INCUBATOR

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In this Issue:

Bioengineers researching smart cameras and sensors that mimic, exceed human capability

UCSD bioengineering professor Gert Cauwenberghs has been selected by the National Science Foundation to take part in a five-year, multi-institutional, $10 million research project to develop a computer vision system that will approach or exceed the capabilities and efficiencies of human vision.

The Visual Cortex on Silicon project, funded through NSF's Expeditions in Computing program, aims to create computers that not only record images but also understand visual content and situational context in the way humans do, at up to a thousand times the efficiency of current technologies, according to an NSF announcement.

Smart machine vision systems that understand and interact with their environments could have a profound impact on society, including aids for visually impaired persons, driver assistance capabilities for reducing automotive accidents, and augmented reality systems for enhanced shopping, travel, and safety.

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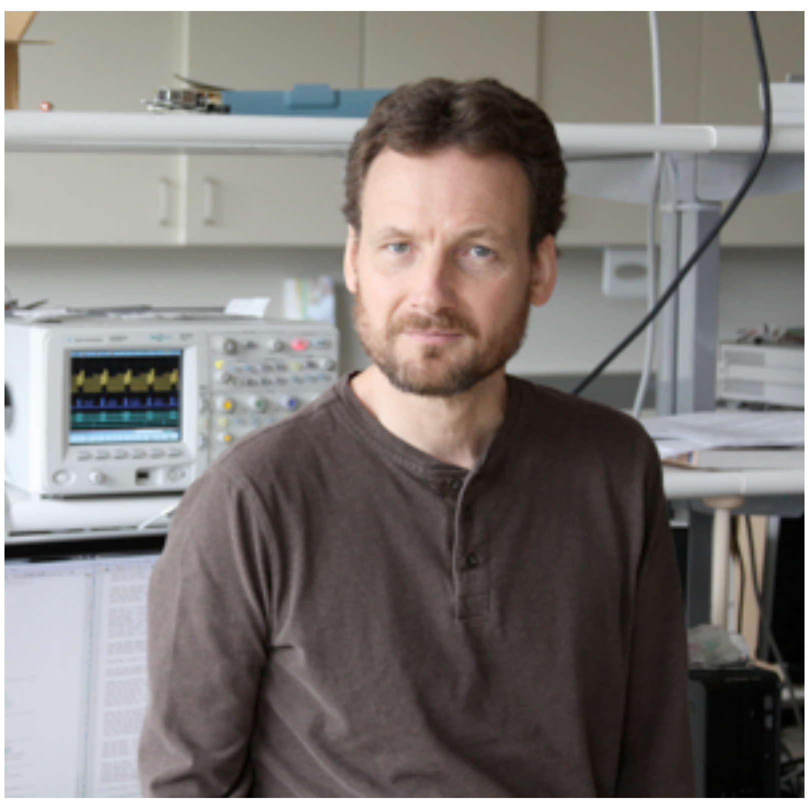

Cauwenberghs' laboratory developed a neuromorphic circuit array that models computation and communication across large-scale networks in the visual cortex in order to understand how the brain receives and processes visual information. Each chip in the array mimics the activity of 65 thousand neurons that make 65 million synaptic connections in memory.

Photo Credit: UC San Diego Jacobs School of Engineering.

Brain Activity Mapping, cont from page 1

For their part in the effort, Cauwenberghs, a professor in the Department of Bioengineering at the UC San Diego Jacobs School of Engineering, and his team are developing computer chips that emulate how the brain processes visual information. "The brain is the gold standard for computing," said Cauwenberghs, adding that computers work completely differently than the brain, acting as passive processors of information and problems using sequential logic. The human brain, by comparison, processes information by sorting through complex input from the world and extracting knowledge without direction.

While several computer vision systems today can each successfully perform one or a few human tasks-such as detecting human faces in point-and-shoot cameras-they are still limited in their ability to perform a wide range of visual tasks, to operate in complex, cluttered environments, and to provide reasoning for their decisions. In contrast, the visual cortex in mammals excels in a broad variety of goal-oriented cognitive tasks, and is at least three orders of magnitude more energy efficient than customized state-of-the-art machine vision systems.

Cauwenberghs and his collaborators around the country aim to understand the fundamental mechanisms used in the visual cortex, with the hope of enabling the design of new vision algorithms and hardware fabrics that can improve power, speed, flexibility and recognition accuracies relative to existing computer vision systems.

Cauwenberghs said the Visual Cortex on Silicon project offers a unique collaborative opportunity with experts across the globe in neuroscience, computer science, nanoengineering and physics.

The project has other far-reaching implications for neuroscience research. By developing chips that can function more like the human brain, Cauwenberghs believes researchers can achieve a number of significant breakthroughs in our understanding of brain function from the work of single neurons all the way up to a more holistic view of the brain as a system. For example, building chips that model different aspects of brain function, such as how the brain processes visual information, gives researchers a more robust tool to understand where problems arise that contribute to disease or neurological disorders.

Ph. D. student Siddharth Joshi at work designing a computer chip that mimics brain.

The Expeditions in Computing program, which started in 2008, represents NSF's largest single investments in computer science research. As of today, 16 awards have been made through this program, addressing subjects ranging from foundational research in computing hardware, software and verification to research in sustainable energy, health information technology, robotics, mobile computing, and Big Data.

The above story is reprinted from materials provided by UCSD News Center.

The original article was written by Catherine Hockmuth.

"The Visual Cortex on Silicon project offers a unique collaborative opportunity with experts across the globe in neuroscience, computer science, nanoengineering and physics."

— Gert Cauwenberghs

Taking A Mindful Approach to the BRAIN Initiative

"As the epicenter of scientific innovation, California must take bold and prompt action to capitalize on the short- and long-term benefits of the BRAIN Initiative," said Senate Majority Leader Ellen M. Corbett (D-East Bay) at a Senate Select Committee on Emerging Technology: Biotechnology and Green Energy Jobs public hearing held Friday at UC San Diego.

The event, "A Mindful Approach to the BRAIN Initiative," was convened by Corbett. It explored the state's role in accelerating the research, development and deployment technologies to support the BRAIN (Brain Research through Advancing Innovative Neurotechnologies) Initiative, first unveiled by the Obama Administration in April 2013.

The research effort—in which UC San Diego, "Mesa" colleagues and private-public partners will play key roles—is designed to revolutionize understanding of how the brain works and uncover new ways to treat, prevent and cure brain disorders such as Alzheimer's, schizophrenia, autism, epilepsy and traumatic brain injury.

The discussions held Friday were attended by Chancellor Pradeep K. Khosla, who also was sitting in the front row at the White House when Obama made the BRAIN Initiative announcement on April 2.

"The president's initiative is charting the next frontier of science and UC San Diego is poised and ready to help our country lead the way," said Khosla. "Neuroscience, biology, and cognitive science are among the premier areas of strength on our campus, and we are really excited to be part of the effort to gain a deep understanding of human beings and how we behave."

In response to Obama's "grand challenge," UC San Diego established the Center for Brain Activity Mapping (CBAM) in May. The new center, headed by Ralph Greenspan, is under the aegis of the interdisciplinary Kavli Institute for Brain and Mind at UC San Diego. CBAM tackles the technological and biological challenge of developing a new generation of tools to enable recording of neuronal activity throughout the brain. It will also conduct brain-mapping experiments and analyze the collected data.

"This is another example of how California is leading the way, both in terms of understanding the human mind and how we can cure Alzheimer's, dementia and other diseases, and also in creating technologies, new innovations and jobs," said Khosla.

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Ralph Greenspan led the panel "Facilitating Success—The Role of Research Institutions and the Private Sector," relating the importance of partnerships between researchers and industry to enable the success of the BRAIN Initiative.

Photos by Erika Johnson/University Communications

At the hearing, Corbett, who is chair of the Select Committee, said she intends to introduce legislation early next year that supports cutting-edge research like the BRAIN Initiative that can bring societal and economic benefits to California.

"Twenty-five years ago, the Human Genome Project led to the 'genomic revolution' and advanced some of the leading industries in our state," she said, "The BRAIN Initiative is the next logical step."

At the hearing, representatives from UC San Diego were joined by other academic and industry leaders in voicing strong support of the initiative. Those testifying included Greenspan, founding director of CBAM and associate director of the Kavli Institute for Brain and Mind at UC San Diego (KIBM); Terry Sejnowski of the Salk Institute for Biological Studies and UC San Diego and director of the campus's Institute for Neural Computation; and Ramesh Rao, director of the Qualcomm Institute, the UC San Diego division of Calit2.

"The last century we went to the moon to explore outer space; this century we're exploring inner space by studying the link between brain activity and behavior," said Sejnowski. "We need to find what it is that excites young people. We need to attract bright young minds the way President John F. Kenney did … In 1969, the year we went to the moon, the average age of a NASA engineer was 27."

When asked by Corbett if the state of California was doing enough to support the education needed by

Chancellor Pradeep K. Khosla welcomed Senate Majority Leader Ellen Corbett and expressed his confidence in the potential of the program to revolutionize the way we understand the brain.

the BRAIN initiative, Greenspan answered by saying that more science should be integrated into the general education curriculum. "It's is important to build STEM programs and make it accessible to students … Students need to see themselves as future scientists."

Corbett concluded the conversation by saying that she thought the discussions helped dispel the notion that people come to California only for the weather. "You come here for the education and innovation," she said.

The above story is reprinted from materials provided by UCSD News Center.

The original article was written by Christine Clark.

San Diego Union Tribune Reports on Poizner Laboratory

UCSD professor Howard Poizner's research on Parkinson's disease (see INCubator Winter 2013 issue) was featured on San Diego Union Tribune on September 13th.

Follow this link to read the full article and watch the video.

Member Spotlight - Tim Mullen

Advancing mobile brain-computer interface systems

In August 2013, INC member Tim Mullen has won the poster prize for technical merit at the 5th International Brain-Computer Interface Meeting. Newsletter editor Tomoki Tsuchida has sat down with Tim to talk about his recent work.

- *Congratulations on your award, Tim! To start, can you describe the lab that you're working for?*

My lab is the Schwartz center for computational neuroscience. It is a lab and a center simultaneously. There're about forty-five researchers, project scientists, PhD students, postdocs, and programmer analysts at the center, and that allows us to collaborate on many different cognitive neuroscience projects. There is a slight partitioning between Scott Makeig and Tzyy-Ping Jung. Tzyy-Ping is also a professor in Taiwan, and he has a lot of students working on more hardware-related projects. Still, we interact very closely with all of the members at the center.

- *Can you tell us about what your lab does, and what some of your long-term goals are?*

We primarily develop new methods and software implementation for EEG and other electrophysiological data analysis used by the cognitive neuroscience community. We developed the EEGLAB platform - currently the most widely used open-source software platform for electrophysiological data - and made other tools public and open-source through that platform. We also develop signal processing software for the brain-computer interfaces.

One new initiative we're involved in is called mobile brain-body imaging. It is associated with the brain-computer interface technology, but it also opens up a new window into how the brain operates in a natural environment. We record eye and body movements and brain activities simultaneously while people are interacting with other people or devices. We're trying to figure out what the brain does in these complex experimental paradigms and how these brain activities relate to the behavior. That is another big initiative here.

- I*n your paper for the Brain-Computer Interface Meeting, one of the major achievements you mentioned was the development of a mobile EEG system. Can you describe the system and how the project came about?*

The whole goal behind the brain-computer interface is to have devices that allow you to control and interact with something out in the world, or to allow devices in the world to receive information about your affective and cognitive mental state. An important requirement for these devices is that they must operate in a natural environment: they're not in the lab, and the subjects are going to be moving around and interacting with the devices. For example, I may want to control a prosthetic arm while I'm running down the street, or I might be sitting in a coffee shop and the coffee shop owner may want to tune the music to the average emotional state of everyone at the coffee shop. These are noisy environments, so we want to develop technology that is robust enough to operate under noisy conditions. Importantly, the sensing devices have to be wearable: they have to be comfortable enough, lightweight enough and robust enough for people to be wearing them on a daily basis, rather than just inside the lab for an hour a day.

Cognionics' 64 channel high-density wireless dry EEG headset allows researchers to acquire high quality EEG signals through its spider shaped electrodes.

This particular project was accomplished by collaborating with several other very talented people. My co-author Christian Cortez and I were fortunate enough to meet up with Mike Chi, a bioengineering student from Gert Cauwenbergh's lab. Mike has a company called Cognionics that specializes in developing wearable EEG sensors. Christian and I developed source information flow toolbox for EEGLAB, which does a variety of dynamical model fitting. We all got together and built a system that allows you to record from Cognionics' wearable hardware device, fit models in the source domain, extract information about the person's connectivity and brain dynamics, and predict the person's mental state.

- Has the system already been put to use?

We consider the system to be a prototype. The hardware is certainly in use, since Cognionics has developed the hardware for researchers and other industry partners. The software has also been used by the research community. In that sense, all of the pieces have been in use, but the particular combination of the pieces we created has not been. Right now, we're demonstrating its use in more than just the examples that we tested in the paper.

- What were the goals of the project, and what were some of the technical challenges you encountered?

What we were interested in this project was error prediction. For example, let's say you're sitting at a traffic control center, and you have to monitor traffic and press a button depending on what you're seeing. When a person presses a button, we want to know if the person made a mistake pressing that button, and if the system can correct that mistake within a very short period of time, by detecting the recognition in the person's head of making that error. Sometimes, you're already starting to recognize the error, but you don't have time to correct it; for these kinds of errors, there's actually a signature of the recognition of error being committed, regardless of whether the person actually consciously realizes he's made a mistake. The signal is enhanced if the person recognizes that he's made a mistake. However, you can create a system that can recognize the mistake well before you end up actually taking a wrong action. Because it'll take you so much more time to press another button to undo previous error, if the system can detect that error as you're making the mistake itself. You can intervene at the hardware level and correct the mistake within a much shorter period of time.

The reason why we picked this task was because there's a huge body of literature on this particular topic already, and we wanted to know whether using network information connectivity could be useful in making these kinds of predictions. Under the error conditions, certain networks of the brain are highly activated. What we did is to have a person doing a task where he would make errors, recorded his EEG data, and with the wearable sensing hardware, reconstructed the activity inside his brain. With the source-reconstructed data, we got similar or slightly better performance compared to the existing technologies.

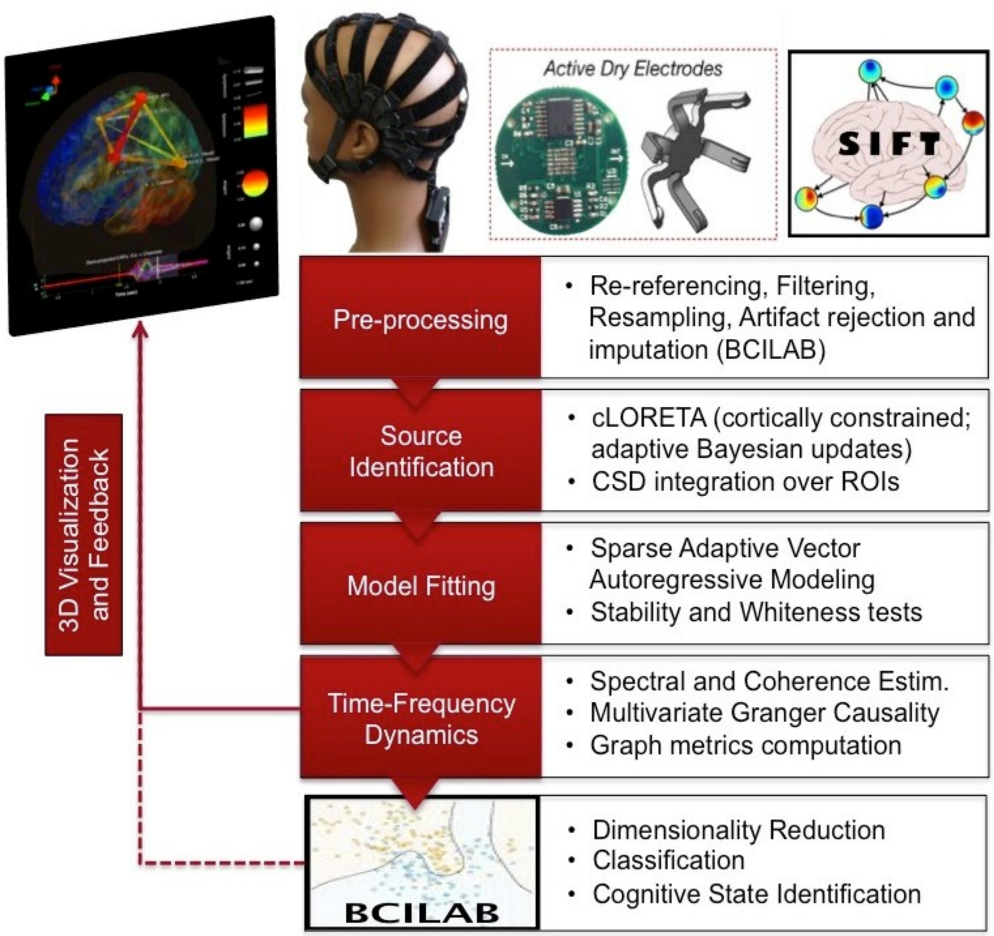
The network we deal with is fairly large and high dimensional: we looked at tens of different regions and hundreds of possible connections between them while recording interactions at multiple frequencies.   We then fit models that describe how different areas of the brain are interacting by looking at the Granger causality in real time. This allowed us to identify how one area of the brain is transmitting information to another area of the brain for each frequency band.

With all that information calculated in real time, we then predict whether the person has just made a mistake or is going to make a mistake. Christian developed a nice classification function that allows us to do that. It's a certain kind of convex optimization scheme that incorporates penalties such as sparsity and smoothness and other prior knowledge about the connectivity structures. Using this classification function, we can predict whether the person made a mistake or not from the connectivity information.

Granted, you can also do very well without using the connectivity information, for example, by using the error-related activity. In fact, there are other methods where you can do as well as you would ever want to do. However, our goal in this project was to not necessarily beat them, but to see whether our method is at least comparable to them. The information we receive is also much richer: you can look at what areas and connectivity of the brain were the most predictive for the task. That tells you something about what the brain is doing when you to make a mistake.

There are other things in the paper that are very important, such as artifact rejection. Artifact rejection is a huge issue in EEG-based analyses, since EEG picks up brain activities as well as other electrical activities, from your muscle movements to power lines and fluorescent lights. When you're moving in a natural environment, those activities are generated even more. Because artifact rejection is so important, our lab has used many different techniques to remove noise in the past. In this work, we used blind source separation methods to find the subspace of the data related to the brain activity and removed the noise related to muscle activities. Independent Component Analysis is one of these approaches.

What Christian developed was a method called "artifact subspace reconstruction" (ASR), which allows you to identify certain portion of the EEG data based on the principal component subspace containing the majority of the artifact. It will not remove artifacts completely, but by projecting some calibration data onto this subspace first, you can reconstruct the EEG data. The details are in the paper, but it is analogous to other source reconstruction techniques in which you project the



An example of a real-time data processing pipeline implemented within the SIFT and BCILAB open-source toolboxes. Cognionics 64-channel system is depicted with flexible active dry electrodes.

"INC is a very rewarding environment, and you can do very cool things here that are much harder to do in any of the individual disciplines."

— Tim Mullen

data onto a subspace, remove high-variance noise in the subspace, and then reconstruct the EEG data. We use that method combined with several other methods to remove most of the very prominent artifacts generated by muscle activities, and we deal with line noise in another way as well. In the end, we are able to get quite clean signal, even when people are blinking and chewing. We can't get rid of all artifacts, but we can reduce it enough to make meaningful predictions.

- How strong is the collaboration within INC, and what is the relationship between SCCN and MoBI Lab (see Incubator Spring 2013 issue), for example?

We're extremely collaborative lab. We collaborate with many partners at UCSD and INC, whether that is through shared grants or software tools. We also collaborate with other universities and institutions around the world. For instance, there's collaboration with Howard Poizner and his MoBI Lab, which is similar to but different from the kinds of things we do in our initiative. We also have active collaboration with Gert Caughwenbergh and his students to develop new algorithms.

In the broader INC family, we have many students and postdocs who come to learn EEG analysis and work with other PIs to do actual application afterwards. SCCN is a well-known training center for EEG techniques, so people from around the world and different backgrounds would come here to learn how to do computationally informed analysis in the center. As an example, my background is in computer science and cognitive neuroscience, and many of the people on this paper also had backgrounds in engineering or computer science. Our perspective is to take what we learned in engineering and computer science and apply it to the rich source of information that EEG technique provides.

The very unique thing about some of the collaborations here is that we try to inform all of our analyses in terms of cognitive neuroscience. We don't take a blind approach where you analyze the data not knowing anything about how the brain works. We combine what we know about the brain and cognitive neuroscience with the latest in machine learning and signal processing to fit our models, and we use a lot of prior information in constructing and informing our models. We believe that is the key to unlocking the power of brain-computer interfaces.

INC is one of these unique places where you have real fusion among many different disciplines, including biomedical engineering, psychology, neurosciences, computer science and physics. It is a very rewarding environment, and you can do very cool things here that are much harder to do in any of the individual disciplines.

- Thank you very much!

Tim Mullen http://www.antillipsi.net/research/

References

Mullen, T., Kothe, C. Chi, Y.M., Ojeda, A., Kerth, T., Makeig, S., Cauwenberghs, G., Jung, T-P. (2013) **Real-Time Modeling and 3D Visualization of Source Dynamics and Connectivity Using Wearable EEG.** 35th Annual International Conference of the IEEE Engineering in Biology and Medicine Society.

INCEVENTS

INC SEMINAR SERIES

10/18/13	**Roozbeh Jafari**	Wireless Health: Challenges and Opportunities

NEUROENGINEERING SEMINAR SERIES

11/04/13	**Pedram Mohseni**	A Miniaturized Brain-Machine-Brain Interface for Restoration of Function After Brain Injury

CHALK TALKS

10/03/13	**Terry Sejnowski**	Connecting the dots on the BRAIN Initiative
10/17/13	**Roozbeh Jafari**	Brain computer interface embedded signal processing
10/31/13	**Tim Mullen**	3-D source dynamics and connectivity using wearable EEG
11/14/13	**Geert Schmid-Schönbein**	Autodigestion, inflammation and disease
11/21/13	**Vikash Gilja**	Towards clinically viable neural prosthetic systems

More information: *http://inc.uscd.edu/events.html*

For more information on current events,
please contact **Kristen Michener** kmichener@ucsd.edu

INC at a glance

Institute for Neural Computation (INC)
http://www.inc.ucsd.edu
Terrence Sejnowski and Gert Cauwenberghs, Co-Directors
Carol Hudson, Management Service Officer

Swartz Center for Computational Neuroscience at INC
http://www.sccn.ucsd.edu
Scott Makeig and Tzyy-Ping Jung, Co-Directors

Machine Perception Laboratory at INC
http://mplab.ucsd.edu/
Javier Movellan, Marian Stewart Bartlett, and Glen Littlewort, Principal Investigators

Temporal Dynamics of Learning Center (TDLC) Motion Capture/Brain Dynamics Facility at INC
http://inc.ucsd.edu/~poizner/motioncapture.html
Howard Poizner and Scott Makeig, Co-Directors

Office of Naval Research (ONR) Multidisciplinary University Initiative (MURI) Center
http://inc.ucsd.edu/~poizner/onr_muri/
Howard Poizner, UCSD (PI); Gary Lynch, UCI (Co-PI); Terrence Sejnowski, Salk Institute/UCSD (Co-PI)

Mobile Brain Imaging Laboratory (MoBI) at INC
Scott Makeig, Principal Investigator

Poizner Laboratory at INC
http://inc2.ucsd.edu/poizner/
Howard Poizner, Principal Investigator

Dynamics of Motor Behavior Laboratory at INC
http://pelican.ucsd.edu/~peter/
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