An R Package for Adaptive Assessment Utilizing Knowledge Space Theory and Formal Psychological Assessment

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Consiglio Nazionale delle Ricerche

September, 19 2024

Outline

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Tests in Education and Clinical Psychology

- Time consuming
- Fatigue effect, social desirability, etc.

(Informal) Definition

A computerized adaptive assessment is an evaluation that adjusts the difficulty and nature of subsequent questions based on the test-taker's responses to previous ones.

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Pros of Adaptive Assessment

- Increased Efficiency and Accuracy in Assessment:
  - Adaptive systems save time by focusing on the appropriate difficulty level.
- Personalized Learning or Therapy :
  - Feedback can be customized to individuals need.
- Immediate Feedback:
  - Results are available as soon as the assessment is finished.

Cons of Adaptive Assessment

- Dependent on the assumptions of the Model :
  - The validity of results depends on the correctness of the model used.
- Complexity of Implementation:
  - Requires sophisticated algorithms and data processing infrastructure.
- Difficulty in Tuning:
  - Fine-tuning the assessment to achieve accurate difficulty adjustments is challenging.

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My computerized adaptive assessment R package

`mycaas package`

```
devtools::install_github(''brancaccioandrea/mycaas")
```

- Based on the strong theoretical foundation
- User-friendly graphical interface made
- Performance analisys to evaluate accuracy and efficiency

Theoretical Framework

Knowledge space theory (KST; Doignon & Falmagne, 1985): The objective is to precisely describe what the individual knows (their knowledge state) in a given domain of knowledge, rather than computing a numerical score.

Formal Psychological Assessment (FPA; Spoto, Stefanutti & Vidotto, 2010): The objective from the clinical perspective is to give an in-depth evaluation of the construct investigated by the questionnaire.

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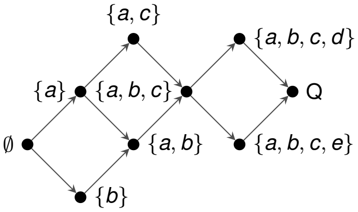
Basic Definitions

Formal definitions of basic concepts encountered so far:

- Domain a either finite or infinite set Q of questions
- State the subset $K \subseteq Q$ of all questions that define the status of individual
- Structure a pair $(Q, \mathcal{K})$, where $\mathcal{K}$ is a collection of subset of Q, containing at least the empty set and Q



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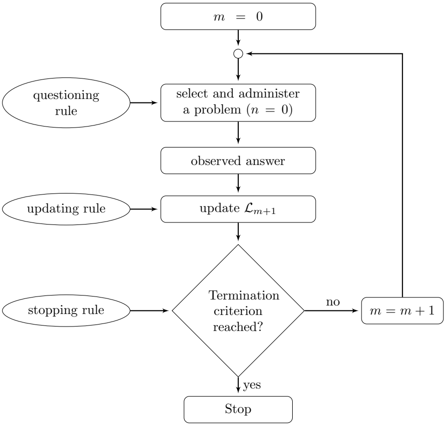
Flowchart of the Adaptive Assessment

Doignon & Falmagne, 1988; Donadello, et al., 2017

The goal of the assessment is to recover the true state of an individual asking the fewest possible questions

- Three rules guide the assessment:
  1. Questioning rule
  2. Updating rule
  3. Termination rule



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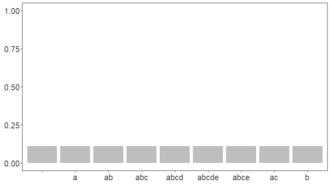
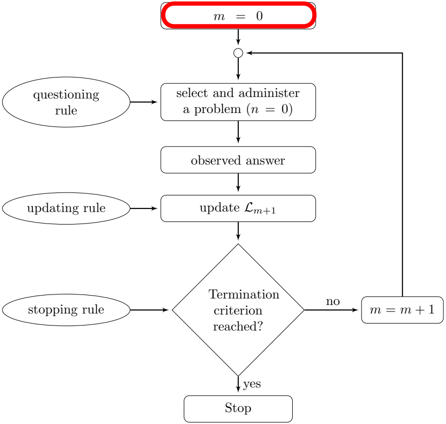
Probability distribution on the states

A probability distribution

$$\mathcal{L}_m : \mathcal{K} \to (0, 1)$$

Without prior knowledge is a uniform distribution

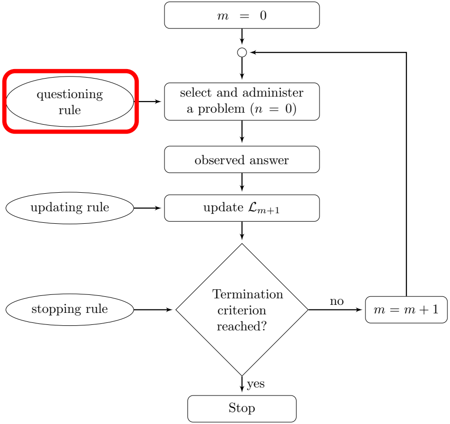




Questioning Rule

Half Split Rule

Select the "best" question to ask



Doignon & Falmagne, 1988

`half_split`: Let $\mathcal{L}_m(K)$ the likelihood of K at the step m, and the subset $\mathcal{K}_q \subset \mathcal{K}$ such that $q \in K$ for each $K \in K_q$.
It selected problem $q \in Q$ that minimize

$$|\mathcal{L}_m(\mathcal{K}_q) - 1/2|$$

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Updating Rule

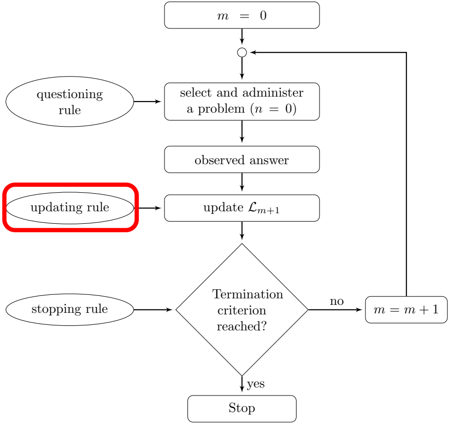
Bayesian Updating Rule

The probability $\mathcal{L}_m(K)$, for each $K \in \mathcal{K}$ is updated in function of the the observed response r_q collected for problem q as follows.

$$\mathcal{L}_{m+1}(K) = \frac{P(r_q|K)\mathcal{L}_m(K)}{\sum_{K' \in \mathcal{K}} P(r_q|K)\mathcal{L}_m(K')}$$

Parameters

$$P(r_q|K) = \begin{cases} \beta_q & \text{if } r_q = 0 \;\&\; q \in K; \\ 1 - \eta_q & \text{if } r_q = 0 \;\&\; q \notin K; \\ 1 - \beta_q & \text{if } r_q = 1 \;\&\; q \in K; \\ \eta_q & \text{if } r_q = 1 \;\&\; q \notin K. \end{cases}$$



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Termination rule

Heller & Repitsch, 2012

`Likelihood Maximization:` The assessment terminate at step m if

$$\max \mathcal{L}_m(K) > SC$$

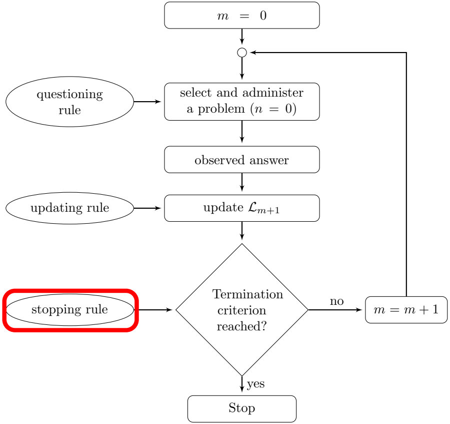
with $SC \in (0.5, 1]$.

Donadello, et al., 2017

`Item Discrimination:` The assessment terminate at step m if for each $q \in Q$

$$\mathcal{L}_m(\mathcal{K}_q) > SC \text{ or } \mathcal{L}_m(\mathcal{K}_q) < 1 - SC$$

with $SC \in [0.5, 1]$.



Outline

Create and Try the Test ...

... without coding knowledge `run_Practice()`

Practice Assessment | Introduction | Upload your Test | Adaptive Assessment | Results

Welcome to the Adaptive Assessment Tools App

This application allows you to conduct adaptive assessments using the continuous Markov procedure by Falmagne and Doignon (CMP; 1988) from Knowledge Space Theory (KST) and/or Adaptive Testing System for Psychological Disorders (ATS-PD; Donatello et al., 2017) from Formal Psychological Assessment (FPA). Whether you are assessing knowledge, evaluating clinical conditions, or any other application, this app provides a structured, efficient, and accurate way to collect your data.

What is Adaptive Testing in KST and FPA?

Adaptive testing is a dynamic process that tailors the assessment to each individual based on their responses. In both Knowledge Space Theory and Formal Psychological Assessment, this means recovering the state that represents the learner's or patient's abilities, among the collection of possible states on the structure.

The Underlying Structure

Both KST and FPA rely on an underlying structure—be it a knowledge structure in KST or a clinical structure in FPA. This structure guides the adaptive process, ensuring that each question or evaluation step is meaningful and relevant. The app can also accommodate a random presentation of questions, providing flexibility in how the assessment is conducted.

How the App Works

1. **Upload Your Assessment:** On the second page, you can upload your assessment data. This includes questions and a skill map or clinical context, which should be in a CSV file format. Alternatively, if you have pre-created an assessment in R, you can upload an RDA file containing a variable of the 'assessment' type.
2. **Adaptive Assessment:** The third page dynamically displays questions based on the adaptive algorithm. You can visualize the progress through a graph diagram, which highlights the likelihood of different states with color coding. This diagram helps to understand the current state. At the top of the diagram are the states that contain most of the items (with the whole collection of items on top), and at the bottom of the diagram are the states with fewer items (with the empty set on the bottom).
3. **Results:** The final page provides a detailed outcome of the assessment. You'll see the cardinality of the recovered state (the score), the identified state (knowledge or clinical), and insights on potential changes in status. This comprehensive result allows for informed decision-making or further evaluation. Moreover, the result of the test can be downloaded and analyzed using R.

This app is designed to be a powerful tool for educators, psychologists, and clinicians, providing deep insights through adaptive assessments tailored to each individual's responses. Explore the pages and see how adaptive testing can enhance your understanding of knowledge or clinical states!

References

Donadello, I., Spoto, A., Sambo, F., Badaloni, S., Granziol, U., & Vidotto, G. (2017). ATS-PD: An Adaptive Testing System for Psychological Disorders. Educational and Psychological Measurement, 77(5), 792-815. https://doi.org/10.1177/0013164416652188

Falmagne, J.C., & Doignon, J.P. (1988). A class of stochastic procedures for the assessment of knowledge. British Journal of Mathematical and Statistical Psychology, 41, 1–23. https://doi.org/10.1111/j.2044-8317.1988.tb00884.x

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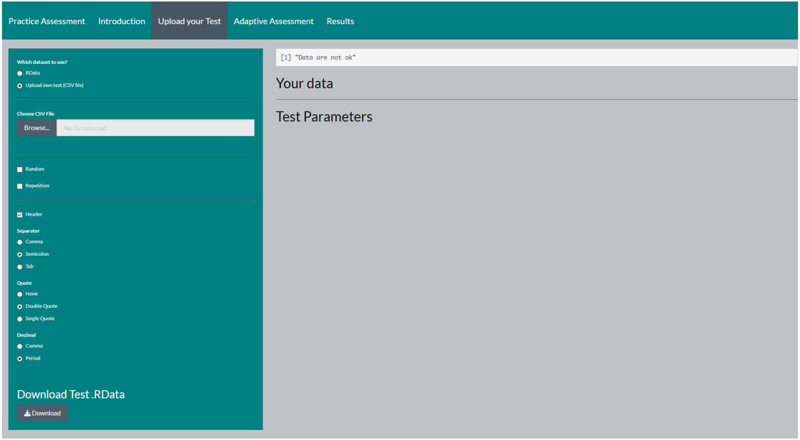

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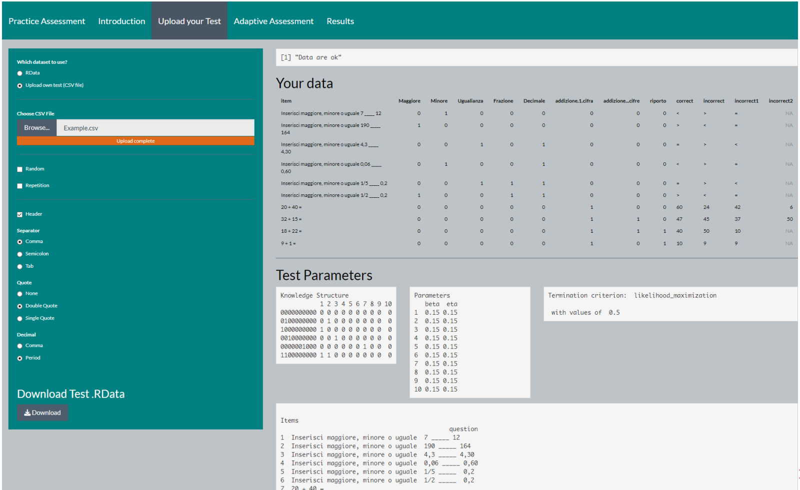

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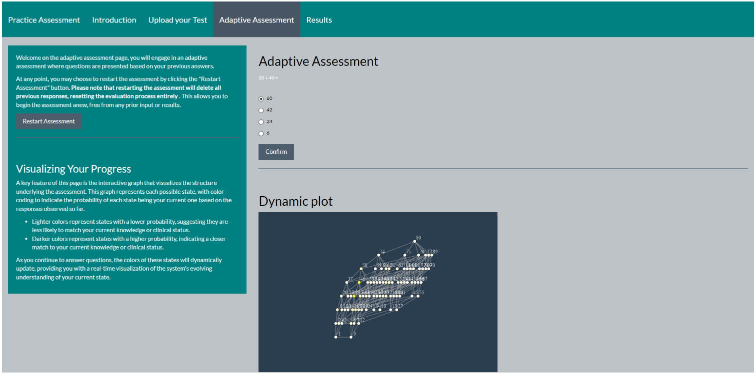

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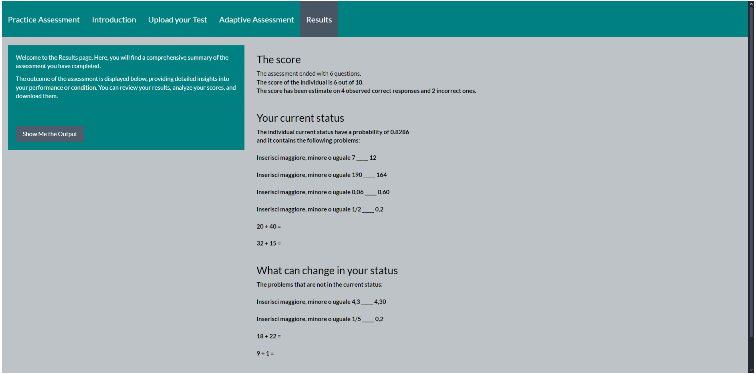

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RAISE - Robotics and AI for Socioeconomic Empowerment

- In collaboration with some middle schools in Lombardia and Liguria
- A pilot test covering the middle school program in in mathematics

Tuning a Test with mycaas

21 items with multiple choice and 595 states

Simulation parameters:

- two termination rules with six stopping criteria $SC = \{.5, .6, .7, .8, .9, 1\}$
- simulate ten response patterns for each $K \in \mathcal{K}$
- lucky guess $\eta_q = .2$ & careless error $\beta_q = .15$

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Performance Analysis

Accuracy and Efficiency Indexes

Given:

- true knowledge state K^w of a student w;
- the probability distribution $\mathcal{L}_m$ at the end of the assessment
- the recovered knowledge state $\hat{K}_m^w$

The following indexes were computed across simulated subjects:

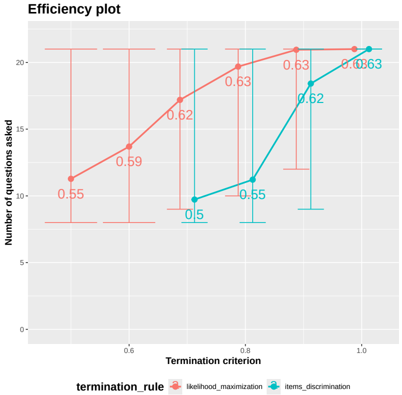
1. The average number of questions asked.
2. The average maximum likelihood $\bar{\mathcal{L}}_m(\hat{K}_m)$.
3. The average Hamming distance $\bar{D}_m(K, \hat{K}_m)$ computed by

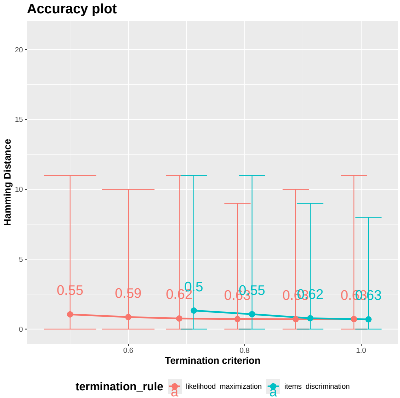
$$\bar{D}_m(K, \hat{K}_m) = \frac{1}{N} \sum_{w=1}^{N} |K^w \Delta \hat{K}_m^w|,$$

where Δ represents the symmetric set difference.

Performance Analysis

`performance_simulation(...)`





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Final Remarks

- The Shiny environment is used to make adaptive assessments more accessible and user-friendly.
- Currently the usability of the package is tested within RAISE in Liguria school
- `https://github.com/brancaccioandrea/mycass`

Acknowledgements:

This work has been supported by the European Commission, NextGenerationEU, Missione 4 Componente 2, “Dalla ricerca all’impresa”, Innovation Ecosystem RAISE “Robotics and AI for Socio-economic Empowerment”, ECS00000035.