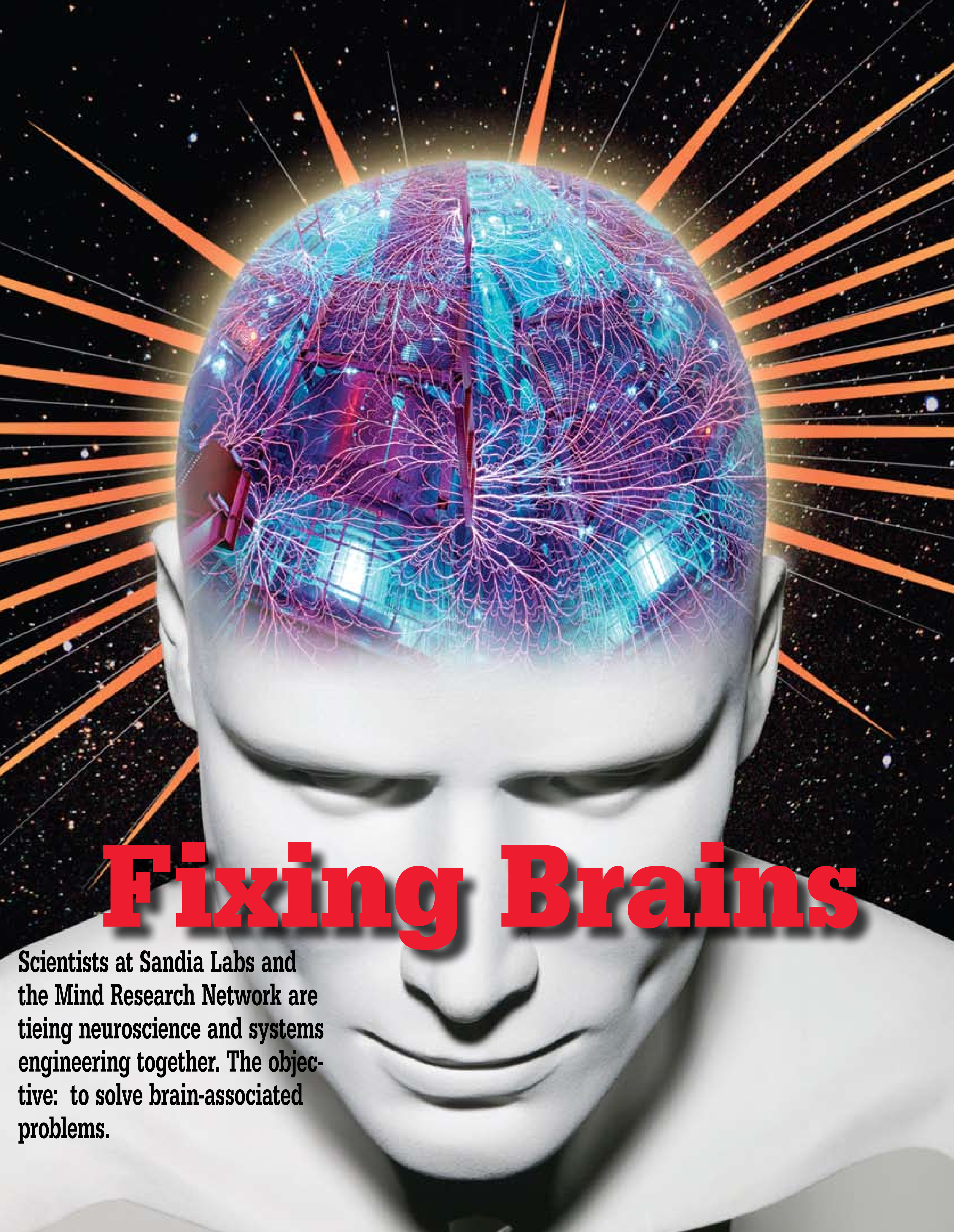


Fixing Brains

Scientists at Sandia Labs and the Mind Research Network are tieing neuroscience and systems engineering together. The objective: to solve brain-associated problems.

They Call It "Neurosystems Engineering"

Scientists at Sandia and the Mind Research Network are creating a new field that bridges neuroscience and systems engineering

By GEROLD YONAS and REX JUNG

THE TWO SCIENTISTS are an unlikely couple embarking on an exciting journey. Rex Jung, a neuropsychologist and research scientist at the Mind Research Network (MRN) in Albuquerque and Gerry Yonas, a physicist/engineer and vice president at Sandia National Laboratories, are attempting to create a new field that bridges the disciplines of neuroscience and systems engineering. The purpose of this nascent field is to leverage advances in neuroscience with well-established approaches in systems engineering to solve important problems—primarily with national security implications—but with broader applications to many societal needs as well.

They are exploring issues including traumatic brain injury, post-traumatic stress disorder, deception detection, training of troops and decision-making as impacted by the high stress of ambiguity, confusion and time urgency. Providing enhancements to learning and decision-making, as well as preventing decline in functioning associated with stress and trauma, could be vital at all national security endeavors from the first responder all the way to the commander of a military operation.

Yonas became interested in this subject when he ran the Advanced Concepts Group at Sandia and found that the weak link in many complex technology-based systems solutions was not the technology, but rather the key person or groups of people who were the ultimate users of the technology. This interest lead to exploring methods to monitor not only what people say they are thinking, and observing how they are behaving when performing high-stress tasks, but also measuring physiology as an indirect indication of what the brain is doing when the person is engaged in the tasks.

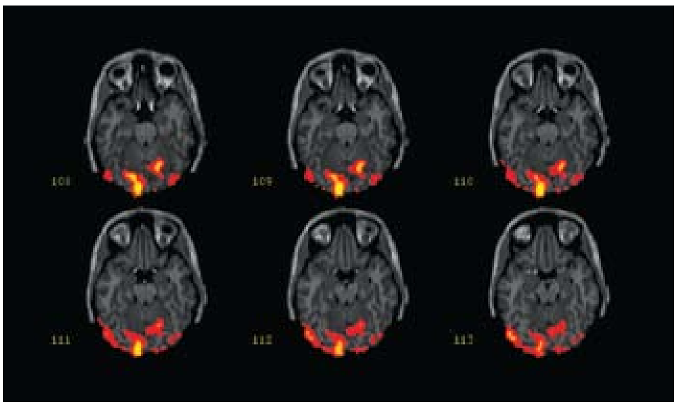
Jung began his career in business before volunteering for the Special Olympics, where he became profoundly interested in brain function, dysfunction and the "wiring of the machine," all of which led him to embark upon a decade-long path toward becoming a neuroscientist. At the Mind Research Network, he has found a perfect venue to merge his clinical interests—diagnosing patients with a wide range of neurological and psychiatric disorders—with his research interests in human intelligence, creativity and positive affect, an area of research he has termed "positive neuroscience."

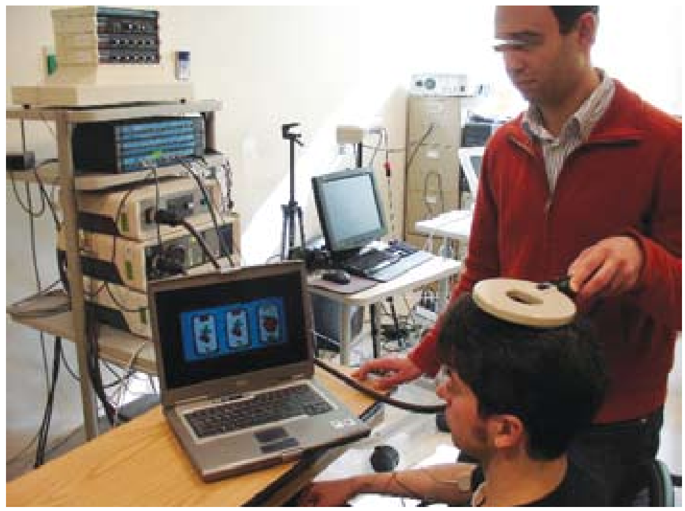
The two key tools at the MRN are Magnetic Resonance Imaging (MRI) and MagnetoEncephaloGraphy (MEG). MRI uses a large and expensive magnet, coupled with a computer, that reads out changes in proton densities (i.e., hydrogen atoms making up water molecules). Three major imaging techniques arise from MRI:

- Structural Magnetic Resonance Imaging (sMRI), where differences in water content between different tissue compartments throughout the brain serve as "contrast" leading to exquisitely detailed images
- Diffusion tensor imaging (DTI), where water diffusion within and between cell membranes in the brain can provide information about structural integrity of the "wiring" or white matter connecting different regions of the brain to each other
- Functional Magnetic Resonance Imaging (fMRI) where subtle differences between blood flow and oxygen levels within the blood can provide information about which neurons are working during cognitive tasks over several seconds.

The MEG uses an array of superconducting quantum interference devices (SQUIDs) that have somewhat reduced spatial resolution as compared to the fMRI but with millisecond temporal resolution. Other techniques for brain functional measurements all have relative strengths and weaknesses compared to each other including ElectroEncephaloGraphy (EEG) and Near InfraRed Spectroscopy (NIRS). When one observes the breathtaking advances in understanding how the brain functions depend, to a large degree, on applications derived from the fields of physics and engineering, one quickly appreciates how multi disciplinary this field truly is.

Thus, Yonas and Jung joined forces to combine physics





Clockwise, from top right: Gerold Yonas and Rex Jung;

and engineering with psychology to better understand the brain signals and patterns of connections that appear in the physiology, which then might be correlated with and predictive of thoughts and behavior. The approach, Neurosystems Engineering (NE), is designed to focus on problem-solving based on iterating theory, experiments and modeling to satisfy ultimately the needs of people with real applications and products. This approach is extremely multidisciplinary involving neuroscientists, psychologists, physicians, engineers, sensor and information system developers, modeling and simulation using high-performance computing and, of course, ethicists, as we are challenged with the prospect of pushing human capabilities to new heights. Since the people in these various disciplines all have their own languages, definitions, and even axes to grind, just bridging the gaps is a major undertaking, and connecting these complex disciplines with the creation of practical systems solutions is one hell of a challenge.

One way Yonas and Jung are trying to close this cross-disciplinary gap is by teaching an NE course, cross-listed in both the electrical and computer engineering and psychology departments at the University of New Mexico, and inviting lecturers from these various disciplines to participate in teaching the students, including the course instructors, faculty, Sandia lab staff members and guest lecturers from such diverse organizations as the Santa Fe Institute, National Institutes of Health, Krasnow Institute and DARPA. Yonas and Jung admit that this approach may help the students who want to enter this field; however, it is mostly a ruse to invite knowledgeable lecturers to teach the instructors.

The lectures have been both broad and deep in terms of the desired goal of bridging neuroscience and systems engineering. The term "lecture," is used, but most of the two-hour sessions quickly degenerate into a discussion between the "lecturer" and the members of the class—most speakers don't get through all of their slides (one only got through four slides in two hours) due to the vigor of the discussion. One speaker, Eric Wasserman from the NIH, lectured on the application of non-invasive electrical brain stimulation. It is already well established that pulsed and direct current electric fields applied to the head can cause temporary changes in underlying brain tissue that provides valuable information regarding where and how complex brain circuits are functioning and can also transiently change brain function depending on the polarity and location of the electrical stimulation. The pulsed version of this electrical stimulation is already undergoing clinical trials for treatment of depression. Yonas and Jung are interested in improving understanding of how electrical interaction with the brain works to improve and extend the ability to both treat disease and improve functioning in the healthy. It is conceivable that a small zap on the right part of the forehead could someday replace your favorite cup of coffee—exchanging chemical modulation of brain functioning with electrical—perhaps with fewer side effects.

One area of research that could have the most widespread applications is a better understanding of stress and how to both harness and manage stress more effectively. Researchers already know that learning can be enhanced with some increase in stress toward improvement of attention and decrease of boredom. But researchers also know that too much stress can lead to an uncontrolled focus on emotionally driven responses that can prevent learning and effective decision making. Many soldiers return from battle with long-lasting impacts of stress that may also be combined with effects of mild brain injury. Measurements of brain function could help us better understand these two often tightly coupled causes of lasting problems for these soldiers, their families and society at large.

But measurement alone is not enough: Neurosystems Engineering could potentially devise applications to identify soldiers at risk prior to deployment, develop mitigating strategies and technologies under conditions of high stress while in battle and ensure that best practice techniques are available to triage soldiers into personalized treatment plans combined with assistive technologies following the unfortunate occurrence of overt or occult battlefield injury once rotated out of battle.

Another potential application of NE is in the field of deception detection, a field that has mostly relied upon the polygraph, a 70-year-old idea that basically uses several indicators of stress, and which has been widely denounced as having no scientific basis. With advances in brain functional measurements, researchers should be able to better understand what parts of the brain are calling the shots during deception and under what circumstances. This subject is extremely complex since there are many different kinds of lies and many different sorts of liars, but this is no more complex than attempts in the neurosciences to identify neural correlates of such complex human attributes as empathy or discern subtypes of heterogeneous brain disorders such as schizophrenia. It is the hope that NE can bring a fundamental understanding of the underlying science that could possibly lead Yonas and Jung to distinguish between "natural born liars" (i.e., psychopaths) and others of us who are just trying to get out of a sticky spot. Even more important, NE could potentially prevent the misapplication of deception detection that has guided the field heretofore.

Applications of NE are already becoming widespread, and are likely to grow as our global population ages, and there are increasing demands for neuroprosthetics, monitoring devices and enhancements. It is likely that the attraction of increased funding and commercial applications will lead to unfortunate misapplications of poorly understood science and technology that is not ready for marketing, but Yonas and Jung hope to emphasize, leverage and apply the fundamental neuroscience as these applications evolve. NE research will be fraught with significant ethical challenges and Yonas and Jung are cognizant that premature and poorly founded applications, unjustified expectations, issues of privacy, unintended consequences and certainly legal issues will be risks to the field now and into the future.

Indeed, any new field characterized by such broad social, political and economic implications is likely to see a preponderance of ethical over technical concerns. Nevertheless, they believe that the magnitude of the potential discoveries that could meet such enormous societal needs, the beginnings of which are emerging in our lifetime, warrant their continued commitment and dedication to this journey toward merging neuroscience and systems engineering.

"I've long recognized that the expertise within the weapons laboratories, like Sandia, could have wonderful applications beyond national defense. Our labs were pivotal to early advances in understanding the human genome. Now, I believe we can greatly improve our understanding of the human brain through the partnership between the MRN and Sandia."

Pete Domenici
United States Senator

Gerold Yonas, Ph.D., is vice president and principal scientist, Sandia National Laboratories, and Rex Jung, Ph.D., is research scientist, Mind Research Network.