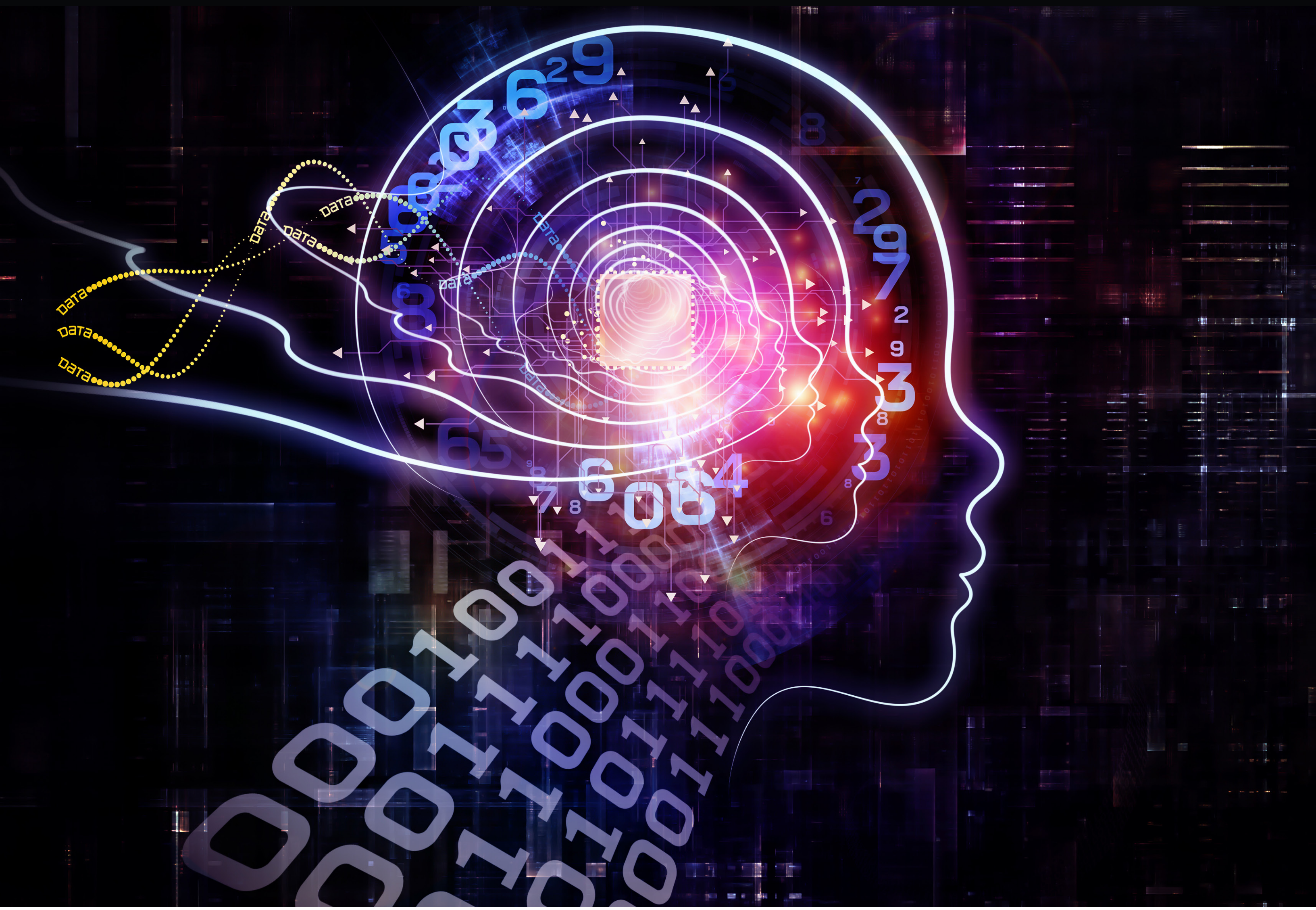
AMERICA'S NEXT FRONTIER: CONQUERING THE MIND



SYMPOSIUM REPORT
September 24, 2014

Sponsored by:
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The sponsors and publisher gratefully acknowledge participants' contributions included in this event report. Please note that the transcript has been edited for publication.

For further information about this symposium series or reports, please contact the Director of the Center for Neurotechnology Studies, Jennifer Buss, Ph.D. at: jbuss@potomacinstitute.org.

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EXECUTIVE SUMMARY

Neuroscience and neurotechnology have the potential to transform every aspect of our lives. Neurotechnology will come to define our future as it leads to improvements in medicine, education, communication, intelligence, our economy, and much more. To achieve all of this, we will need a national neurotechnology initiative that is well funded, coordinated across many federal agencies, and integrated with other cutting edge fields in science and technology. To this end, the Potomac Institute for Policy Studies held a symposium on Capitol Hill, hosted by Congressman Chaka Fattah, on September 24, 2014. This symposium brought together industry leaders, academics, and government officials to discuss the future of human intelligence, collaborative neuroscience research and development, and the goals of the BRAIN Initiative.

Mike Swetnam, Potomac Institute for Policy Studies, opened the seminar with a discussion about the role that government plays in significant, innovative technological advances. Representative Chaka Fattah (PA, 2nd District) delivered the opening remarks. His remarks were followed by a seminar and panel discussion from Dr. James L. Olds, George Mason University; Dr. Amy Kruse, Intific; and Dr. Peter B. Littlewood, Argonne National Laboratory. The symposium concentrated on the interaction between converging scientific fields, whose interaction can lead to better tools for studying neuroscience and creating neurotechnology. The symposium participants agreed that the BRAIN Initiative needs to deliver a clear message and well-defined goals. Dr. Jennifer Buss, Potomac Institute for Policy Studies, moderated the panel discussion and gave closing comments. The panel covered topics including the investigation of the functional maps within the brain and targeted important requirements for successful neuroscience research from academic, industry, and federal perspectives. It was concluded that there is an opportunity for a sustained investment in neurotechnology that will invigorate scientific research, kick-start an industry, and create a better future.

The report that follows has been prepared by the Potomac Institute for Policy Studies and is intended to contain a factual summary of the events and discussions that occurred at the symposium. The views contained in the report are those of the individual symposium participants and do not necessarily represent the views of all symposium participants or the Potomac Institute for Policy Studies.

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

THEME #1: EXPANDING THE BRAIN INITIATIVE INTO A NATIONAL NEUROTECHNOLOGY INITIATIVE

FINDINGS

- **Brain mapping alone does not improve our understanding of the brain.**

  The most informative neuroscientific findings originate from understanding communication between the different scales and functional areas of the brain – not from simply mapping their connections. While we can accurately map the connections between the individual neurons of the brain, just using these connections to understand the brain is as helpful as using a paper map to assess traffic patterns. Neuroscience research needs to integrate mapping data with high resolution, dynamic information from all neural processes.

- **The BRAIN Initiative has mismatched goals and implementations.**

  The President's BRAIN Initiative will not deliver on its promises unless it is driven by greater, more robust goals. It is narrowly focused on mapping the brain as a tool for obtaining advances in medicine and health. The current effort is reminiscent of the Human Genome Project that promised personalized medicine from the sequence of human DNA. Ten years after the project was declared a success, we are still waiting for cures to diseases and individualized medicine. The Human Genome Project did not live up to its expectations and neither will the BRAIN Initiative if it continues to follow in these footsteps. The BRAIN Initiative will be much more likely to succeed in its stated goals if it expands its scope beyond medicine and health to include all domains of neuroscience research, commercial and industrial development, and education programs.

- **Neuroscience is converging with revolutions in other technological fields.**

  The digital, biologics, and nanotechnology disciplines have all provided their own technological leaps for society, and now, neuroscience is at the cusp of sparking its own revolution. The convergence of all of these disciplines will revolutionize the way in which society functions through the enhancement of human intelligence and physical abilities. When neurotechnology begins to reach into every aspect of our lives, the benefits to our health, education, and economy will be limitless.

CONCLUSIONS

- **Mapping alone is an unsatisfactory approach to solving difficult neuroscience problems.**

  Mapping the brain contributes to a fundamental understanding of the scales on which the brain operates, but it is greatly augmented by research into the microscale and macroscale mechanisms that drive neural activity. The BRAIN Initiative needs to ensure that it is investing heavily in all of neuroscience's research areas, rather than exploring connectivity alone. A singular focus on brain mapping will lead to failure to achieve the goals of this initiative.

- **The BRAIN Initiative needs to expand its program scope and range of activities to successfully reach its goals.**

  There is no precise definition of what constitutes a map of the brain, and when the map would be considered a completed process. With the Human Genome Project, it was clear what the end goal would be: the complete map of every base pair in the human genome. There is no equivalent end state with neuroscience, so the goals for a neurotechnology initiative need to be more far-reaching and more clearly defined.

- **A neurotechnology initiative needs to reflect the interdisciplinary nature of neuroscience research.**

  Previous research in sequencing the human genome, improving imaging technology, advanced modeling and simulation, improvements in our understanding of biochemical pathways, and developing nanoscience all supplement and inform the field of neuroscience. In turn, neuroscience will have an enormous impact on artificial intelligence, engineering, computing, and the entire biomedical field. This mutually beneficial, converging relationship between many scientific disciplines can accelerate progress, but such interdisciplinarity requires coordination.

RECOMMENDATIONS

- **A neurotechnology initiative should fund research into all of the domains of neuroscience.**

  Research in all aspects of neuroscience, from the micro to the macro, is necessary to improve our understanding of the brain. Developing an understanding of neural systems requires measurement and data collection in conjunction with advanced computing, modeling, and simulation. Neuroscience research should include methodological development of technologies that incorporate the dynamics of neural systems from multiple research perspectives. Just as Google Maps provides salient information about changing traffic patterns overlaid onto a road map, neuroscience research should augment mapping data with improved, high resolution, dynamic information.

- **It is necessary to build up both the fundamental science and the technological applications of neuroscience.**

  Fundamental neuroscience research will lead to greater understanding of neural structure and function, a theory of brain and cognition, and the architecture of these complex systems. This will enable success in brain-computer interface technologies, brain injury prevention and repair, neuroenhancement, cognitive computing, and artificial intelligence. The Potomac Institute for Policy Studies' *Neurotechnology Futures Report* delves further into the roadmap for success in neuroscience research. The roadmap has two tracks. The first track involves understanding the fundamental science, or scientific discovery and understanding of the brain and cognition. The second track involves the development of technology and applications, which will feed back into scientific discovery and into the development of products and applications for medicine, the military, and the public. A successful neurotechnology initiative will develop research side-by-side with commercial infrastructure and resources.

THEME #2: BUILDING A NATIONAL NEUROTECHNOLOGY INDUSTRY

FINDINGS

- **Previous national investments revolutionized the way that the world works.**

  Investments in computing, transportation, space systems, and nuclear power have transformed society and enabled great progress in areas beyond their original scientific application. These national investments bolster science research, but they also create an industry for technology that empowers communication and learning, strengthens our nation's defense, and amplifies our economic productivity.

- **A shift from a focus on academic endeavors to a robust, multidimensional industry has not occurred for neuroscience.**

  Researchers in neuroscience are recognizing the need for collaboration with neurotechnology industry leaders, but no mechanism for coordinating this partnership currently exists. The National Nanotechnology Initiative helped to create a profession and industry for its field. Government involvement in developing nanotechnology established industry standards and practices, accelerated the deployment of nanotechnology, and promoted business in the field. Compared to other fields like nanotechnology, neuroscience has seen little government activity to integrate academia and industry.

CONCLUSIONS

- **To maximize the benefits of the Neurotechnology Initiative for society, we need a world-class neurotechnology research and development strategy.**

  Neurotechnology has the potential to bring about incredible changes to our capabilities in technology, communications, commerce, and education. Successful research in the field will spawn an industry that brings us the ability to repair brain function through medicine and enhance our cognitive abilities through brain-computer interfaces.

- **Neurotechnology can transform into a profession and industry that augments the work of academic research.**

  A working relationship between academic institutions, businesses, and government can help to establish a neurotechnology industry, replete with resources for the establishment of standards and practices, deployment and application of neurotechnology research and development, assistance for startup companies and small businesses, and the facilitation of testing and evaluating devices and medicines for commercial usage.

RECOMMENDATIONS

- **The federal government should build a national neurotechnology industry.**

  The government is the most qualified entity capable of driving this transition and federal initiatives should focus on this problem space. The government can create national centers for technology development, develop nurturing environments for startups, and connect researchers with entrepreneurs and businesses. This coordinated platform for research and business will expedite the introduction of revolutionary neurotechnologies. All of our nation's past investments were based on promising and delivering a better future, so the BRAIN Initiative should do this and more. The United States government needs to invest in neurotechnology.

- **The neurotechnology initiative should prioritize collaboration between scientists and researchers in different fields.**

  There is significant value in unifying knowledge from scientific fields like biology, nanotechnology, big data, computer science, and engineering to solve problems in neuroscience research. In the vein of the Nanotechnology Initiative, the BRAIN Initiative can support research facilities where talented biologists, engineers, computer scientists, and physicists can work together. This collaboration will bring together engineers and computer scientists who had not previously tackled the problems posed by the brain and biologists and neuroscientists who previously did not have access to the technical skill sets to compute big data and working models. This convergence is already occurring, but it doesn't have the means to be sustainable unless the neurotechnology initiative gets behind it.

THEME #3: COORDINATING A NEUROTECHNOLOGY INITIATIVE ACROSS FEDERAL AGENCIES

FINDINGS

- **Many technological advancements in society are the result of a large-scale coordination of resources.**

  For revolutions in computing technologies, genetics, and nanotechnology, success was predicated on the convergence of multiple disciplines and a coordinated effort from many different agencies. Research agencies like NSF, DARPA, and the Department of Energy's National Laboratories contributed to basic and applied research breakthroughs, while regulatory agencies like NIST and the FDA improved standards and frameworks for successful implementation of technology. Previous national research initiatives in computing and nanotechnology were successful because they were directed by government coordinating offices. The National Nanotechnology Coordinating Office provides the National Nanotechnology Initiative with technical and administrative support; informational resources; the primary executor of multiagency planning, budget, and assessment; and a public outreach clearinghouse.

- **The Department of Energy's National Laboratories and other technology centers have powerful assets for research.**

  The overwhelming trend among neuroscientists is to design and build the tools in their labs; everything from electrodes and amplifiers to instruments that record neural activity. This trend is similar to other big science initiatives where expensive tools were highly limited. The National Laboratories contain resources and toolsets to bring large-scale data analytics to neuroscience research; however, these tools are highly specialized, owned by individual labs, and are not easily accessible to other researchers. Bridging neuroscientists with advanced computing facilities, such as the Department of Energy's National Laboratories, will allow for use of the analytical tools needed for neuroscience innovation.

CONCLUSIONS

- **A concerted effort from multiple agencies will be imperative to a revolution in neurotechnology.**

  The National Science Foundation and the National Institutes of Health are not the only agencies that benefit from neuroscience research. As such, the goals of this collaborative project will need to be clear and the steps taken moving forward must be purposeful. This can be based on previously successful models in which government agencies, including the National Science Foundation, the National Institutes of Health, the Department of Defense, the Department of Energy, the Department of Education, the Department of Veterans Affairs, the Food and Drug Administration, and the National Institute of Standards and Technology, were required to coordinate money and resources among different sectors, in order to accomplish a shared goal. The same concerted effort from multiple agencies will be imperative to a revolution in neurotechnology.

- **The National Laboratories have a place within neuroscience research.**

  The National Laboratories' resources will amplify our ability to address both sides of the current data collection and analysis problem in neuroscience research. When we point to gaps in our understanding of the brain, lack of data and resolution is often the culprit. The immense capabilities of the National Laboratories will promote collaboration across different scientific fields and provide a platform where scientists have unbridled access to innovative technologies and data sets.

RECOMMENDATIONS

- **The federal government needs to create a National Neurotechnology Initiative Coordinating Office.**

  A National Neurotechnology Initiative Coordinating Office would organize federal neuroscience and neurotechnology activities between involved agencies, including NSF, NIH, DoD, DoE, and more. The goals of this office would be to serve as a point of contact and an exchange for technical and programmatic information for government organizations, academia, industry, professional societies, and the general public. The federal government needs to create brain observatories that can leverage the computational and analytical tool kits that the National Laboratories provide, and the coordinating office should mediate these relationships. Neuroscience research will benefit from access to multidisciplinary computational and analytical tools that can enable large-scale analyses of data. Whether this big data strategy is applied to brain mapping, genetics, single cell recordings, or functional imaging data, it will lead to breakthroughs that are currently out of reach today.

- **The federal government needs to fuel the convergence of science and technology, construct data-sharing systems that feed into data-sharing repositories, and provide resources for individual investigators.**

  The best way to gather the inputs for truly big data analysis is to draw from researchers' work all over the world, and this process needs to be facilitated. Researchers should be working to generate data that can be utilized by other scientists, neurotechnology developers, and large-scale data aggregators like the National Laboratories. In return, researchers should also be able to access large repositories of tools and datasets so that they can conduct secondary analyses and develop new hypotheses. This open data framework enhances the cyclical relationship between science theory and resultant technology: being able to freely utilize scientific findings will lead to technological developments that then feed back into new research projects. A dynamic, living relationship between the National Laboratories and individual neuroscientists is the best use of our resources.

EVENT TRANSCRIPT

JENNIFER BUSS

Opening Remarks

Thank you all for joining us today.

Welcome to today's symposium America's Next Frontier: Conquering the Mind to discuss the biggest mystery to mankind, the mind, through the convergence of neuroscience, biologics, nanotechnology, and the digital revolution. The digital, biologics, and nanotechnology disciplines have all provided their own technological leaps for society, from machine intelligence to nano-scale smart devices. Neuroscience is on the cusp of its own leap forward: it has great potential to restore and augment human cognitive, and physical abilities. Enhancing human intelligence through technology will revolutionize business, education, communication, and the way in which society functions. As part of the 2014 Neuroscience Policy Symposia Series, today we will continue to elaborate on the need for the expansion of the BRAIN Initiative into a National Neurotechnology Initiative. The distinguished individuals at this symposium will draw from their experience in industry, government, and academia to discuss important topics in neuroscience and the future of intelligence.

Today's topic is really about how we can enhance human intelligence by the technology that has brought us to the current sate of machine intelligence. The current fields to get us there have already had their debut – digital, biologics, and nano - and now neuroscience will bring the concept of enhanced or improved intelligence to fruition. It is no longer a field of artificial intelligence because it will be real and not artificial – each individual field is developing their own road to intelligence. Digital is through machine intelligence. Biologics is through creating your own organism; creating organisms that do what you want them to do, forcing evolution. The field of nanotechnology is selling it on the premise of "smart devices". The only way to get to an improved intelligence is to have the Neurotech Initiative (President's BRAIN Initiative) lead us through the neurotech revolution, and combine it with the impacts of the other initiatives we have seen in the past, including the current nano tech initiative.

Without further ado, I'd like to introduce Mike Swetnam, CEO and President of the Potomac Institute for Policy Studies to provide a few opening remarks.

MIKE SWETNAM

Introduction

I am Mike Swetnam, CEO and chairman of the Potomac Institute for Policy Studies. I would like to express my gratitude to Congressman Fattah for his awareness of neurotechnology issues. He works very hard to support neuroscience funding and program-building. We thank him for hosting us today here on Capitol Hill and allowing us to have this important conversation.

Big, revolutionary ideas are important to our nation. Without investment into these big ideas, we would not have many of the things that make our way of life possible today. Take the cell phone for example. This piece of technology is something we all have and use, but many of us do not know what went into making this possible. Without government investment, nobody here would have a cell phone.

It began with an investment into SEMATECH. This investment by the United States government was essential for the development of the cell phone and this was just a continuation of the trend of government investment in big ideas that changed our world. A recurring trend in our nation's history is that the government is capable of investing in and leading the development of revolutionary technology. Neurotechnology is a new scientific application, but it is certainly not the first time we have placed large investments into extremely successful national accomplishments.

The Chesapeake and Ohio Canal was a great engineering feat that enabled the development and economic growth of Washington, D.C. Likewise, our investments into the Tennessee-Tombigbee Waterway proved to be not only an economic stimulant, but also a transformative asset that changed the way we looked at how we could take control of our future. We followed this up with investments into railways that made it easier to rapidly move goods and people across our great nation. We helped create the commercial airline industry and built innovations that took us from the skies to space and then even the Moon. All of these developments transformed our nation, helped define our greatness, and would have never been possible without support and leadership from our government.

The American dream is only possible in an environment that promotes innovation, creativity and intelligence. When we provide support for big ideas we help create a place where we help inspire people like Frank Garcia. In 1975, computers were thought of as just big calculators and their role in society was always going to be just that. Despite this, Frank Garcia pioneered the vision that, one day, computers could do much more than simply perform basic arithmetic and he outlined these ideas in his magazine called *Byte Magazine*. People thought he was crazy because they lacked the foresight to see the potential applications of the computer. Without that kind of foresight though, we would have missed out on one of the greatest revolutions our country has ever seen.

Neuroscience represents that next great American frontier. Our big question today is what should U.S. policy be in developing neuroscience? What role do we play? The knowledge gained from neuroscience offers great promise to create a better world, a better society and a better America. All of our investments in the past have been driven by the desire to create a better future. Neuroscience promises a better future, so it seems clear that we should do what we always do: get the United States involved in its development by investing in this new opportunity towards greatness.

It is important though that we recognize that this endeavor is currently unlike those we have taken on the past. We cannot take an unfocused approach at researching and deciphering the human mind. Last year, the President announced the BRAIN Initiative, which seeks to map the networks and connections inside the human brain. The President's initiative is a great start. This investment into understanding neuroscience and developing neurotechnologies is likely to be the beginning of one of the greatest investments of time and money the human race has ever committed to.

It is the type of investment that 30 years from now our children will look back on and be grateful that we understood what others might have not; that neurotechnology and neuroscience will have created not just a better society, but also a better world. I would hate to think of what they may look back and think if we failed to recognize what will likely seem so obvious in the future. Fortunately, I stand here in this room with people who do understand the transformative potential of this field and that the conversation we have today may very well be the most important conversations the human race has had in a long time. I want to emphasize that this is an idea that we need to continue to discuss, to think about and commit to further research.

The Potomac Institute is always striving to make the connection between science and technology that affect policy as well as policy that strengthens science and technology for the good of the human race. The neurotechnology revolution that we will discuss today will only come to fruition with the full support of all levels of government: the President, Congress, and federal agencies. A truly successful initiative will require the participation of NSF and NIH, as well as agencies like the Department of Energy, DARPA, and the intelligence community. Neurotechnology needs to take advantage of the new knowledge and tools that research in nanotechnology, computer science, and artificial intelligence provides. This coordinated research focus will bring about the next revolutionary, big ideas that will shape our future.

CONGRESSMAN CHAKA FATTAH

Opening Remarks

Thank you all for attending this seminar today. First, I would like to thank the Potomac Institute for hosting this seminar and for its work in neurotechnology over the past decade. Their *Neurotechnology Futures* report concluded that leaps forward like the information technology revolution and the nanotechnology revolution will pale in comparison to the neurotechnology revolution. We know that neuroscience will directly improve the lives of millions of Americans (and nearly a billion worldwide) with mental disorders and neurodegenerative diseases, and will also have far-reaching effects on society as a whole. The Potomac Institute, the President's BRAIN Initiative, and the Fattah Neuroscience Initiative are all moving forward to build and sustain a strong national neuroscience effort.

There are many difficult challenges ahead for neuroscience research. We do not yet have the technologies that will allow us to categorize and understand the functions of the billions of neurons in our brain. Nor can we observe, chemically or electrically, how the trillions of neural connections in the brain actually function in real-time. Mapping the brain is an enormous challenge that needs to draw from the collective efforts of the Human Brain Project and our own BRAIN Initiative. We need to understand the basic elements of a brain map and understand how these neural circuits work. A working theory of how the components of the brain interplay with each other is necessary to understand our big questions in neuroscience. We must leverage new tools, big data, and high-powered computing to effectively research how the brain functions.

It is great to see the ongoing research and accomplishments of the Human Brain Project, our own BRAIN Initiative, and the work that is being done across the globe. I participated in the BrainTech Israel Conference last year in Tel Aviv and I was greatly encouraged by their efforts and research. It is absolutely necessary to ensure that these research efforts are cooperating and coordinating with each other. Neurotechnology and neuroscience research will need to pick up on novel and different approaches from different countries and research bodies like the Human Brain Project. We need to demonstrate their commitment to this important area of research by participating in international collaboration; neuroscience research asks very complex questions that can only be answered by the collective efforts of many nations' neuroscience programs.

This neuroscience investment needs to be an ongoing and continuous effort. It cannot be a short-term commitment with only three to five years of funding. This research will build on itself and lead to discoveries and innovations that we are not yet even aware of. The BRAIN Initiative and other funding for neuroscience will be a long-term investment. Allow me to explain what I mean by this iterative process of innovation with a story about a young girl I met recently. I was visiting Dr. Andrew Schwartz' lab at the University of Pittsburgh when I met a 5 year old girl suffering from a neurodegenerative condition which did not even allow her to give me a high-five. Using the innovative methods that Dr. Schwartz utilized, she was actually able to give me a high-five by simply using her thoughts to control a prosthetic arm. That was an amazing moment, but it did not just happen by itself. The research that led to point began 30 years ago when neuroscientists performed research on how firing patterns in the motor cortex of monkeys was tied to movement. They did this by implanting electrodes in the monkey's brain that were capable of tracking which circuits were firing when certain muscles were moving. At the time, the usefulness of this investment was difficult to understand, and yet today we can see the direct fruits of that labor in our development of brain-computer interfaces that allow for neural control of robotic prostheses. It was this technology, only developed through a continued, long-term investment into neuroscience that made it possible to implant electrodes into that little girl's motor cortex and allow her to give me that high-five. It is life-changing technologies like this brain-computer interface and robotic prosthesis that show how neuroscience is a truly revolutionary field.

Research like this is a great contribution to neuroscience and our society. Our distinguished speakers today are also significant contributors to neuroscience, from the commercial markets to policy and decision-making. We really look forward to hearing their remarks and discussions on the right policies that will ensure the continued success of neuroscience research and the BRAIN Initiative.

PANEL

PANEL SUMMARY

The panel brought together a set of distinguished speakers to discuss the future of impacts of neurotechnology on society and the steps we need to take in order to get there. The speakers utilized their experience in policy, labs, and industry to discuss the need for a map of the human brain, the level of detail necessary, and the tools necessary for accomplishing this goal. This will all be made possible by partnerships between private and public entities, similar to the collaborations implemented in the Human Genome Project. The speakers advocated for effective research, with a focus on increased federal funding, collaboration, and basic science. By discussing the need for a National Neurotechnology Initiative, the speakers established the critical significance of the convergence in scientific fields.

JAMES L. OLDS

The "How's and Why's" of Brain Mapping

Good afternoon and thank you for having me here today. I am going to start off by discussing brain maps. Maps are incredibly important, just ask Magellan. If we want to understand the brain, we need a map of it. This poses a difficult challenge, as there are roughly 10^{15} synapses and hundreds of types of neurons in the human brain. The brain is never uniform and each part has specific roles. We can reduce the challenge by understanding how different regions evolved and finding similarities in model organisms to make broad categorizations. If we assume that different types of neurons do similar things, which serves as a great simplifying base, we are on the way to mapping the brain.

Our brain is very complicated, but I would like to argue that other brains are less complicated and we are using existing tools to analyze them. The mouse and rat brain certainly have less neurons than a human brain. As we have exquisite genetic control over a mouse as a model organism, it is very worthwhile to study neural function in a mouse. The mouse then serves as a model to determine what is occurring in the human brain. It is very interesting to see how a mouse's brain connects, develops, and learns new things. It would be important to see what happens to its brain as it learns to navigate around a new environment and how to map it. Although the mouse brain certainly is a model organism, as it is simpler, it presents limitations. Researchers would never ask the mouse how to make political decisions or to analyze literature, yet using the mouse as a model could be very beneficial in moving human brain research forward.

Another model organism of study is the fruit fly. The fruit fly has significantly fewer neurons than either humans or mice. We are approaching a system that is manageable in this era of petascale and exascale computing. We also have exquisite engineering and molecular control over the fruit fly, so we can think of it as an engineered machine. In the fruit fly, we are able to analyze the entire universe of neurons, as opposed to a random sample, and that gets us a whole lot further to understanding the human brain. Looking at the zebrafish, we can understand another universe of neurons. Analyzing a universe of neurons provides vital knowledge to brain mapping. When we examine the human forest of neurons, the analysis is always reduced to a sample of the entire population. Looking at the entire universe of nerve cells for an organism and analyzing the connections between synapses using sophisticated pattern recognition is a key step in decoding the neural network.

We can continue down the organism scale to the worm *Caenorhabditis elegans*, which has approximately 300 neurons. Moving lower into very simple eukaryotic cell organisms such as yeast, we can get into the same signal transduction molecules that are critical for human action. In humans, these molecules are responsible for learning, while in yeast they are responsible for the plasticity of a single cell.

The first step in building a map is to place things where they belong. When I think about brain research, which is over a century old in its modern form, I think of Nobel Prize winner Santiago Ramón y Cajal and Camillo Golgi. Their research represents the period when we stopped thinking of the brain as a complicated machine and simply went in and used engineering to understand it. Again, modern neuroscience is over 100 years old. Starting with the discoveries of Cajal and Golgi, we have been able to sample individual neurons, put them in the correct location in the physical brain, and begin to understand the brain's architecture.

In the last twenty years, this knowledge has been applied noninvasively to the human brain. It is wonderful to discover that the human brain operates similarly to many model organisms. In fact, we have very similar neural circuits to the Rhesus monkey. Two dangers stemmed from this type of imaging. First, our mapping technique yielded aesthetic pictures for the media, the courts, and other decision makers. The danger is those beautiful images are severely mismatched from the reality of the human brain; these images are off by a thousand, in terms of both spatial and temporal resolution. In simple terms, this means we are seeing a very blurry picture of human brains in action and this results in very broad and problematic conclusions on how the brain works. The second danger is the assumption that all images and research is truthful. I urge all of you to be very critical of scientific research. We will eventually draw accurate conclusions about how the interior of the brain works as we create better maps. Already, we are able to visualize the function of entire networks of the zebrafish brain. The options for humans are still limited to either visualizing a discrete subsample or viewing a blurry image of a million neurons.

Returning to the concept of mapping, a map of the brain is very useful. My colleague and friend Giorgio Ascoli asserts that when you lay out what you can possibly learn, you will discover constraints. As a biologist, these constraints include the physical proximity of what a single neuron can touch. If a neuron cannot touch another neuron, it is unable to create a synapse or to change the weight of the synapse. Physical proximity is everything for the nervous system. If we are able to map that physical proximity and understand it between cells in the brain, we can create important constraints on what the brain can compute.

Another constraining aspect is even more compelling. We already understand that diseases act on the brain map. For example, Parkinson's acts on the neurons of the striatum fiber and kills those neurons. In schizophrenia, discrete segments of the brain are differentially affected. When the brain is mapped, we will be able to superimpose the constellation of molecular activity with what is going awry in schizophrenia. We will then have a better shot of making a difference in that disease and a whole host of other diseases.

Now, I want to turn to the most exciting aspect of mapping, which takes a note from engineering. If you want to know how something works (a watch for example), there are many things you can do. First, we can smash it with a hammer and sift through the pieces slowly putting the watch back together. That is the reductionist approach. It seems a little absurd, but it is potentially viable. Second, we could carefully disassemble the watch. As we take an individual piece out, we could then put it back in and determine what role it plays for the functionality of the unit. I think that is a very powerful approach. Lastly, I think we can all agree that staring at the watch will get us nowhere, so we must do something to get inside the watch.

The same is true for the brain. The translation of this example in brain science is optogenetics, where neural engineers can turn on and off pieces of the brain at will. In the non-brain world, this is how you reverse engineer a circuit. Optogenetics is a very important tool to brain science but we need a map of the brain first to use it effectively. After we build the map, we can remove pieces and observe what changes in an animal's phenotype or behavior. In the last decade, the technology has greatly advanced and given us the power to understand how the pieces of the brain work in concert to give us a marvelous result.

Brain mapping can be thought of as a multilevel process. The noninvasive brain scanning pictures represents a low-resolution map. On the other hand, electron microscopy can be used on model system brains to create a physical map of every single synapse. There are researchers using these industrial techniques, as Craig Venter did with the Genome Project, for mapping the brain. They are building up electromagnetic spectrum maps of the mouse cortex at the level of resolution of a synapse. That is the level we need to be at in order to understand this complex machine. The computing power needed to process this data is beyond exascale.

There are many intermediate computing maps. In the days of Santiago Ramón y Cajal, the technique invented by Golgi was simply a method for randomly staining every 1 in 10,000 neurons. Those pictures are beautiful and still used in modern teaching and artwork. Even those simple pictures presented us with important clues about how the brain map comes together to create function. We have modern versions of that Golgi technique that has allowed us over the years to make sense of this map. That is the "how's and why's" of brain mapping.

Now let me speak briefly about the brain projects. Congressman Fattah raised a good point about international collaboration. First, if you look at global investments in brain science, they tend to be large and uncorrelated. This presents young neuroscientists with the opportunity to receive grant money (if they are willing to travel the globe) but there is not a cohesive structure. In addition, understanding the brain requires collaboration, as the equipment and devices are expensive. This is not a problem one nation can solve. It requires a real international effort and the utilization of individual strengths to generate progress. I recently met with contributors to the European Human Brain Project. We discussed the challenge of working collaboratively and how to avoid spending duplication between the European and U.S. initiatives. Accomplishing all of these things will allow us to make progress in an efficient manner and be good stewards of our finances. I think there are challenges that have always existed with international sciences. We know that big science is possible. Just look to the physics domain as an example of great success. Neuroscience needs to utilize this knowledge to advance their efforts. Another difference is found in the style of research conducted on either side of the Atlantic. The European Human Brain Project is funding a single primary investigator, which is now creating problems among the rank and file neuroscientists in Europe. The American system, which is roughly the same fiscal size annually as the European project, is dispersed across many primary investigators and labs. I believe our system is more opportunistic, rather than systematic. There is room in research for both styles of science. I am a firm supporter of distributed investment, especially since World War II. This is the era of team science, more so than ever before, as these challenges are huge. These grand challenges create a need for shared resources and a team approach.

AMY KRUSE

Developing Neurotechnology for the Brain

Thank you for joining us today, and thank you for your very elegant remarks, Dr. Olds. I think mapping and cartography can really get us somewhere. Thank you for the Potomac Institute's leadership in this field. It is slightly embarrassing to say, but I been having these conversations with Mike Swetnam for 15 years. The Potomac Institute has been persistent on this topic even when public interest has waned. I would like to begin with a couple of personal stories that frame today's discussion. I have already promised Dr. Littlewood that I would tell him about my experience as a high school summer student at Argonne National Laboratory and how it sparked my interest and created the scientist I am today. I would like to thank Congressman Fattah for his legislative leadership in neurotechnology. It is very important for those of us working in the business of neuroscience to have an advocate in Congress.

My current position is as the Vice President of Innovation Research at Intific. I received my Ph.D. in Neuroscience from the University of Illinois; I was a National Science Scholar, and a recipient of the National Science Foundation Graduate Fellowship in Neuroscience. The first time I came to D.C. was actually under the care of the NSF. The Society of Neuroscience arranged a trip of science graduate students to Congress as a symbol of the importance of the NSF and graduate student research.

My fellow students and I were trotted through Congress. It was an important lesson for me as a graduate student. That trip solidified for me the concept of the nature of support and sponsorship and how these things came to be. I was from the wonderful state of Illinois, so I met with Congressman Dennis Hastert, former Speaker of the U.S. House of Representatives, and his chief of staff. I met with him and discussed the importance of neuroscience, its value for society, and simply all the things we are still talking about today. Later that day, we attended a hearing on the Hill where I was introduced to Congressman Vernon Ehlers, who is a physicist. Representative Ehlers was very gracious to the budding graduate student that I was and his remarks and support served as a galvanizing moment for me. I have come very far since those days. Even 15 years ago, I knew that neuroscience could change the world.

When I received a call from DARPA, it was a changing point for me. DARPA was looking for neuroscientists to support new developing programs. That day, I knew I would be passionate about their work because it was applied research. I became a technical consultant for DARPA and quickly learned how exciting translational research could be. Eventually, I evolved to become a Program Manager at DARPA within the Defense Sciences Office from 2005 to 2010. There is a term limit to a program manager's time, so after departing, I moved on to Intific to be the Director of the Neuroscience Division. Now, I am their Director of Innovation and the Cubic Corporation recently acquired Intific. It is important that large companies are looking forward and seeing the long-term value of neuroscience. Together, our work with the Cubic Corporation is focused on neuroscience and education.

In the past 15 years, I have been an academic researcher, a consultant, a program manager, a small business woman of a private industry, and now an executive at a publicly traded large business. When I look at the work I have done, I believe it covers all of the aspects of neurotechnology and the direction it is headed. My pursuit is what is next in neurotechnology, which I use explicitly to mean applied neuroscience. I am here to report on what is next for neuroscience and neurotechnology. As a citizen and a neuroscientist, I am ecstatic to see the energy and funding around the President's BRAIN Initiative. As a researcher in that field, it is like winning the lottery ticket to see someone of that standing who recognizes the importance of neuroscience. On the other hand, as a businesswoman and a neurotechnologist, I want a bit more. I want to be able take our investments beyond basic research. If we solely look at the research aspect of funding, we leave out those within business and industry, which is very concerning for me.

I think the great potential of neurotechnology is not just its impact on the health and wellbeing of individuals, but also the creation of a new industry to fulfill its grand promises. Yes, the pharmaceutical industry and others will play a major role in establishing this, but I believe we are on the verge of creating our own neurotechnology industry. We have had decades of work and that work is ready to be transitioned into the hands of users, consumers, patients, students, parents, the military, and more.

Returning to my narrative, I once led a project at DARPA titled Operational Neuroscience that focused on the concept of transitioning research from the lab to the field. The goal was to move devices from a closed research setting into the home, office, or in the field. I want to caution that neurotechnology is in danger of losing its leadership voice in the conversation. The market will not wait around for us to decide what the most appropriate technology is. The folks interested in enhancing human intelligence and other concepts of conquering the human mind will not wait for the official answer. This weekend I have a colleague headed to the Life Hacking Bulletproof Executive Conference, where attendees will hear from experts and perhaps a few charlatans on how to optimally enhance their cognition. This conference is very representative of what the market is interested in.

Recently, we attended the Neurogaming Conference, which was bigger than it ever had been. The venture capital individuals there would not be seen at a Society for Neuroscience meeting, but they were excited to be there and explore their options. I argue that the market is ready and we as the industry are not. I am very appreciative of the funding venture capitalists are willing to pour in. I also believe that crowd source funding, such as Indiegogo, is very effective. Many of these efforts, whether venture funded or crowd funded, are device related, such as an electroencephalograph device that measures brain activity in real-time.

Based on my time at DARPA and my current position, I recognize that we need to build up the middle ground. This middle space is a common ground between entertainment and research. That is where I believe the other pieces, such as enhancing human intelligence, will thrive. I would like to be the one to help set the agenda for rigor and validation. As a scientist, I know what types of rigor and validation I would trust from industry. The potential for enhancement is great and the appetite is substantial, but the output from regulated or trusted entities is lacking.

The funding for trusted providers would come from both small and large business. In Congressman Fattah's example, the prosthetic arm funding began with an NSF grant and then DARPA brought it home in the final stretch. A similar pattern occurred with the Google Autonomous Car: many had been working on autonomous cars and Google used their funding to tie it all together and produce the final car. It is the purpose of the government to take risk off of the table so industry can pursue innovative research.

Neuroenhancement is primarily an off-label space consisting of the life hackers, DIY community, and concerned parents. The off-label space is composed of those that want to experiment on themselves and those that want to fix their children. I would prefer a world where neurotechnology is more like an enhancement available at a drug store under the guidance of a trusted professional, rather than the guise of something like "As Seen on TV" or eBay. We need to act and provide leadership fairly quickly so that it ends up in the correct camp.

I am going to give you very clean and concrete example from my experience at DARPA. I started a program at DARPA titled "Accelerated Learning", which is something I think we can agree we all want. I started programs that I thought would be useful in the future. The program asked two questions. "Do the brains of experts show signs of expertise and are these signs quantifiable?" If the answer is yes, then the second question was "Can you take what you know about the expertise brain to change the learning trajectory of a novice?" Our experiment was based on a simple motor task, marksmanship. Through our project, we showed that the expert brain showed unique and measurable patterns for perfect or near-perfect shots. The measurements were conducted using an electroencephalograph headset to measure brain activity, as well as physiological markers such as heart and respiration rate. Ultimately, we showed that novices were able to emulate the brain states of experts using a neuro-feedback paradigm. Without even practicing on the range the novices' performance improved. Our novices were trained with brain training and their performance improved simply through it alone.

This is an example of a multi-million dollar investment from DARPA that is ready to be translated into a product that we are working on with collaborators right now. The project was military focused, but the results have been shown to hold true for non-military applications as well. This experiment has rigor, data, and evidence. Those are my qualifications for something to move forward to the application stage. We can take an applied neuroscience perspective to look for signals of interest for things that enhance performance and cognition, backed with rigor, data, and evidence. We set out to find specific signals, going off of Dr. Old's mapping. In order to find those signals, we must know what questions to ask and how to ask them rigorously. The work is too expensive for small business to take on and the funding is geared towards the gadgets. We have seen great progress in this space, but it needs continued regulation and focused funding.

Today I have talked little about neurostimulation, which is a very exciting field teetering on the edge between respectable science and the "As Seen on TV" realm. It would be my hope that we can move neuro-tropics and neuro-ceutics out of the GNC world and into a safe environment with trusted professionals. As we hear about the great promise of neurotechnology, it reminds me of its significance and large potential impact on society. I stand completely behind the National Neurotechnology Initiative and I believe that combined effort from government, academia, and industry will pack the punch to get this moving. This initiative is too important to slowly piece together. The work needs to be direct and purposefully driven.

I would like to conclude by going back to my story. We must take a leadership position in this space with both funding and initiatives. That was the purpose in my visit to D.C. so many years ago: to put a face to the funded graduate student. That is what I said when I shook Representative Ehler's hand. Here I am, one of the students that you have chosen to fund, and I am not going to let you down. Someone invested in me many years ago, and I certainly carried out my side of the bargain in that investment. Neurotechnology is now at a similar point and we will not let investors down. I would like to benefit from this investment, but as with the prosthetic arm, someone often begins the research and then someone else finishes it up. Thank you all for joining us today and for this opportunity.

PETER LITTLEWOOD

Toward a National Brain Observatory

I thought I would begin with a bit about my own background. I am a physical scientist, not a neuroscientist. My involvement with neuroscience began with my time at Bell Labs, where I worked for twenty years. Bell Labs is one of the great research laboratories and always had a broad view of all of the important things they could do. They tackled the broad question of what communication technology could entail. To them, the answer included satellites, hearing aids, and of course, brains. The view at Bell Labs was to bring physical technology to bear on the ways we understood things.

While I was there, one of my young colleagues was Winfried Denk. He invented two-photon excitation microscopy as a tool to see through dense media. He went on to become a champion of the European brain project, where he does brain mapping. Another group of colleagues were working on functional magnetic resonance imaging, which produces images of the brain. These advances produced some new views and new ideas about the brain. This in turn led us to begin asking the question, "Can we rethink how models of the brain work?"

It was a very interesting question, and ultimately a very interesting fight. There are some very interesting ideas about neurocomputation, including neural networks, which are algorithmic ways of making different methods of calculation. This has been an exciting field but "neural networks" do not actually have a great deal in common with what the brain actually does. This is a very good demonstration of how you can get inspired by something, but with insufficient information, you can easily get going in the wrong (but perhaps inspiring) direction.

What has always been interesting to me about neuroscience is how theory driven it is. And there are all kinds of theories, some more respectable than others. However, I believe that an excess of theory over experimentation is a very bad thing. Thus, we ask if it is possible to obtain a lot more data. It is on that topic which I will be speaking today.

Consider some of the things we have accomplished over the last few years: we sequenced the human genome, improved brain mapping, and substantially improved imaging technology. In my opinion, we can add nanoscience as one of the big and successful scientific investments. It is the hope of many people that the merging of some of these might be incredibly powerful, and not only to neuroscience. It is my view that we must also look at cross-disciplinary efforts. This includes physics, computation, x-ray science, and energy science. These are some of the things that Dr. Jennifer Buss talked about, that these disciplines might have different but complementary styles of doing things.

Working as physicists at Argonne, we are used to dealing with big things that require many teams and have to be curated. As has already been mentioned, there are one hundred billion neurons. How big is one hundred billion? That is about the number of stars in the Milky Way. Now there are about one hundred trillion (an order of magnitude greater) synapses in the brain. If you were to create a Google brain map, the amount of data that would need to be collected to make that brain map is about one zettabyte. That is a new unit, something you have never seen before. A zettabyte is one quadrillion gigabytes, 10 to the 21 bytes. That is about the total data that flows over the global Internet in one year. That is a very big number, but not too far out. It is a number that we can think about.

As you all have remarked, the level of information we have now can produce these pictures of our brains. Here we have a heart-wrenching picture of late stage Alzheimer's disease. This is a PET scan, positron emission tomography. The problem is that the imaging is relatively low resolution so you can only accurately identify a severely diseased brain and you cannot see anything in early stages of Alzheimer's.

Another point that might actually surprise someone who works at the Department of Energy is that the brain only uses forty watts. This leads to an interesting point. As we start to perform large scale or exascale computing, the power needs will be tremendous. When that computer is installed, it will require roughly twenty-five megawatts of power to operate. As a point of comparison, the DeSoto Next Generation Solar Energy Center (the largest photovoltaic power plant in Florida) is only rated at twenty-five megawatts when at optimal output.

The scale efficiency between current computations we do on regular machines and the computations that the brain performs is just extraordinary. To put this in perspective, if you keep buying laptops, you will find that they are not getting much faster with each iteration. What the manufacturers do is just put another processor in them. They are reaching limits on running any faster because the components simply get too hot. They are very energy inefficient.

If you are storing your data in the cloud, you are actually storing it in Northern Europe, likely Sweden or Finland. It cost so much and takes so much energy to store all that data that it is more cost-effective to store it somewhere cold. This is what most large data storage companies like Google and others do.

We have a real need to understand how the brain works so that it can help us drive better technology. I am now going to go through a set of pictures that explain the concepts we discussed earlier. Why is the brain so interesting, so difficult, and so complicated? If you look across the scales in the brain, the individual neurons are long cells, and they are spindly and stick out all over the place. All the things you really care about go down to really small scales. This example neuron has many spines where it makes contact with other neurons. If you want to find those contacts, you have to use an electron micrograph to 100 microns. Researchers are beginning to do this kind of imaging. If you wanted to image the whole human brain to that scale, you would be working on the scale of millions of petabytes. I believe we will get to this point.

X-ray imaging is also being implemented in neuroscience. This is nice because you have a technique where you do not have to slice through cells to get to the important information. With X-rays, you can actually scan through whole bodies and you can follow the neurons. So combining those three things together you can actually create a registry. It is a little problematic that these are not in vivo recordings, but this is not a bad start. Optogenetics gives us great images like this one here, where you see the top and side of the brain of a zebrafish. The nice thing about young zebrafish is that they are transparent and you are actually following neural activity mapped on an optogenetic scale. If you contrast that to where we are with conventional neuroscience skills, it far surpasses the spatiotemporal resolution of those techniques.

For humans, this is uncharted space because PET scans are up on the scale of seconds and millimeters. Functional magnetic resonance imaging and electroencephalography are also around that scale. We do not yet have the basic tools for human imaging that can work at this sharp scale and I think that there are real opportunities to get these tools. If you are going to have all of this data, what are you actually going to do with it? You have to extract important information from things that happen at the surface-level all the way down to microcircuits. We need to cover all of the scales and thus need data that connects each level.

What is there to be done? I think that the best thing you can do, particularly if you are a scientist who comes from a physical science background with physical science tools, is to provide the support for a much bigger neuroscience community. The tools that are available are really specialized and owned by individual labs; only a few people around the world can use them. That trend is similar to other big science initiatives where expensive tools are highly limited. As an astronomer for example, if you get help so that you can launch a hundred million dollar telescope, you are then obligated to take the data that you get from the telescope and make it available to the whole scientific community to analyze.

We have to find ways of making investments that enable lots of individual neuroscientists to access the tools that they need in order to work with the data that comes out of other scientists' work. We need to support the user available tools in the neuroscience community, various kinds of microscopy, at a very significant level. This ties into the fact that this country is so strongly associated with computation methods and analysis. In my view, neurotechnology is a vast space that requires very consistent methods for in vivo application. I would like to do optogenetics research with X-rays so that I could see through a body and have a better spatiotemporal visualization of the workings of the brain. The idea of injecting nano-devices inside neural tissue and being able to monitor and manipulate the individual neurons is very exciting. I think that we should set a goal of building a National Brain Observatory that brings in high performance computing and tools and enables us to move into the next century for neuroscience.

PANEL Q&A SUMMARY

The panel discussion focused on the future of neurotechnology regarding mapping the brain and the ability to enhance human and artificial intelligence. The panelists examined these topics from the vantage point of data sharing, ethics, constrained resources, and translation of research to application. Financial support is imperative for the success of a scientific initiative of this magnitude. Due to the disparity between stated goals and actual successes of past science initiatives, it will be difficult to convince Congress that neuroscience is the answer. Funding that is solely dedicated to neuroscience and neurotechnology will continue to face pressure. Brain mapping faces the same dilemma as prior scientific endeavors, in that it is only the first step in research and the stated goals offer no guarantee of progress towards understanding the brain. Accomplishing these grand scientific goals will be encouraged by a multidisciplinary coalition on neuroscience modeled after the Nanotechnology Initiative, as well as a coordinating office within the National Science Foundation.

Questions for the panel:

Predictions ahead: how can we integrate these leading fields today, what will come from this convergence now and in 5 years?

Differences in outcomes between current funding level and the huge influx that we're looking for: how do things become easier, what can we actually accomplish?

What is the end goal for a BRAIN/National neurotech initiative? National strategy: when to declare victory, how to manage risk, what are the objectives that we can apply policies to?

PANEL DISCUSSION

Jennifer Buss

To begin our panel discussion, I would like to reintroduce our topic. Today, we are focused on how we can enhance human intelligence through technology. We have discussed in great length how nanotechnology, the bio-revolution, and the revolutions of other fields have led to scientific advancement. Now it is time for neuroscience to shine and that is what we will talk about today.

Mike Swetnam

Much of the Potomac Institute's agenda has heavily reflected the desire for neurotechnology. The ideas and goals discussed here present grand challenges for humanity to accomplish. They require a very broad scope and cooperation. The current focus is on mapping the brain. Maps may be absolutely necessary, but are nowhere near sufficient. Within the intelligence community, a map does not provide the detailed level of intelligence necessary to complete an objective. A map cannot communicate whether the people inside the map want to hurt me or intend to hurt someone else. To determine what the people wanted to do, we took lots of pictures. If you take enough pictures, you can see movements and that may give you an idea, but it is still not enough to predict future action. The intelligence community then took it to the next level. They took pictures of individual people and tracked them over a map, which was still not enough. Next, we invented signals intelligence to find out what people were saying to each other. Understanding what people were saying provided a better judgment than images alone. However, people often lie. We really wanted to know what was going on, so the next step was to develop human intelligence. That meant sending someone in there to watch them. In the President's daily brief, 75% of intelligence relayed to him comes from signals intelligence while only 5-10% is based on maps. In other words, the most informative science comes from communication between actors, not the maps. Returning to the brain, we need to go much further than maps to get to where we want to be in our understanding of this complex system. Ten years ago, we told people that we were going to cure the world of disease by mapping the human genome. We paraded around the Capitol, asking for money to map the human genome with the promise of knowing how to cure all diseases. Once completed, there was a great chunk of information, but knowing how those genes interacted was vastly more important. Clearly, we are still learning how to cure diseases, years after mapping the human genome. I hope that I convinced some of you that the BRAIN Initiative is a great start, but we still have a ways to go. What are your thoughts on that?

James Olds

When you speak of signals intelligence, you are acknowledging that we cannot decipher the language of the brain. We can track with great fidelity that neurons in the brain are signaling each other, yet we are unable to translate those signals into English or any other logical form. One of the great challenges of neuroscience is decoding the language that neurons use to communicate with each other, so that we may perform signals intelligence on them. It is a tremendous frontier that is perfectly suited for the National Science Foundation's focus on the brain project. The potential of performing signal intelligence on neurons is very exciting. Of course, you have to pick the right neurons that are having the interesting conversations, so that you may learn what you intended to study.

Amy Kruse

I would like to add to what Mr. Swetnam was saying. I enjoy discussing new ways of looking at the brain. Not to criticize the neuroscience community, but the overwhelming trend among them is to create their own tools, including electrodes, amplifiers, and building up their labs from scratch. They do these things for economic reasons and training purposes. There are techniques in the larger engineering and physical sciences community that may be brought to bear on our signals intelligence problem that could be productive. I was not successful in funding signals intelligence as a program manager, but we did do explorations in it. This requires a shift in the collective mindset of the neuroscience community. The problem may be that we are not collecting the signals in a way that is beneficial for data analysis. Another alternative is that we have the correct signals and have yet to successfully bring the correct analysis to bear. I find this a particularly exciting area of fusion. The prospect of a brain observatory and the classical concepts of brain mapping are what excite me.

Peter Littlewood

A quick historical point, I am old enough to remember the war on cancer. The war on cancer is regarded as one of the successes similar to the Human Genome Project. However, there is a distinction between the two. The war on cancer was a great aspiration, but unable to progress. The Human Genome Project was a great aspiration that provoked a well-defined set of methods to achieve an answer. I find it highly important to construct projects like this with bold and well-defined goals. These goals set a course to assist researchers in getting from point A to point B. There may be a homologue waiting to be found in the brain.

Mike Swetnam

I agree. We need very narrowly defined goals that our political leaders agree with and then we, as researchers, need to go out and achieve those goals. In the case of the Human Genome Project, we promised a map that would help us solve every disease. We failed in this mission and did not come through on our promises to those funding us on Capitol Hill. With the BRAIN Initiative, we are promising that we will solve diseases like Parkinson's. I suggest that we sharpen this message or that we refocus to include the other frontiers of neuroscience. In order to accomplish these lofty goals, researchers will need to do more than to map the brain. Similarly, we need more than the map of the human genome to solve diseases. I am pushing this as a personal agenda. A fundamental purpose of the Potomac Institute is to push scientific issues here on the Hill. In the past, we lobbied for Congress to fund the Human Genome Project. Scientist now say that they are accomplished in that work, while members of Congress feel tricked, as they were promised the cure to all diseases. This inspires a lack of future funding and trust. Fifteen years ago, the Potomac Institute swarmed Capitol Hill, selling the National Nanotechnology Initiative and everyone bought in. We sold the Human Genome Project and many bought in.

Now, we are attempting to sell the National Neurotechnology Initiative and many are skeptical. Responses often include, "I have heard this pitch before that a map will solve everything." Our efforts need to be refocused. We need to request more funding and provide a concrete direction than simply a map of the brain.

Jennifer Buss

In summary, we are all concluding that we need to narrowly define what we are requesting. Mapping the brain is a good step, but how will it be implemented? Our goal is to come together and define these boundaries.

Mike Nelson

There are many interesting things happening in this sector. The most exciting news I have read recently was on the link between autism and our microbiome, essentially how the bacteria in our gut affect brain function. A large experiment being performed on Americans right now involves the hundreds of millions of people who are prescribed antidepressants. Going back to the previous discussion on computational analysis, can you see the impact that distinct chemicals have on the brain? Is another piece of the puzzle determining how chemical reactions cause neurological disorders and diseases?

Peter Littlewood

Looking specifically at the example of autism, individuals with autism have been shown to have poor connections in their brains. Therefore, the answer to your question is that controlled experiments allow you to remove a particular chemical and determine the effect. This is a proper engineering experiment. I believe this is a goal beyond having a brain map. The brain map is simply a baseline.

James Olds

Earlier this week I had a meeting in Richmond with folks from AstraZeneca, one of the largest pharmaceutical corporations. The debrief was titled, "Why We Failed at Neuropharmacology." It is not just those at AstraZeneca that feel this way, they were a representative of all those in the psychopharmaceutic industry. When the initiative launched in the early 1960s, there was a large amount of excitement for the psychopharmaceutic industry that lasted into the late 1980s. They expected to gain a simple functional understanding of the correlation between specific neurotransmitters and diseases. It was believed that understanding this relationship would lead to therapeutic outcomes. AstraZeneca confessed that this was entirely the wrong approach. It was an oversimplification of how chemicals and biologics interact in the brain. The process should have been thought of as a vast interconnected spatial and temporal signal network, rather than as a linear chain. The system was far more complex than Big Pharma was willing to tackle.

Mike Nelson

Do we see the effects of these chemicals on the brain topography or function?

James Olds

I have seen hints of it in my research, and we often overstate the substance of these conclusions.

Deborah Harry

I am a glia biologist, so I appreciate you mentioning that. It has been difficult to get glia accepted in the BRAIN Initiative, as it is a neuron-centric system. Just as in the Human Genome Project, we had messenger RNA and genes. The system can be neuron-centric, but concepts on how glia modify the neurons need to be added. This is not a static system. The synapses are retracting, recording, and interacting. I would like to put in a word with all those having an impact on the future of research: do not let other cells in the brain get lost. Using the beautiful optical genetics we perform with neurons, we will be able to create that map, but I believe the modifiers are what are going to control it.

James Olds

We hear you loud and clear.

Paul Werbos

Two points. I really thank Mike Swetnam for introducing these questions. In physics, we try to understand the principles of how things work. Getting the map of the brain would be beneficial, but first we need to understand the principles. If we understood the principles of how the brain was built, it would require less data than a detailed map. Secondly, we need to look at the theoretical bases of this data. How are we going to determine what it means? Lastly, the Neurotechnology Initiative must make special care to include everyone in the conversation. Last year, after the launch of the BRAIN Initiative, there was uproar from the neuroscience community that they were being left out. If people are left out, then they will raise important questions that redirect focus such as Kennedy's letter, which includes how he wants to redirect funding focus for the BRAIN Initiative. In addition, The National Science Foundation hosted a conversation in May on the achievable goals of the BRAIN Initiative. We cannot promise things we are unsure we can provide.

Stuart Washington

I wanted to add to the conversation on maps for neuroscience. Let me give an example. Say you have a map with a house on it. At that particular location, there is nothing but a house; however, that house may serve multiple functionalities. In addition, there could be a tangentially related object that serves a similar functionality. In the brain, Broca's area has been shown to affect speech, mathematical processing, and memory. I wanted to know if anyone would like to elaborate on that.

James Olds

As my colleague, the glia biologist, pointed out, the structure of the brain is dynamic; it is dancing with itself. If you follow the synapses of the brain, they are dancing over time. The complexity of the structure is not only in the map, but also in the simultaneous levels of the dynamics. This gets into the principles of how the brain is organized. My friend, Mike Roco at the NSF, coined the term "cognome." The cognome can be thought of as the rule set for how this machine is organized. These rules, like the rules of chess, will be quite compact. We have a dynamic machine that is dancing with itself and is working to develop the cognome. Those are the huge challenges we are working to answer. Overall, I would ask what is the payoff to the American public of understandings of the cognome and the brain map? I believe all of us on the panel, and many of you in audience are engaged in this important conversation, but this conversation must remain inclusive or we are going to come up short.

Theodore Dumas

I think getting down to detail and the reductionism approach is very important. I would like to focus for a moment on the pharmaceutical industry and its failure to find a magic bullet for all diseases. I believe this failure occurs because we are all different, and at a certain level of detail each individual is different. These differences could render these rules, maps, and principles useless. At what level of detail do we need to understand the brain and these principles in order create more accurate models of cognition?

Peter Littlewood

I find it interesting that after 100 years we are still asking these fundamental questions. I am not a neuroscientist, so my assumption is that we need more data. I would like to clarify that we do not actually need a zettabyte of data to understand the brain. The process may go forward by taking that initial zettabyte of data we have and analyzing it so we can gain a better understanding of the brain.

Amy Kruse

My perspective in the applied space is that it is important to acknowledge that individual differences do exist and that a large portion of the population must be included to make these studies accurate. In terms of medicine, women react differently than men, yet there are traditionally very few women in pharmaceutical studies. I would say that there is certainly a case for more data. There is also an option from applied space. While there are individual differences at the cognition level, there are certainly pieces of information or trends that are conserved. Part of what is going to happen is the sorting out of those pieces. It is not going to be one of the other, but likely a combination. Yes, I am arguing for more data, but also for the fundamentals.

Jennifer Buss

If we think of the example on Dr. Littlewood's slide of cognition from one mouse all the way down to a cellular level, how much of that is translated to another mouse?

Peter Littlewood

In great detail, none of it can be translated. It is based, in a sense, in statistics. The information will vary in different regions of a mouse brain. Already understanding the levels of connectivity cuts down on the number of theoretically conceivable models. As a theoretical physicist, I can construct any model necessary. We should not impose unnecessary constraints on our models. It is not necessarily true that all mice are the same, but maybe that is the point.

Jennifer Buss

That is the point. We do not need that much detail on how every human works to understand how we all work. We can apply generalizations across the board.

Paul Werbos

This brings up three hard questions. Where is the ultimate big impact for society? Dr. Amy Kruse's first project at DARPA was completely noninvasive. However, we can agree that improving cognition of normal people has huge potential. Second, I agree with Dr. Olds if you stare at a watch, nothing will be accomplished. This is like being in Britain and funding leaf collectors to help Darwin for what he is going to do one day. That is not what this is all about. We need the mathematical principles, but I think we can address the new mathematics. The most frightening thing to me is the ethical dimension of this problem. Recently, we had a huge shift in the nanotechnology research infrastructure. The big complaint from the community was we had a small contribution from ethicists, but that there was no overarching entity concerned with the social and legal implications of the work we were doing. Now, we want to modify the system to do so. I believe the ethical implications, the mathematical boundaries, and the overall impact are all important to consider.

Jennifer Buss

I will take a stab at that. One of the recommendations we made in our Neuro Futures Study was directly related to ethics. In terms of the technology, we are developing and we should be forging on and talking about the ethical and policy implications later. If we begin now with the ethical discussions, we will never get anywhere. The work needs to begin now.

Mike Swetnam

I will pile on that. My recent feelings on the topic of the ethical, legal, and social implications (ELSI) of technology, which I believe was a term coined by the Potomac Institute a decade ago, are that it should come after the science. After studying all of the neurotechnology options, we at the Potomac Institute thought our role was to take on the ELSI aspects of neurotechnology. To this note, we wrote, talked, and held seminars on ELSI. Between Dr. Jonathan Moreno and us, we managed to scare half of the world to death. We likely impeded funding for all of neuroscience with our efforts. I agree with you though that all really important science needs to be examined from the ELSI perspective, but that should happen the day after it is funded.

Deborah Runkle

I would like to make a couple comments. First, the term ELSI was coined twenty years ago and built into the Human Genome Project. There was a program created at the NIH that was responsible for this task and we at AAAS were collaborating on this. Also, there is a neuroethical society that meets annually prior to the neuroscience meeting, this year they will be meeting in Washington D.C. There will be an "open to the public" and free portion of this meeting at AAAS headquarters. Second, we should not see neuropsychopharmacology as a complete failure. I worked at the NIH for quite some time. We were treating patients who were essentially crippled. Now these individuals, with the help of correctly prescribed pharmaceutics, are able to return to their everyday lives. In the area of bipolar disorder and depression, the research has turned out well. Schizophrenia on the other hand is still lacking.

James Olds

For some reason, the folks writing the checks at Pfizer, Kaiser, and AstraZeneca have concluded that that side of business is no longer working. Some may say this is due to a lack of new ideas. I think this is a very important piece of data. They are publicly traded firms working to increase economic value, who do not see the area of psychopharmacology as being remunerative in profit terms. They view that as a failed side of their business and are now turning their focus to cancer, specifically the cancer-immune junction. That is a business decision, but these are holistically pretty smart individuals. It is important for scientists to have this piece of information. It tells us that something is not right with transitioning therapeutics to the public.

Jennifer Buss

I would like to mention that neurotechnology could impact so much more than the medical world. It can have so many societal impacts. We need to be focusing on that as we move forward. The discussion keeps returning to medicine as it has a lot of funding, a lot of the drive, and many examples. Now, we need to focus on how neuroscience can help society move forward.

Peggy Evans

I am not a scientist; I am a public policy official. Having worked on the Hill and at the White House doling out money, there are two ways to get focus in money. One is that you need a charismatic champion and it does not matter if your science is good or bad, old or new, or if it falls through the cracks or is blossoming. You need someone who is going to stand up and say that this is something that we have to do. In the past, we had the robber barons that pushed technologies everywhere from the national trading system to other types of more mechanical and engineering functions. We have a lot of very brilliant and rich people. We must start thinking about how to capitalize on that audience who are still interested in monetizing things; they are not entirely altruistic. Which brings us back to your point, Amy. We are not going to see a company that is not going to immediately benefit in the next quarter or next fiscal year jumping on board. It is going to be someone with a vision and very deep pockets.

Amy Kruse

I also think an important factor in all of this is public and private partnerships. This summer, I had an opportunity to work with Stand Up To Cancer, which is based out of Hollywood. There are obstacles when working with private industry or foundations; however, it can be done. Therefore, I think it is extremely important that we discuss how public and private entities can work together.

James Olds

When I look at the differences between the European and American neuroscience initiatives, the most exciting part of the American initiative is the private partnership. This is more than just sharing the financial load. It conveys that the American private sector is extraordinarily innovative, in terms of its approaches and how it operates on engineering problems, essentially using different methodologies. The marriage of the two approaches is what will actually move the needle faster. To me, that is very exciting. I am a native of California and I have been out to the Valley quite a bit recently. It is clear to me that there is a tremendous amount of interest in moving the needle in neuroscience right now from the folks in the Valley. I think the real question on their minds is how to partner with the U.S. federal investors in a way that makes the biggest difference. Neither side would be well suited to clone the other.

Sam Bockenhauer

So clearly there is a big data problem and I would like to know your thoughts on how it affects infrastructure, in regards to data sharing and storage change in the future.

Peter Littlewood

I know a half-dozen scientists who turn up at my door, asking, "What do I do with all this data?" It is already happening in labs and it just keeps growing and growing. Researchers have data and they do not know what to do with it. They do not want to use their post docs to analyze the data, they cannot afford the storage, and they do not know how to visualize it. Often, people are collecting so much data that you cannot even look at the entire data set. This is actually where I think places like the National Laboratories can really help because we have those set of skills and we have the infrastructure. These are the sorts of things that we should be contributing to neuroscience. I would like to see it modeled after the way that the big databases for the human genome and proteomics are being compiled.

James Olds

I have a concrete example. The Sandia National Laboratory has a software package for circuit design but they use super computers. This package is extremely useful in the context of cognitive neuroscience. Has it been deployed yet? No, but there is motivation on both sides to deploy it. It is important to facilitate those concrete interactions that we have been talking about.

Peter Littlewood

That point in particular is causing jurisdictional boundaries to be formed between two agencies. It's a good thing for us to do but we are not allowed to do it because we don't own a piece of this space. We look at each other across this gulf and we ask how we can help but if we cross it in the wrong way then we get into trouble and that I think that is a policy issue.

Deborah Harry

How do you fund this? We are not going to fund this on your standard NIH primary investigator model. We have a limited number of people who have the equipment to do it, which is going to limit us to this "slant of the champion" and what they are going to push. Their preferences are closely aligned with the pharmaceutical industry and addressing neurodegenerative diseases. Is it a possibility that this movement could be used as a template or a soapbox in how we achieve change in acquiring research funding?

Mike Swetnam

I think there is an answer there and it may be the wrong answer. This is a good discussion to have. There are a couple of funding models out there for interdisciplinary government-funded science. The U.S. has used several of these models very successfully. The first instance of such a model was with supercomputing and semiconductor research. This project was coordinated by the NSF and funded with several billion dollars a year spread across the DOD, DOE, and NASA. All of the important agencies with computing projects shared a piece of the pie. The role of the NSF was to ensure that the research was being done as a portfolio. This project was an example of success for twenty years. Following on its heels, Mike Roco wanted to do something called nanotechnology. It was clear from the onset that this was a multi-disciplinary project. They used exactly the same model as the supercomputing and semiconductor research to fund a $1.7 billion Nanotechnology Initiative. This money was again spread across agencies. We at the Potomac Institute are advocating that the neurotechnology initiative needs engineers, computer scientists, and biologists to work together. We believe that this is a good model to follow and that a National Neurotechnology Initiative coordinated by the NSF with money in all these different sectors would be a great success. There are many models to choose from; however, I stand behind this one, as it is what our country has been successful at in the past. One of the attributes of this type of system is that this method is inclusive. It protects both territorial issues by ensuring that work is not duplicated and that no one is stepped over through coordination.

Jennifer Buss

It is certainly helpful for the private and public partnership we discussed earlier.

Krastan Blagoev

I think that the Nanotechnology Initiative and the Neurotechnology Initiative can work together as they are very complementary.

Mike Swetnam

It is difficult to set up due to the current system of distributing money. It is a different process when the DOD and the DOE ask for money from Congress. It would require a separate report labeled a National Neurotechnology Initiative.

Deborah Harry

Earlier we looked about information about the myelin sheath, which accounts for only 7% of the brain. Is there any effort or attention devoted to collecting higher quality data rather than a higher quantity? Ultimately, the change in science will result in huge data pools that require extreme computing power. The question is whether post-docs should focus on going after hundreds of neurons or a small bundle that has a key function. Are there any efforts being taken to this aim? How are we going to use the data to inspire new technology?

James Olds

If you think back to the Human Genome Project, Craig Venter and Francis Collins had different approaches. Craig was my lab chief at the time. His approach was the shotgun sequencing notion. It seemed to sort of follow the category that the quality of the data would be at risk in exchange for more data. I believe that Moore's Law came into favor in this instance. The marriage of computing power with the notion of shotgun sequencing created a critical advantage, yet still these are very different styles of doing science. One thing that I have learned is that it is not always obvious what the appropriate approach is. In some cases it may be both approaches, but overall they are very different approaches to doing science.

Peter Littlewood

I would like to make a more general comment about advances in bioengineering and big data. At the Argonne Lab, we have a large X-ray machine that produces many more photons than other similar machines. X-ray data collection has improved by 18 orders of magnitude over the course of its history, while computers have only improved by 12 orders of magnitude in this same time frame. In each one of the many fields affected by the expansion of data, there needs to be a system in place. What we do know is that when many people experiment with similar concepts in regards to releasing their data sets, it allows them to discover large trends. Rather than having to conduct a new experiment, a postdoc can generate an idea and then go explore the existing data.

Amy Kruse

I wanted to make a comment that occurred to me as I was thinking about initiatives for nanotechnology and semiconductors. In those fields, it was an accepted track for graduate students to enter industry. Those students had the choice between entering academia or leaving and heading to a private industry. Jim just shared the disheartening news that the neuropharmacology industry is one of the very few options for those with a Ph.D. in neuroscience. The most practical outcome for me is that industry for neuroscience would become not just about the money, but also a robust world for neuroscientist to find employment. I have been thinking about multidisciplinary research and we kept running into this problem at DARPA. Money would force people to collaborate, which is a great way to get people to work with others who they would not necessarily collaborate with on their own. The system is still extremely driven by publications and tenure. It is essentially a very academic track. As I am sitting here, there is one part of this topic that we have not talked about: breaking that solely academic stronghold on neuroscience in a way that helps us push forward.

Mike Swetnam

You are very perceptive and insightful. I am old enough to remember the days where we were taught how to design circuits. I wanted to actually design the use of a transistor within a circuit. The truth is that if you wanted to design how each transistor went into a microprocessor with a hundred million transistors in it, it would take you thirty years to design that microprocessor. It took a multidisciplinary effort, where the electrical engineers were pushed aside by programmers, who said, "Show us how to design a transistor and then we can build a program that puts that on a module, which then can be depicted on the program and designed in a much smaller length of time." The multidisciplinary aspect of turning electronics into microelectronics was that the government paid for it; which was a real eye-opening endeavor. In regards to discussion about nanotechnology, Rita Colwell, the director of the NSF at the time, wanted to create a multidisciplinary system that took the science away from academia. How do you take a world-class physicist, a world-class mathematician, a world-class electrical engineering professor, and have them participate in a multidisciplinary endeavor and still get tenure in their department? Well, world class physicists are not going to get tenure in their department by working on a nanotechnology project, whose publications are not going to be in any recognized journals. So rather than funding a multidisciplinary, $100,000 coordinating center to pay each of these people, she created a $100 million center where Ph.D.'s could work together on nanotechnology. They could get their tenure there, since they could never get it in their stovepipe departments with this kind of work. Her whole goal was to create the nanotechnology profession. Neuroscience is still very academic and this shift needs to happen in this field. How it happens is not as important or more important than the money. You are in one of the most influential positions to actually determine how to spend the money on the stage of academia.

Faysal Shaikh

We talked a little bit before about dancing neurons. Is there anything that we can incorporate concepts like neuroplasticity into brain mapping?

James Olds

Here is an analogy. On your smartphone, your maps application displays the traffic on the roads ahead of you. That is a cool functionality, and even though it is probably distracting, it is a lot more convenient than using the old method of listening to the radio and waiting for ten minutes for the next traffic report to get the sense that I-66 isn't looking so good today. This is an example of a dynamic map and it is very powerful. Imagine if brain maps were actually like this. You can actually see the dynamics of the dancing neurons, if you will, overlaid and fused on the map. In a sense, that is what we are doing with functional magnetic resonance imaging. It is just that our dynamics are very blurry. However, the notion of non-invasive functional brain imaging is a powerful one. Superimposing the dynamics (glucose utilization in the case of fMRI) provides a biomarker for functional, normal activity. So the idea is great, but what is important about the map app on your smartphone is that it is at the right level of resolution so that you can dial up the interstate and see the traffic ahead of you. The problem right now in neuroscience is that our dynamics are at a very poor level of resolution in respect to the map itself, but we are working on it.

Christopher Cross

My name is Christopher Cross and I used to be an intern with the Potomac Institute. I was going to add another dimension to your earlier question, Mr. Swetnam. I think that we need to diversify not only the academic aspect but also the policy aspect. It seems to me, working here on the Hill for a different office that others recognize my knowledge in neuroscience. I inject little pockets of information on neuroscience to my coworkers wherever I can and I think that really goes a long way in advancing neuroscience as far as recognition for the topic. Anything that can get more information out there to our officials and lawmakers will help to change the way they think about neuroscience.

Krastan Blagoev

A lot of people in the rest of the biology community are nervous because the funding for such an initiative has to be taken from microcellular biology, protein structure research, and ecological projects because there is no other money coming in. The White House and Congress have determined the budget. These unfunded mandates come in, which means that you have to spend the money, but it has to come from the NSF budget. What is the solution to that problem? You are really scaring the rest of the scientific community and of course they pay us backwards so it is hard to do things when you do not have the money.

Mike Swetnam

This is a priority for you. If the research is really important, it never comes out of hide. It happens every year. This building and the one across the street put in billions of dollars more than the White House asks for and every year the White House comes up and states which initiatives they think are important. The President says to the Secretary of Defense or NSF that they need to be part of an initiative and to go take it out of hide. Congress really cares if the President tells NSF that something is important. When the members of Congress find something really important to support, they will find money and trade things off.

Peggy Evans

There is never a group of senators standing around in a hallway deciding to stand behind a cause. Doing something like this requires a charismatic individual who is in an important position to be able to turn the tide. This is not just the way Washington works. It is human nature and applies across many situations. You need to identify your champion or a group of advocates for this to work. It is not spontaneous combustion.

Mike Swetnam

If you can convince people that something is important, they will create the money. There is always a champion. In nanotechnology, it was Mike Roco and Rita Colwell that stormed the Hill and created money. In that case, there was no tradeoff for money.

Peggy Evans

If you could find multiple Congressman Fattah's or determine who his natural allies are, then it would be a beautiful process. This is not something scientists are necessary inclined to do.

Mike Swetnam

The worst thing in the world is for there to be something really important that causes something else to be traded off. When this occurs, it causes tension and creates enemies. This highlights the absolute necessity for a strong champion and an advocate that can explain the importance of this initiative.

CLOSING REMARKS

JENNIFER BUSS

I'd like to thank our speakers for taking the time today to share their views on how the time is ripe for neuroscience and technology to make a huge impact on our society. We began today on the premise that the convergence of the biologics, digital and nano revolutions have primed us for the technical advances that allow for the deep study of neuroscience and creation of neurotechnology.

Neuroscience and technology have the potential to really revolutionize the way we interact with each other and the world. We will be able to communicate differently and share our thoughts in a way that looked like magic, science fiction or telepathy but is actually connecting our brains via technology we, humans, have invented. We will be able to diagnose disease and deliver specific medication – personalized medicine that was promised from the Human Genome Project – based on the way the revolutions are converging and the availability of new neuroscience and technology. The manners in which these technologies are implemented are up to us.

We, the United States, have to take a leadership stance in insuring these technologies are created under our wings. We must invest in our future. If we don't invest in these technologies, we know our adversaries will do so without any hesitation. There are many benefits to the US being the first to "map the brain." First, well, we're first – we win! I'm kidding. Second, we gain all of the societal improvements in intelligence, business, education, and communication. Third, we create jobs and strengthen our economy. The return on investment an Initiative like this could have is 1000 to 1 by following a investment roadmap that ensures all aspects of the technology are covered as well as focusing on partnerships with industry and throughout government.

Scientists and engineers are busting at the seams to get started. They are, WE ARE antsy. Too much energy with too little focus. We need leadership and we need it now.

Leadership means choosing the direction that is best for the country, taking a stance and not wavering, standing up to the nay-sayers and believing in the future. Leadership is what we have not had in this Initiative since its announcement last February a year and a half ago, and it's time we start making moves.

We must lead with action. We ask you to enact bills so we, the scientists, can do the things we all agree we want to do. This has continuously been referred to as the President's Initiative. I implore you to take this as a Congressional Initiative, backed by the President.

So how do we do this? We need to follow an investment roadmap. We should set definitive goals and define success. How will we know when to pop champagne and celebrate? For the Space Race and the Human Genome Project, success was very straightforward. We landed on the moon, stuck a flag in the ground, and returned home safely. We sequenced the entire human genome. So what does "mapping the brain" really mean? Which aspects of the brain are we going to map?

We have so many questions – How do we think? How do our thoughts lead to action? We could go on and on…

What questions do we really want answered first? Success needs to be clearer and explicitly defined.

Additionally we all need to work together – government industry and academia- to coordinate our efforts. We should partner with the European Commission's Human Brain Project to achieve the most success.

Only then will we truly begin to watch the magic unfold, and have the artificial intelligence become real, improved human intelligence. Neuroscience will be immersed in the convergence of the revolutions.

As we pave the way forward for our country, we are out to conquer America's next frontier: the mind.

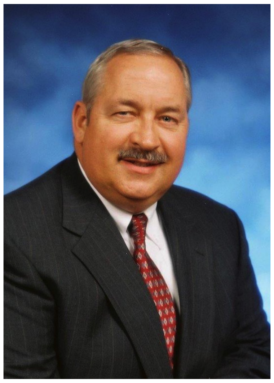
Thank you all for coming today. Thank you to the panelists for your time, and the people who made this happen. We look forward to continuing this discussion with your support.

CONGRESSMAN CHAKA FATTAH

U.S. House of Representatives

Congressman Chaka Fattah is a senior member of the House Appropriations Committee. This committee is responsible for setting spending priorities for over $1 trillion in annual discretionary funds. Congressman Fattah is Ranking Member on the Subcommittee on Commerce, Justice, Science and related agencies (CJS). The Subcommittee on CJS oversees close to $51 billion in discretionary spending including the Commerce and Justice Departments, NASA. NOAA and the National Science Foundation. Congressman Fattah is the lead Democrat responsible for funding some of the largest science agencies in the federal system, including NASA, NSF, and the Office of Science and Technology Policy. Through his position in the Appropriations Committee Fattah directed the OSTP to establish an Interagency Working Group on Neuroscience, which convenes representatives across the Federal government to make recommendations about the future of neuroscience research. The Fattah Neuroscience Initiative is a policy initiative designed to make major progress understanding the human brain by intensifying, in a collaborative fashion, federal research efforts across brain disease, disorder, injury, cognition and development. The initiative aims to coordinate Federal research across agencies and draw upon public-private partnerships and the world of academia. Fattah is also Chair of the Congressional Urban Caucus, a bipartisan group of Members representing America's metropolitan centers.

Chaka Fattah is serving in his 10th term in the U.S. House of Representatives. Before his election to United States Congress in 1994, Fattah served six years as a Representative in the State House followed by six years as a State Senator. In May of 1986, Congressman Fattah earned a Master's degree in Governmental Administration from the University of Pennsylvania, Fels Institute of Government. Fattah is the recipient of numerous honors and awards including 10 honorary doctorates and the University of Pennsylvania's Fels Institute of Government Distinguished Alumni Achievement Award. *Time Magazine* named Fattah one of the 50 most promising leaders in the country. In 1984 Fattah attended Harvard University's John F. Kennedy School of Government where he received a certificate in the Program for Senior Executives in State and Local Government.



MIKE SWETNAM

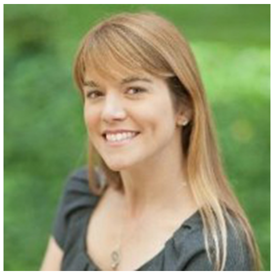
CEO and President, Potomac Institute for Policy Studies

Mike Swetnam assisted in founding the Potomac Institute for Policy Studies in 1994. The Potomac Institute for Policy Studies focuses on Science and Technology Policy. Since its inception, he has served as Chairman of the Board and currently serves as the Institute's Chief Executive Officer. He has authored and edited several books and articles including: *#CyberDoc, No Borders, No Boundries*; *Al-Qa'ida: Ten Years After 9/11 and Beyond*; *Cyber Terrorism and Information Warfare*, a four volume set he co-edited; *Usama bin Laden's al-Qaida: Profile of a Terrorist Network*; *ETA: Profile of a Terrorist Group*; and *Best Available Science: Its Evolution, Taxonomy, and Application*. Mr. Swetnam is currently a member of the Technical Advisory Group to the United States Senate Select Committee on Intelligence. In this capacity, he provides expert advice to the U.S. Senate on the R&D investment strategy of the U.S. Intelligence Community. He also served on the Defense Science Board (DSB) Task Force on Counterterrorism and the Task Force on Intelligence Support to the War on Terrorism. From 1990 to 1992, Mr. Swetnam served as a Special Consultant to President Bush's Foreign Intelligence Advisory Board (PFIAB) where he provided expert advice on Intelligence Community issues including budget, community architecture, and major programs. He also assisted in authoring the Board's assessment of Intelligence Community support to Desert Storm/Shield. He has served in several public and community positions including Northern United Kingdom Scout Master (1984-85); Chairman, Term limits Referendum Committee (1992-93); President (1993) of the Montgomery County Corporate Volunteer Council, Montgomery County Corporate Partnership for Managerial Excellence (1993); and the Maryland Business Roundtable (1993).

JAMES L. OLDS, Ph.D.

Director and Chief Academic Unit Officer at George Mason University's Krasnow Institute for Advanced Study

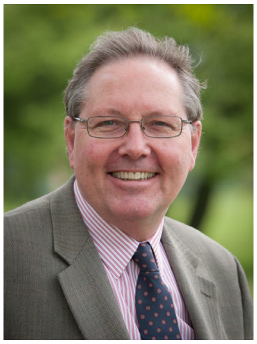
James Olds, Ph.D. is the Director and Chief Academic Unit Officer at George Mason University's Krasnow Institute for Advanced Study. He is concurrently the Shelley Krasnow University Professor of Molecular Neuroscience. The current White House BRAIN Initiative has its origins in the international Decade of the Mind project that began at the Krasnow Institute. Dr. Olds serves on numerous private and public boards ranging from the Commonwealth of Virginia and the White House to advising heads of ministries internationally. He spent eight years as chair of Sandia National Laboratory's External Cognitive Science Board. Dr. Olds has been treasurer of Americans for Medical Progress and he has also served as a Virginia State Commissioner. Prior to taking the leadership role at the Krasnow Institute, Dr. Olds was the CEO of the American Association of Anatomists. Dr. Olds received his undergraduate degree from Amherst College in chemistry and his doctorate from the University of Michigan, Ann Arbor in neuroscience. His postdoctoral research at the National Institutes of Health led to fundamental advances in understanding the molecular basis of learning and memory, for which he was awarded the NIH Merit Award in 1993.



AMY KRUSE, PH.D.

Vice President of Innovation, Intific

Amy Kruse, Ph.D. joined Intific in January 2010 as an Executive Director, forming their new Neuroscience Division. She has recently led Intific in the release of their first commercial product, the RealWorld with NeuroBridge software platform. She also directs active Intific programs with the Office of Naval Research (Team Neurogaming), DARPA (ENGAGE, NowTu, Narrative Networks, DCAPS, SMISC), and the intelligence community. Dr. Kruse has more than 10 years of experience developing novel neuroscience-based programs and technologies for the Department of Defense. From January 2005 to January 2010, she served as a government civilian Program Manager in the Defense Sciences Office at the DARPA in Arlington, VA. During her tenure at DARPA, Dr. Kruse managed more than nine programs including efforts in Augmented Cognition, Neurotechnology for Intelligence Analysts, Accelerated Learning, and Cognitive Technology Threat Warning Systems among others. Prior to DARPA, Dr. Kruse served as a technology and program management consultant at Strategic Analysis Inc. in Arlington, VA. During her time with SAINC, she provided hands-on technical assistance to nascent neuroscience programs at DARPA, the Office of Naval Research, and the Naval Research labs. She has been actively involved in neuroscience research for over 15 years. Dr. Kruse earned her B.S. in cell and structural biology (1995) and her Ph.D. in neuroscience (2001) from the University of Illinois at Champaign-Urbana where she was awarded a National Science Foundation Graduate Fellowship in Neuroscience.



PETER B. LITTLEWOOD, Ph.D.

Director of Argonne National Laboratory

Peter B. Littlewood, Ph.D. is the Director of Argonne National Laboratory, one of the nation's largest science and engineering research centers, and a Professor of Physics in the James Franck Institute at the University of Chicago. Dr. Littlewood came to Argonne in 2011 after being appointed Associate Laboratory Director of Argonne's Physical Sciences and Engineering directorate, which focuses on discovery science across a broad range of disciplines, and on creating and understanding new materials and chemistries that address the grand challenges in energy and the environment. Before that, he spent 14 years at the University of Cambridge in the United Kingdom, where he last served as the head of the Cavendish Laboratory and the Department of Physics. Dr. Littlewood started his career at Bell Laboratories, beginning in 1980 as a postdoctoral member of the technical staff; by 1992, he had worked his way up to head of Theoretical Physics Research. Dr. Littlewood is an internationally respected scientist who holds six patents, has published more than 200 articles in scientific journals and has given more than 200 invited talks at international conferences, universities and laboratories. He is a fellow of the Royal Society of London, the Institute of Physics and the American Physical Society, and is an associate member of The World Academy of Sciences. Dr. Littlewood holds a bachelor's degree in Natural Sciences (Physics) and a Ph.D. in Physics, both from the University of Cambridge.

JENNIFER BUSS, Ph.D.

Research Fellow, Director of Center for Neurotechnology Studies at the Potomac Institute for Policy Studies

Jennifer Buss, Ph.D. is a Research Fellow at the Potomac Institute for Policy Studies. She is a member of the CEO's office and provides the scientific background for the think tank within the Potomac Institute, where she has been for two years. She is the Director of the Center for Neurotechnology Studies (CNS) at the Potomac Institute, having special interests in topics such as music and the brain as well as creativity and cognition. As Director of the CNS, she leads a team studying issues in neuroscience technology and policy and has been instrumental in organizing the Neuroscience Symposia Series 2014. Dr. Buss is a Fellow in the Center for Revolutionary Scientific Thought, a group at Potomac Institute that brings together individuals from a variety of backgrounds to foster discussion on science and technology futures from both an academic and policy perspective. In addition to these efforts, she has supported contracts for DMEA, OSD, and the Office of Corrosion Policy and Oversight. She is the Program Manager for the Rapid Reaction Technology Office contract for OSD in searching for innovative technologies to enhance government systems.

Dr. Jennifer Buss was awarded a doctorate in biochemistry from the University of Maryland Department of Chemistry and Biochemistry in 2012. Her dissertation was on iodide salvage in the thyroid and the evolution of halogen conservation in lower organisms. She performed graduate research in the areas of enzymology, bioinformatics, molecular and structural biology. Dr. Buss received her B.S. in biochemistry with a minor in mathematics from the University of Delaware. She is a member of the American Chemical Society, the American Association for the Advancement of Science and the American Society for Biochemistry and Molecular Biology.

BRIAN BARNETT

Research Assistant, Potomac Institute for Policy Studies

Brian Barnett is a Research Assistant at the Potomac Institute for Policy Studies. He performs research and coordinates initiatives within the Center for Neurotechnology Studies. Brian obtained his B.S. in Neurobiology and Physiology at the University of Maryland, College Park, where he participated in the Gemstone research program and the Global Semester program. At the university, he worked in Dr. Matthew Roesch's behavioral neuroscience laboratory. Brian completed a thesis that investigated the behavioral and neural components of an animal model of ADHD. He also contributed to publications on the valuation and representation of reward within the rat fronto-striatal circuit.

KATHY GOODSON, Ph.D.

Research Associate, Potomac Institute for Policy Studies

Kathy Goodson, Ph.D. is a Research Associate in the CEO's Office at Potomac Institute for Policy Studies. Dr. Kathy Goodson joined the Potomac as a CReST Fellow in 2014 in the Center for Revolutionary Scientific Thought. As a Research Associate she leads outreach and communications components of a joint Potomac Institute and Office of Corrosion Policy and Oversight effort. Dr. Goodson was awarded a doctorate in biochemistry from the University of Maryland Department of Chemistry and Biochemistry in 2012. Her dissertation research focused on spectroscopic determination of protein-DNA complex conformations using organic dye molecules. Her areas of graduate research study included biochemistry, physical chemistry, biophysical chemistry, and molecular biology. Dr. Goodson received her B.S. in Chemistry from Virginia State University. She is a member of the American Chemical Society and the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChE).

CHARLES W. MUELLER, Ph.D.

Research Associate, Potomac Institute for Policy Studies

Charles Mueller, Ph.D. recently joined the Potomac Institute for Policy Studies (PIPS) as Research Associate in the CEO's office and a Fellow at the Center for Revolutionary and Scientific Thought (CReST). He is currently working with Dr. Alan Moghissi and Mike Swetnam in establishing a Regulatory Science and Engineering Center (RSEC) through PIPS. He obtained his doctorate in biochemistry from the University of Maryland's Chemistry and Biochemistry department in 2014. His dissertation involved the characterization of two putative DNA metabolizing enzymes in the bacterium *Deinococcus radiodurans* and required a combination of molecular biology, cell biology, microscopy, and biochemical analyses. He obtained a B.A. in chemistry from Elon University and then worked at the National Cancer Institute at the National Institutes of Health studying the effects of selenium on cancer using both live mouse models and tissue cultures prior to his graduate work.

AMERICA'S NEXT FRONTIER: CONQUERING THE MIND SYMPOSIUM REPORT

On September 24th, 2014 the Potomac Institute for Policy Studies held a seminar on Capitol Hill titled "America's Next Frontier: Conquering the Mind". This seminar featured remarks from Congressman Chaka Fattah, Dr. James Olds, Dr. Amy Kruse, Dr. Peter Littlewood, and representatives from the Potomac Institute. The panelists discussed the need for a National Neurotechnology Initiative, a comprehensive effort to understand the human brain. To succeed, this initiative requires well-defined project objectives, strong leadership, and unprecedented levels of interdisciplinary collaboration. The discussion focused on the key technologies and collaborations between fields that will enable our scientists to map the multitude of connections between neurons in the brain, interpret how the brain encodes information within these connections, in order to ultimately uncover the biological bases of behavior. We must build on the successes of previous science initiatives and capitalize on the revolutionary technologies that they created to enable neuroscience to become a powerful driver for all aspects of society.

SYMPOSIUM SPONSORS

The Potomac Institute for Policy Studies is an independent, 501(c)(3), not-for-profit public policy research institute. The Institute identifies and aggressively shepherds discussion on key science, technology, and national security issues facing our society. The Institute hosts academic centers to study related policy issues through research, discussions, and forums. From these discussions and forums, we develop meaningful policy options and ensure their implementation at the intersection of business and government. The Institute remains fiercely objective, owning no special allegiance to any single political party or private concern. With over nearly two decades of work on science and technology policy issues, the Potomac Institute has remained a leader in providing meaningful policy options for science and technology, national security, defense initiatives, and S&T forecasting.

Center for Neurotechnology Studies (CNS) provides neutral, in-depth analysis of matters at the intersection of neuroscience and technology—neurotechnology—and public policy. The Center anticipates ethical, legal, and social issues (ELSI) associated with emerging neurotechnology, and shepherds constructive discourse on these issues. The Center partners with the research community for discourse and consultation on ethically sound neurotechnology research and applications. CNS serves as authoritative counsel to government agencies pursuing neurotechnology by providing expertise in the sciences, law and social policy through discussion on the implications of neurotechnology in academic, administrative, entrepreneurial, regulatory, legislative and judicial enterprises.