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Surprising Prevalence of Electroencephalogram Brain–Computer Interface to Internet of Things

By Narisa N.Y. Chu

Three hackathons were sponsored by the IEEE Brain Initiative in the fall of 2016:

- U.S. West Coast, held in San Diego, California, 10–11 September 2016
- U.S. East Coast, held in Philadelphia, Pennsylvania, 23–25 September 2016
- Europe, held in Budapest, Hungary, 8–9 October 2016.

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Each Hackathon demonstrated its creativity, often combining multiple senses (muscle, vision, and heartbeats) beyond simply the brain and group interactions over single, personal brain detection. Results and lessons learned are summarized in this article. Winning projects reached beyond health-care aids toward creative group learning and various entertainment and social game applications. Extensions to serve popular disease treatment, including epilepsy and attention deficit disorder (ADD), were attempted, exceptionally linking to brain signals. Culture, age, and the gender of user brain signal data were collected and evaluated. Guides to safe driving based on brain-signal-triggered alerts were also explored for future adaptation of the brain computational technology.

WHAT ARE THESE HACKATHONS?

During the first workshop of the IEEE Brain Initiative held at Columbia University in December 2015, I proposed holding EEG Brain Signal Hackathons as an activity leading to education,

The awards jury team.

The first-place winners from the University of California, San Diego.


An EMG demonstration at Temple University, Philadelphia, Pennsylvania.

standardization, and encouragement for the development of consumer applications based on nascent technology borne from electronics, neuroscience, and medicine. This proposal was primarily triggered by the advent of various electroencephalogram (EEG) headsets made available for consumer use in the last eight years. A hackathon committee was formed, with efforts to organize such competitions in a friendly environment on the east and west coasts of the United States, in San Diego, California, and Philadelphia, Pennsylvania, respectively, and joined by the Brain Workshop anchored on the IEEE Systems, Man, and Cybernetics (SMC) Society annual conference in Budapest, Hungary. Three spectacular hackathons took place in series between 9 September and 9 October 2016.

THE EEG BRAIN–COMPUTER INTERFACE HACKATHON

The EEG is a signal extracted from the brain in an invasive or noninvasive manner from a person's head. It has been used to diagnose brain injury and lately to aid in rehabilitation and personal brain development extending from the severely sick to the general population. To obtain an EEG signal electronically, sensors are placed both inside and outside of the human scalp with varying degrees of accuracy and performance depending on the goals. The IEEE Hackathon group is focused on the noninvasive placement of brain sensors, i.e., without any surgery on the human head and with wearable devices. The goals are to explore brain signal data through multimodal connectivity into brain communication across the Internet, a significant challenge, but the potential is on the horizon. The scope is open to imagining applications and moving beyond the limitations of current technology.

The brain–computer interface (BCI) has been under development for decades. The brain–machine interface (BMI) has been investigated to a greater extent in robotic and medical research, less so in direct consumer application. As processors have advanced in terms of a remarkably high-performance/cost ratio, BCI for popular use outside of the capital-intensive medical environment has made huge strides to arrive within consumers' reach in the last decade. Similar fundamental challenges about multidisciplinary collaboration involving electronics, mechanics, and neurosciences have also been forged, taking advantage of BCI and BMI.

The hackathons stimulated brainstorming and collaborative development to rapidly produce illustratable prototypes. These three IEEE Hackathons brought scientists, engineers, developers, technologists, and sociologists as well as entrepreneurs together for over 24 h into a cramped space to build any solutions that could be demonstrated on the spot.

Each hackathon was identified with a certain theme advocated by local leaders. For example, the San Diego Hackathon called out multiple biosignal and connected devices affected by the brain with the attempt of database sharing through the Internet cloud. The Philadelphia Hackathon stretched the limitation of the EEG signal by exploring more of the muscle signal, which is believed to be directed by interaction with the brain signal. The Budapest Hackathon emphasized vision impact on the brain as well as demographical differences, in addition to the scenarios experimented in San Diego and Philadelphia. Photos and videos are available at the following links:

- *overall*: http://brain.ieee.org/news/ieee-brain-initiative-sponsor-3-hackathons-fall/
- *San Diego, California*: https://www.facebook.com/augmentedbrain/
- *Philadelphia*: http://www.tubrainhack.com/projects/
- *Budapest*: https://drive.google.com/drive/u/0/folders/0B-uAZDFh31LTbHB2ck9Fcm5vLTA.

THE ENVIRONMENT

The objectives of the hackathons were to learn and develop

- state-of-the-art brain technology platforms
- EEG interactions with other biosignals, e.g., ECG, EMG, and electrooculography (EOG)
- BCI, including those incorporating virtual reality (VR)/augmented reality (AR)
- creative applications.

The hardware choices and the actual usage are listed in Table 1. The software choices are identified in Table 2. Table 3 reveals the overall characteristics and certain statistics of these three BCI hackathons.

The first-place team on an eMotiv BCI-controlled robotic arm (shown barely at the extreme center right).

The use of inMEx collecting EEG photoplethysmogram combined data.

The use of an OpenBCI headset.

Table 1. The brain headset hardware used in hackathons.

Hardware Choices	San Diego	Philadelphia	Budapest
EEG			
Brain Rhythm Inc. [BR8+ (eight channels)]	✓		✓
Cognionics [Quick-20 Mobile (21 channels)]	✓		✓
Emotiv [Epoch (14 channels), Insight (five channels)]	✓	✓	✓
InteraXon [Muse (four channels)]	✓	✓	✓
NCU (inMEx—EEG six inputs, eight channels total)	✓		✓
Neuroelectrics [Enobio (21 channels)]	✓		
NeuroSky [MindWave Mobile (one channel)]	✓		✓
OpenBCI [Ultracortex (eight channels)]	✓	✓	✓
Wearable Sensing [DS-24 (seven, 21 channels)]	✓		
EMG and ECG			
NCU (inMEx—EEG, EMG, and ECG, eight channels)	✓		✓
Thalmic Myo (EMG)		✓	
Vision			
Level glasses			✓
VR			
Oculus Rift			✓
HTC Vive			✓

Table 2. Software tools for BCI and augmented/VR.

Software Choices	San Diego	Philadelphia	Budapest
Android	✓	✓	✓
AWS Managed Services	✓	✓	✓
BCILAB (Matlab)	✓	✓	✓
Google Cloud Platform (GCP)	✓	✓	✓
HTC Vive StreamVR SDK	✓	✓	✓
iOS	✓	✓	✓
Lab Streaming Layer (Multiplatform)	✓		✓
NeuroPype CE (Python)	✓		✓
NeuroScale Cloud BCI Platform (Multiplatform)	✓		✓
Oculus SDK	✓	✓	✓
Unity	✓	✓	✓
Vizzario SDEP (Python, Java)			✓

SAN DIEGO

The San Diego Hackathon started off first, with projects designed to treat EEG headsets as Internet of Things, extracting, but not limited to, the EEG signal technology, encouraging applications to link multimodal biosignals, and exploring VR and emotional reflection for commercial utilization in the Internet and cloud environment. Are these attempts total fantasy without realizing how noisy the brain signal can be? Stimulated by inspirational and entrepreneurial talks from experts, hackers had high hopes that solutions could be reached with interdisciplinary tools.

Winning projects are identified in the "Results and Lessons Learned" section. Other projects experimented include

- Android apps
- BCI placement optimization

Table 3. BCI Hackathons at a glance.

	San Diego	Philadelphia	Budapest	Summary
Dates (2016)	10–11 Sept.	23–25 Sept.	8–9 Oct.	
Characteristic	First	Student-centric	Biggest	
Number of teams	15	7	29	51
Total attendance	71	34	180	285
Making final presentations	12	7	23	42
Number of hackers	52	30	153	235
Number of student hackers	36	30	82	148
Number of faculty hackers	3	0	23	26
Number of industry/business/government	13	0	48	61
Number of organizing and supporting staff, spectators	19	4	27	50
Countries represented	5	1	22	
Percent of student hackers	69%	100%	54%	
Percent of other academic participants	6%	0%	15%	
Percent of industry participants	25%	0%	31%	

- control media player using motor imagery BCI
- device control and communication
- EEG controlling phone
- EEG controlling of electric car steering wheel
- EEG versus mood
- record EEG data for motor intent
- scalability
- steady-state visually evoked potential musical interface
- sustainable attention
- VR
- web apps powered by BCI.

The hungry, tired, and those in VR at midnight, 9 October 2016.

PHILADELPHIA

The event in Philadelphia was well attended by people from campuses along the east coast of the United States, such as Temple University in Philadelphia, the University of Pennsylvania in Philadelphia, and Columbia University in New York City. Seven teams and 30 student participants worked on a variety of projects: control of video games with thoughts and electromyography (EMG) signals, robotic cars, and a quadcopter drone, and one team focused on biometric authentication. In terms of equipment, every team received one Emotiv Insight and two Backyard Brains Muscle SpikerShield boxes. In addition, two teams received 16-channel OpenBCI systems, and two teams worked with eight-channel OpenBCI systems. There was a significant challenge in getting raw and meaningful streaming data from the neural headsets (suspecting constraint for commercial purposes). One could easily spend the whole hackathon period getting data to stream from OpenBCI into Python. Most teams tried to use some mixture of brain and muscle controls in the interfaces. The frustration with the EEG systems were somewhat offset with the supplemental EMG boxes, which provided visible data and more touch-and-feel effect.

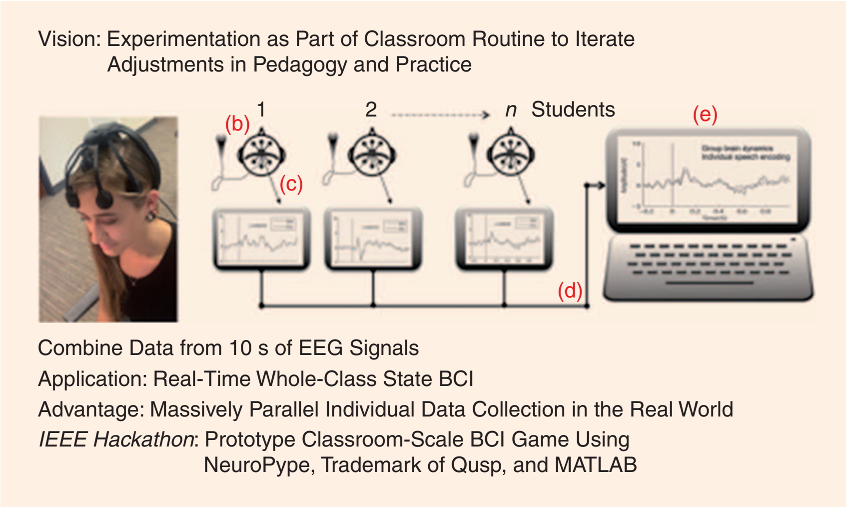

FIGURE 1. The Group Brain Dynamics in Learning Network project at the San Diego Hackathon.

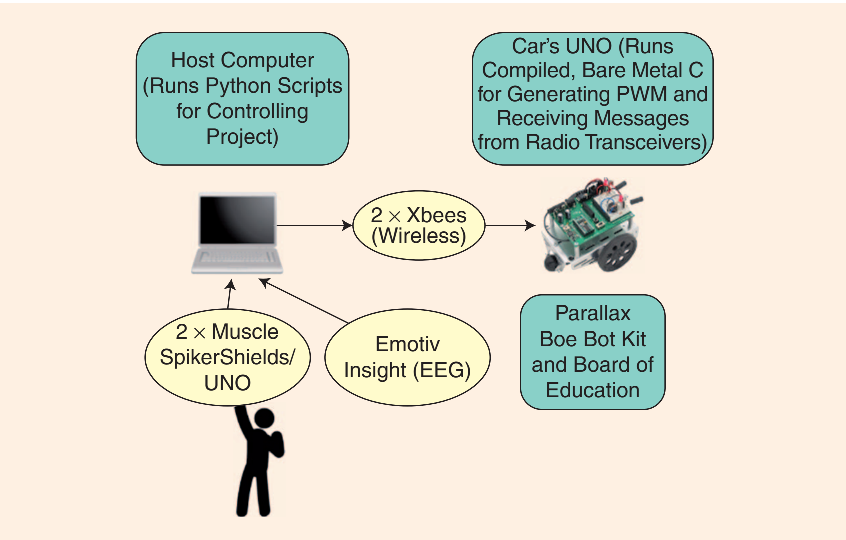

FIGURE 2. The design flow of the EMG/EEG Controlled RC Car project in Philadelphia.

BUDAPEST

The Budapest Hackathon marked the biggest event in the IEEE landscape this year. Creative, earnest, and sophisticated academic and industry participants concentrated on brain-related signaling applications with highlighted impact due to vision. The experience gained from the last two hackathons was well utilized, and the colocation with the SMC annual conference forged an intensive level of technical applications in areas of neuro-disease treatments, autocontrol, games, and lifestyle gimmicks. Participation was also motivated by the most prizes offered to the dynamic, showy teams. There was also cross-continental team participation, with team members working across an 11-h time-zone difference.

Winning team projects are identified in the "Results and Lessons Learned" section. Other projects included

- mind your own sound
- last-attempt command line interface
- push-up apps game
- portable and robust virtual keyboard for patients and disabled people
- thought-controlled educational software for children with special needs using gamification
- driver alert
- mind movies—visualization tools
- cloud analysis of EEG/electrocardiogram (ECG) for mood detection: like/dislike
- ImPaint, to let impaired people create
- brain-tac-toe
- brain alarm
- attention attack.

RESULTS AND LESSONS LEARNED

WINNERS OF THE 2016 SAN DIEGO HACKATHON

- First-place prize of US$1,000 went to Team Goblin. Project title: Group Brain Dynamics in Learning Network. The project is highlighted in Figure 1. Team Goblin consisted of three members: John Iversen, University of California, San Diego (UCSD); Alex Khalil, UCSD; and Joseph Heng, UCSD
- Second-place prize US$500. Project title: The Match Maker—Can We Solve This with BCI? Individual Hacker: Ruggero Scorcioni of Brainyno Inc., San Diego, California
- Third-place prize US$300. Project title: EEG Monitoring of "Focus." Team Better Living Through Brain–Computer Interfaces consisted of Larry Muhlstein, UCSD; John Berkowitz, UCSD; Gabriel Ibagon, UCSD; and Alex Rosengarten, Intuit, San Diego, California
- Fourth place: honorary mention certificate. Project title: Cloud Analysis of Frontal EEG for Online "Like/Dislike" Detections. Team NCUEE consisted of Po-Lei Lee, National Central University (NCU), Taoyuan City, Taiwan; Kuo-Kai Shyu, NCU; Hao-Teng Hsu, NCU; Te-Min Lee, NCU; and Wei-Yang Chiu, National Dong Hwa University, Hualien County, Taiwan.

WINNERS OF THE 2016 PHILADELPHIA HACKATHON

- First-place prize of US$1,000 went to Team GetRekt. Project title: EMG/EEG Controlled RC Car. The project is described in Figure 2. Team GetRekt consisted of Andrew Powell, Temple University (TU), Philadelphia; James Kollmer, TU; Robert Irwin, TU; and Christian Ward, TU
- Second-place prize of US$500 went to Team UPenn from the University of Pennsylvania, Philadelphia. Project title: Robot State Control with Muscle Commands

- Third-place prize of US$300 went to Team Bae-ta Waves for the project BCI-NES. The team consisted of Derek Netto, Columbia University (CU), New York City; Uma Mohan, CU; Ankeet Parikh, CU; and Salman Qasim, CU.

WINNERS OF THE 2016 BUDAPEST HACKATHON

There are multiple prizes, with a total of US$8,000 offered including Vizzario and Vision Service Plan, Vision Care Company prizes, two first places (tied) and one third place.

- First-place (tied) prize of US$2,000 went to Team Namanjini Sinovi and Team BraiNerds. Project title: Zapier. The project is depicted in Figure 3. Team Nemanjini Sinovi (all from industry) consisted of Nemanja Stančić (New and Rising, Belgrade, Serbia), Aleksandar Stančić (New and Rising), Miloš Kresović (New and Rising), Aleksandar Slijepčević (Jarovid, Serbia, and Mladen Trišić (Jarovid, Serbia)
- First-place (tied) prize US$2,000. Project title: BCI-Controlled Robotic Arm. The project is illustrated in Figure 4. Team BraiNerds consisted of Gergely Marton, Research Centre for Natural Sciences, Hungarian Academy of Sciences, Budapest; Nora Nyirfas, Budapest University of Technology and Economics, Hungary; Andras Bohn, Budapest University of Technology and Economics; Janos Csipor, Budapest University of Technology and Economics; and Andrea Domotor, Pazmany Peter Catholic University, Budapest, Hungary.

Because there was a tie for first place, the second-place award was omitted.

- Third-place prize US$1,000. Project title: SlideHill. Team Default Company consisted of Gregor Weiss, University of Ljubljana, Slovenia; Amela Rakanović, University of Ljubljana; Katja Perme, IEEE Student Branch, University of Ljubljana.

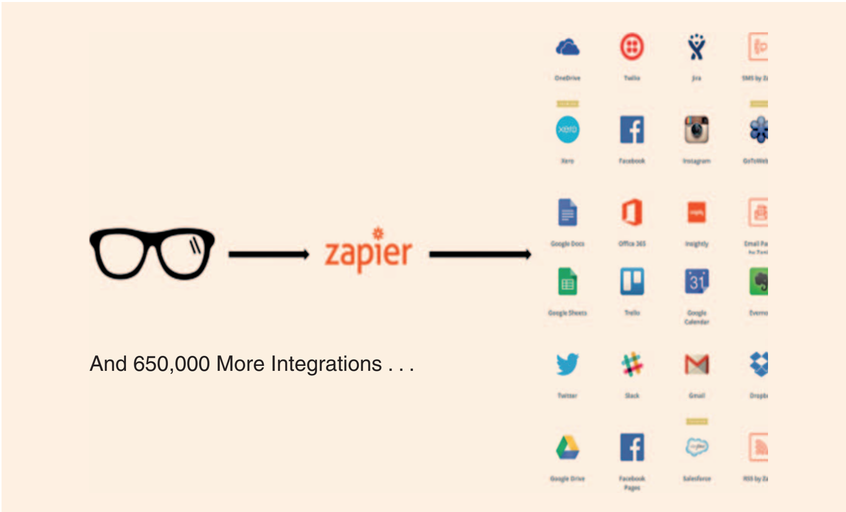

FIGURE 3. The vast integration options by Zapier utilizing Level glasses.

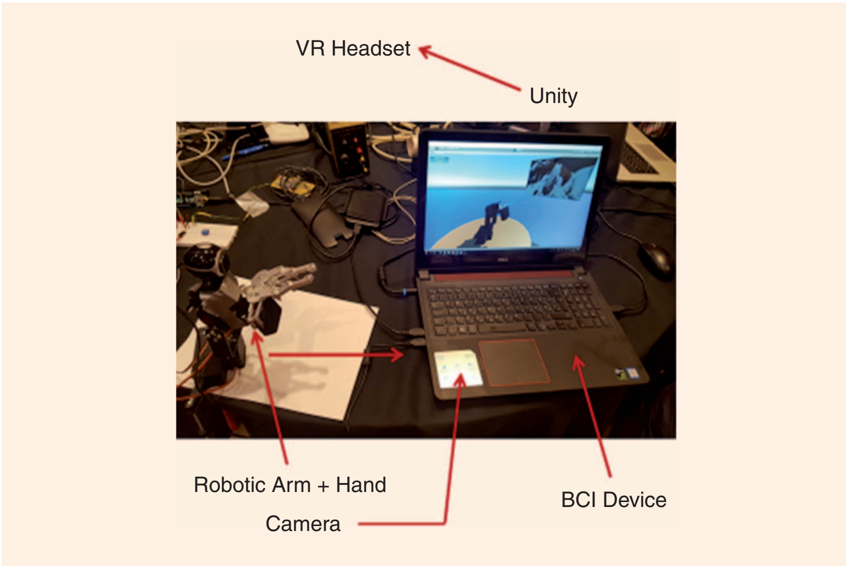

FIGURE 4. A display of hardware and software to make a BCI-controlled robotic arm.

ADDITIONAL HACKATHONS

IEEE BRAIN INITIATIVE BRAIN HACKATHON PRIZE

- First-place prize of US$1,000 went to Team Neurofeedback Loop. Project title: Neurofeedback Loop. Team Neurofeedback Loop consisted of Aleš Breznik, IEEE Student Branch, University of Maribor, Slovenia; Stuart M. Dambrot, interdisciplinary researcher; Irene Vigue Guix, IEEE; Katja Rutnik, IEEE Student Branch, University of Maribor; Martin Krauser, IEEE Student Branch, University of Maribor; and Ras Milutinovic, IEEE Student Branch, University of Maribor.

IEEE SMC BRAIN HACKATHON PRIZE

- First-place prize of US$1,000 went to Team BraiNerds. Project title: BCI-Controlled Robotic Arm. Team BraiNerds consisted of Gergely Marton, Research Centre for Natural Sciences, Hungarian Academy of Sciences, Budapest; Nora Nyirfas, Budapest University of Technology and Economics, Hungary; Andras Bohn, Budapest University of Technology and Economics; Janos Csipor, Budapest University of Technology and Economics; and Andrea Domotor, Pazmany Peter Catholic University, Budapest, Hungary.

QUSP BRAIN HACKATHON PRIZE

- First-place prize of US$1,000 went to Team Artificial Neurons for their

Table 4. Summary characteristics of IEEE BCI Hackathons in 2016.

	San Diego	Philadelphia	Budapest	Remarks
Signals				
ECG	✓		✓	More visible than EEG
EEG	✓	✓	✓	Hard to extract
EMG		✓	✓	Focused in Philadelphia
EOG	✓		✓	Demonstrated in Budapest
AR/VR	✓		✓	
IoT	✓		✓	Headsets becoming IoT
Cloud access	✓		✓	Via NeuroPype, NeuroScale
On-site tutorial	✓			By Tim Mullen and Christian Kothe, Qusp, San Diego, California
Inspirational talks	✓			By Todd Coleman, UCSD, and Jordan Greenhall, DivX, San Diego, California
Applications				
ADD			✓	
Handicapped	✓		✓	
Epilepsy			✓	
Rehabilitation	✓		✓	
Wellness training			✓	
Games	✓	✓	✓	
Music	✓		✓	
Painting			✓	
Movies			✓	
Car control	✓	✓	✓	
Robotic control	✓	✓	✓	
Demographics				
Age spread	15–72	20–35	18–70	
Number of students	36	30	82	
Number of faculty	3	0	23	
Number of industry professionals	13	0	48	
Cross-continental team			✓	

project using NeuroScale to explore cloud access of EEG data. Team Artificial Neurons (all from industry) consisted of Tamas Nagy, Synetiq, Budapest, Hungary; Daniel Palma, Synetiq; Norbert Majubu, Swiss Federal Institute of Technology in Lausanne; Balazs Jager, Nokia, Budapest, Hungary; and Agoston Török, Synetiq.

DEPTH AND BREADTH

The IEEE Brain Initiative has conducted three BCI hackathons with a total participation of nearly 300 motivated parties and 20 manufacturers and institutions that supplied open and closed BCI headset systems. It marks the first such intensive development with a multidisciplinary approach for fast prototyping to learn and scrutinize BCI tools of professional as well as consumer grades.

EEG signal extracting is a challenging effort. EEG working in conjunction with other biosignals can be more measureable than EEG alone, as it alone presents too meager a signal to derive any meaningful value. EEG is used in diagnosing neuro abnormality and for brain injury rehabilitation, but entertainment, education, and marketing applications abound. Significantly novel use has resulted in potential disruptive technologies making use of EEG.

Games and video triggered by brain signals are intriguing. Training in neuroscience is recognized as the next job skill in high demand. Interoperable brain data in cloud computing is open for widespread brain pattern storage and recognition. These traits have manifested in the three Hackathons with more awareness than in conventional practice.

In summary, Table 4 describes the depth and the breadth of tools and applications that can be done with the BCI. Although proprietary interfaces are still the dominant implementation, potentially standard interfaces exist in OpenBCI, inMEx, NeuroPype, and NeuroScale, if not more development down the line.

ABOUT THE AUTHOR

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Interoperable Nanoscale Communication

By Stephen F. Bush

Nanoscale communication fills a gap, namely, ad hoc communication among entities whose length scale is on the order of nanometers. These entities may be entirely synthetic, but in practice they have more often involved machine communication with small-scale biological entities, namely, subcellular components. Communication directly with and through neurons is a prime example. However, prior to the IEEE 1906.1-2015 standard, there was no clear and consistent definition of nanoscale communication because it encompasses a broad set of disciplines nor were the research results interoperable or even directly usable by others to build upon. The IEEE 1906.1-2015 standard has helped to alleviate this problem by defining a conceptual model, practical framework, and common metrics that allow industry and research to speak a common language and to develop interoperable simulations and hardware components without constraining innovation or creativity. The developers of the standard realize that this is an emerging technology and that new ideas and inventions that leverage change in length scale for communication have yet to be developed.

This article originally appeared in *IEEE Transactions on Molecular, Biological, and Multi-Scale Communications*, vol.1, no. 1, March 2015.

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I was invited by Dr. Narisa Chu, a Governor of the IEEE Consumer Electronics (CE) Society Board and a primary contributor to *IEEE Consumer Electronics Magazine*'s "Standards" column, to include a reprint of the article that follows. Narisa Chu and I are Society representatives in the IEEE Brain Initiative, a newly inaugurated multidisciplinary domain under the charter of IEEE Future Directions. I was invited by Dr. Chu to elaborate upon nanoscale communications in *IEEE CE Magazine* "Standards" column because the technology described in IEEE P1906.1 is fundamental to neuro-technology applications impacting consumers and communications that are happening in health care, education, and entertainment in disruptive forms to the realization of Internet of Things and fifth-generation (5G) evolutions.

The title of the reprinted article is derived from Richard Feynman's 1959 talk "There's Plenty of Room at the Bottom." As I've stated in other opinion pieces, I believe that, within this vast ocean, at the bottom there will be a requirement for communication. Medicine and quantum physics continue to discover new forms of communication in nature that have yet to be efficiently harnessed. These ideas are discussed in more detail in S.F. Bush, *Nanoscale Communication Networks* (Norwood, MA: Artech House, MA, 2010), which is the classic text on the topic (https://www.amazon.com/Nanoscale-Communication-Networks-Science-Engineering/dp/1608070034).

The following reprint is an efficient way to obtain a quick grasp of the IEEE 1906.1-2015 standard. However, it's always important to caution the reader that the actual standard contains much more detail than is covered in this reprint and not to attempt to use this reprint in place of the actual standard.

There are many ways to learn more about nanoscale communication, leverage it for your company, and participate in its development. First, a "Best Readings in Nanoscale Communication Networks" (http://www.comsoc.org/best-readings/nanoscale-communication-networks) is freely available for those