Cognitive Study
Understanding how calculus is encoded in the brain

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One of the most used strategies of learning rely on positive conditioning in an associative learning framework [1]. We make the hypothesis that one could increase the efficacy of learning by strengthening a network of clues associated with the learned subject. To do so we propose the design of an application to give tools helping a more efficient learning. As a demonstrator, we project to study how calculus is encoded within the brain to help improve performance on simple calculus task. This document presents the key points associated to this project.

Description of the project

The project is designed around three axes:

- Modelling the structure of simple calculus processing and how it can be encoded within the brain
- Using Electroencephalography (EEG) to measure subject during calculus task and develop a metric of the calculus process
- Develop strategies based on the previous model to help subject improving their calculus performances

The main idea being as follow. When an individual performs calculus she or he splits the initial problem in easier operations until reaching minimal operations to perform. we assume these operations to be simple additions and multiplication based on usual tables. Therefore one can factorise all calculus task in a base of fundamental operations. Then, by probing the subject with a series of task, an algorithm could identify the fundamental operations associated with lower performances and focus the training on problematic operations, increasing consequently the rate of improvement. Such an algorithm would build its estimate of one calculus weaknesses based on accuracy to the task and time required to answer. Other clues based on learned synesthesia [2], such as coloring the numbers depending on their parity or other features, could be implemented and eventual proof of their efficacy could be systematically checked.

Modelling Calculus seems to be a good learning task to allow unbiased quantification of someone accuracy. Based on computational tree theory, there exist a theoretical description of its structure [3]. It is on this structure that calculus task can be decomposed and further used to identify individuals calculus mechanisms. In a first place, should be investigated a group of subject to see how they effectively structure their computation. A series of computation would be asked to be performed and the process used to perform the computation as well. Based on this first experiment, one could see the eventual prevalence of alternative strategies such as factorisation of big numbers for multiplication ($12 \times 637 \rightarrow 2 \times 6 \times (600 + 30 + 7)$) or clustering of round additions($3 + 4 + 7 + 6 \rightarrow (3 + 7) + (4 + 6)$). After this study each operation should be decomposable in multiple models of successive fundamental operations. The goal is then to decipher which is chosen for each individual based on metrics such as speed and accuracy [4]. An algorithm should be able to select the strategy used by someone and therefore identify in the space of sub operations which are the weak ones. Both supervised and non supervised machine learning strategies can be followed at this stage.

Physiological recordings In order to increase the relevance of the previous study, one could also record multiple physiological data. The *EEG signals* could be used in order to refine the metrics of accuracy. The idea is that specific evoked pattern would be registered during the task [5]. From these patterns, could be extracted biomarkers of an individual confidence during the task. If successful, this approach could lead to a biofeedback procedure in order to direct learning methods. In addition, using an eye tracking apparatus could allow a better understanding of the sub-operations the subject performs during the task improving the choice of calculus model chose by the individual. Other recording, like heart rate and respiratory rate could be used to regress physiological state from the model.

Learning Strategies Based on the previous work could be defined a learning scheme to improve learning rate. A learning scheme can be define as a series of operations to perform in order to improve calculus performances. Then, could be compared two groups of subjects. The first one would train its calculus skills on random operations. Due to active training, improvement of these individuals to the task can be expected. It is this learning curve that will act as reference. The second group will be given a series of tasks based on their own performance to focus on weak operations. Both groups will be compared on the same set of operations. Thanks to this experimental pipeline, as discussed above, multiple strategies can then be evaluated in term of improvement of calculus efficiency.

Applications

This work can, if successful, can be seen as a first step in a entreuprenarial project. As a a next step, an application could be designed to be distributed to the public. This tool would have two purposes, for the person using it, improving their calculus skills, for the developpers, building a dataset to further investigate learning. The planned algorithm could be generalised to other types of learning that we call «the stupid learning» such as historical dates, chemical elements or physics constants and so on. All these tasks could be decomposed following a network of connected knowledge that could be improved by conditioning, using adapted cues targeted onto weak nodes. If the time allows such generalisation could be implemented.

The first application would be for education professionals who could use it to improve learning for their students. In addition, such a generally accessible tool could allow implementation of *Big Data* approaches in order to data mine learning process [6]. These methods are being intensively to scan population and try to find marker for psychiatric pathologies. On a low level one could see specialised doctors using the app to detect learning impairements but also more general disorder such as attention defficit and hyperactivity. On a higher level and in a more speculative way, it could allow probing for less linked diseases such as dementia, Alzheimer's disease or autism spectrum disorder.

References

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