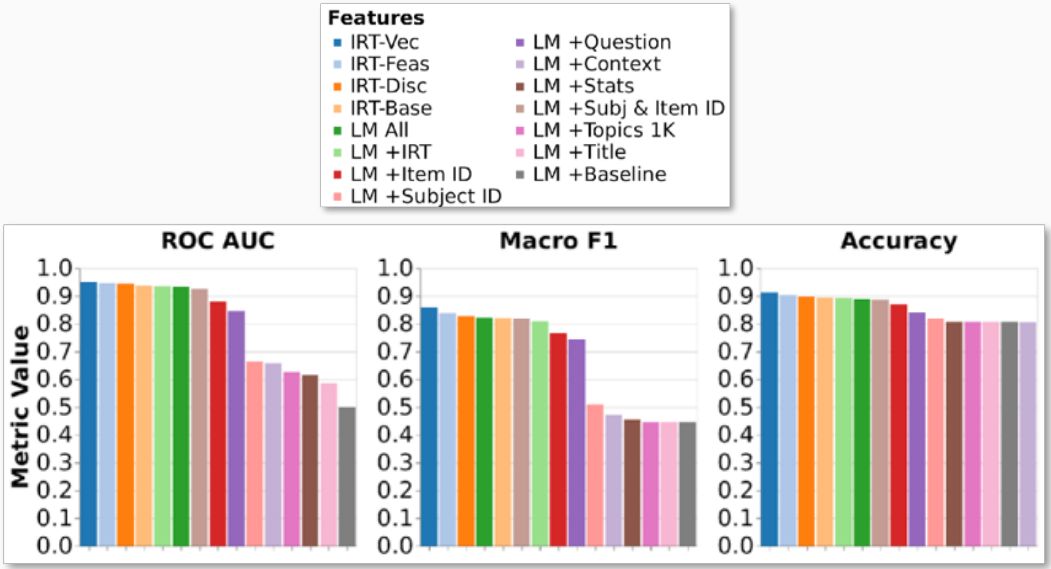


- 1.9 million subject-item pairs

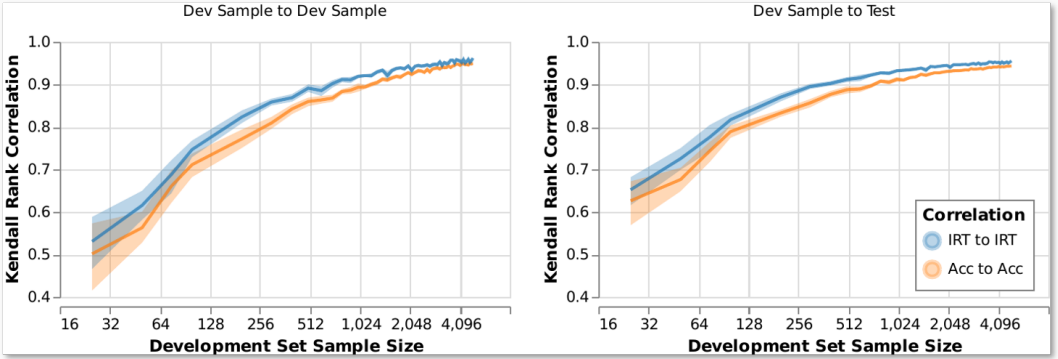
IRT for SQuAD



Predicting Correct Responses



Ranking Performance



The py-irt Package

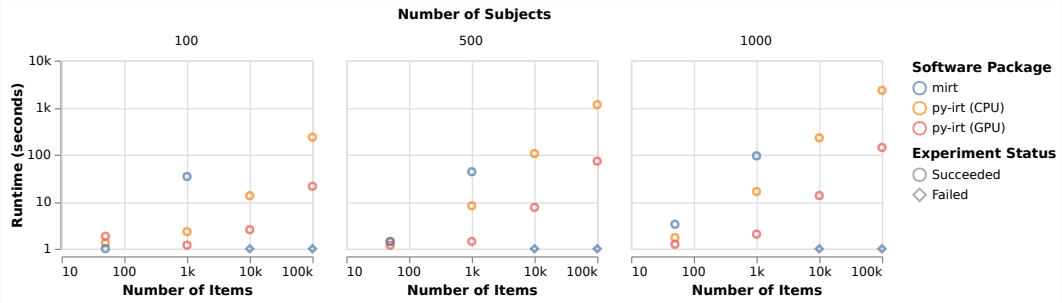
IRT in Python: py-irt

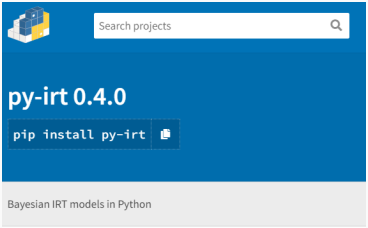
```
{"subject_id": "pedro",    "responses": {"q1": 1, "q2": 0, "q3": 1, "q4": 0}}
{"subject_id": "pinguino", "responses": {"q1": 1, "q2": 1, "q3": 0, "q4": 0}}
{"subject_id": "ken",      "responses": {"q1": 1, "q2": 1, "q3": 1, "q4": 1}}
{"subject_id": "burt",     "responses": {"q1": 0, "q2": 0, "q3": 0, "q4": 0}}
```

```
py-irt train 1pl data/data.jsonlines output/1pl/
```


```
{
  "ability": [
    -1.7251124382019043,
    -0.06789101660251617,
    1.6059941053390503,
    -0.20248053967952728
  ],
  "diff": [
    0.008014608174562454,
    9.654741287231445,
    -5.5452165603637695,
    -0.2792229950428009
  ],
  "irt_model": "1pl",
  "item_ids": {
    "0": "q2",
    "1": "q4",
    "2": "q1",
    "3": "q3"
  },
  "subject_ids": {
    "0": "burt",
    "1": "pinguino",
    "2": "ken",
    "3": "pedro"
  }
}
```

IRT in Python: py-irt





https://github.com/nd-ball/py-irt