The Physics of Mind-Reading

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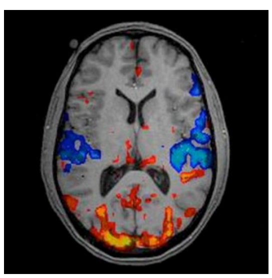
What is fMRI?

Magnetic Resonance Imaging, or MRI, is used in many medical applications to gain an image of what is going on inside a patient's body. It works because of humans' unique molecular makeup. Because our bodies contain so much water, we are approximately 63% Hydrogen atoms. The protons in these atoms each possess a unique ‹spin', or angular momentum. During an MRI scan, a radio wave pulse is sent through a large metal tube, which produces a very strong magnetic field ranging from 0.5 to 2.0 Teslas. This magnetic field interacts with the angular momentum of the Hydrogen atoms and aligns their spins in one direction (this is called ‹resonance'). At this point, the atoms are in a higher energy state, so when the field is removed, the atoms return to their lower energy resting state and give off a signal that is converted into a physical image.

Functional Magnetic Resonance Imaging, or fMRI, is a similar process, but rather than relying on atomic manipulation, fMRI measures changes in blood flow within the brain. It is known that when a particular region of the brain is actively firing, blood will flow there to supply needed energy.



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Because this blood is supplying energy, it comes from the lungs and contains a high level of oxygen, as opposed to blood that has been in circulation already and given off much of its oxygen content. This rush of highly oxygenated blood behaves uniquely in that it does not give off a magnetic signal, like other blood (it becomes ‹diamagnetic'). When an fMRI is performed and the strong magnetic field is applied to a patient's brain, the diamagnetic blood interacts with the field much differently than the other surrounding blood. This allows scientists to map out exactly which regions of the brain are actively firing.

Current Research in Thought Detection:

There have been a number of recent findings in the field of neuroscience that are leading researchers closer to unlocking the key to mind-reading. All of these experiments include the use of fMRI, as explained above, to visualize brain activity in real-time.

Dr. Moran Cerf and colleagues have been able to connect the activity of single neurons to images on a computer screen. Participants are then able to fade these images in and out based on what they are thinking about. Initially, the study participants looked at hundreds of images in order for the researchers to build a database of image-neuron associations. The researchers then instructed participants to focus on one of two superimposed images. They were, with great accuracy, able to determine which picture the participants were looking at based on only their thoughts (Cerf et al. 2010).

Dr. Gallant and colleagues used the results from previous studies to develop a novel method of peering into the mind. This pioneering experiment involved the use of a newly developed machine that can recreate a moving image from the brain activity of a participant watching a video. While the results are grainy and crude, the researchers were able to make out, for instance, the outline of a man in a white shirt from the brain activity of a participant watching a video with Steve Martin. The machine integrates information from multiple processing centers in the brain to literally draw a picture of the participant's thoughts. Dr Gallant feels that his technology is close to becoming a practical form of mind reading, in which doctors can look into the mind of schizophrenic patients, or judges can look into the minds of criminals (Naselaris et al. 2009).

In order to begin reading abstract thoughts, researchers must first be able to read the most basic visual information from the primary visual cortex. Frank Tong and colleagues proposed that the areas of the brain used to deconstruct visual information is also involved with processing memories associated with this information. Using this basis, the researchers conducted a study in which volunteers were shown two different patterns, and told to remember their pattern for a short period after viewing. Based on fMRI brain activity patterns, the researchers were able to detect which pattern a participant was thinking about (Kamitani & Tong, 2006).

In addition to understanding the basic processing mechanisms in the primary visual cortex, mind-reading of abstract thoughts requires the use of extremely complex computer programs that are able to map abstract activity to a concrete idea. Mitchell and colleagues designed a computational model that predicts fMRI neural associations with words for which fMRI activation information is not yet available. This is one of the first forays into mind-reading that does not require the subject to be looking at a picture of what he/she is thinking about. Their new model integrates the use of a trillion-word text corpus and observed fMRI data associated with several dozen concrete nouns. From this initial information, the researchers are able to, with a high degree of accuracy, predict fMRI activation for thousands of different concrete nouns (Mitchell et al. 2008).

One application of mind-reading is its ability to extract the truth from individuals in a court setting. Dr. Haynes and colleagues are interested in reading an individual's intentions rather than simply decoding information about a concrete object. In this study, the researchers allow the subjects to choose one of two tasks to complete. From fMRI readings, the researchers are able to reliably pick which task will be completed before the subject initiates the task. These results suggest that covert goals or intentions can be represented by patterns of activity in the pre-frontal cortex, which researchers are then able to decode using fMRI. While basic, the ability to read one's intentions are clearly possible, which will have large implications in matters of the law in the near future (Haynes et al. 2007).

Mind-reading research is not only being assessed in an academic research setting. Large corporations are researching the technology, and developing advanced machines that can decode fMRI information faster than humans. Intel Corporation showed off its own software that can quickly decode fMRI information, and reliably predict what an individual is thinking about based on neuronal activity. Researchers from Intel Labs believe that this is the first step towards one day being able to control technology with our minds (Gross, 2010).

Future Applications in Mind Reading Technology:

Recent developments in real-time brain imaging are the first steps toward a greater understanding of mental activity. We can make objective observations and quantitative measurements about what's going on in someone's brain, assess subjective experience, and analyze the patterns we see in each to figure out -- to a limited extent -- what that person is thinking. Compared to prior methods for neural research, functional neuroimaging techniques such as fMRI let us see a highly distributed, highly parallel view of current neural activity across the entire brain (deCharms, 2008).

Other techniques, such as electro-encephalography (EEG) and magnetoencephalo-graphy (MEG), can give better temporal resolution (on the order of milliseconds instead of seconds), but they are worse at figuring out where in the brain signals and activity originated -- called "spatial source localization" -- and do not give the same 3D perspective. That said, fMRI measures changes in blood flow, and is thus inherently indirect and noisy -- blood flows to regions in which neurons are active but with a delay of several seconds (deCharms, 2008). And despite having greater resolution than EEG and MEG, even one cubic millimeter of brain can contain more than a million cells. Techniques for measuring neural activity will need to improve in both spatial and temporal accuracy before *true* mind-reading will be possible.

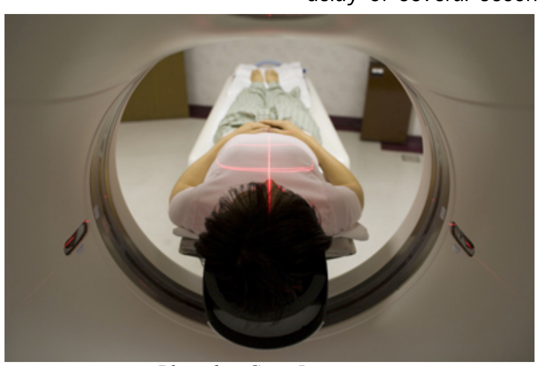

Photo by: Getty Images

Potential applications are numerous, and as mentioned above, preliminary research in many areas is already being done. Daniel Langleben (2008), for example, claims that fMRI can be used to detect deception, discriminating between lies and truth or other comparative states. Deception requires extensive working memory and may be mediated by prefrontal-parietal systems involved in control of behavior and attention. Because fMRI is only sensitive to differences between brain states, we cannot yet positively identify deception without also having a comparison state.

As this technology progresses, careful attention must be paid to ethical issues and how the law should be influenced, specifically in cases where neuroimaging could be used to determine truth, lies, and guilt. Joëlle Anne Moreno (2009) discusses how we will have to be very careful not to endanger cognitive freedoms. At present, as Langleben (2008) notes, fMRI requires the participant's physical cooperation -- one needs to remain immobile for at least ten minutes to get usable data -- and that restraining an uncooperative person would probably induce enough stress to mask the subtle differences between truth and lie signals. But as accuracy of measurement and reliability of the technique improve, concerns about privacy and unauthorized access to thoughts will certainly become relevant.

Another prominent area of research is in brain-computer interfaces, using fMRI and EEG signals for direct brain communication and control of electronic devices (e.g., see Birbaumer & Cohen, 2007; Daly & Wolpaw, 2008). Current systems are limited -- answering "yes" and "no" to questions, managing elements of the environment such as lights and television, controlling a hand orthosis. Eventually, as our understanding of information flow in the brain becomes more complete, it is hoped that these interfaces will be extended to allow paralyzed patients and stroke patients to regain independence, and help improve and restore motor control (Graham-Rowe, 2011).

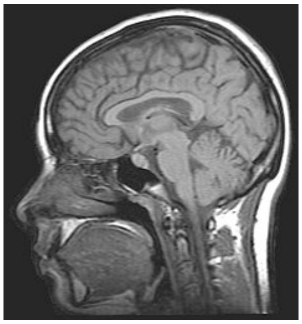

Photo by: Reigh LeBlanc

The root of any mind-reading technology is in pattern analysis, "decoding" patterns of electric and magnetic activity in the brain. Marquand, Howard, Brammer, et al. (2010) demonstrate a method of analyzing fMRI data with supervised machine learning algorithms, which they use to predict people's subjective pain ratings. This method, they suggest, could be extended to make general qualitative predictions about brain states. Norman, Polyn, Detre, et al. (2006) argue that with the right kind of pattern-classification and if spatial resolution of fMRI was improved, the exact information present in a patient's brain at a particular moment in time could be determined. It's possible these methods could lead to advances in reading and recording dreams (Biever, 2008), to counter terrorism (Debrosse, 2010), or to read unconscious attitudes and preferences (BBC News, 2005). No matter where it leads, it is certain that mind reading technology stands on the brink of entering many exciting new domains.

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