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Exploring the Mind

What Our Brain Reveals about Our Thoughts

Scientific Coordinators: Professor John-Dylan Haynes and Professor Gabriel Curio

Statements of the Speakers

Editing: Kristina Vaillant and Marlene Schoofs, Berlin

Professor Gisbert zu Putlitz
President of the Board, Gottlieb Daimler and Karl Benz Foundation, Ladenburg

Reading thoughts – Accessing our innermost lives

Dr. Gisbert zu Putlitz is a physicist at the University of Heidelberg, specializing in elementary particle physics, nuclear physics and quantum fluids. When the Gottlieb Daimler and Karl Benz Foundation was founded in 1986, he was appointed Executive Director of the Board. He has also served as Scientific Director of GSI (a heavy-ion accelerator facility), Chairman of the Arbeitsgemeinschaft der Großforschungseinrichtungen (today's Helmholtz Association of German Research Centres), Rector of the University of Heidelberg and Rector of the Heidelberg College of Jewish Studies, and President of the Heidelberg Academy of Sciences and Humanities.

Rapid improvements in imaging processes and other scanning systems since the 1990s have triggered a boom in brain research. Every experiment lengthens the list of regions and structures in the brain that correlate with certain mental abilities. Brain research is now also benefiting from a movement known as "converging technologies", in which biosciences, medicine, informatics, cognitive sciences and philosophy are becoming ever more closely linked.

Identifying thoughts via brain activity alone has become an independent field of neuroscience. There is an enormous number of potential applications for "reading thoughts". One development of interest here is that of brain-computer interfaces, which can help disabled people move more freely and communicate more easily by means of thought-controlled prostheses. This colloquium will also discuss the possibility of high-tech lie detectors that yield more reliable results than the systems currently in use.

Attention will be devoted to the ethical implications of this research as well, especially to the question of how we can protect our "private mental sphere" against technology-based interventions. The applications in question are invariably marked by far-reaching incursions into neuronal processes, which touch the very core of our private lives – consciousness and mind, thoughts and feelings. As such, they are of enormous social and cultural importance, and at the same time open up broad areas of health and economic policy. Although the technologies are not yet developed to the point at which they can be applied outside the laboratory, we are well advised to discuss the potential applications, the benefits that can be derived from them, and the accompanying dangers.

For over twenty years now, the Gottlieb Daimler and Karl Benz Foundation headquartered in the northern Baden town of Ladenburg has worked to shed light on interrelationships among “Humanity, the Environment, and Technology”. Together with the Ladenburger Kollegs, a set of research programs, it has promoted interdisciplinary work in this complex area since 1986. The Ladenburger Diskurse, a series of colloquia, sponsors interdisciplinary exchange among scientists and experts. The Foundation also works to further international scientific cooperation by funding fellowships for doctoral candidates abroad and supporting joint projects between scientists in Germany and South East Asia. With this annual Berlin colloquium, the Foundation has created a public forum at which researchers, experts, policy makers, and public figures can discuss major current issues in scientific research.

Professor Cornelius Borck
McGill University, Montreal, Quebec

Making brains write: Electrical strategies in the history of mind-reading

Cornelius Borck is Associate Professor and Canada Research Chair in Philosophy and Language of Medicine with a joint appointment in the Department of Social Studies of Medicine and the Department of Art History and Communication Studies at McGill University in Canada.
Before joining McGill in 2004, he worked at the Institute for Science Studies of the University of Bielefeld, the Max Planck Institute for the History of Science in Berlin, and directed a research group at the Bauhaus University in Weimar. Trained as a philosopher and a medical doctor with research expertise in the neurosciences, he has recently finished a monograph on the cultural history of electroencephalography.
He is especially interested in visualization techniques as the interface between knowledge and its objects, and his current work looks at ways in which biomedicine contributes to cultural constructions of body, mind, and self.

Increasing use of electricity around 1900 opened up new areas in which to study mind-body interaction, and revived the notion of a close link between psychic life and electricity. An early example of this tendency was "diagnoscopy", a method of profiling personalities that attracted enormous attention in Weimar Germany. It appeared to offer "objective" personality testing at a time when having the right people fill the right jobs was considered crucial for economic recovery. Although diagnoscopy was quickly denounced as fraudulent, a few years later the press became very excited about electroencephalography and the possibility of using it to read minds. Electroencephalography (EEG) measures the electrical activity of the brain by recording from electrodes placed on the scalp. Its zigzag traces promised direct access to the brain and prompted a constant stream of interpretations. Electroencephalography was developed by German psychiatrist Hans Berger, who worked tirelessly to counter both his own and neuroscientists' skepticism about the technology. When others finally confirmed diagnostic uses of EEG in the mid-1930s, ever greater attempts were made to decipher the meaning of brain waves, yet without definitive results. After World War Two, cybernetics and computer technology provided new tools to crack the EEG code. Many of these studies produced significant results and electroencephalography became firmly established. However, early expectations of reading the mind via electrical recordings from the brain were not fulfilled. Instead, the long history of attempts to decipher brain waves seems to have yielded a much more complex understanding of brain processes.

Professor Gabriel Curio
Charité University Medicine Berlin

Non-invasive brain-computer interfaces – On thoughts that move

Gabriel Curio is a neurologist and psychiatrist who heads the Neurophysics Group at the Charité University Medical School in Berlin. His research focuses on integrating the neurophysics of non-invasive electromagnetic brain monitoring with basic and clinical neuroscientific concepts. Recent topics include high-frequency 'spike-like' activities in non-invasive EEG recordings, injury currents, cortical processing of musical chords, speaking-hearing interactions, temporal lobe mechanisms for processing visual objects, and brain-computer interfacing.

'To make matter move just by thinking about it' – yesterday's fiction is turning into today's science in a prolific research area where brain-computer interfaces (BCIs) exploit our growing knowledge of 'how the mind acts through its brain on the world'.

A major motivation for developing BCIs is to help people who are paralyzed from the neck down due to trauma to their upper spinal cords. Because their brains are uninjured, they can still plan body movements and even try to execute them. The goal of BCI systems is to use such preserved mental capacities to make up for lost physical abilities. The principle works in three steps: 1) brain activity is recorded during a period of intended movements; 2) user-specific computer programs extract 'thought-related' patterns from this data; and 3) the patterns are categorized to control technical devices such as motorized wheelchairs, text programs, and possibly even body-moving exoskeletons.

Thoughts are fleeting. To keep pace, BCI systems have to measure brain activity with a resolution of milliseconds. Many BCI strategies are being explored, including conventional non-invasive EEG recordings, invasive electrocorticography (electrodes are placed directly on the brain), and intracortical recordings from hundreds of single neurons. These options will enable future BCI users to decide on their personal balance between innocuous but moderately precise non-invasive systems and the higher precision of invasive decoding systems carrying risks of intracranial bleeding and infection.

One non-invasive approach is the Berlin Brain-Computer Interface (www.BBCI.de). An interdisciplinary project of the Charité Neurology Clinic and the Fraunhofer FIRST Institute, its machine-learning algorithms use diverse EEG signs of intended movements such as slow 'readiness-potentials' and movement-related attenuation of EEG 'idling rhythms' in brain motor areas. Studies of long-term amputees show that such EEG signs are usually preserved when people try to move a 'phantom hand'. BCI feedback settings include controlling computer cursors, 'mental typewriters', gaming applications, and virtual prostheses.

These evolving concepts can be put not only to medical and mercantile but also military use. As BCI applications move toward ever more futuristic fantasies, both scientists and the public at large should be aware of the ethical implications of this potential 'triple use' scenario.

Professor Miguel A. L. Nicolelis
Duke University Medical Center

Computing with neural ensembles

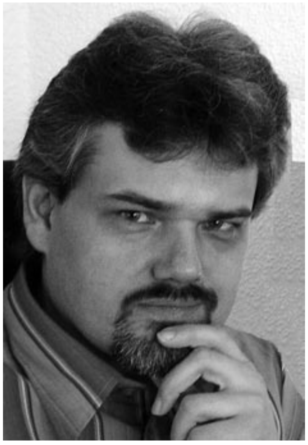
Dr. Miguel A. L. Nicolelis is the Anne W. Deane Professor of Neuroscience in the departments of neurobiology, biomedical engineering, and psychological and brain sciences at Duke University Medical Center. He is also Co-Director of the Duke Center for Neuroengineering. He earned a medical degree as well as a doctorate in physiology at the University of Sao Paulo, where he subsequently worked as an assistant professor before joining the faculty at Hahnemann University and then Duke University. His research interests include the computational properties of large neural ensembles in animals and the neuronal basis of sensorimotor learning and tactile perception, as well as the development of brain-machine interfaces for restoring neurological function.

A series of recent experiments has demonstrated the possibility of using real-time computational models to investigate how ensembles of neurons encode motor information, i.e. the information needed to move parts of the body. These experiments have revealed that brain-machine interfaces can be used not only to study fundamental aspects of neural ensemble physiology; they can also serve as an experimental paradigm for testing the design of modern neuroprosthetic devices, such as artificial limbs that can be controlled by thoughts alone.

In addition to these experiments, there is also evidence indicating that continuous operation of a closed-loop brain-machine interface, which utilizes a robotic arm as its main actuator, can induce significant changes in the physiological properties of neurons located in multiple motor and sensory cortical areas. In other words, use of a brain-machine interface to manipulate a robotic arm appears to exert a feedback influence on various parts of the brain involved in both movement and perception. This raises the hypothesis of whether the properties of a robot arm, or any other tool for that matter, can be assimilated by neuronal representations as if they were simple extensions of the subject's own body.

Professor Rainer Goebel
Maastricht University

Real-time mind-reading and BOLD brain interactions



Rainer Goebel received a PhD in cognitive psychology from Braunschweig Technical University. As a postdoctoral fellow at the Max Planck Institute for Brain Research in Frankfurt/Main, he developed and commercialized "BrainVoyager", a leading fMRI software package. Following a year at the Institute for Advanced Studies in Berlin, he joined Maastricht University in 2000 as a full professor of cognitive neuroscience. Currently he is a fellow and board member of the F.C. Donders Center for Cognitive Neuroimaging (Nijmegen, Netherlands), head of the Maastricht Brain Imaging Center, and chair-elect of the Organization for Human Brain Mapping. Rainer Goebel has pioneered the development of fMRI-based neurofeedback.

Two experiments using functional Magnetic Resonance Imaging (fMRI) based on the BOLD (blood oxygen level dependency) effect have increased our understanding of "mind-reading".

In one study, subjects use motor imagery, imagining music, and mental calculations to control activity levels over time in three different areas of the brain. A visual guidance paradigm lets them encode all the letters of the alphabet plus the empty space, without extensive training. The results show how the brain learns to modulate its own activity in specific areas, and can also help train 'locked-in' patients who are fully aware of their surroundings but unable to move any part of their body due to brain injury or stroke. This fMRI-based "brain-writing" technique could help these patients communicate solely by voluntarily changing their brain activity patterns.

In the second study, brain signals from two subjects in different rooms are scanned simultaneously by fMRI. Both individuals watch a simple computer ping-pong game, and move rackets on the screen to hit the ball and gain points – but with "brain power" instead of a joystick. They don't move their bodies at all.

A brain-computer interface converts the fMRI signals into racket position on a vertical axis: the higher the signal level, the higher the racket. Training involves imagining objects or scenes at varying intensities. One subject imagined dancing alone or with an increasing number of partners. Another imagined driving a racing car with a varying number of other contestants. The brain area that follows the imagery best is used for the ping-pong game. Feedback is crucial, because fMRI signals lag about 6 seconds behind "thoughts". So players have to increase brain activity to move the racket 6 seconds later. Despite these difficulties, they achieved hit rates of about 80% compared to a chance level of 20%.

By showing that the brain activity of two interacting individuals can be measured simultaneously in real time, this research can inspire further fMRI studies into the neural substrate of social cognitive processes.

Professor John-Dylan Haynes
Bernstein Center for Computational Neuroscience Berlin

Decoding conscious and unconscious thoughts from fMRI signals

The brain researcher and psychologist John-Dylan Haynes is a Professor at the Bernstein Center for Computational Neuroscience Berlin, and he also heads the "Attention and Awareness" research group at the Max Planck Institute for Cognitive and Brain Sciences in Leipzig. He obtained his PhD at Bremen University, and following a post doc at the Plymouth Institute for Neuroscience, he worked for several years at the Functional Imaging Laboratory and Institute of Cognitive Neuroscience at University College London. His research deals with the neural mechanisms of conscious and unconscious information processing. Specifically, he uses functional MRI to reveal how individual thoughts are encoded in the brain, and also how they can be read out. He was able to show that even complex thoughts such as concealed intentions can be read out of brain activity patterns using suitable mathematic techniques. This has important implications for applications of "brain reading" technology in forensic and medical purposes.

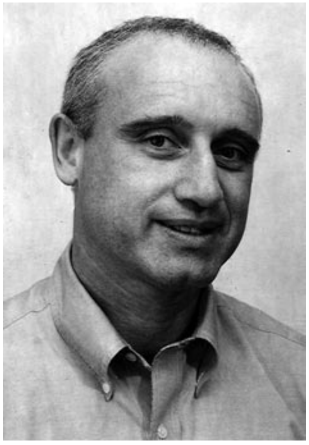
Is it possible to predict what a person is thinking of – or even what they are planning to do – based on their current brain activity alone? The novel research field of "brain reading" investigates ways to decode and predict a person's thoughts using modern brain scanning technology. The key is that each thought is associated with a unique brain activation pattern that can be used as a signature for that particular thought. By training a computer to recognize the specific patterns of brain activity associated with different thoughts, it is possible to "read out" what a person is thinking based on their brain activity alone.

There are a number of fundamental techniques that allow us to perform such "brain reading", i.e. to identify diverse aspects of mental activity. Mental states thus far decoded range from conscious and unconscious visual perception to high-level thoughts such as intentions. In fact, even unconscious action plans can be decoded from brain activity long before a person decides how to act.

However promising such findings are, it is important to bear in mind that several problems need to be solved before practical applications become feasible. A number of such core challenges to "brain reading" will be presented here. For example, it is very difficult to build a "universal brain-reading device", namely, a machine that can read out a randomly selected individual's thoughts in full detail without requiring long periods of training. Not only technical limitations stand in the way of such a machine, but also several important conceptual problems need to be solved. These include how to detect specific mental contents independently of the context in which they appear, which is currently very difficult. Another major problem is that there is an infinite number of possible thoughts, whereas training time is limited. Here we will present the first emerging approaches that point towards solutions for these fundamental problems.

Professor Daniel D. Langleben
University of Pennsylvania, Philadelphia

Studies of Deception with Functional MRI and their Application to Lie-detection



Daniel Langleben is a practicing psychiatrist and clinical neuroscientist at the University of Pennsylvania School of Medicine. He was trained in medicine, psychiatry and nuclear medicine at the Hebrew University, The Mount Sinai Hospital, the University of California, and Stanford University. His research focuses on functional brain imaging correlates of deception, as well as of related conditions such as attention deficit hyperactivity disorder and addiction.

In his treatise De Mendacio of 395 AD, Saint Augustine defined lying as "to have a thought and, by words or other means of expression, to convey another one." Separating lies from truth is an age-old quest, and a costly undertaking in modern industrialized societies. Unlike conventional polygraph tests which rely on the peripheral nervous system, functional Magnetic Resonance Imaging (fMRI) measures brain activity. Since deception emanates from the brain, fMRI may present a superior alternative to traditional physiological means of lie detection. Early fMRI studies detected differences in brain activity for lying and telling the truth on a group-average level.

These data support the Augustinian definition of deception as a process involving behavioral control, and suggest that truth is the basic state of the human mind. Further studies have differentiated between lies and truth in individuals, paving the way for clinical applications in both forensics and medicine. These applications may vary in their minimum accuracy requirements, as well as ethical and practical dimensions. Many questions regarding the associated risks, the effects of medication, medical and psychiatric disorders, possible countermeasures, and the influence of age, gender, language, and use of the technology under 'real-life' conditions remain to be answered.

Furthermore, neither experimental nor applied 'lie detection' should be equated with "mind-reading". While lie detection focuses on a brief and singular act of deception, 'mind-reading' would analyze patterns of brain activity representing highly variable cascades of language and memory and pose technical hurdles beyond lie-detection.

Although we cannot predict which combination of behavioral tests and brain-imaging technology will ultimately become the method of choice, both public demand and scientific progress are likely to generate clinical applications for fmri-based studies of deception in the near future.

Professor Adrian Owen
MRC Cognition & Brain Sciences Unit, Cambridge

Detecting residual cognitive function in the vegetative state

Adrian M. Owen is Assistant Director of the MRC Cognition and Brain Sciences Unit in Cambridge, England. His work combines functional neuroimaging with neuropsychological studies of brain-injured patients. Specific interests include localizing functions within the frontostriatal system (which is subject to numerous disorders including schizophrenia, autism and Parkinson's disease), assessing cognitive deficits in patients with Parkinson's disease, and detecting residual cognitive function in the vegetative state and related disorders. He has published two books and over 130 articles, with his recent work on consciousness in the vegetative state attracting widespread international media interest.

The vegetative state is one of the least understood and most ethically troublesome conditions in modern medicine. It is a rare disorder in which patients who emerge from a coma appear to be awake, but show no signs of awareness. It is extremely difficult to assess cognitive function in such individuals, because their movements may be minimal or inconsistent, or because no cognitive output is possible.

Functional neuroimaging can identify residual cognitive function and even conscious awareness in some patients who are assumed to be vegetative, but still have abilities we cannot detect by standard means. I will describe a series of functional neuroimaging paradigms that systematically increase in complexity with respect to the cognitive processes required, and therefore allow us to infer how much cognition remains based on 'normal' patterns of activation.

We start with responses to various speech stimuli. A significant minority of vegetative patients produce speech-related responses in the superior temporal-lobe region that are indistinguishable from those in a healthy brain. More complex linguistic stimuli, which produce distinct patterns of activation associated with comprehension, also elicit normal responses in some, but fewer, patients. However, an appropriate neural response to the meaning of spoken sentences is not unequivocal evidence of conscious awareness. We have therefore developed a new approach in which patients assumed to be vegetative are instructed to perform mental imagery tasks at specific points during a scan. Results from a small group confirm that some patients retain the ability to understand spoken commands and to respond via their brain activity rather than speech or movement. Reproducible and robust task-dependent responses to commands without the need for practice or training could be a novel way for some vegetative, minimally conscious, or locked in patients to use their residual cognitive capacities to communicate thoughts by modulating their own neural activity.

Professor Henrik Walter
Bonn University School of Medicine

From brain to bedside? Implications of brain reading for psychiatry

Following training in psychiatry, neurology, and philosophy, Dr. Henrik Walter joined the philosophy department at Braunschweig University, then became an assistant medical director of psychiatry in Ulm, and later a professor of biological psychiatry in Frankfurt am Main. In 2006, he was appointed Director of the Medical Psychology Division at the Bonn University Medical School. His research focuses on cognitive and affective neuroscience, neuroimaging, and neurophilosophy as well as clinical neuroscience. He is interested in topics such as emotions and their regulation, memory, free will, and responsibility. His book Funktionelle Bildgebung in Psychiatrie und Psychotherapie was published in 2005.

"Your doctor knows what you're thinking" – This slogan was recently used to advertise magnetic resonance tomography (MRT) systems in medical journals. But we all know not to trust ads, and that holds here as well. Nevertheless, functional imaging has triggered a veritable research boom in psychiatry and psychology. And the reason is simple: For the first time, we have a realistic prospect of objectively measuring mental processes, or their neuronal signatures. Thus far, psychiatrists have only been able to access the inner lives of their patients via careful observation of language and behavior, and subjective reports. These are the sole reliable bases for diagnosis, treatment, and evaluation.

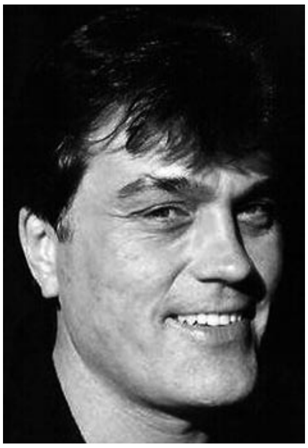
Functional imaging, however, now offers a way to "watch the brain think". In more sober terms, this means we can run psychological experiments in which we observe brain activity by measuring its signals, and then interpret the data to draw conclusions about the mechanisms of thinking and feeling. Moreover, high-resolution measurements enable us to map the structure of the brain on a scale of millimeters, identify links between different brain regions, and measure molecular concentrations. This has raised hopes of one day turning psychiatric diagnostics into a normal branch of medical practice that can use objective measuring techniques in addition to clinical observation and experience.

It should be noted that appraisals of functional imaging as an examination technique vary widely. A few researchers, and especially the media, harbor exaggerated expectations. At the other extreme, technology skeptics consider the method unreliable, insufficient, or even hazardous – when used to test for e.g. health risks or aggression.

Yet even where functional imaging has already become a standard research tool, it is irrelevant for clinical research whether "the doctor knows what the patient is thinking". Rather, it is far more important for psychiatrists to obtain objective information about brain functions that can help them make clinical decisions. I will discuss how useful imaging techniques actually are for psychiatric conditions such as schizophrenia, depression, and personality disorders.

Professor Thomas Metzinger
Johannes Gutenberg University, Mainz

Philosophical implications of brain-reading: Ethical and anthropological consequences



A professor of philosophy at the Johannes Gutenberg University Mainz, Thomas Metzinger directs the Theoretical Philosophy Group and heads the Neurophilosophy Section at the Interdisciplinary Neurosciences Center. He is a founder and board member of the Association for the Scientific Study of Consciousness, and was appointed Adjunct Fellow of the newly founded Frankfurt Institute for Advanced Studies (FIAS) in May 2005. In addition to neuroethics, his research centers on philosophy of mind. Published in 2003, his book Being No One lays out his "self-model theory of subjectivity". His most recent work, Grundkurs Philosophie des Geistes 2: Das Leib-Seele-Problem, provides an introduction to recent philosophical theories on the relation between the brain and the mind. Professor Metzinger has set up the first German/English Internet portal for neuroethics (German: http://www.neuroethik.ifzn.uni-mainz.de/index.php?id=2&L=0; English: http://www.neuroethik.ifzn.uni-mainz.de/index.php?id=index&L=1)

Thoughts are "mental representations" or inner displays of the content carried by states of the human mind. According to traditional philosophical views, they are composed of both substrate and content. The concrete substrate of thought content takes the form of specific neuronal activity patterns. By contrast, the content is something abstract and non-public, because it is bound up with the subjective inner perspective of the person experiencing it. According to traditional philosophy of mind, therefore, it is impossible in principle to decipher what a person is thinking or feeling via the methods of natural science: You never see the content but only the substrate.

Later "connectionist" and "dynamicist" theories of mental representation, however, hold that the content seems to be incorporated directly in the substrate. Whatever the outcome of these theoretical debates may be, success in predicting human behavior is already raising significant practical and ethical issues. If we are getting better all the time at predicting what people feel and what they say about the content of their own consciousness, then as far as the social consequences are concerned, it may only be of secondary importance whether this success is based on a conceptually dubious philosophical theory of mind.

The potential of brain research is dramatically changing our image of mankind, and thus the foundation of our culture and the basis for our ethical and political decisions. Given rapid technological advances and the demand for applying these methods in law enforcement and the military (e.g. high-tech lie detectors) as well as in medicine (e.g. neuropharmacology and brain-computer interfaces), it is advisable to consider the resulting problems sooner rather than later.

To rise to the larger challenge in the background, we not only need a research ethic, but also what I call a "consciousness ethic". In other words, if we can increasingly monitor and influence our own consciousness, then one thing we should think about is which states of consciousness are desirable. We should also come up with answers to very specific questions – such as whether we need some type of "Fourth Amendment protection" for the brain, i.e. analogously to the right to be secure in our home and physical person, an inviolable right to privacy in our mental person.

Professor Christof Koch
California Institute of Technology, Pasadena

Decoding the contents of perception from single neurons in the human brain

Born in 1956 in the American Midwest, Christof Koch grew up in Holland, Germany, Canada, and Morocco. He studied physics and philosophy at the University of Tübingen, and received a doctorate in biophysics.
After four years at the Massachusetts of Technology, Dr. Koch joined Caltech in 1986, where he is the Lois and Victor Troendle Professor of Cognitive and Behavioral Biology. The author of three hundred scientific papers and journal articles as well as several books, Dr. Koch studies the biophysics of computation and the neuronal basis of visual perception, attention, and consciousness. Together with Francis Crick, he is one of the pioneers of the neurobiological approach to consciousness.

Half a century ago, many people did not think it possible to understand the secret of life. Then two scientists, Jim Watson and Francis Crick, discovered the structure of DNA, forever changing biology and the way we view ourselves in the natural order of things. We are now facing a similar pursuit in determining the material basis of the conscious mind. Consciousness is one of the major unsolved problems in science today. How do the salty taste and crunchy texture of potato chips, the unmistakable smell of dogs after they have been in the rain, or the awfulness of a throbbing toothache emerge from networks of neurons and their associated synaptic and molecular processes?

One way we can approach this question is by recording data from multiple (up to 64) chronically implanted electrodes in the human medial temporal lobe (MTL). Our subjects were patients with pharmacologically intractable epilepsy at the ward headed by neurosurgeon and neuroscientist Dr. Itzhak Fried. He implanted them with depth electrodes to localize the focus of seizure onset, and we then briefly showed them pictures of famous individuals, landmark buildings, etc.

We found the following: 1) neurons that only respond to consciously perceived stimuli and not to images that were present on the retina but not seen; and 2) neurons that respond in a very specific and invariant manner to famous individuals such as movie stars. Furthermore, we can detect with far better than random probability which image the patient is currently seeing (decoding) based on a small number of action potentials in a handful of neurons.

I will conclude by discussing the possible limitations of a scientific approach to consciousness – in particular, can science move beyond observing correlations between mental and physical events – and noting the potential implications of this research for ethical issues such as the "right to die"/"right to live" debate, and animal rights.