TG4 Panel: Virtual reality, artificial intelligence and machine learning for mathematics education

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This is a summary of the *TG4 Panel: Virtual reality, artificial intelligence and machine learning for mathematics education* that took place at the Symposium on Artificial Intelligence for Mathematics Education (AI4ME), held at CIEM Castro Urdiales, February 28th - March 1st, 2020. Full list of authors: Theodosia Prodromou, Adrián Pérez, Martha Ivón Cárdenas, Roman Hašek, Steven Van Vaerenbergh, Alvaro Martínez Sevilla, and José Luis Rodriguez Blancas.

Summary

The *TG4 Panel: Virtual reality, artificial intelligence and machine learning for mathematics education* focused on artificial intelligence based technologies and their direct application to the learning and teaching of mathematics.

The session started with the invited talk by Theodosia Prodromou, "Orientations of research when integrating digital technologies in mathematics education: Emerging technologies and emerging types of learning" and was followed by four talks about AI in mathematics education:

1. Adrián Pérez: *Opportunities of machine learning in education*
2. Martha Ivón Cárdenas: *From graphs to neural networks: complexity and simplicity in the framework of mathematics*
3. Roman Hašek: *Artificial Intelligence, a promising agent of mathematical education*
4. Steven Van Vaerenbergh: *Recent advances in machine learning for mathematical reasoning*

Each talk touched on a different aspect of AI in mathematics education. Nonetheless, as we will conclude below, they allowed us to piece together the parts of

a bigger picture of the interaction between students, teachers and AI technology.

In his talk, Adrián Pérez provided an overview of several areas in which machine learning (ML) is used for the analysis of educational data. A first such application is the analysis and prediction of student performance, which has been studied using regression techniques. As mentioned by Adrián, an interesting aspect of these techniques is that they allow to identify student features that are correlated, such as study time and performance. Next, a promising application of AI-based computer vision is sentiment classification, which, though currently in an experimental stage, could be used in real time in the classroom to provide the teacher with feedback. Lastly, two nascent research areas of ML applied to educational data are fair machine learning, which aims to avoid biases that may be underlying the data, and causal machine learning, which allows to estimate causal effects in student data that contain known causal directions.

Martha Ivón Cárdenas talked about strategies to teach secondary and high school students some of the fundamental concepts in AI. First, she showed how relational graphs can be taught with simple and intuitive examples, for instance by turning geometric constructions into graphs or by looking at real-world examples of graphs. Then, she described a bottom-up strategy to introduce the topic of artificial neural networks, starting at the mathematical equations that govern the functioning of individual neurons.

Roman Hašek explored the question "Can AI be applied as an agent to support the school education of pupils with specific needs?", which concerns pupils with a disability or learning disorder as well as gifted pupils. The research towards this goal requires a specific focus on the collaboration between the teacher and the AI agent, such that the contributions of both are complimentary. Currently, a realistic scenario consists in employing the AI to collect data on the educational progress of the pupil, which is shared with the teacher and analyzed to suggest an individualized learning path.

Steven Van Vaerenbergh discussed recent developments in machine learning for automating mathematical reasoning, which is a key component in constructing systems that can model mathematical learners. Sparked by its success in other computational problems, machine learning is being applied in several areas that work towards automating mathematical reasoning: In the field of automated theorem proving, ML techniques are being applied to encode human provers' intuitions and to predict the best next step in the demonstration of a theorem. Advances in neural networks for natural language processing are being used to train machines to solve word problems and to perform symbolic reasoning, yielding currently some limited but promising results. Finally, in the AI and ML communities there is a growing interest in automating abstract reasoning. The research in this area currently focuses on automating visual IQ tests, such as variants of Raven's Progressive Matrices.

In the second part of the session, two practical projects were presented and demonstrated in real time:

5. Alvaro Martínez Sevilla: *MonuMAI: Artificial Intelligence and Mathematics working over monuments*

6. José Luis Rodriguez Blancas: *Exploring dynamic geometry through immersive virtual reality with Neotrie VR*

Alvaro Martínez Sevilla presented the project MonuMAI, which applies machine learning to recognize artistic styles and geometrical models in monumental architecture. He demonstrated the MonuMAI app, which is capable of extracting such mathematical knowledge from pictures taken by the user. In order to obtain sufficient geometrical examples to train the deep learning model behind MonuMAI, Alvaro explained the novel technique of generating a data set of geometrical models through GeoGebra.

In the final talk, José Luis Rodriguez Blancas presented Neotrie VR, an immersive virtual reality environment for learning geometry. He demonstrated its practical uses in the classroom, by creating and manipulating 3D geometrical objects in a virtual world, which the user accesses through a virtual reality headset.

Conclusions

Students and teachers are at the center of the many AI-based innovations in mathematics education. Firstly, AI is being used to extract mathematical knowledge from the real world, facilitating its interpretation by the student. Virtual worlds are also being built, allowing students to interact directly with geometrical objects that may otherwise seem too abstract. The interactions of students with technology generate large amounts of data, out of which AI can extract concrete knowledge. As students become more and more used to being surrounded by AI-based technologies, it is also important to teach them some of the basic mathematical principles on which AI is based. Finally, in order to assist students in their learning process, research is being conducted in AI techniques that guide the student, whose long-term goal is to produce a machine that can model the mathematical learner.