//ENIAC

Real-time fMRI decoding

Reading minds with brain imaging

By: Adnan Niazi
Researcher at Donder Institute for Brain, Cognition and Behavior

Reading human thoughts and intention has been one of man's biggest fantasies in recent times and over the years, these fantasies have trickled into our popular media as well. In the 1983 film Brainstorm, Christopher Walken playing a scientist, was able to record movies of people's mental experiences, then play them back into the minds of other people. More recently, in 2010, in the episode 'Black Hole' of the popular TV series, House M.D., Dr. House was able to make a medical diagnosis of a patient suffering from hallucinations. By using a fictitious sci-fi gadget, dub-bed the 'Cognitive Pattern Recogni-tion' device, the doctor was able to tap into the patient's brain and visualize reconstructions of the hallucinogenic thoughts as they were happening in the patient's brain.

Although these scenarios might seem like a huge stretch of imagination, the current state-of-the art is getting fairly close to making these fictions a rea-lity. In a groundbreaking study in 2011, researchers at UC Berkeley, utilizing functional Magnetic Resonance Ima-ging (fMRI) and computer models, demonstrated the visual reconstructi-ons of brain activity of human subjects watching movie trailers (see Figure 1); in other words, they could see what the people's brains were seeing. Hence mind reading is no longer a science fiction.

Although decoding of mental activity has been demonstrated in many prior fMRI studies, none of them were performed in real time. In all these experiments, brain images were collected from the subjects in an MRI scanner during long scanning sessions. After all the data had been acquired, it took several hours to build the models or train the classifiers, and then these models/classifiers were used offline on a portion of the previously collected data to predict the brain state of the subject at the time data was originally acquired. If mind reading is to be viable for any future mind reading application, then the decoding has to be done on-the-fly. In other words, decoding the mental activity of a person should be done while these mental states are being generated in the brain.

> "If mind reading is to be viable, the decoding has to be done on-the-fly."

That's where our work comes into the picture. We designed a real-time fMRI processing pipeline, which can analyze fMRI images as soon as these images

Figure 1: A decoding study performed at UC Berkeley in 2011. A short clip of Steve Martin in Pink Panther 2 was presented to the subject and it was recreated from the fMRI images to produce the representation on the right.

are acquired by the scanner thereby allowing us to decode human mind and thoughts as soon as they are produced in the brain. By using smarter and faster algorithms to process fMRI data, we reduced the processing time of fMRI scans from hours to less than a second. The goal of this article is not to choke you with the nitty-gritty of these algorithms but to explain how the de-veloped system has been deployed suc-cessfully to perform some cool mind reading experiments.

> "Our system demonstrated that the semantic contents of the human mind can be decoded in real time and with very high accuracy."

Decoding visual attention

In our daily life, we are continuously flooded w ith m ultiple i nformation streams, each competing for our attention. However, only a small amount of information can be assimilated at any given time due to limited information-processing capacity of human mind. To effectively cope with this influx of information, our brain must filter out task-relevant information from the en-vironmental stimuli based on current task demands. Selective attention drives this filtering by focusing processing resources on particular aspects of the environment or stimuli, whilst disregarding others.

So in our first experiment, we wanted to investigate if we can decode visual attention while it is happening in brain. To do that, we scanned subjects in an MRI scanner, and while they were being scanned, they were shown superimposed picture of a face (Jim Carey) and a scene (Eiffel Tower) as shown in Figure 2. The subject's task was to attend to only one of these pictures, i.e. either Jim Carey or the Eiffel Tower. The fMRI brain images acquired during this time were immediately decoded to find which of the two pictures the subject was attending to at any given time.

But how is it possible to find what people are attending to? Well, a human brain has certain distinct regions for processing faces and scenes. By figuring out which of these two regions was more activated, the computer was able to predict which of the two pictures (Jim Carrey or Eiffel tower) the subject was attending to. The system was able to decode the attended picture with 80% accuracy. We demonstrated that the semantic contents of the human mind can be decoded in real time and with very high accuracy. This study will prove instrumental in future research to explore if humans can be trained to leng-then or improve their attentional span which can be very useful for attention demanding jobs.

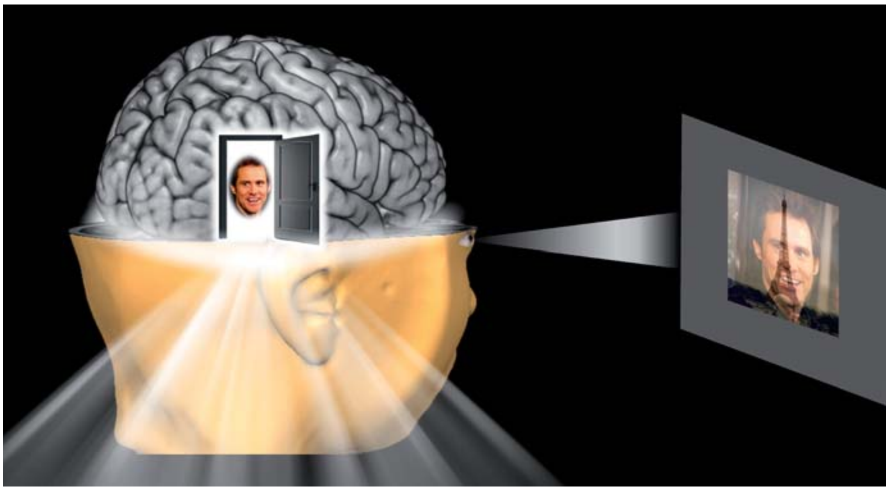

Figure 2: Superimposed pictures of Jim Carey and Eiffel Tower were presented and the subjects were asked to attend to only one of them. Using real-time fMRI, we were able to decode which of the two pictures the subject was attending to at any given time.

Decoding visual perception

In our second experiment, we took things a bit further. Rather than decoding the high-level semantic category information (face or scene) of the sti-

About Adnan

I was born and raised in Pakistan. During my undergraduate studies, I became obsessed with brain-computer interfaces but pursuing my interest in this field was severely hindered due to lack of proper research resources in Pakistan. So I decided to move to the Netherlands and started my master's in Human Media Interaction at UT where I was able to fully explore my passion for BCIs. Later on for my master's thesis, I decided to move to Donders Institute in Nijmegen and started working on MRI-based BCIs. Loved Nijmegen so much that I have been living and working in Nijmegen ever since. I love nature and whenever I get some free time, I like travelling to scenic secluded places.

About Donders Institute

The Donders Institute for Brain, Cognition and Behaviour is a leading research institute of the Radboud University Nijmegen where researchers from about 20 different countries are conducting cutting-edge fundamental research in cognitive neuroscience.

muli, we wanted to investigate if we can also decode low-level details such as the shape of the stimulus. More specifically, we wanted to investigate if we can decode complex shapes such as alphabets from the human visual cortex. So in this experiment, we showed some alphabets to the subjects while they being scanned in the MRI scanner. The fMRI brain images acquired during this time were then analyzed and the perceived alphabets were reconstructed from these fMRI brain images.

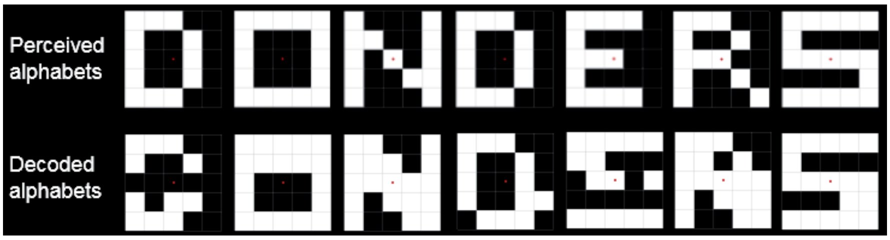

Figure 4: The top rows shows the alphabets that were seen by the subjects. The bottom shows the alphabets reconstructed from the fMRI brain activations.

But how is it possible to infer the shape of perceived stimuli from activations in human visual cortex? The answer lies in a breakthrough made by Roger Tootell in 1970 which showed that the visual cortex is retinotopically organized. In that experiment, a geometric pattern of flashing lights was shown to a monkey after it was injected with a radioactive sugar, which is taken up into brain cells in proportion to their level of activity. This stains the brain cells which are active. In other words, the radioactive sugar traces out those cells in the brain that responded to light. The monkey was trained to stare at the stimulus and was then sacrificed so that its brain could be examined. The occipital cortex of the monkey showed dark bands revealing those neurons that were most activated while the animal viewed the pattern. Surprisingly, this pattern of activation in the brain resembled the geometric structure of the stimulus seen by the monkey (see figure 3).

Tootell's experiment was a remarkable demonstration of how the visual cortex is retinotopically organized i.e., this part of the brain is organized similar to how the light hits our retinas. Everything that we see gets mapped in a certain specific manner onto the visual cortex. If only we can somehow learn this stimulus-to-cortical activation mapping non-invasively, then we can use it to infer the shape of almost any stimuli presented in the visual field.

To learn this mapping, we first presented totally random patterns to subjects and used the corresponding fMRI brain images to train an elastic net logistic regression classifier. Once the classifier learned how various regions in the visual field get mapped onto the visual cortex, we presented alphabets to the subjects in the visual field. Using the fMRI brain activations of the alphabets and the previously trained classifier, w e w ere able to infer the shape of the perceived alphabet. In essence, it is like reverse engineering the shape of the alphabet that subject was seeing from the corti-cal activations elicited by that alphabet. The results of this decoding is shown in figure 4.

"Using the fMRI brain activations, we were able to infer the shape of the perceived alphabet"

Figure 3: Tootell's experiment in which flashing circular patterns were shown to a monkey. The exact same pattern was found to be imprinted on the visual cortex, implicating that the visual cortex is retionotopically organized.

The next step in this research would be to decode imagined alphabets. Research has shown that activation patterns for imagined stimuli are more or less the same as perceived stimuli. If visual perception and imagination share the same neural substrates, then a classifier trained for decoding perceived stimuli can also be used to decode imagined stimuli. This research is currently under way and if we are successful, it would result in a true thought-reading device.

Future of mind reading

Although mind reading is still in its infancy, the technology will make a profound impact on the lives of many. It would permit the profoundly handicapped, those paralyzed by conditions such as motor-neuron disease and cerebral palsy, to communicate more easily. It might unlock the mental prison of patients suffering from diseases like Locked-in-Syndrome (LIS). For the able-bodied, it could allow workers to dictate documents silently to computers simply by thinking about what they want to say. And most importantly, such a device might one day be able to detect lies and help judicial systems to prosecute criminals and deliver justice.

Acknowledgements

The author gratefully acknowledge the support of the Brain-Gain Smart Mix Programme of the Netherlands Ministry of Economic Affairs and the Netherlands Ministry of Education, Culture and Science.