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In this Issue:

Apple Acquisition of UC San Diego Startup Paves Way for Further Robotics Research

Two years ago a team of six Ph.D. scientists at the University of California, San Diego decided to commercialize their artificial-intelligence (AI) technology for reading emotions based on facial recognition and analysis. They launched the startup, San Diego-based Emotient, Inc., which grew to more than 50 employees as of the end of 2015.

Now, the Wall Street Journal reports that Apple, Inc. has confirmed its purchase of Emotient for an undisclosed price. As part of the deal, Emotient's three co-founders from UC San Diego – Javier Movellan, Marian Stewart Bartlett and Gwen Littlewort – agreed to leave the university to join Apple in Cupertino, Calif., along with at least four former UC San Diego students who are currently employed by Emotient. January 11th was the team's first as Apple employees.

The Emotient leadership team will also leave behind the research group they created: the Machine Perception Laboratory, now based in the Qualcomm Institute, which is the UCSD division of the California Institute for Telecommunications and Information Technology (Calit2). Movellan, Bartlett and Littlewort will also step down as researchers affiliated with the university's Institute for Neural Computation (INC).

According to Qualcomm Institute Director Ramesh Rao, Movellan and his colleagues will leave behind a research lab developed over the past decade, as well as a state-of-the-art robot named Diego-san (a fully-built robot originally designed to approximate the intelligence of a one-year-old human).

"The Qualcomm Institute will take advantage of past involvement with the Machine Perception Lab and will reconfigure the facility to expand use of Diego-san research as a testbed for developing new software and hardware for more specialized robotic systems," said QI's Rao. "We are exploring ways to showcase the Diego-san robot while also leveraging the lab for faculty and staff researchers to develop other types of robotic systems to serve a variety of purposes and environments."

MPLab and Emotient co-founder Javier Movellan joined Apple. Credit: UC San Diego

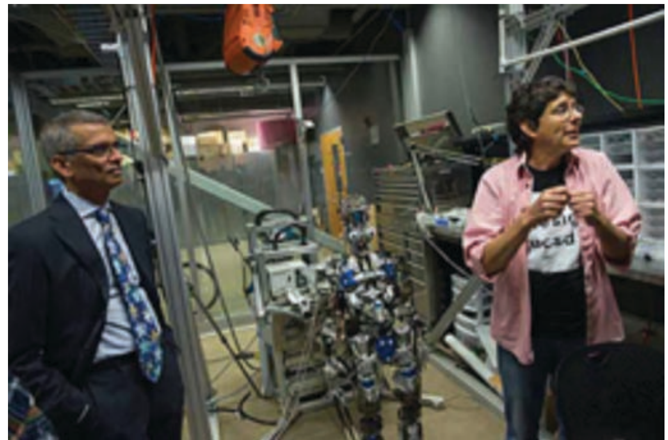
Apple Acquisition, cont from page 1

The MPLab is best known for developing AI systems to analyze facial and body gestures. The lab, for example, developed the algorithm that became the centerpiece of Sony's "Smile Shutter" technology, similar to features now built into many consumer digital cameras (to prevent snapping a photo if the subject is not smiling). The lab also developed several generations of RUBI, a robot designed for applications such as early childhood education (for teaching pre-schoolers to interact with, and learn from, the robot).

In 2012 Movellan, Bartlett and Littlewort set up Emotient off-campus to create a commercial leader in "emotion detection and sentiment analysis." The company was at the "vanguard of a new wave of emotion analysis that will lead to a quantum leap in customer understanding and emotion-aware computing," according to the company's website. "Emotient's cloud-based services deliver direct measurement of a customer's unfiltered emotional response to ads, content, products and customer service or sales interactions."

In May 2015, Emotient received a U.S. Patent on its software to crowdsource, collect and label up to 100,000 facial images daily to track expressions and what they say about a person's emotional state. A year earlier, Emotient filed a patent application for its system to "analyze and identify people's moods based on a variety of clues, including facial expression," the Wall Street Journal reported. According to prior claims by the startup, its Emotient Analytics system delivered over 95 percent accuracy in detecting primary emotions based on single video frames in real-world as well as controlled conditions.

The startup's technology has already helped advertisers assess how viewers are reacting to advertisements in real time. Physicians have used Emotient software to interpret pain levels in patients who otherwise have difficulty expressing what they're feeling, while a retailer has employed the company's AI technology to monitor consumers' reactions to products on store shelves.



The Machine Perception Lab in the Qualcomm Institute, with QI director Ramesh Rao and lab researcher Deborah Forster.
Credit: UC San Diego

Apple has made no public comment about its buyout of Emotient, nor about how it intends to use the startup's technology. Time magazine, however, suggested that "camera software that can read subtle facial movements could allow for a more advanced photo library on the iPhone," perhaps through a combination of features offered by Emotient and improved search capabilities that Apple added to its Siri system last September.

Emotient is one of several Apple acquisitions of AI-related small companies in the past six months. The others include: Perceptio for deep-learning image recognition on mobile processors; and VocalIQ, whose technology can enhance a computer's ability to decipher natural speech.

The above article was originally written by Doug Ramsey.

The world's first 64-channel "dry" EEG doesn't need conductive paste. *(Credit: Jacobs School of Engineering)*

Researchers Develop Portable Brain Monitoring Technology

A team of bioengineers and cognitive scientists led by UCSD alumni recently developed the first ever portable electroencephalography monitor headset and analytical software system, which will be accessible in the future outside of the lab setting.

The EEG is a medical test used to diagnose epilepsy, sleep disorders, coma and other focal brain disorders or injuries. It functions by using sensors in the form of electrodes to detect spontaneous electrical impulses in the brain; it can show the presence of diseases and injuries, identifying abnormalities in the EEG readings by comparing those conditions to their average baselines.

UCSD professor of bioengineering and Co-Director of the Institute for Neural Computation Gert Cauwenberghs is one of the principal investigators on the project. He described to the UCSD Guardian the “it factor” for this recently developed system that makes the device unique.

“Brain imaging typically relies on bulky and expensive instruments, such as magnetic resonance or positron emission tomography scanners,” Cauwenberghs explained. “This work originating from research in the Institute for Neural Computation and the Department of Bioengineering in the Jacobs School of Engineering is the first to provide real-time, high-resolution imaging of brain electrical activity using unobtrusive, dry-electrode electroencephalography.”

Cauwenberghs also told the Guardian how this system is a significant step for brain monitoring and the applications for the device are broad.

“Interpreting these dynamic images of brain activity help neurologists in identifying and monitoring disorders of the brain such as Parkinson’s, epilepsy, Alzheimer’s etc.,” Dr. Cauwenberghs elaborated. “The quick setup of the EEG headset is also useful in ambulatory settings by allowing the caregiver for prompt on-site diagnosis of critical medical conditions that call for immediate clinical intervention, such as possible traumatic brain injury after a head impact and suspected stroke.”

The newly developed system is comprised of a 64-channel dry-electrode wearable EEG headset making the system applicable in the real-world; dry sensors are easier to apply than wet sensors and can simultaneously provide data on the brain’s high-density electrical impulses. EEGs tend to use wet sensors to detect spontaneous electrical impulses in the brain, both while an individual is awake or asleep.

Portable EEG, cont from page 3

"The Cognionics EEG headset operates without wires, so it permits the subject to roam around freely," Cauwenberghs further elaborated on the headset. "And the dry electrodes don't require any gel or other messy or abrasive skin preparation, so they avoid discomfort to the user and long preparation times of typical wired and gel-based commercial EEG systems."

The headset was developed by co-lead researcher and chief technology officer Mike Yu Chi of Cognionics, Inc. Chi, a Jacobs School alumnus and co-founder of Cognionics, spearheaded the headset project and led the team that developed it.

The EEG headset is an octopus-like shaped device with multiple elastic arms and the dry sensors are placed at the end of each arm and designed to make optimal contact with the scalp. These sensors designed to work on hair are made from silver and carbon with a silver, silver-chloride coating being the crucial material needed to make sure that the sensors conduct high quality signals while remaining durable and flexible. Bare skin sensors are comprised of a hydrogel encased inside a conductive membrane with an amplifier equipped to help boost signal quality and shield the sensors from other electrical interference.

The headset works optimally if the subject at hand is stationary, but the researchers and developers at Cognionics are trying to improve the its performance so that it functions properly while the subject is engaged in a more strenuous activity than walking.

Along with the transportable EEG headset, the system also runs on a sophisticated software which has been coded to work on data interpretation of the data obtained through the headset. This software was developed by a team led by another UCSD alumnus and lead author Tim Mullen, who is currently the chief executive officer of the startup he cofounded that focuses on analytics, Qusp. Mullen and his team developed the software with an algorithm so that the EEG data from the headset will be separated and distinguishable from the other electrical noise that would otherwise tamper the EEG data, such as walking or talking.

"Our vision at Qusp is to embed advanced neurotechnology into everyday life," Mullen told the UCSD Guardian. "We envision a future where technology for brain and body sensing is as pervasive and useful as smart phones are today. Wearable, mobile EEG hardware, such as the Cognionics system, are an important step towards that future… We hope to empower developers to rapidly create brain- and body-aware applications transforming not only medicine and health, but also the way we work, play, communicate and learn."

The above article by Gurkirat Singh originally appeared at The Guardian.

"Our vision at Qusp is to embed advanced neurotechnology into everyday life."

- Tim Mullen, Qusp Labs founder

Memory Capacity of Brain Is 10 Times More Than Previously Thought

Data from the Salk Institute shows brain's memory capacity is in the petabyte range, as much as entire Web

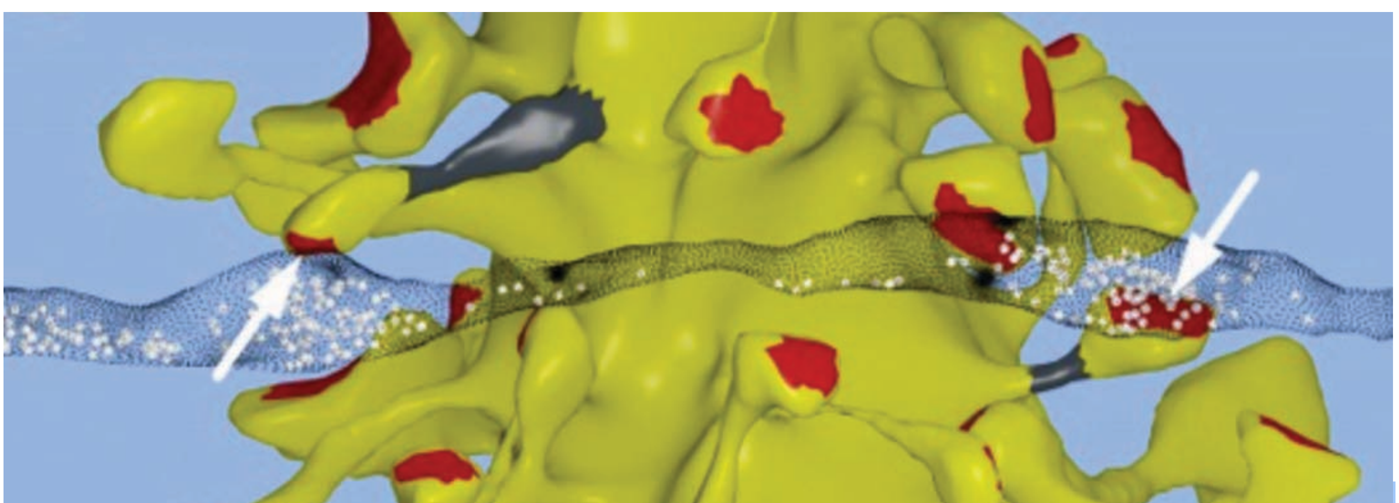
Salk researchers and collaborators have achieved critical insight into the size of neural connections, putting the memory capacity of the brain far higher than common estimates. The new work also answers a longstanding question as to how the brain is so energy efficient and could help engineers build computers that are incredibly powerful but also conserve energy.

"This is a real bombshell in the field of neuroscience," says Terry Sejnowski, Salk professor and co-senior author of the paper, which was published in eLife. "We discovered the key to unlocking the design principle for how hippocampal neurons function with low energy but high computation power. Our new measurements of the brain's memory capacity increase conservative estimates by a factor of 10 to at least a petabyte, in the same ballpark as the World Wide Web."

Our memories and thoughts are the result of patterns of electrical and chemical activity in the brain. A key part of the activity happens when branches of neurons, much like electrical wire, interact at certain junctions, known as synapses. An output 'wire' (an axon) from one neuron connects to an input 'wire' (a dendrite) of a second neuron. Signals travel across the synapse as chemicals called neurotransmitters to tell the receiving neuron whether to convey an electrical signal to other neurons. Each neuron can have thousands of these synapses with thousands of other neurons.

"When we first reconstructed every dendrite, axon, glial process, and synapse from a volume of hippocampus the size of a single red blood cell, we were somewhat bewildered by the complexity and diversity amongst the synapses," says Kristen Harris, co-senior author of the work and professor of neuroscience at the University of Texas, Austin. "While I had hoped to learn fundamental principles about how the brain is organized from these detailed reconstructions, I have been truly amazed at the precision obtained in the analyses of this report."

Synapses are still a mystery, though their dysfunction can cause a range of neurological diseases. Larger synapses—with more surface area and vesicles of neurotransmitters—are stronger, making them more likely to activate their surrounding neurons than medium or small synapses.



In a computational reconstruction of brain tissue in the hippocampus, Salk scientists and UT-Austin scientists found the unusual occurrence of two synapses from the axon of one neuron (translucent black strip) forming onto two spines on the same dendrite of a second neuron (yellow). Separate terminals from one neuron's axon are shown in synaptic contact with two spines (arrows) on the same dendrite of a second neuron in the hippocampus. The spine head volumes, synaptic contact areas (red), neck diameters (gray) and number of presynaptic vesicles (white spheres) of these two synapses are almost identical. *(Credit: Salk Institute)*

The Salk team, while building a 3D reconstruction of rat hippocampus tissue (the memory center of the brain), noticed something unusual. In some cases, a single axon from one neuron formed two synapses reaching out to a single dendrite of a second neuron, signifying that the first neuron seemed to be sending a duplicate message to the receiving neuron.

At first, the researchers didn't think much of this duplicity, which occurs about 10 percent of the time in the hippocampus. But Tom Bartol, a Salk staff scientist, had an idea: if they could measure the difference between two very similar synapses such as these, they might glean insight into synaptic sizes, which so far had only been classified in the field as small, medium and large.

To do this, researchers used advanced microscopy and computational algorithms they had developed to image rat brains and reconstruct the connectivity, shapes, volumes and surface area of the brain tissue down to a nanomolecular level.

The scientists expected the synapses would be roughly similar in size, but were surprised to discover the synapses were nearly identical.

"We were amazed to find that the difference in the sizes of the pairs of synapses were very small, on average, only about eight percent different in size. No one thought it would be such a small difference. This was a curveball from nature," says Bartol.

Because the memory capacity of neurons is dependent upon synapse size, this eight percent difference turned out to be a key number the team could then plug into their algorithmic models of the brain to measure how much information could potentially be stored in synaptic connections.

It was known before that the range in sizes between the smallest and largest synapses was a factor of 60 and that most are small.

But armed with the knowledge that synapses of all sizes could vary in increments as little as eight percent between sizes within a factor of 60, the team determined there could be about 26 categories of sizes of synapses, rather than just a few.

"Our data suggests there are 10 times more discrete sizes of synapses than previously thought," says Bartol. In computer terms, 26 sizes of synapses correspond to about 4.7 "bits" of information. Previously, it was thought that the brain was capable of just one to two bits for short and long memory storage in the hippocampus.

"This is roughly an order of magnitude of precision more than anyone has ever imagined," says Sejnowski.

What makes this precision puzzling is that hippocampal synapses are notoriously unreliable. When a signal travels from one neuron to another, it typically activates that second neuron only 10 to 20 percent of the time.

"We had often wondered how the remarkable precision of the brain can come out of such unreliable synapses," says Bartol. One answer, it seems, is in the constant adjustment of synapses, averaging out their success and failure rates over time. The team used their new data and a statistical model to find out how many signals it would take a pair of synapses to get to that eight percent difference.

The researchers calculated that for the smallest synapses, about 1,500 events cause a change in their size/ability (20 minutes) and for the largest synapses, only a couple hundred signaling events (1 to 2 minutes) cause a change.

"This means that every 2 or 20 minutes, your synapses are going up or down to the next size. The synapses are adjusting themselves according to the signals they receive," says Bartol.

"Our prior work had hinted at the possibility that spines and axons that synapse together would be similar in size, but the reality of the precision is truly remarkable and lays the foundation for whole new ways to think about brains and computers," says Harris. "The work resulting from this collaboration has opened a new chapter in the search for learning and memory mechanisms." Harris adds that the findings suggest more questions to explore, for example, if similar rules apply for synapses in other regions of the brain and how those rules differ during development and as synapses change during the initial stages of learning.

"The implications of what we found are far-reaching," adds Sejnowski. "Hidden under the apparent chaos and messiness of the brain is an underlying precision to the size and shapes of synapses that was hidden from us."

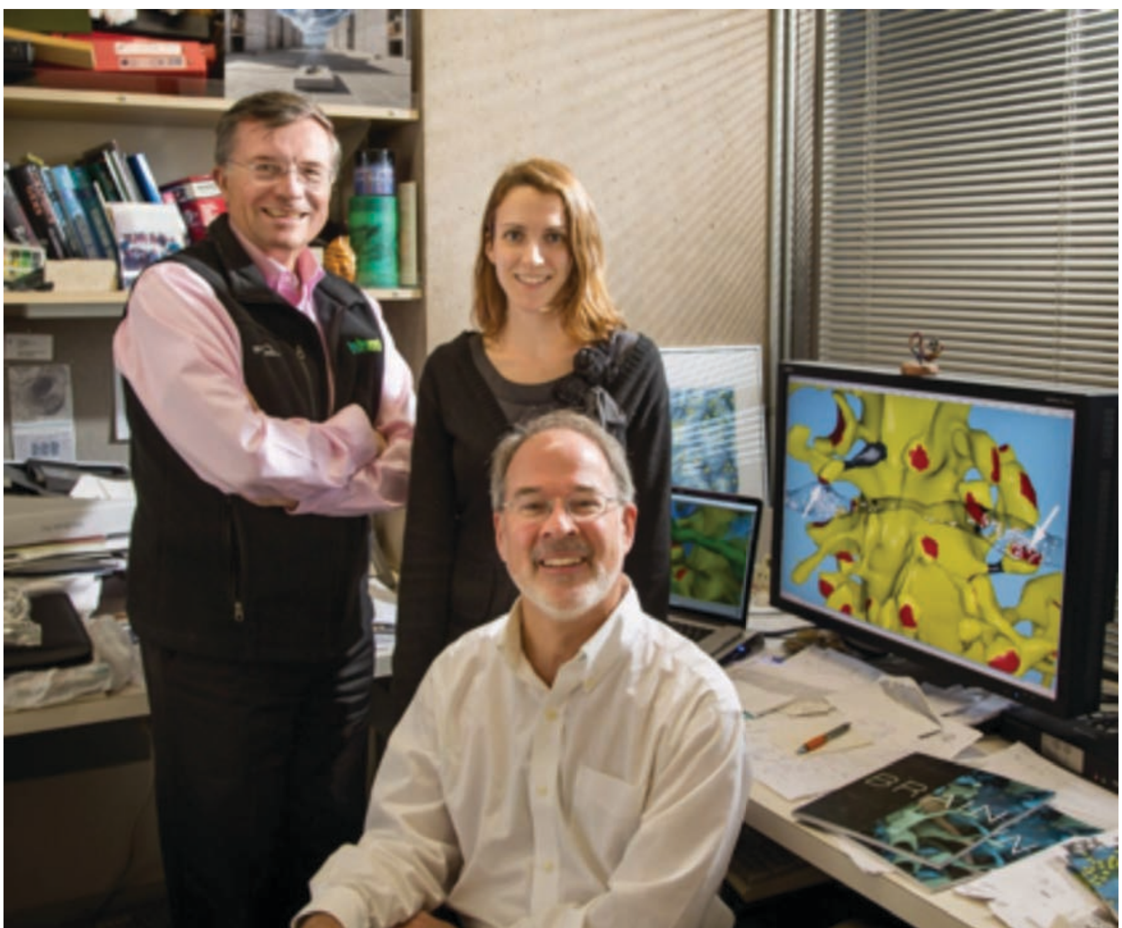
The findings also offer a valuable explanation for the brain's surprising efficiency. The waking adult brain generates only about 20 watts of continuous power—as much as a very dim light bulb. The Salk discovery could help computer scientists build ultraprecise, but energy-efficient, computers, particularly ones that employ "deep learning" and artificial neural nets—techniques capable of sophisticated learning and analysis, such as speech, object recognition and translation.

"This trick of the brain absolutely points to a way to design better computers," says Sejnowski. "Using probabilistic transmission turns out to be as accurate and require much less energy for both computers and brains."

Other authors on the paper were Cailey Bromer of the Salk Institute; Justin Kinney of the McGovern Institute for Brain Research; and Michael A. Chirillo and Jennifer N. Bourne of the University of Texas, Austin.

The work was supported by the NIH and the Howard Hughes Medical Institute.

The above article originally appeared at [Salk News.]



From left: Terry Sejnowski, Cailey Bromer and Tom Bartol *(Credit: Salk Institute)*

The Beasts That Keep the Beat

New insights from neuroscience — aided by a small zoo's worth of dancing animals — are revealing the biological origins of rhythm.

(from the Quanta Magazine, by Ferris Jabr)

There are moments when we witness an animal do something so far outside its presumed repertoire of behavior — something so uncannily human — that we can never look at that animal, or ourselves, the same way again. For Irena Schulz, one of those moments happened on an otherwise ordinary day in August, 2007. Schulz lived in Schererville, Ind., where she managed a sanctuary for abandoned parrots. A man named Dane Spudic came by with a young male Eleonora cockatoo called Snowball — a striking creature with milk-white plumage and a sweep of lemon feathers on his nape that fanned into a mohawk when he was excited. Spudic explained that his family could no longer give the increasingly cantankerous Snowball the attention and care he needed.

Oh, and by the way, he added, this bird is an incredible dancer. You should see what he can do. Spudic left behind a burned CD of Snowball's favorite music.

Schulz was someone who already had a deep appreciation for the intelligence and myriad talents of birds. She had even seen some parrots sway and bob to music. But Spudic's claims seemed a bit hyperbolic. "We were humoring him, saying, 'Sure, sure,'" Schulz recalls. Later that evening, she and her husband popped Spudic's CD into the computer in their living room. "Everybody (Backstreet's Back)" by The Backstreet Boys started playing. Immediately, Snowball, who was perched on Schulz's arm, began kicking up his feet and bouncing his head with great zeal — and precision. His movements were synced with the beat. "I couldn't believe my eyes," Schulz said. "This bird was like a choreographed phenomenon. He wasn't just picking up his leg and gingerly putting it down. He was literally foot stomping. I thought, 'My god — the bird is enjoying this.'"

In time, the whole world would delight in Snowball's exuberant jig. Schulz posted a video of the dancing parrot on the shelter's blog, which someone else — possibly someone in Russia — copied to YouTube. It went viral, earning more than 200,000 views in one week. (Today, the video, which is now hosted on Snowball's official YouTube channel, has more than five million views). Snowball appeared on The Late Show with David Letterman, Good Morning America and numerous other talk shows, and starred in commercials for Taco Bell, Geico and Loka bottled water.

Snowball®, a male Eleonora cockatoo, shows off his ability to keep beats to pop music. *(Credit: Bird Lovers Only)*

Snowball's public debut also caught the attention of two scientists at the Neurosciences Institute in La Jolla, Calif. John Iversen and Aniruddh Patel were interested in the evolutionary origins and neuroscience of rhythm and music. At the time, there was no documented evidence that nonhuman animals could dance — or, in more scientific terms, that they could "entrain" their movements to an external beat. "We saw this video, and it really knocked us out — it was the first time we had ever seen this," Iversen said. "As scientists, you love these kinds of moments."

Iversen and Patel tested Snowball in controlled experiments, altering the tempos of his favorite songs and observing how he responded without any training or encouragement. Snowball danced in bouts, rather than continuously, but frame-by-frame video analysis confirmed that he adapted his movements to match the altered beats. Soon after, other studies by separate research teams showed that numerous species of parrots could entrain to a beat, as could elephants. Monkeys, on the other hand, did not display much rhythmic talent in the lab.

The findings seemed to fit a hypothesis Patel had recently conceived: Musical rhythm, he argued, is a byproduct of "vocal learning" — the ability to reproduce sounds one has never heard before. Humans, parrots and elephants are all vocal learners. Elephants have been documented imitating the sounds of trucks and other animals, and parrots are literally synonymous with mimicry. Monkeys, on the other hand, are stuck with an inborn set of hoots and screams. Patel's notion was that the evolution of vocal learning in select species strengthened the links between brain regions in charge of hearing and movement, which made musical rhythm possible. In the years following its introduction, the vocal learning hypothesis seemed to fit all the relevant data.

Iversen and Patel's study of Snowball turned out to be just the prelude to a new concerto of research on musicality in the animal kingdom. In recent years, scientists have tested various species and found evidence that nonvocal learners such as sea lions and bonobos have rhythm too. In parallel, pioneering studies have begun to elucidate how the brain tracks a beat, work that may help corroborate that rhythm is not restricted to the planet's most loquacious creatures. The new findings suggest that rhythm has a more ancient and universal evolutionary origin than was originally thought. "I don't think the vocal learning hypothesis has much to teach us anymore," said Peter Cook, a comparative psychologist at Emory University. "Beat keeping might be rooted in a really old, widely conserved mechanism, which is basically how brains communicate. What is more interesting is why some animals don't do it."

A World of Wild Rhythms

Patel and Iversen published their first study on Snowball in 2008. (Irena Schulz was a co-author on the paper.) The following year, Adena Schachner, at the time a researcher at Harvard University, and her colleagues demonstrated that an African grey parrot named Alex — the Koko of the bird world, famous for his large vocabulary — could also move to a beat, as could Asian elephants and 13 other parrot species identified through an exhaustive search on YouTube. Further evidence came from Columbia University neuroscientist and musician David Sulzer, also known as Dave Soldier, who had been recording albums with an orchestra of Asian elephants in Thailand, for whom he had constructed supersized drums, gongs and chimes. Meanwhile, Yoshimasa Seki of the Brain Science Institute in Japan and his team successfully trained budgerigars (parakeets) to peck an LED in time to a wide range of tempos. In related experiments by other researchers, rhesus monkeys largely failed to learn rhythmic tapping tasks: They took more than a year to grasp the concept and even then were inconsistent and tended to lag behind the rhythm.

By 2012, the vocal learning hypothesis seemed to be transitioning from a tentative notion to a promising explanation of rhythm's biological origins. Because people, parrots and elephants had all evolved to be vocal copycats, they had an innate talent for recognizing and replicating auditory rhythms; in contrast, acoustically inflexible primates did not. But then a single maverick mammal — one not known for musical prowess — leapt from sea to stage, stole the spotlight and urged the scientific community to reconsider.

A few years after word of Snowball got around, Cook, then a graduate student at the University of California, Santa Cruz, was contemplating a suitable research project for himself and Andrew Rouse, a UCSC undergrad. Cook was studying cognitive psychology, in particular the behavior of pinnipeds — walruses, seals and sea lions — and he knew that Rouse had a passion for music. Perhaps, Cook thought, they could combine their interests and really put the vocal learning hypothesis to the test.

Though not quite as vocally proficient as parrots, walruses and seals can mimic novel sounds. In the 1970s and '80s, one especially remarkable Atlantic harbor seal named Hoover learned to imitate human speech, greeting New England Aquarium visitors with phrases such as, "Hello there," "How are ya?" and "Get outta here," all reproduced with a thick Kennedy-esque accent. Sea lions, however — separated from their pinniped cousins by more than 20 million years of divergent evolution — are not nearly as vocally flexible. "They can bark and grunt on command, at a fast or slow rate," Cook said. "But they don't seem to be able to alter frequency or produce novel calls."

So Cook, Rouse and their colleagues decided to try to teach a sea lion named Ronan to dance. At first, Cook trained Ronan to bob her head to simple metronome-like pulses of 80 and 120 beats per minute (bpm). But that did not prove Ronan had a general ability to identify a rhythm and move in sync; she might have learned to simply move at two specific speeds in response to two distinct sounds, the same way a dog might trot at one whistle and sprint at another. In a second experiment, Cook presented Ronan with beats she had never encountered before: 96, 88, 108, 132 and 72 bpm. This time she had to bob her head in time with the beats without any training or practice rounds. She performed superbly, sometimes slightly ahead of slower beats, or a smidge behind the faster ones.

The real test, however, was whether Ronan could dance to genuine music — to pop and rock songs with all their phrases and flourishes overlaid on the underlying beat. Could she, like Snowball, extract the rhythm from The Back Street Boys' "Everybody," or "Boogie Wonderland" by Earth Wind and Fire? She could. Even playing "Boogie Wonderland" at varying tempos did not throw her off — she adjusted her bobs accordingly. "She was incredibly precise. Right out of the gate, she nailed it," Cook said. "We showed that there is no way she could have hit all of those beats by chance."

Cook and his colleagues published their results in the Journal of Comparative Psychology in 2013. Several more-recent studies have indicated that other animals classified as nonvocal learners — in particular the great apes — also have a sense of rhythm.

Unlike parrots, elephants and Hoover the harbor seal, the great apes are not adept at mimicking sounds or even the basics of human speech. Nonetheless there have long been inklings that apes might know how to follow a beat: Wild chimpanzees and bonobos drum their hands and feet on their bodies, or on resonant objects like logs and tree roots, when playing or reinforcing their dominance. In 2012 Yuko Hattori of Kyoto University published the first evidence from a controlled experiment showing that chimpanzees will spontaneously tap to a beat. And last year Patricia Gray, a concert pianist and director of the biomusic (music created by nonhuman animals) program at the University of North Carolina, Greensboro, revealed that she had discovered Snowball's equal among a group of bonobos.

One day in 2010, while waiting for an experiment to be set up at a great ape research center in Des Moines, Iowa, Gray began idly tapping her

Bonobos are the latest example of non-vocal learners that are also able to keep a beat. (*Credit: Wandering Panda*)

hand on the side of a glass enclosure. From the other side of the glass, a bonobo named Kanzi started to tap as well, matching Gray's tempo. "Well, this is interesting," she thought. "I wonder how long we can keep it up?" They kept going — and going. Even when it was time for Kanzi's snack, he rolled onto his back, ate his helping of green onions with his hands and continued tapping with his dexterous feet.

The following year, Gray embarked on an experiment to formally answer a simple question: Can bonobos drum to a beat? She and Edward Large, a neuroscientist at the University of Connecticut specializing in music perception, studied a group of bonobos at Jacksonville Zoo and Gardens in Florida — in particular a 29-year-old female name Kuni. Unlike Kanzi, none of these apes had any prior exposure to musical instruments. But Gray and Large did not want to give the primates any old instrument. Bonobos, it should be noted, are much stronger than humans and could easily break a typical drum. The scientists commissioned the drum maker Remo to design a sturdy tube drum that was an appropriate height for a bonobo and could withstand 500 pounds of pressure. For good measure, they bolted it to a concrete floor in the bonobos' living quarters.

At first the apes approached the drum with trepidation, but once the researchers and zoo staff started demonstrating, the bonobos were rapt. By the fall of 2011, several high-ranking females, including Kuni, were voluntarily drumming along with staff members, which encouraged others to join in too. The real experiments began in December 2011 and continued through the spring. On one side of a steel mesh door, an experimenter listened to a metronome through headphones and drummed along. On the other side, Kuni — the most proficient player — could choose to beat on her drum. Kuni's performance was comparable to Snowball's: Both matched the abilities of a human child, accurately tracking a beat in bouts rather than continuously. "We wanted the bonobos to choose to participate," Gray said. "They can be as moody as humans. The data we collected clearly demonstrated that Kuni could entrain to a beat, even if she was only interested for a short time. Every time we have new species such as a sea lion or bonobo demonstrating this timing ability, it pokes a hole into what we thought was going to be clear-cut delineation of who has rhythm and who does not."

The Brain's Beats

Despite these new findings, Patel and Iversen are not quite ready to let go of the vocal learning hypothesis. "I think it still explains most of the data," said Iversen, who is now at the Swartz Center for Computational Neuroscience at the University of California, San Diego. They want to see more experiments with other species, in particular dogs and horses, both of which are decidedly not vocal learners. "Some researchers have raised the question: Why don't dogs dance? After all, dogs have been exposed to our music and dancing for tens of thousand of years," Iversen said. "It could be intrinsic neural limitations. Maybe you need the right brain circuits."

If, however, future experiments parallel the latest studies and confirm that an innate sense of rhythm does not depend on neural circuits unique to vocal learners, then how does the brain follow a beat? And what explains the evolutionary origins of this ability? An alternative explanation is coming into focus.

Scientists have known for decades that the brains of all creatures are highly rhythmic biological machines. Both individual neurons and groups of brain cells display repetitive fluctuations in their electrical and chemical activity. But when scientists speak of neural oscillations, they are usually referring to cyclic changes in the strength of the electric fields generated by thousands or millions of interconnected brain cells. Devices such as an electroencephalogram (EEG) — a net of electrodes placed on the scalp — can detect these fluctuations and graph them as sinuous lines similar to those drawn by a seismograph.

Although researchers know that these rhythms vary widely depending on someone's behavior and that certain rhythms correlate with specific physiological states — wake versus sleep, for instance — their exact purpose remains unclear. Some have argued that they are inevitable and largely ineffectual byproducts of the brain's wiring. Others think that such vacillations might encode and transmit information. Since at least the 1970s, researchers have proposed that neural oscillations might be especially important for recognizing patterns and rhythms in the environment — that the brain's own rhythms might actually sync up with those in the world around us. Until recently, however, there was no experimental evidence to support that idea.

In 2005, Large and Joel Snyder, now at the University of Nevada, Las Vegas, published an EEG study showing that when people listen to tones played at regular intervals, certain neural circuits begin to oscillate in time with the tones. It was the first study of its kind. "Oddly, no one had looked before," Large said. "There had been behavioral evidence accumulating for 40 years, in experiments with people tapping along to beats. But we wanted to go in and see if the brain's own oscillations sync with what we hear." Since then, dozens of similar experiments have demonstrated that neural oscillations in both human and other animal brains — including those of monkeys and zebrafish — consistently synchronize with auditory rhythms, including those that come from a simple metronome, classical music or human speech.

Initially, Large and other researchers focused such studies on oscillations in the auditory cortex — a small, centrally located brain region that organizes and interprets neural signals related to sound. In the last eight years, however, studies using magnetoencephalography (MEG) and fMRI — a measurement that tracks blood flow in the brain — have revealed that neural circuits specialized for movement are also used to perceive auditory rhythms. "What was surprising is that motor areas are active even when people are sitting still and just listening," Large said. "The emerging picture is that the auditory and motor regions sync with each other at the same time as they synchronize to external rhythms, which might help us store and remember the patterns so we can generate them later."

Patel and Iversen view these findings as further support for the vocal learning hypothesis. The fact that neural oscillations match patterns in speech and music is not sufficient to explain how we or other animals track a beat, they argue. Rather, musical rhythm emerges only in species that have robust bridges between brain areas specialized for hearing and movement, which allows them to synchronize oscillations in those regions all the more precisely. According to their model, when we sit perfectly still and listen to music, brain regions responsible for planning our movements predict when the next beat will drop. It's as though these regions were anticipating an upcoming footfall while running or the subsequent swing of an arm. The brain's auditory regions then use the motor regions' predictions to sync with the beat as well. Put another way, the brain can only make sense of music by relating it to rhythmic bodily movements, even if we aren't moving at all.

Large thinks this is a misinterpretation. "I don't think any especially complex circuitry is needed for a sense of rhythm," he said. "If a brain has connections between the auditory and motor regions, then we should be able to see them synchronize."

Cook agrees. The first thing to realize, he said, is that what we think of as musical rhythm — singing, dancing or otherwise following an auditory beat — is just one form of rhythm among living things. Consider the synchronous flash of the lustful firefly; or the lockstep of cheetah and gazelle; the ease with which millions of bats move together like living smoke in the night sky; the highly coordinated hunts of wolves and orcas; and the intricate mating dances of tropical birds. Clearly rhythm is fundamental to life — a fact reflected in the numerous links between sensory organs and muscles as well as between sensory and motor regions in all animal brains. Indeed, the fundamental purpose of neurons and brains is to form those connections: to guide behavior using information gathered from the outside world. "You can take this really far back in the evolution of brains," Cook said. "Brains are basically networks of circuits, and the way they work together is by synchronizing their firing patterns. Rhythm is baked in."

If rhythm itself is so commonplace among living things, then why is musical rhythm so rare? Perhaps it's not. What the latest evidence suggests is that the latent ability to follow a beat is much more widespread than previously realized — but, in many species, it probably needs some coaxing to reveal itself. Humans, parrots and elephants are all highly intelligent social species that depend on vocal communication to reproduce and survive. It makes sense that species like these will be especially responsive to auditory rhythms. But their precocious skills necessarily build upon far more common abilities and neural wiring found in a wide range of animals. When these less ostentatious creatures are given appropriate opportunities and encouragement, their latent musical abilities divulge themselves. "The tricky part is motivation," Cook said. "At first Ronan [the sea lion] didn't give a crap about the beat. But once we gave her the right training and impetus, she was like, 'Oh, yeah, of course I can do that.'"

Up until now, the idea has been that biological differences explain humans' unique musical gifts. Perhaps, though, that discrepancy stems more from culture than biology. Some human infants instinctively bob up and down and shake their limbs when they see people singing and dancing, which implies an innate sense of rhythm. Yet studies show that children do not learn to synchronize their movements to a beat until preschool-age at the earliest, and even then they are not very consistent. And if a child were never exposed to dancing or music, would she develop any musical rhythm at all?

Maybe we're more like Snowball and Ronan than we'd like to admit: We all have an inborn capacity for rhythm that requires the right environment to reveal itself. Perhaps it's not that we're biologically so different or superior, but rather that we're so much better at creating that suitable environment. Some scholars believe that our hominin ancestors were dancing and singing long before they evolved language, investing considerable resources in ritual performances and the construction of drums and flutes. Today, music continues to suffuse every phase of our lives, from lullaby to elegy. We may not be the only species with rhythm, but we are the only ones with a universal culture of music and dance. We have become the ultimate keepers of the beat.

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The above article by Ferris Jabr originally appeared at [The Quanta Magazine.]()

Faculty Spotlight - Dr. Alexander Khalil

Music and the Group Brain Dynamics

We sat down with Dr. Alexander Khalil, who has been working on understanding how rhythm affects the brain dynamics of a group.

Can you tell us a bit about your background?

My journey is a bit different than most, but that is what everyone at INC might say, I suppose. I started out in UCSD at the music department, and I did my Ph.D. in music. My interest in music has always been in what we call transmission, which is about how people transmit musical behaviors to each other. The concept encompasses musical pedagogy and how everyone in a certain community does music in a certain way, inter-generationally and culturally. There are many components to the idea of transmission, and there are many things that are interesting to me.

In particular, I have been studying different types of pedagogy in traditional societies. I was conducting research on the way music was being taught and transmitted both formally and informally in Indonesia and Istanbul. Back here in the United States, I also taught music to kids. At some point, I realized that there are certain peculiarities of rhythm that kids exhibited in their playing that corresponded to other characteristics. Specifically, I felt I could hear kids who had ADHD, because they were not able to lock in with everyone else's rhythm. This began to really interest me, and I started reading literature in neuroscience and psychology about ADHD and timing. It turned out that, even though there was a lot of literature on the topic, there were no real answers to how we could help these kids. So I dove into that topic myself.

As soon as I graduated, I became a post-doc at Andrea Chiba's lab in the cognitive science department. I had to study very intensely, as I had to catch up with all of the knowledge everyone else had in the field. At Chiba labs, I developed a close working relationship with Victor Minces, with whom I continue to work and the two of us also went to Marta Kutas lab to learn EEG. I have worked as a post-doc for five years, and eventually I became a project scientist at INC. Since then, I have been working on two tracks: one is electrophysiology, and the other is behavioral work.

What are some of the projects you are working on currently?

My main projects right now are to develop a large-scale longitudinal study that aims to understand how learning music might affect other cognitive characteristics and to further a project that investigates electrophysiology in a group setting. I am a co-PI on this latter project, called "Group Brain Dynamics in Learning" with John Iversen and Tzyy-Ping Jung. We recently were funded for this project by NSF. I'm mostly working with mobile headsets that were developed specifically for this project

We are really excited about this project for two main reasons. One is that we get to be really efficient: the project goal is to have a large group of people together and record data all at once. In the next three years, we plan to have 25 people capped and recorded together, perhaps kids in the classroom environment. The EEG headsets we use are very adjustable, so we will be able to get younger subjects too. This setup will let us perform traditional EEG experiments very efficiently, as we will have 25 recordings in an hour instead of one. In a few days, we can record from the whole school that way.

Second, we will be able to examine the group brain dynamics, which include things like how well each student tracks the teacher's speech envelope. This can then be correlated against other measures of the classroom performance, such as how much attention is paid in the classroom. We will attempt to quantify whether sitting in different places in the classroom has an effect on attention, for example. Or, suppose that the students all clap a rhythm together, and at some point, someone gets off. We will be able to see the brain dynamics of what happened right before they got off, and how everyone else's dynamics are affected by the event.

The key aspect to the whole project is the proximity we have to the subjects' perception. For instance, this headset has audio inputs that plug directly into the headphone, so we can record the exact audio signal coming into the ears along with the EEG data. This allows us to choose various aspects of the audio signal as event codes for averaging. We also record audio directly into the headset in order to capture — and time-lock — events happening around the subject, such as people clapping or singing. This is important, because we are especially interested in very low-latency responses of the brain, and even small distances can affect how well we can average over such signals. It also gives us the flexibility to record whatever is happening in the classroom and decide how we are going to average the recording later.

We are also devising some games for the students to play, partly because this has to be a fun experiment. We can't only do our experiments and expect people to play along. One of the games we are thinking involves linking individual EEG outputs – such as the beta waves - to the motors of the fans under a ball. Such "Jedi mind trick" games have been developed before, but we are adding the group aspect, so that the group has to work together to levitate the ball.

How close are you to running these studies?

Right now, the project is at the nuts and bolts stage, and we are working to improve the new headset. We have been working with Mike Chi, who has a company called Cognionics, to constantly go back and forth to adjust the design. So, the headsets are really designed for us.

That said, the headsets are basically working now. We're recording small groups of people and working on different methods of analyzing their brain data, using the audio signal to time-lock everything together. We will very soon be running our first experiments.

"We will be able to see the brain dynamics of what happened right before they got off, and how everyone else's dynamics are affected by it."

What kind of research questions will the GOBLIN project answer?

The GOBLIN project will be answering questions about the group brain dynamics. There are lots of questions that single electrophysiological equipment can answer, but they can't involve more than one person. The advantage of recording more than one person at a time is that it can capture what I describe as a "group flow". There is something unusual that happens when you play with someone - when you harmonize or synchronize in a group. Musicians experience this: when you are locked in, it's different than playing with a metronome or a recording. You are adjusting for each other, but somehow you do it in a very efficient way. It feels almost like you are leaning on each other, since if the other person does something wrong, you lose your balance too. The question is, what are the neural correlates of that phenomenon? Is it possible to see the group brain activity when people are synchronized? You can envision performing experiments, like having people separated in different rooms and playing together through headphones. You would control how much of each other they hear, or the change latency of what they are hearing. Then, using our headsets, we can look for the brain dynamics: when everyone is locked in, what do we see differently than when they are not?

The idea of finding the neural correlates for the group flow has a wide applicability, because many kinds of teamwork or group activities have a component of that. But since music is so finely grained, you can analyze tens of milliseconds of data points and figure out exactly when the flow is happening very easily. In contrast, it would be more difficult to measure group flows in sports activities or interpersonal communications, because you will not get the same kind of data points, even though you may have the same feeling. I think music is a good place to start looking for the signature of this type of activity, and it will be easier to find similar signatures in other activities once you have that baseline.

How do you feel about collaborations within INC?

INC is a ridiculously helpful place. Not only am I collaborating with Tzyy-Ping Jung and Ying Wu, but even when it is not something we are specifically working on together officially, I can just go out of office, go down the hall and find one of the top experts in the field. It accelerates whatever we are doing so much to be in that space. If I were alone in some other university or a more pigeon-holed department, then when you have a question, you would have to send emails to someone from some other department. It would just take forever. Here, it has been a tremendous experience, because I can just show up and ask anyone anything, and there is always someone who has a strong idea about it. People do that with me too, which I really appreciate. Coming into neuroscience from music, I always felt uncomfortable. But here, when people have issues related to music, I often get included in that dialog, which I really appreciate. I hope I bring that value in the lab, because creativity and transmission are fostered by communication that goes both ways.

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INCEVENTS

INC CHALK TALKS

01/14/16	**Tim Mullen**	Towards Pervasive and Real-World Neuroimaging and BCI
01/21/16	**Zewelanji Serpell**	Training for Transfer: Opportunities and Challenges for Application in Schools
02/04/16	**Vivienne Ming**	Engineering Superpowers: Leveraging Theoretical Neuroscience to Maximize Human Potential
02/11/16	**Mateusz Gola**	Can Porn Be Addictive? The Use of the Research Domain Criteria (RDoC) Framework in Studies of New Psychological Disorders
02/18/16	**Nadir Weibel**	Computational Ethnography and Multimodal Sensing for Healthcare
02/25/16	**Aaron Seitz**	Applying Perceptual Learning Principles to Brain Training Games
03/03/16	**Jorge Jose**	Micro-movement Statistics Biomarkers May Help Diagnose and Develop Therapies for Individuals with Autism Spectrum Disorders
03/10/16	**Mark McDonnell**	A Neurobiological Learning Model Inspired By Deep Learning, and Its Application to Image Classification
04/07/16	**Thorsten Zander**	Towards Neuroadaptive Technology: Symmetrical Human-Computer Interaction Based on a Cognitive User Model
04/14/16	**Lyle Muller**	Multichannel Recordings in Neuroscience: Methods for Spatiotemporal Dynamics
04/21/16	**Joaquin Rapela**	Our Brain Oscillations Follow Our Motor Rhythms
05/05/16	**Ulysses Bernardet**	Social Action Selection and Reflexive Behavior Architecture

Special Events

01/22/16 - 01/23/16

TDLC All Hands Meeting

Location: San Diego Supercomputer Center East

Every funded project planned on showing progress through a presentation. This is in the form of either a poster at the main meeting or a trainee talk at the Fellows Retreat.

Full agenda and more details can also be found here.

at a glance

INC Research Groups and staff

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

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

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

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

Office of Naval Research (ONR) Multidisciplinary University Initiative (MURI) Center
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