Human Brain Project

The human brain is smaller than most people imagine, it can be held in one hand and weighs about 3 pounds. However, the innocuous looking gray matter is infinitely complex and barely understood. But part of the challenge to understanding, despite the number of researchers, scientists, and doctors dedicated to its study, is that there is no central hub of information, mapping, or data gathering for brain research. Soon though, the Human Brain Project (HBP) hopes to change all that. [28]

Many universities and institutes suggested that inside microtubules of brain cells, quantum vibrational computations were orchestrated. [27]

New research proposes a way to test whether quantum entanglement is affected by consciousness. [26]

Using atomic-scale quantum defects in diamonds known as nitrogen-vacancy (NV) centers to detect the magnetic field generated by neural signals, scientists working in the lab of Ronald Walsworth, a faculty member in Harvard's Center for Brain Science and Physics Department, demonstrated a noninvasive technique that can image the activity of neurons. [25]

Neuroscience and artificial intelligence experts from Rice University and Baylor College of Medicine have taken inspiration from the human brain in creating a new "deep learning" method that enables computers to learn about the visual world largely on their own, much as human babies do. [24]

What is the relationship of consciousness to the neurological activity of the brain? Does the brain behave differently when a person is fully conscious, when they are asleep, or when they are undergoing an epileptic seizure? [23]

Consciousness appears to arise naturally as a result of a brain maximizing its information content. So says a group of scientists in Canada and France, which has studied how the electrical activity in people's brains varies according to individuals' conscious states. The researchers find that normal waking states are associated with maximum values of what they call a brain's "entropy". [22]

New research published in the New Journal of Physics tries to decompose the structural layers of the cortical network to different hierarchies enabling to identify the network's nucleus, from which our consciousness could emerge. [21]

Where in your brain do you exist? Is your awareness of the world around you and of yourself as an individual the result of specific, focused changes in your *brain, or does that awareness come from a broad network of neural activity? How does your brain produce awareness? [20]*

In the future, level-tuned neurons may help enable neuromorphic computing systems to perform tasks that traditional computers cannot, such as learning from their environment, pattern recognition, and knowledge extraction from big data sources. [19]

IBM scientists have created randomly spiking neurons using phase-change materials to store and process data. This demonstration marks a significant step forward in the development of energy-efficient, ultra-dense integrated neuromorphic technologies for applications in cognitive computing. [18]

An ion trap with four segmented blade electrodes used to trap a linear chain of atomic ions for quantum information processing. Each ion is addressed optically for individual control and readout using the high optical access of the trap. [17]

To date, researchers have realised qubits in the form of individual electrons (aktuell.ruhr-uni-bochum.de/pm2012/pm00090.html.en). However, this led to interferences and rendered the information carriers difficult to programme and read. The group has solved this problem by utilising electron holes as qubits, rather than electrons. [16]

Physicists from MIPT and the Russian Quantum Center have developed an easier method to create a universal quantum computer using multilevel quantum systems (qudits), each one of which is able to work with multiple "conventional" quantum elements – qubits. [15]

Precise atom implants in silicon provide a first step toward practical quantum computers. [14]

A method to produce significant amounts of semiconducting nanoparticles for light-emitting displays, sensors, solar panels and biomedical applications has gained momentum with a demonstration by researchers at the Department of Energy's Oak Ridge National Laboratory. [13]

A source of single photons that meets three important criteria for use in quantum-information systems has been unveiled in China by an international team of physicists. Based on a quantum dot, the device is an efficient source of photons that emerge as solo particles that are indistinguishable from each other. The researchers are now trying to use the source to create a quantum computer based on "boson sampling". [11]

With the help of a semiconductor quantum dot, physicists at the University of Basel have developed a new type of light source that emits single photons. For *the first time, the researchers have managed to create a stream of identical photons. [10]*

Optical photons would be ideal carriers to transfer quantum information over large distances. Researchers envisage a network where information is processed in certain nodes and transferred between them via photons. [9]

While physicists are continually looking for ways to unify the theory of relativity, which describes large-scale phenomena, with quantum theory, which describes small-scale phenomena, computer scientists are searching for technologies to build the quantum computer using Quantum Information.

In August 2013, the achievement of "fully deterministic" quantum teleportation, using a hybrid technique, was reported. On 29 May 2014, scientists announced a reliable way of transferring data by quantum teleportation. Quantum teleportation of data had been done before but with highly unreliable methods.

The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the Wave-Particle Duality and the electron's spin also, building the Bridge between the Classical and Quantum Theories.

The Planck Distribution Law of the electromagnetic oscillators explains the electron/proton mass rate and the Weak and Strong Interactions by the diffraction patterns. The Weak Interaction changes the diffraction patterns by moving the electric charge from one side to the other side of the diffraction pattern, which violates the CP and Time reversal symmetry.

The diffraction patterns and the locality of the self-maintaining electromagnetic potential explains also the Quantum Entanglement, giving it as a natural part of the Relativistic Quantum Theory and making possible to build the Quantum Computer with the help of Quantum Information.

Contents

Author: George Rajna

Preface

Where in your brain do you exist? Is your awareness of the world around you and of yourself as an individual the result of specific, focused changes in your brain, or does that awareness come from a broad network of neural activity? How does your brain produce awareness? [20]

While physicists are continually looking for ways to unify the theory of relativity, which describes large-scale phenomena, with quantum theory, which describes small-scale phenomena, computer scientists are searching for technologies to build the quantum computer.

Australian engineers detect in real-time the quantum spin properties of a pair of atoms inside a silicon chip, and disclose new method to perform quantum logic operations between two atoms. [5]

Quantum entanglement is a physical phenomenon that occurs when pairs or groups of particles are generated or interact in ways such that the quantum state of each particle cannot be described independently – instead, a quantum state may be given for the system as a whole. [4]

I think that we have a simple bridge between the classical and quantum mechanics by understanding the Heisenberg Uncertainty Relations. It makes clear that the particles are not point like but have a dx and dp uncertainty.

Imagine Being Able to Explore the Brain Like a Website

The human brain is smaller than most people imagine, it can be held in one hand and weighs about 3 pounds. However, the innocuous looking gray matter is infinitely complex and barely understood. But part of the challenge to understanding, despite the number of researchers, scientists, and doctors dedicated to its study, is that there is no central hub of information, mapping, or data gathering for brain research. Soon though, the Human Brain Project (HBP) hopes to change all that.

“The brain is too complex to sit in your office and solve it alone,” says Katrin Amunts, a neuroscientist who co-leads the 3D-PLI project at Jülich. The 3D-PLI project, short for a 3D polarized light image, is just one example of hundreds of different brain-related studies happening across the world. The project is imaging slices of a brain, only 60 micrometers wide, to track the orientation of nerve fibers. The images are so detailed that each slice creates 40 gigabytes of data and when the entire 3D digital reconstruction is completed, a single brain will take a few petabytes of storage,

With these scans, combined with the results of studies and experiments around the world, neuroscientists anticipate that fundamental advancements can occur in the field and important questions will be answered. The human brain could be searched and flipped through to examine in detail nerve fibers and see how it’s all related on the cellular level with connections to the most recent, permanent research regarding that part of the brain.

“We don’t have the faintest idea of the molecular basis for diseases like Alzheimer’s or schizophrenia or others. That’s why there are no cures,” says Paolo Carloni, director of the Institute for Computational Biomedicine at Jülich. “To make a big difference, we have to dissect [the brain] into little pieces and build it up again.”

In order to build a central resource, scientists not only need funding, but also the computing hardware and software, and they need most labs and scientist to work together and share freely. The future of neuroscience needs researchers to make the leap from individual projects and labs to a worldwide association. But the road to a concentrated consortium is not an easy one as the Human Brain Project has already discovered.

Funded in 2013 by the European Commission, a badly needed influx of €1 billion sets the Human Brain Project up to provide the infrastructure of such an organization from data analytics and modeling software to powerful computers and simulations.

Initially, the goal for HBP is similar to that of the Human Genome Project, which was an international endeavor that resulted in the complete and searchable model of the human genome. Because of the Human Genome Project, genetic research took a great jump forward in understanding and became a model for sequencing genes in numerous species. In the same way, the Human Brain Project will employ informatics, pioneered by HGP, to create a searchable database for the brain where researchers from California to Italy can use the same deeply detailed data.

Originally conceived of by neuroscientist Henry Markram, who presented his version at a 2009 Ted Talk, the Human Brain Project has gone through a little controversy to get where it is today. Markham wanted to use a supercomputer to simulate the human brain, all hundreds of trillions of synapses of it, inside of 10 years. However, once the funding came in, many scientists criticized the endeavor, other labs refused to join, while more withdrew later on.

In July of 2014, 800 researchers pleaded in an open letter to the European Commission for an independent review of “both the science and the management of the HBP” or threatened to boycott the project.

After a make-over and a 53-page report criticizing the management and science of the HBP, the organization refocused on realistic goals and “concentrate on enabling methods and technologies.” In the two years since then, the Human Brain Project has deterred from simulation and is instead aiming for an immensely detailed map of the brain. “After having trouble at the beginning, we are now on a good road,” said Amunts, scientific research director of the HBP.

“It’s a big relief,” says Henry Kennedy, research director at the Stem-Cell and Brain Research Institute and a signer of the open letter. “They’ve done what they said they would do in the mediation process.”

Unfortunately, Markram is no longer in an executive for the project and is less enthusiastic about the changes and new direction. “I dedicated three years to win the HBP grant, bringing hundreds of scientists and engineers around the focused mission of stimulating the brain,” he said. He still believes in his original vision but also sees the merit still in the existing HBP. “Building many different models, theories, tools, and collecting all kinds of data and a broad range of experiments serves a community vision of neuroscience very well,” he added.

Now, researchers are doing the grunt work, the unglamorous building of hardware and software, the nitty-gritty of data collating but that’s what has to happen, and now more than ever as the group is under scrutiny to produce, according to Simon B. Eickhoff, an imaging specialist with the HBP informatics team.

“Coming up with something premature, selling it big, and having people go to the website and being disappointed is the very last thing we can do now,” Eickhoff says. “It’s on us now to deliver.”

With the pressure to prove viability, HBP researchers are facing a maze of advisory boards, platforms, and subprojects throughout Europe but it’s not the first large-scale neuroscience project to do so. China, Israel, and Japan each have the own neuroscience research projects. And in the United States there is the Allen Institute for Brain Science, started in 2003, as well as the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiatives, started the same year as the HBP in 2013.

But the difference with HBP is its unique approach with informatics. The main part of HPB will be high-powered analytics and computation provided by teams dedicated to the creation of software for the purposes of sharing data on the brain.

Again similar to how the Human Genome Project, which has helped cancer researchers combine and analyze the genomes of a large group of patients to find abnormalities in tumors, neuroscientists hope that with the Human Brain Project they might one day compare brain scans sourced from a number of labs to detect similarities uncommon neurological disorders.

Once the infrastructure is fully operational, researchers will have the ability to coordinate and work together online with easy access to data, like human and rodent brain atlases, and tools. Instead of having to pull random information from various journals, using a neuroinformatics platform, researchers could systematically research data and simultaneously view various types of information, the cell density data and anatomical images of the visual cortex, for example.

Already researchers see interesting results by the duration and combination of various imaging data as Eickhoff's team composes the HBP brain atlases. While compiling brain scans taken during behavioral experiments the team noticed that the dorsal premotor cortex, previously believed to have a grab bag of functions for spatial attention to motor preparation, was found to instead have distinct elements each with a separate specific function.

A shortage of data is not the problem but the incompatibility of various data sets. "The data is there, but it's up to us to curate it," says Timo Dickscheid, the leader of the big-data analytics team at the Institute of Neuroscience and Medicine at Jülich.

His team is building a so-called "Google Brain" where users can zoom into any part of the brain from the folds to neuron paths and back out again. Part of the reason this is such a challenging job is the size and imaging differential between sources and anchoring scale amongst them. For example, they must make it possible to use MRI data of the almond sized amygdala while also easily being able to focus down to the micrometer scale neuron images of two-photon microscopy.

Another challenge the project must face is the disparate methods of classification and naming across the world. An example of this is the hippocampus, a seahorse-shaped area of the brain responsible for memory. As yet scientists do not agree on the specifics of where this part of the brain starts or stops and there are almost 20 diverse names for the different parts of the section. A single authoritative voice needs to unite this information before the HPB's brain atlas can be completed.

Another simulation project is working to better NEST, the Neural Simulation Tool, created by Markus Diesmann and Marc-Oliver Gewaltig in 1994 for brain-scale mathematical models. Still working on NEST, Diesmann and colleagues modeled a full second of activity in a network 1 percent the size of the brain. The experiment of 1.73 billion nerve cells connected by 10.4 billion synapses used up 82, 944 processors on the Japanese K supercomputer in 2013.

"It showed us that this is doable," says Diesmann, "but it also showed us the limitations." Aside from being an almost insignificant fraction of the human brain, the 1 second of biological time, too short a time to simulate brain events like memory and learning, took the supercomputer 40 minutes for the supercomputer to recreate. However, due to the superior computing power being provided by the

Human Brain Project, Diesmann can work on quicker algorithms and expects an improved NEST in two years.

“The plan in the HBP is to have people working on the infrastructure, but they are surrounded by neuroscientists to keep the infrastructure construction on track,” says Diesmann. Because they want to ensure researchers use the HBP tools, to keep the records up to date and useful, feedback from neuroscientists is essential. In previous large-scale efforts, like Great Britain’s CARMEN, or Code Analysis Repository and Modeling for E-Neuroscience, portal few scientists needed to share or store electrophysiology data sets, and thus very few used it. In the end, the information quickly became out of date, and the platform launched in 2008 isn’t in use today.

At the same time, HBP has commercial goals: to use knowledge gained about the human brain to improve computer networks and robotics. “In the end, we want to develop new products out of this,” says Alois C. Knoll, chair of robotics and embedded systems at the Technical University of Munich.

To do him the Human Brain Project is building on the back of two previous brain computing tools, BrainScalesS and SpiNNaker, both of which try to mimic the power and speed of the brain as well as its low-energy consumption.

With Knoll leading the neurorobotics team, they are developing a simulation environment based on a cloud that allows scientists to operate virtual robots with nervous systems based on the brain. It would be extremely complex for every lab to have a computer that can do this onsite but with an online simulation interface, scientists can choose a body, an environment, and a task that can be connected to a brain and then experiment away.

“Essentially, we are virtualizing robotics research,” says Knoll, who hopes to advance robotics by “orders of magnitude.”

Six early versions of HPB tools have been available to the public since March of 2016. Many scientists can’t wait to use the HBP tools: “Our work will sit quite happily on one of their platforms,” says Kennedy, not currently a part of the project. Some still have reservations.

Like previously mentioned, other international big neuroscience cooperatives have fallen through a number of times before. A computational neuroscientist from the University of Geneva, Alexandre Pouget who signed the open letter criticizing HBP but isn’t currently a part of the project says “Trying to do it across all of the neuroscience might be too ambitious, but we shall see.”

At least one thing they don’t have to worry about is computing power, according to Boris Orth, the head of the High-Performance Computing in Neuroscience division of the Jülich Supercomputing Center. JuQueen is one of the supercomputers the HBP is currently using for research. JURON and JULIA were commissioned by Jülich as pilot supercomputers with added memory to aid neuroscientists wth simulations.

And if successful, these systems could one day actually fulfill Markram’s first vision of the Human Brain Project a biologically realistic virtual brain model in silico. However, Orth’s team only hope neuroscientists use the supercomputers, for now. “It’s a challenge sometimes to understand each other when we discuss requirements," added Orth. "People think something should be straightforward to do, when in fact it's not."

Whatever challenges lie ahead, the Human Brain Project ends in 2023. "We don't think brain research will be over when the Human Brain Project comes to an end," adds Knoll. He, Amunts, and colleagues want to continue the project after it's ten years as an independent entity that gains raise it's own funds and have already submitted applications to make it so.

If approved, and with the right backing, the Human Brain Project, might one day be a physical center for the advancement of neuroscience, like a CERN for the brain. Then even more impressive discoveries might be made about the brain, it's diseased, and ourselves. [28]

Quantum Vibrations Discovered in Brain Cells Reveal Something Thought-Provoking about Human Consciousness

What if our brain is a quantum organ?

In the mid-1990s, Sir Roger Penrose, a mathematical physicist, put forward a theory called "orchestrated objective reduction." Many universities and institutes suggested that inside microtubules of brain cells, quantum vibrational computations were orchestrated. They were orchestrated by memory and synaptic inputs harnessed inside microtubules and later eliminated by objective reduction. These microtubules are important components of the cell structural skeleton.

The Critics

Orchestrated objective reduction has been highly criticized from the beginning. The brain has been weighed too noisy, wet, and warm for exquisite quantum processes. As of late, however, plant photosynthesis, our ability to smell, and bird brain navigation have shown us evidence of warm quantum coherence.

The Data

Higher temperatures of quantum brain vibrations located in microtubules inside brain neurons were discovered by a research group led by Anirban Bandyopadhyay, Ph.D., from the National Institute of Material Sciences in Tsukuba, Japan. The research gives evidence to the theory and says that EEG rhythms also come from denser level microtubule vibrations.

Furthermore, data from the labs of Roderick G. Eckenhoff, MD, from the University of Pennsylvania, says that anesthesia erases consciousness by selection in part while sparing non-conscious brain functions. They tend to act as microtubules in brain neurons.

Supporting the Evidence

Throughout twenty years of criticism, evidence obviously supports orchestrated objective reduction. This new evidence proves that qubits serve as helical routes in microtubule lattices. Six of twenty predictions were confirmed and none were argued according to the evidence published from 1998.

New and important elements of the theory have been introduced. Microtubule quantum vibrations in example appear to disrupt and produce slower EEG (which is beat frequencies). After a hundred years of clinical use, the beginning of EEG rhythms is still a mystery. Brief brain stimulation that is pointed at microtubule resonances in concordance with megahertz mechanical vibrations uses cranial ultrasound. This, in part, has shown reports of mood improvements and useful versus Alzheimer's disease and future brain injuries.

The most successful theory of consciousness

In the latest research led by Penrose and Hameroff, Orch-OR (Orchestrated Objective Reduction) is said to be the most comprehensive and successfully tested theory of consciousness ever brought before us. At the same time, treating brain microtubule vibrations might have the possibility of benefitting cognitive, neurological, and mental conditions of its host.

In the midst of a session on "Microtubules and the Big Consciousness Debate," which was a part of the Brainstorm Sessions, Bandyopadhyay, Penrose, and Hameroff delved into their theories. The Brainstorm Sessions was a three-day event located at the Brakke Grond in Amsterdam, the Netherlands from January 16th through January 18th, 2014.

The researchers Hameroff, Penrose, and Bandyopadhyay grouped microtubule vibrations from functioning neurons to play musical instruments of the Indian culture. Hameroff states,

"Consciousness depends on harmonic vibrations located in microtubules inside neurons, much like certain types of Indian music, but not like music from the western culture." [27]

A quantum case of mind over matter?

New research proposes a way to test whether quantum entanglement is affected by consciousness.

Quantum entanglement is a concept so counter-intuitive that Albert Einstein called "spooky" — and it may be even spookier than he thought.

New research by Perimeter Institute physicist Lucien Hardy proposes a way to potentially test whether entanglement could be affected by human consciousness.

For decades, an experiment called the Bell test has confirmed what Einstein described as "spooky action at a distance," in which the state of one particle seems to instantly determine the state of its entangled partner, regardless of the distance separating them.

Some physicists have suggested that the correlations could be affected by something outside of the known physical world, such as a hitherto unknown force of consciousness. Hardy has proposed a test for this idea, involving roughly 100 people separated by 100 kilometres, all wearing EEG headsets to monitor their brainwaves.

"[If] you only saw a violation of quantum theory when you had systems that might be regarded as conscious, humans or other animals, that would certainly be exciting," Hardy told New Scientist. [26]

Researchers trace neural activity by using quantum sensors

It's one of the purest and most versatile materials in the world, with uses in everything from jewelry to industrial abrasives to quantum science. But a group of Harvard scientists has uncovered a new use for diamonds: tracking neural signals in the brain.

Using atomic-scale quantum defects in diamonds known as nitrogen-vacancy (NV) centers to detect the magnetic field generated by neural signals, scientists working in the lab of Ronald Walsworth, a faculty member in Harvard's Center for Brain Science and Physics Department, demonstrated a noninvasive technique that can image the activity of neurons.

The work was described in a recent paper in the Proceedings of the National Academy of Sciences, and was performed in collaboration with Harvard faculty members Mikhail (Misha) Lukin and Hongkun Park.

"The idea of using NV centers for sensing neuron magnetic fields began with the initial work of Ron Walsworth and Misha Lukin about 10 years ago, but for a long time our back-of-the-envelope calculations made it seem that the fields would be too small to detect, and the technology wasn't there yet," said Jennifer Schloss, a Ph.D. student and co-author of the study.

"This paper is really the first step to show that measuring magnetic fields from individual neurons can be done in a scalable way," said Ph.D. student and fellow co-author Matthew Turner. "We wanted to be able to model the signal characteristics, and say, based on theory, 'This is what we expect to see.' Our experimental results were consistent with these expectations. This predictive ability is important for understanding more complicated neuronal networks."

At the heart of the system developed by Schloss and Turner, together with postdoctoral scientist John Barry, is a tiny—just 4-by-4 millimeters square and half a millimeter thick—wafer of diamond impregnated with trillions of NV centers.

The system works, Schloss and Turner explained, because the magnetic fields generated by signals traveling in a neuron interact with the electrons in the NV centers, subtly changing their quantum "spin" state. The diamond wafer is bathed in microwaves, which put the NV electrons in a mixture of two spin states. A neuron magnetic field then causes a change in the fraction of spins in one of the two states. Using a laser constrained to the diamond, the researchers can detect this fraction, reading out the neural signal as an optical image, without light entering the biological sample.

In addition to demonstrating that the system works for dissected neurons, Schloss, Turner, and Barry showed that NV sensors could be used to sense neural activity in live, intact marine worms.

"We realized we could just put the whole animal on the sensor and still detect the signal, so it's completely noninvasive," Turner said. "That's one reason using magnetic fields offers an advantage over other methods. If you measure voltage- or light-based signals in traditional ways, biological tissue can distort those signals. With magnetic fields, though the signal gets smaller with stand-off distance, the information is preserved."

Schloss, Turner, and Barry were also able to show that the neural signals traveled more slowly from the worm's tail to its head than from head to tail, and their magnetic field measurements matched predictions of this difference in conduction velocity.

While the study proves that NV centers can be used to detect neural signals, Turner said the initial experiments were designed to tackle the most accessible approach to the problem, using robust neurons that produce especially large magnetic fields. The team is already working to further refine the system, with an eye toward improving its sensitivity and pursuing applications to frontier problems in neuroscience. To sense signals from smaller mammalian neurons, Schloss explained, they intend to implement a pulsed magnetometry scheme to realize up to 300 times better sensitivity per volume. The next step, said Turner, is implementing a high-resolution imaging system in hopes of producing real-time, optical images of neurons as they fire.

"We're looking at imaging networks of neurons over long durations, up to days," said Schloss. "We hope to use this to understand not just the physical connectivity between neurons, but the functional connectivity—how the signals actually propagate to inform how neural circuits operate over the long term."

"No tool that exists today can tell us everything we want to know about neuronal activity or be applied to all systems of interest," Turner said. "This quantum diamond technology lays out a new direction for addressing some of these challenges. Imaging neuron magnetic fields is a largely unexplored area due to previous technological limitations."

The hope, Schloss said, is that the tool might one day find a home in the labs of biomedical researchers or anyone interested in understanding brain activity.

"We want to understand the brain from the single-neuron level all the way up, so we envision that this could become a tool useful both in biophysics labs and in medical studies," she said. "It's noninvasive and fast, and the optical readout could allow for a variety of applications, from studying neurodegenerative diseases to monitoring drug delivery in real time."

Walsworth credits the leadership of Josh Sanes, the Paul J. Finnegan Family Director of the center, and Kenneth Blum, executive director, for enabling this biological application of quantum diamond technology. "Center for Brain Science leadership provided the essential lab space and a welcoming, interdisciplinary community," he said. "This special environment allows physical scientists and engineers to translate quantum technology into neuroscience." [25]

Rice, Baylor team sets new mark for 'deep learning'

Neuroscience and artificial intelligence experts from Rice University and Baylor College of Medicine have taken inspiration from the human brain in creating a new "deep learning" method that enables computers to learn about the visual world largely on their own, much as human babies do.

In tests, the group's "deep rendering mixture model" largely taught itself how to distinguish handwritten digits using a standard dataset of 10,000 digits written by federal employees and high school students. In results presented this month at the Neural Information Processing Systems (NIPS) conference in Barcelona, Spain, the researchers described how they trained their algorithm by giving it just 10 correct examples of each handwritten digit between zero and nine and then presenting it with several thousand more examples that it used to further teach itself. In tests, the algorithm was more accurate at correctly distinguishing handwritten digits than almost all previous algorithms that were trained with thousands of correct examples of each digit.

"In deep-learning parlance, our system uses a method known as semisupervised learning," said lead researcher Ankit Patel, an assistant professor with joint appointments in neuroscience at Baylor and electrical and computer engineering at Rice. "The most successful efforts in this area have used a different technique called supervised learning, where the machine is trained with thousands of examples: This is a one. This is a two.

"Humans don't learn that way," Patel said. "When babies learn to see during their first year, they get very little input about what things are. Parents may label a few things: 'Bottle. Chair. Momma.' But the baby can't even understand spoken words at that point. It's learning mostly unsupervised via some interaction with the world."

Patel said he and graduate student Tan Nguyen, a co-author on the new study, set out to design a semisupervised learning system for visual data that didn't require much "hand-holding" in the form of training examples. For instance, neural networks that use supervised learning would typically be given hundreds or even thousands of training examples of handwritten digits before they would be tested on the database of 10,000 handwritten digits in the Mixed National Institute of Standards and Technology (MNIST) database.

The semisupervised Rice-Baylor algorithm is a "convolutional neural network," a piece of software made up of layers of artificial neurons whose design was inspired by biological neurons. These artificial neurons, or processing units, are organized in layers, and the first layer scans an image and does simple tasks like searching for edges and color changes. The second layer examines the output from the first layer and searches for more complex patterns. Mathematically, this nested method of looking for patterns within patterns within patterns is referred to as a nonlinear process.

"It's essentially a very simple visual cortex," Patel said of the convolutional neural net. "You give it an image, and each layer processes the image a little bit more and understands it in a deeper way, and by the last layer, you've got a really deep and abstract understanding of the image. Every self-driving car right now has convolutional neural nets in it because they are currently the best for vision."

Like human brains, neural networks start out as blank slates and become fully formed as they interact with the world. For example, each processing unit in a convolutional net starts the same and becomes specialized over time as they are exposed to visual stimuli.

"Edges are very important," Nguyen said. "Many of the lower layer neurons tend to become edge detectors. They're looking for patterns that are both very common and very important for visual interpretation, and each one trains itself to look for a specific pattern, like a 45-degree edge or a 30-degree red-to-blue transition.

"When they detect their particular pattern, they become excited and pass that on to the next layer up, which looks for patterns in their patterns, and so on," he said. "The number of times you do a nonlinear transformation is essentially the depth of the network, and depth governs power. The deeper a network is, the more stuff it's able to disentangle. At the deeper layers, units are looking for very abstract things like eyeballs or vertical grating patterns or a school bus."

Nguyen began working with Patel in January as the latter began his tenure-track academic career at Rice and Baylor. Patel had already spent more than a decade studying and applying machine learning in jobs ranging from high-volume commodities training to strategic missile defense, and he'd just wrapped up a four-year postdoctoral stint in the lab of Rice's Richard Baraniuk, another co-author on the new study. In late 2015, Baraniuk, Patel and Nguyen published the first theoretical framework that could both derive the exact structure of convolutional neural networks and provide principled solutions to alleviate some of their limitations.

Baraniuk said a solid theoretical understanding is vital for designing convolutional nets that go beyond today's state-of-the-art.

"Understanding video images is a great example," Baraniuk said. "If I am looking at a video, frame by frame by frame, and I want to understand all the objects and how they're moving and so on, that is a huge challenge. Imagine how long it would take to label every object in every frame of a video. No one has time for that. And in order for a machine to understand what it's seeing in a video, it has to understand what objects are, the concept of three-dimensional space and a whole bunch of other really complicated stuff. We humans learn those things on our own and take them for granted, but they are totally missing in today's artificial neural networks."

Patel said the theory of artificial neural networks, which was refined in the NIPS paper, could ultimately help neuroscientists better understand the workings of the human brain.

"There seem to be some similarities about how the visual cortex represents the world and how convolutional nets represent the world, but they also differ greatly," Patel said. "What the brain is doing may be related, but it's still very different. And the key thing we know about the brain is that it mostly learns unsupervised.

"What I and my neuroscientist colleagues are trying to figure out is, What is the semisupervised learning algorithm that's being implemented by the neural circuits in the visual cortex? and How is that related to our theory of deep learning?" he said. "Can we use our theory to help elucidate what the brain is doing? Because the way the brain is doing it is far superior to any neural network that we've designed." [24]

Consciousness and Entropy

What is the relationship of consciousness to the neurological activity of the brain? Does the brain behave differently when a person is fully conscious, when they are asleep, or when they are undergoing an epileptic seizure? A recent study by R. Guevara Erra, D. M. Mateos, R. Wennberg, J.L. Perez Velazquez of the University of Toronto, suggests that consciousness if correlated to a maximum number of neurological connections. In thermodynamics, this quantity, describing the complexity of a system, is entropy. In their paper, published in Physics Letters, they write:

It has been said that complexity lies between order and disorder. In the case of brain activity, and physiology in general, complexity issues are being considered with increased emphasis. We sought to identify features of brain organization that are optimal for sensory processing, and that may guide the emergence of cognition and consciousness, by analysing neurophysiological recordings in conscious and unconscious states. We find a surprisingly simple result: normal wakeful states are characterised by the greatest number of possible configurations of interactions between brain networks, representing highest entropy values. Therefore, the information content is larger in the network associated to conscious states, suggesting that consciousness could be the result of an optimization of information processing. These findings encapsulate three main current theories of cognition, as discussed in the text, and more specifically the conceptualization of consciousness in terms of brain complexity. We hope our study represents the preliminary attempt at finding organising principles of brain function that will help to guide in a more formal sense inquiry into how consciousness arises from the organization of matter.

The authors are rightly cautious about the significance of the correlation. Just because A and B are correlated, does not mean that A causes B. However the recognition that a phenomenon such as entropy may describe consciousness opens a new direction for consciousness research. [23]

Consciousness is tied to 'entropy', say researchers

Consciousness appears to arise naturally as a result of a brain maximizing its information content. So says a group of scientists in Canada and France, which has studied how the electrical activity in people's brains varies according to individuals' conscious states. The researchers find that normal waking states are associated with maximum values of what they call a brain's "entropy".

Statistical mechanics is very good at explaining the macroscopic thermodynamic properties of physical systems in terms of the behaviour of those systems' microscopic constituent particles. Emboldened by this success, physicists have increasingly been trying to do a similar thing with the brain: namely, using statistical mechanics to model networks of neurons. Key to this has been the study of synchronization – how the electrical activity of one set of neurons can oscillate in phase with that of another set. Synchronization in turn implies that those sets of neurons are physically tied to one another, just as oscillating physical systems, such as pendulums, become synchronized when they are connected together.

The latest work stems from the observation that consciousness, or at least the proper functioning of brains, is associated not with high or even low degrees of synchronicity between neurons but by middling amounts. Jose Luis Perez Velazquez, a biochemist at the University of Toronto, and colleagues hypothesized that what is maximized during consciousness is not connectivity itself but the number of different ways that a certain degree of connectivity can be achieved.

Many ways of connecting

Perez Velazquez's colleague Ramon Guevarra Erra, a physicist at the Paris Descartes University, points out that there is only one way to connect each set of neurons in a network with every other set, just as there is only one way to have no connections at all. In contrast, he notes, there are many different ways that an intermediate medium-sized number of connections can be arranged.

To put their hypothesis to the test, the researchers used data previously collected by Perez Velazquez showing electric- and magnetic-field emissions from the brains of nine people, seven of whom suffered from epilepsy. With emissions recorded at dozens of places across the subjects' scalps, the researchers analysed every possible pairing of these data "channels" to establish whether the emissions in each case were in phase with one another. They added up the number of synchronized pairs and plugged that figure along with the total number of all possible pairings into a fairly straightforward statistical formula to work out how many different brain configurations that level of synchronicity yields. They then took the logarithm of that number to establish the brain's entropy.

The data were analysed in two parts. In one, they compared the emissions from four of the epileptic patients when undergoing a seizure and when in a normal "alert" state. In the second, they compared emissions from the other five individuals when sleeping and when awake. In both cases, the bottom line was the same: subjects' brains display higher entropy, or a higher value of a similar quantity known as Lempel–Ziv (LZ) complexity, when in a fully conscious state.

Varying results

Guevarra Erra admits that the results are not watertight. Indeed, the LZ complexity of one of the four epileptic patients in the first analysis showed no change between seizure and alert states (although that person did remain conscious during part of the seizure). In another individual, LZ complexity actually increased in the second analysis while that person was asleep. Guevarra Erra says that he and his colleagues didn't carry out a statistical analysis of their results in part because of the "very heterogeneous" nature of those results. But he nevertheless remains "highly confident" that the correlations they have identified are real, particularly, he argues, because they were seen in "two very different sets of data".

Peter McClintock, a physicist who works on nonlinear dynamics at Lancaster University in the UK, describes the research as "intriguing" but says that the consciousness–entropy correlation should be confirmed using a larger number of subjects. He also suggests investigating "what happens in other brain states where consciousness is altered", such as anaesthesia.

Emergent property

Perez Velazquez and colleagues argue that consciousness could simply be an "emergent property" of a system – the brain – that seeks to maximize information exchange and therefore entropy, since doing so aids the survival of the brain's bearer by allowing them to better model their environment. On the question of entropy, however, Guevarra Erra is cautious. He says that personally he would like to have a better understanding of the physical processes taking place in the brain before employing the label "entropy", explaining that Perez Velazquez was keen to use the term in their paper. One option, he says, would be to carry out fresh experiments that measure thermodynamic quantities in subjects' brains. He notes, for example, that magnetic resonance imaging can be used to measure oxygenation, which is directly related to metabolism and therefore to the generation of heat.

Guevarra Erra adds that he would like to extend their investigations beyond the hospital to cover more subtle but general cognitive behaviour. The idea would be to monitor a person's changing brain activity as they focus on carrying out a specific task, such as discriminating between musical tones or trying to find their way round a labyrinth. This, he says, should help to establish whether varying "entropy" correlates with degree of awareness as well as simply with the presence or absence of consciousness.

A paper describing the work will be published in Physical Review E and is also available on arXiv. [22]

A new study looks for the cortical conscious network

New research published in the New Journal of Physics tries to decompose the structural layers of the cortical network to different hierarchies enabling to identify the network's nucleus, from which our consciousness could emerge.

The brain is a very complex network, with approximately 100 billion neurons and 100 trillion synapses between the neurons. In order to cope with its enormous complexity and to understand how brain function eventually creates the conscious mind, science uses advanced mathematical tools. Ultimately, scientists want to understand how a global phenomenon such as consciousness can emerge from our neuronal network.

A team of physicists from Bar Ilan University in Israel led by Professor Shlomo Havlin and Professor Reuven Cohen used network theory in order to deal with this complexity and to determine how the structure of the human cortical network can support complex data integration and conscious activity. The gray area of the human cortex, the neuron cell bodies, were scanned with MRI imaging and used to form 1000 nodes in the cortical network. The white matter of the human cortex, the neuron bundles, were scanned with DTI imaging, forming 15,000 links or edges that connected the network's nodes. In the end of this process, their network was an approximation of the structure of the human cortex.

Previous studies have shown that the human cortex is a network with small world properties, which means that it has many local structures and some shortcuts from global structures that connect faraway areas (similar to the difference between local buses and cross-country trains). The cortex also has many hubs, which are nodes that have a high number of links (like central stations), that are also strongly interconnected between themselves, making it easy to travel between the brain's information highways.

Nir Lahav, the lead author of the study, says, "In order to examine how the structure of the network can support global emerging phenomena like consciousness, we applied a network analysis called K-shell decomposition. This analysis takes into account the connectivity profile of each node, making it easy to uncover different neighborhoods of connections in the cortical network, which we called shells."

The most connected neighborhood in the network is termed the network's nucleus. Nir says, "In the process, we peel off different shells of the network to get the most connected area of the network, the nucleus. Until today, scientists were only interested in the network's nucleus, but we found that these different shells can hold important information about how the brain integrates information from the local levels of each node to the entire global network. For the first time, we could build a comprehensive topological model of the cortex."

This topological model reveals that the network's nucleus includes 20 percent of all nodes and that the remaining 80 percent are strongly connected across all of the shells. Interestingly, comparing this topology to that of other networks, such as the internet, noticeable differences are apparent. For instance, in internet network topology, almost 25 percent of the nodes are isolated, meaning they don't connect to any other shells but the nucleus. In the cortical network, however, there are hardly any isolated nodes. It seems that the cortex is much more connected and efficient than the internet.

Looking at all the shells of the cortical network, the authors were able to define the network's hierarchical structure and essentially model how information flows within the network. The structure revealed how shells of low connectivity are nodes that typically perform specific functions like face recognition. From there, the data is transferred to higher, more connected shells that enable additional data integration. This reveals regions of the executive network and working memory. With these areas, researchers can focus on task performance, for example.

The integrated information then 'travels' to the most connected neighborhood of nodes, the nucleus, which spans across several regions of the cortex. According to Nir, "It's an interconnected collective which is densely linked with itself and can perform global functions due to its great number of global structures, which are widespread across the brain."

Which global function might the nucleus serve? The authors suggest the answer is no less than consciousness itself.

"The connection between brain activity and consciousness is still a great mystery," says Nir. The main hypothesis today is that in order to create conscious activity, the brain must integrate relevant information from multiple areas of the network. According to this theory, led by Professor Giulio Tononi from the University of Wisconsin, if the level of integrated information crosses a certain limit, a new and emergent state is entered—consciousness. This model suggests that consciousness depends on both information integration and information segregation. Loosely speaking, consciousness is generated by a "central" network structure with a high capacity for information integration, with the contribution of sub-networks that contain specific and segregated information without being part of the central structure. In other words, certain parts of the brain are more involved than others in the conscious complex of the brain, yet other connected parts still contribute, working quietly outside the conscious complex.

The authors demonstrate how the nucleus and the shells satisfy all of the requirements of these recent consciousness theories. The shells calculate and contribute to data integration without actually being part of the conscious complex, while the nucleus receives relevant information from all other hierarchies and integrates it to a unified function using its global interconnected structure. The nucleus could thus be this conscious complex, serving as a platform for consciousness to emerge from the network activity.

When the authors examined the different regions that make up the nucleus, they revealed that, indeed, these regions have been previously associated with conscious activities. For example, structures within the brain's midline, which form the majority of the network's nucleus, were found to be associated with the stream of consciousness, and some researchers, like Professor Georg Northoff from the University of Ottawa, have suggested that these regions are involved with creating our sense of self.

"Now, we need to use this analysis on the whole brain, and not only on the cortex in order to reveal a more exact model of the brain's hierarchy, and later on understand what, exactly, are the neuronal dynamics that lead to such global integration and ultimately consciousness." [21]

Network theory sheds new light on origins of consciousness

Where in your brain do you exist? Is your awareness of the world around you and of yourself as an individual the result of specific, focused changes in your brain, or does that awareness come from a broad network of neural activity? How does your brain produce awareness?

Vanderbilt University researchers took a significant step toward answering these longstanding questions with a recent brain imaging study, in which they discovered global changes in how brain areas communicate with one another during awareness. Their findings, which were published March 9 in the Proceedings of the National Academy of Sciences, challenge previous theories that hypothesized much more restricted changes were responsible for producing awareness.

"Identifying the fingerprints of consciousness in humans would be a significant advancement for basic and medical research, let alone its philosophical implications on the underpinnings of the human experience," said René Marois, professor and chair of psychology at Vanderbilt University and senior author of the study. "Many of the cognitive deficits observed in various neurological diseases may ultimately stem from changes in how information is communicated throughout the brain."

Using graph theory, a branch of mathematics concerned with explaining the interactive links between members of a complex network, such as social networks or flight routes, the researchers aimed to characterize how connections between the various parts of the brain were related to awareness.

"With graph theory, one can ask questions about how efficiently the transportation networks in the United States and Europe are connected via transportation hubs like LaGuardia Airport in New York," Douglass Godwin, graduate student and lead author on the research, said. "We can ask those same questions about brain networks and hubs of neural communication."

Modern theories of the neural basis of consciousness fall generally into two camps: focal and global. Focal theories contend there are specific areas of the brain that are critical for generating consciousness, while global theories argue consciousness arises from large-scale brain changes in activity. This study applied graph theory analysis to adjudicate between these theories.

The researchers recruited 24 members of the university community to participate in a functional magnetic resonance imaging (fMRI) experiment. While in the fMRI scanner, participants were asked to detect a disk that was briefly flashed on a screen. In each trial, participants responded whether they were able to detect the target disk and how much confidence they had in their answer. Experimenters then compared the results of the high-confidence trials during which the target was detected to the trials when it was missed by participants. These were treated as "aware" and "unaware" trials, respectively.

Comparison of aware and unaware trials using conventional fMRI analyses that assess the amplitude of brain activity showed a pattern of results typical of similar studies, with only a few areas of the brain showing more activity during detection of the target than when participants missed seeing it. The present study, however, was interested not simply in what regions might be more activated with awareness, but how they communicate with one another.

Unlike the focal results seen using more conventional analysis methods, the results via this network approach pointed toward a different conclusion. No one area or network of areas of the brain stood out as particularly more connected during awareness of the target; the whole brain appeared to become functionally more connected following reports of awareness.

"We know there are numerous brain networks that control distinct cognitive functions such as attention, language and control, with each node of a network densely interconnected with other nodes of the same network, but not with other networks," Marois said. "Consciousness appears to break down the modularity of these networks, as we observed a broad increase in functional connectivity between these networks with awareness."

The research suggests that consciousness is likely a product of this widespread communication, and that we can only report things that we have seen once they are being represented in the brain in this manner. Thus, no one part of the brain is truly the "seat of the soul," as René Descartes once wrote in a hypothesis about the pineal gland, but rather, consciousness appears to be an emergent property of how information that needs to be acted upon gets propagated throughout the brain.

"We take for granted how unified our experience of the world is. We don't experience separate visual and auditory worlds, it's all integrated into a single conscious experience," Godwin said. "This widespread cross-network communication makes sense as a mechanism by which consciousness gets integrated into that singular world." [20]

Neuromorphic computing mimics important brain feature

When you hear a sound, only some of the neurons in the auditory cortex of your brain are activated. This is because every auditory neuron is tuned to a certain range of sound, so that each neuron is more sensitive to particular types and levels of sound than others. In a new study, researchers have designed a neuromorphic ("brain-inspired") computing system that mimics this neural selectivity by using artificial level-tuned neurons that preferentially respond to specific types of stimuli.

In the future, level-tuned neurons may help enable neuromorphic computing systems to perform tasks that traditional computers cannot, such as learning from their environment, pattern recognition, and knowledge extraction from big data sources.

The researchers, Angeliki Pantazi et al., at IBM Research-Zurich and École Polytechnique Fédérale de Lausanne, both in Switzerland, have published a paper on the new neuromorphic architecture in a recent issue of Nanotechnology.

Like all neuromorphic computing architectures, the proposed system is based on neurons and their synapses, which are the junctions where neurons send signals to each other. In this study, the researchers physically implemented artificial neurons using phase-change materials. These materials have two stable states: a crystalline, low-resistivity state and an amorphous, high-resistivity state. Just as in traditional computing, the states can be switched by the application of a voltage.

When the neuron's conductance reaches a certain threshold, the neuron fires.

"We have demonstrated that phase-change-based memristive devices can be used to create artificial neurons and synapses to store and process data," coauthor Evangelos Eleftheriou at IBM Research-Zurich told Phys.org. "A phase-change neuron uses the phase configuration of the phase-change material to represent its internal state, the membrane potential. For the phase-change synapse, the synaptic weight—which is responsible for the plasticity—is encoded by the conductance of the nanodevice."

In this architecture, each neuron is tuned to a specific range, or level. Neurons receive signals from many other neurons, and a level is defined as the cumulative contribution of the sum of these incoming signals.

"We have introduced the biologically inspired architecture of level-tuned neurons that is able to distinguish different patterns in an unsupervised way," Eleftheriou said. "This is important for the development of ultra-dense, scalable and energy-efficient neuromorphic computing."

One of the main advantages of these highly selective level-tuned neurons is their improved learning ability. In neuromorphic computing, learning occurs through repeated incoming signals, which strengthens certain synaptic connections. The researchers showed that level-tuned neurons are very good at learning multiple input patterns, even in the presence of input noise.

"Even a single neuron can be used to detect patterns and to discover correlations in real-time streams of event-based data," Eleftheriou said. "Level-tuned neurons increase the capability of a single-neuron network for discriminating information when multiple patterns appear at the input. Level-tuned neurons, along with the high-speed and low-energy characteristics of their phase-change-based implementation, will be particularly useful for various emerging applications, such as Internet of Things, that collect and analyze large volumes of sensory information and applications to detect patterns in data sources, such as from social media to discover trends, or weather data for real-time forecasts, or healthcare data to detect patterns in diseases, etc."

In the future, the researchers plan to further develop the concept of artificial level-tuned neurons in order to design enhanced large-scale neural networks.

"We will be looking into more complex computational tasks based on artificial spiking neurons and their synapses," Eleftheriou said. "We are interested in studying the scaling potential and applications of such neuromorphic systems in cognitive computing systems." [19]

IBM scientists imitate the functionality of neurons with a phase-change device

IBM scientists have created randomly spiking neurons using phase-change materials to store and process data. This demonstration marks a significant step forward in the development of energy-efficient, ultra-dense integrated neuromorphic technologies for applications in cognitive computing.

Inspired by the way the biological brain functions, scientists have theorized for decades that it should be possible to imitate the versatile computational capabilities of large populations of neurons. However, doing so at densities and with a power budget that would be comparable to those seen in biology has been a significant challenge, until now.

"We have been researching phase-change materials for memory applications for over a decade, and our progress in the past 24 months has been remarkable," said IBM Fellow Evangelos Eleftheriou. "In this period, we have discovered and published new memory techniques, including projected memory, stored 3 bits per cell in phase-change memory for the first time, and now are demonstrating the powerful capabilities of phase-change-based artificial neurons, which can perform various computational primitives such as data-correlation detection and unsupervised learning at high speeds using very little energy."

The artificial neurons designed by IBM scientists in Zurich consist of phase-change materials, including germanium antimony telluride, which exhibit two stable states, an amorphous one (without a clearly defined structure) and a crystalline one (with structure). These materials are the basis of re-writable Blu-ray discs.

However, the artificial neurons do not store digital information; they are analog, just like the synapses and neurons in our biological brain.

In the published demonstration, the team applied a series of electrical pulses to the artificial neurons, which resulted in the progressive crystallization of the phase-change material, ultimately causing the neuron to fire. In neuroscience, this function is known as the integrate-and-fire property of biological neurons. This is the foundation for event-based computation and, in principle, is similar to how our brain triggers a response when we touch something hot.

Exploiting this integrate-and-fire property, even a single neuron can be used to detect patterns and discover correlations in real-time streams of event-based data.

For example, in the Internet of Things, sensors can collect and analyze volumes of weather data collected at the edge for faster forecasts. The artificial neurons could be used to detect patterns in financial transactions to find discrepancies or use data from social media to discover new cultural trends in real time. Large populations of these high-speed, low-energy nano-scale neurons could also be used in neuromorphic coprocessors with co-located memory and processing units.

IBM scientists have organized hundreds of artificial neurons into populations and used them to represent fast and complex signals. Moreover, the artificial neurons have been shown to sustain billions of switching cycles, which would correspond to multiple years of operation at an update frequency of 100 Hz. The energy required for each neuron update was less than five picojoule and the average power less than 120 microwatts—for comparison, 60 million microwatts power a 60 watt lightbulb.

"Populations of stochastic phase-change neurons, combined with other nanoscale computational elements such as artificial synapses, could be a key enabler for the creation of a new generation of extremely dense neuromorphic computing systems," said Tomas Tuma, a co-author of the paper. [18]

Programmable ions set the stage for general-purpose quantum computers

An ion trap with four segmented blade electrodes used to trap a linear chain of atomic ions for quantum information processing. Each ion is addressed optically for individual control and readout using the high optical access of the trap.

Quantum computers promise speedy solutions to some difficult problems, but building large-scale, general-purpose quantum devices is a problem fraught with technical challenges.

To date, many research groups have created small but functional quantum computers. By combining a handful of atoms, electrons or superconducting junctions, researchers now regularly demonstrate quantum effects and run simple quantum algorithms—small programs dedicated to solving particular problems.

But these laboratory devices are often hard-wired to run one program or limited to fixed patterns of interactions between the quantum constituents. Making a quantum computer that can run arbitrary algorithms requires the right kind of physical system and a suite of programming tools. Atomic ions, confined by fields from nearby electrodes, are among the most promising platforms for meeting these needs.

In a paper published as the cover story in Nature on August 4, researchers working with Christopher Monroe, a Fellow of the Joint Quantum Institute and the Joint Center for Quantum Information and Computer Science at the University of Maryland, introduced the first fully programmable and reconfigurable quantum computer module. The new device, dubbed a module because of its potential to connect with copies of itself, takes advantage of the unique properties offered by trapped ions to run any algorithm on five quantum bits, or qubits—the fundamental unit of information in a quantum computer.

"For any computer to be useful, the user should not be required to know what's inside," Monroe says. "Very few people care what their iPhone is actually doing at the physical level. Our experiment brings high-quality quantum bits up to a higher level of functionality by allowing them to be programmed and reconfigured in software."

The new module builds on decades of research into trapping and controlling ions. It uses standard techniques but also introduces novel methods for control and measurement. This includes manipulating many ions at once using an array of tightly-focused laser beams, as well as dedicated detection channels that watch for the glow of each ion.

"These are the kinds of discoveries that the NSF Physics Frontiers Centers program is intended to enable," says Jean Cottam Allen, a program director in the National Science Foundation's physics division. "This work is at the frontier of quantum computing, and it's helping to lay a foundation and bring practical quantum computing closer to being a reality."

The team tested their module on small instances of three problems that quantum computers are known to solve quickly. Having the flexibility to test the module on a variety of problems is a major step forward, says Shantanu Debnath, a graduate student at JQI and the paper's lead author. "By directly connecting any pair of qubits, we can reconfigure the system to implement any algorithm," Debnath says. "While it's just five qubits, we know how to apply the same technique to much larger collections."

At the module's heart, though, is something that's not even quantum: A database stores the best shapes for the laser pulses that drive quantum logic gates, the building blocks of quantum algorithms. Those shapes are calculated ahead of time using a regular computer, and the module uses software to translate an algorithm into the pulses in the database.

Putting the pieces together

Every quantum algorithm consists of three basic ingredients. First, the qubits are prepared in a particular state; second, they undergo a sequence of quantum logic gates; and last, a quantum measurement extracts the algorithm's output.

The module performs these tasks using different colors of laser light. One color prepares the ions using a technique called optical pumping, in which each qubit is illuminated until it sits in the proper quantum energy state. The same laser helps read out the quantum state of each atomic ion at the end of the process. In between, a separate laser strikes the ions to drive quantum logic gates.

These gates are like the switches and transistors that power ordinary computers. Here, lasers push on the ions and couple their internal qubit information to their motion, allowing any two ions in the module to interact via their strong electrical repulsion. Two ions from across the chain notice each other through this electrical interaction, just as raising and releasing one ball in a Newton's cradle transfers energy to the other side.

The re-configurability of the laser beams is a key advantage, Debnath says. "By reducing an algorithm into a series of laser pulses that push on the appropriate ions, we can reconfigure the wiring between these qubits from the outside," he says. "It becomes a software problem, and no other quantum computing architecture has this flexibility."

To test the module, the team ran three different quantum algorithms, including a demonstration of a Quantum Fourier Transform (QFT), which finds how often a given mathematical function repeats. It is a key piece in Shor's quantum factoring algorithm, which would break some of the most widely-used security standards on the internet if run on a big enough quantum computer.

Two of the algorithms ran successfully more than 90% of the time, while the QFT topped out at a 70% success rate. The team says that this is due to residual errors in the pulse-shaped gates as well as systematic errors that accumulate over the course of the computation, neither of which appear fundamentally insurmountable.

They note that the QFT algorithm requires all possible two-qubit gates and should be among the most complicated quantum calculations.

The team believes that eventually more qubits—perhaps as many as 100—could be added to their quantum computer module. It is also possible to link separate modules together, either by physically moving the ions or by using photons to carry information between them.

Although the module has only five qubits, its flexibility allows for programming quantum algorithms that have never been run before, Debnath says. The researchers are now looking to run algorithms on a module with more qubits, including the demonstration of quantum error correction routines as part of a project funded by the Intelligence Advanced Research Projects Activity. [17]

Realizing quantum bits

A research team from Germany, France and Switzerland has realised quantum bits, short qubits, in a new form. One day, they might become the information units of quantum computers.

To date, researchers have realised qubits in the form of individual electrons (aktuell.ruhr-uni-bochum.de/pm2012/pm00090.html.en). However, this led to interferences and rendered the information carriers difficult to programme and read. The group has solved this problem by utilising electron holes as qubits, rather than electrons.

A report has been published in the journal Nature Materials by a team of researchers from Ruhr-Universität Bochum, the University of Basel, and Lyon University; among its contributors were the two Bochum-based researchers Prof Dr Andreas Wieck and Dr Arne Ludwig from the Chair of Applied Solid State Physics. The project was headed by the Swiss researcher Prof Dr Richard Warburton.

Electrons as qubits

In order to realise qubits in the form of electrons, an electron is locked in a tiny semiconductor volume, the so-called quantum dot. The spin turns the electron into a small permanent magnet. Researchers are able to manipulate the spin via an external magnetic field and initiate precession. The direction of the spin is used to code information.

The problem: the nuclear spins of the surrounding atoms also generate magnetic fields, which distort the external magnetic field in a random, unpredictable manner. This, in turn, interferes with programming and reading qubits. Consequently, the team searched for another method. The solution: rather than locking individual electrons in the quantum dot, the team removed specific electrons. Thus, positively charged vacancies were generated in the electron structure, so-called electron holes.

Advantages of electron holes

Electron holes have a spin, too. Researchers can manipulate it via the magnetic field in order to code information. As the holes are positively charged, they are decoupled from the nuclei of the surrounding atoms, which are likewise positively charged. This is why they are virtually immune against the interfering forces of the nuclear spin.

"This is important if we one day want to manufacture reproducible components that are based on quantum bits," explains Andreas Wieck. However, this method is only applicable at low temperatures, as the holes are more likely to be disturbed by warmth than the electrons.

At Ruhr-Universität, researchers are able to generate quantum dots of outstanding quality. The experiment could be conducted thanks to a structural design developed by Arne Ludwig in Basel and subsequently realised at the RUB Department headed by Andreas Wieck. It enabled the researcher to apply not just individual electrons to quantum dots, but also electron holes. Sascha René Valentin, PhD student from Bochum, utilised the technique for the purpose of the current study. [16]

Russian physicists discover a new approach for building quantum computers

Physicists from MIPT and the Russian Quantum Center have developed an easier method to create a universal quantum computer using multilevel quantum systems (qudits), each one of which is able to work with multiple "conventional" quantum elements – qubits.

Professor Vladimir Man'ko, Aleksey Fedorov and Evgeny Kiktenko have published the results of their studies of multilevel quantum systems in a series of papers in Physical Review A, Physics Letters A, and also Quantum Measurements and Quantum Metrology.

"In our studies, we demonstrated that correlations similar to those used for quantum information technologies in composite quantum systems also occur in non-composite systems – systems which we suppose may be easier to work with in certain cases. In our latest paper we proposed a method of using entanglement between internal degrees of freedom of a single eight-level system to implement the protocol of quantum teleportation, which was previously implemented experimentally for a system of three two-level systems," says Vladimir Man'ko.

Quantum computers, which promise to bring about a revolution in computer technology, could be built from elementary processing elements called quantum bits – qubits. While elements of classical computers (bits) can only be in two states (logic zero and logic one), qubits are based on quantum objects that can be in a coherent superposition of two states, which means that they can encode the intermediate states between logic zero and one. When a qubit is measured, the outcome is either a zero or a one with a certain probability (determined by the laws of quantum mechanics).

In a quantum computer, the initial condition of a particular problem is written in the initial state of the qubit system, then the qubits enter into a special interaction (determined by the specific problem). Finally, the user reads the answer to the problem by measuring the final states of the quantum bits.

Quantum computers will be able to solve certain problems that are currently far beyond the reach of even the most powerful classical supercomputers. In cryptography, for example, the time required for a conventional computer to break the RSA algorithm, which is based on the prime factorization of large numbers, would be comparable to the age of the universe. A quantum computer, on the other hand, could solve the problem in a matter of minutes.

However, there is a significant obstacle standing in the way of a quantum revolution – the instability of quantum states. Quantum objects that are used to create qubits – ions, electrons, Josephson junctions etc. can only maintain a certain quantum state for a very short time. However, calculations not only require that qubits maintain their state, but also that they interact with one another. Physicists all over the world are trying to extend the lifespan of qubits. Superconducting qubits used to "survive" only for a few nanoseconds, but now they can be kept for milliseconds before decoherence – which is closer to the time required for calculations.

In a system with dozens or hundreds of qubits, however, the problem is fundamentally more complex.

Man'ko, Fedorov, and Kiktenko began to look at the problem from the other way around – rather than try to maintain the stability of a large qubit system, they tried to increase the dimensions of the systems required for calculations. They are investigating the possibility of using qudits rather than qubits for calculations. Qudits are quantum objects in which the number of possible states (levels) is greater than two (their number is denoted by the letter D). There are qutrits, which have three states; ququarts, which have four states, etc. Algorithms are now actively being studied in which the use of qudits could prove to be more beneficial than using qubits.

"A qudit with four or five levels is able to function as a system of two "ordinary" qubits, and eight levels is enough to imitate a three-qubit system. At first, we saw this as a mathematical equivalence allowing us to obtain new entropic correlations. For example, we obtained the value of mutual information (the measure of correlation) between virtual qubits isolated in a state space of a single four-level system," says Fedorov.

He and his colleagues demonstrated that on one qudit with five levels, created using an artificial atom, it is possible to perform full quantum computations—in particular, the realization of the Deutsch algorithm. This algorithm is designed to test the values of a large number of binary variables.

It can be called the fake coin algorithm: imagine that you have a number of coins, some of which are fake – they have the same image on the obverse and reverse sides. To find these coins using the "classical method", you have to look at both sides. With the Deutsch algorithm, you "merge" the obverse and reverse sides of the coin and you can then see a fake coin by only looking at one side.

The idea of using multilevel systems to emulate multi-qubit processors was proposed earlier in the work of Russian physicists from the Kazan Physical-Technical Institute. To run a two-qubit Deutsch algorithm, for example, they proposed using a nuclear spin of 3/2 with four different states. In recent years, however, experimental progress in creating qudits in superconducting circuits has shown that they have a number of advantages.

However, superconducting circuits require five levels: the last level performs an ancillary role to allow for a complete set of all possible quantum operations.

"We are making significant progress, because in certain physical implementations, it is easier to control multilevel qudits than a system of the corresponding number of qubits, and this means that we are one step closer to creating a full-fledged quantum computer. Multilevel elements offer advantages in other quantum technologies too, such as quantum cryptography," says Fedorov. [15]

Precise atom implants in silicon provide a first step toward practical quantum computers

Sandia National Laboratories has taken a first step toward creating a practical quantum computer, able to handle huge numbers of computations instantaneously.

Here's the recipe:

A "donor" atom propelled by an ion beam is inserted very precisely in microseconds into an industry-standard silicon substrate.

The donor atom—in this case, antimony (Sb) —carries one more electron (five) than a silicon atom (four). Because electrons pair up, the odd Sb electron remains free.

Instruments monitor the free electron to determine if, under pressure from an electromagnetic field, it faces up or down, a property called "spin." Electrons in this role, called qubits, signal "yes" or "no" from the subatomic scale, and so act as the information bearers of a quantum computer.

The ability to precisely place a donor atom in silicon means that it should be possible to insert a second donor atom just far enough away, in the "Goldilocks" zone where communication is neither lost through distance nor muffled by too-close proximity. Sandia will try to do this later this year, said lead researcher Meenakshi Singh, a postdoctoral fellow. Qubits "talking" to each other are the basis of quantum computing circuits.

The successful Sandia first step, reported in Applied Physics Letters, makes use of electromagnetic forces provided by a neighboring quantum dot pre-embedded in the silicon. The quantum dot—itself a tiny sea of electrons—contains a variety of energy levels and operates like a transistor to block or pass the qubit.

If an available dot energy level is compatible with the electron, the transistor gate is effectively open and the electron jumps into the dot. If not, the qubit stays put. That action is reported back to the surface by a photodiode sensor sensitive to current flows rather than photon movement. Because of the multiple "gates" in the quantum dot, many qubits at different energy levels could pass through the transistor, or be denied passage, theoretically making possible an extremely wide array of information processing.

"Our method is promising because, since it reads the electron's spin rather than its electrical charge, its information is not swallowed by background static and instead remains coherent for a relatively long time," Singh said. "Also, we use silicon as our basic material, for which commercial fabrication technologies are already developed, rather than employing superconducting components that can be expensive."

A third unique quality of the Sandia method is the precise and rapid placement of donor atoms exactly where they should be, placed in microseconds within nanometers of their target, instead of a buckshot approach that places qubits only where they statistically average to Goldilocks distances.

While components of this experiment have been demonstrated before, this is the first time all have worked together on a single chip, with researchers knowing accurately the vertical and horizontal placement of each qubit, instead of mere statistical approximations.

Sandia researcher and paper author Mike Lilly expects "the Sandia technique will allow fabrication of more complicated multi-qubit structures and do so at higher yield than existing donor implant approaches."

Components of the successful silicon device were fabricated in Sandia's Microsystems and Engineering Sciences Application (MESA) facility. The donor atoms were placed at Sandia's Ion Beam Laboratory. Experiment measurements were made at the Sandia/Los Alamos Center for Integrated Nanotechnologies, a user facility supported by DOE's Office of Basic Energy Sciences.

The method in its entirety is straightforward but requires a range of technical expertise and machinery, Singh said. "We used ion beams, silicon fabrication facilities, low-temperature measurements and simulations. It's hard to find a non-commercial place outside of a national lab that can do all of this." [14]

Team demonstrates large-scale technique to produce quantum dots

A method to produce significant amounts of semiconducting nanoparticles for light-emitting displays, sensors, solar panels and biomedical applications has gained momentum with a demonstration by researchers at the Department of Energy's Oak Ridge National Laboratory.

While zinc sulfide nanoparticles - a type of quantum dot that is a semiconductor - have many potential applications, high cost and limited availability have been obstacles to their widespread use. That could change, however, because of a scalable ORNL technique outlined in a paper published in Applied Microbiology and Biotechnology.

Unlike conventional inorganic approaches that use expensive precursors, toxic chemicals, high temperatures and high pressures, a team led by ORNL's Ji-Won Moon used bacteria fed by inexpensive sugar at a temperature of 150 degrees Fahrenheit in 25- and 250-gallon reactors. Ultimately, the team produced about three-fourths of a pound of zinc sulfide nanoparticles - without process optimization, leaving room for even higher yields.

The ORNL biomanufacturing technique is based on a platform technology that can also produce nanometer-size semiconducting materials as well as magnetic, photovoltaic, catalytic and phosphor materials. Unlike most biological synthesis technologies that occur inside the cell, ORNL's biomanufactured quantum dot synthesis occurs outside of the cells. As a result, the nanomaterials are produced as loose particles that are easy to separate through simple washing and centrifuging.

The results are encouraging, according to Moon, who also noted that the ORNL approach reduces production costs by approximately 90 percent compared to other methods.

"Since biomanufacturing can control the quantum dot diameter, it is possible to produce a wide range of specifically tuned semiconducting nanomaterials, making them attractive for a variety of applications that include electronics, displays, solar cells, computer memory, energy storage, printed electronics and bio-imaging," Moon said.

Successful biomanufacturing of light-emitting or semiconducting nanoparticles requires the ability to control material synthesis at the nanometer scale with sufficiently high reliability, reproducibility and yield to be cost effective. With the ORNL approach, Moon said that goal has been achieved.

Researchers envision their quantum dots being used initially in buffer layers of photovoltaic cells and other thin film-based devices that can benefit from their electro-optical properties as light-emitting materials. [13]

Superfast light source made from artificial atom

All light sources work by absorbing energy – for example, from an electric current – and emit energy as light. But the energy can also be lost as heat and it is therefore important that the light sources emit the light as quickly as possible, before the energy is lost as heat. Superfast light sources can be used, for example, in laser lights, LED lights and in single-photon light sources for quantum technology. New research results from the Niels Bohr Institute show that light sources can be made much faster by using a principle that was predicted theoretically in 1954. The results are published in the scientific journal, Physical Review Letters.

Researchers at the Niels Bohr Institute are working with quantum dots, which are a kind of artificial atom that can be incorporated into optical chips. In a quantum dot, an electron can be excited (i.e. jump up), for example, by shining a light on it with a laser and the electron leaves a 'hole'. The stronger the interaction between light and matter, the faster the electron decays back into the hole and the faster the light is emitted.

But the interaction between light and matter is naturally very weak and it makes the light sources very slow to emit light and this can reduce energy efficiency.

Already in 1954, the physicist Robert Dicke predicted that the interaction between light and matter could be increased by having a number of atoms that 'share' the excited state in a quantum superposition.

Quantum speed up

Demonstrating this effect has been challinging so far because the atoms either come so close together that they bump into each other or they are so far apart that the quantum speed up does not work. Researchers at the Niels Bohr Institute have now finally demonstrated the effect experimentally, but in an entirely different physical system than Dicke had in mind. They have shown this so-called superradiance for photons emitted from a single quantum dot.

"We have developed a quantum dot so that it behaves as if it was comprised of five quantum dots, which means that the light is five times stronger. This is due to the attraction between the electron and the hole. But what is special is that the quantum dot still only emits a single photon at a time. It is an outstanding single-photon source," says Søren Stobbe, who is an associate professor in the Quantum Photonic research group at the Niels Bohr Institute at the University of Copenhagen and led the project. The experiment was carried out in collaboration with Professor David Ritchie's research group at the University of Cambridge, who have made the quantum dots.

Petru Tighineanu, a postdoc in the Quantum Photonics research group at the Niels Bohr Institute, has carried out the experiments and he explains the effect as such, that the atoms are very small and light is very 'big' because of its long wavelength, so the light almost cannot 'see' the atoms – like a lorry that is driving on a road and does not notice a small pebble. But if many pebbles become a larger stone, the lorry will be able to register it and then the interaction becomes much more dramatic. In the same way, light interacts much more strongly with the quantum dot if the quantum dot contains the special superradiant quantum state, which makes it look much bigger.

Increasing the light-matter interaction

"The increased light-matter interaction makes the quantum dots more robust in regards to the disturbances that are found in all materials, for example, acoustic oscillations. It helps to make the photons more uniform and is important for how large you can build future quantum computers," says Søren Stobbe.

He adds that it is actually the temperature, which is only a few degrees above absolute zero, that limits how fast the light emissions can remain in their current experiments. In the long term, they will study the quantum dots at even lower temperatures, where the effects could be very dramatic. [12]

Single-photon source is efficient and indistinguishable

Devices that emit one – and only one – photon on demand play a central role in light-based quantum-information systems. Each photon must also be emitted in the same quantum state, which makes each photon indistinguishable from all the others. This is important because the quantum state of the photon is used to carry a quantum bit (qubit) of information.

Quantum dots are tiny pieces of semiconductor that show great promise as single-photon sources. When a laser pulse is fired at a quantum dot, an electron is excited between two distinct energy levels. The excited state then decays to create a single photon with a very specific energy. However, this process can involve other electron excitations that result in the emission of photons with a wide range of energies – photons that are therefore not indistinguishable.

Exciting dots

This problem can be solved by exciting the quantum dot with a pulse of light at the same energy as the emitted photon. This is called resonance fluorescence, and has been used to create devices that are very good at producing indistinguishable single photons. However, this process is inefficient, and only produces a photon about 6% of the time.

Now, Chaoyang Lu, Jian-Wei Pan and colleagues at the University of Science and Technology of China have joined forces with researchers in Denmark, Germany and the UK to create a resonance-fluorescence-based source that emits a photon 66% of the time when it is prompted by a laser pulse. Of these photons, 99.1% are solo and 98.5% are in indistinguishable quantum states – with both figures of merit being suitable for applications in quantum-information systems.

Lu told physicsworld.com that nearly all of the laser pulses that strike the source produce a photon, but about 34% of these photons are unable to escape the device. The device was operated at a laser-pulse frequency of 81 MHz and a pulse power of 24 nW, which is a much lower power requirement than other quantum-dot-based sources.

Quantum sandwich

The factor-of-ten improvement in efficiency was achieved by sandwiching a quantum dot in the centre of a "micropillar" created by stacking 40 disc-like layers (see figure). Each layer is a "distributed Bragg reflector", which is a pair of mirrors that together have a thickness of one quarter the wavelength of the emitted photons.

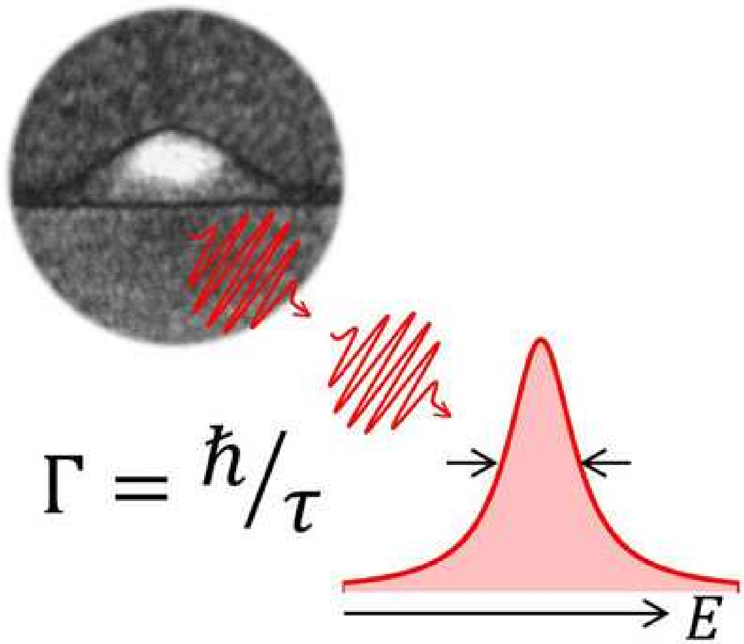
The micropillar is about 2.5 µm in diameter and about 10 µm tall, and it allowed the team to harness the "Purcell effect", whereby the rate of fluorescence is increased significantly when the emitter is placed in a resonant cavity.

Lu says that the team is already thinking about how the photon sources could be used to perform boson sampling (see "'Boson sampling' offers shortcut to quantum computing"). This involves a network of beam splitters that converts one set of photons arriving at a number of parallel input ports into a second set leaving via a number of parallel outputs. The "result" of the computation is the probability that a certain input configuration will lead to a certain output. This result cannot be easily calculated using a conventional computer, and this has led some physicists to suggest that boson sampling could be used to solve practical problems that would take classical computers vast amounts of time to solve.

Other possible applications for the source are the quantum teleportation of three properties of a quantum system – the current record is two properties and is held by Lu and Pan – or quantum cryptography.

The research is described in Physical Review Letters. [11]

Semiconductor quantum dots as ideal single-photon source



A single-photon source never emits two or more photons at the same time. Single photons are important in the field of quantum information technology where, for example, they are used in quantum computers. Alongside the brightness and robustness of the light source, the indistinguishability of the photons is especially crucial. In particular, this means that all photons must be the same color. Creating such a source of identical single photons has proven very difficult in the past.

However, quantum dots made of semiconductor materials are offering new hope. A quantum dot is a collection of a few hundred thousand atoms that can form itself into a semiconductor under certain conditions. Single electrons can be captured in these quantum dots and locked into a very small area. An individual photon is emitted when an engineered quantum state collapses.

Noise in the semiconductor

A team of scientists led by Dr. Andreas Kuhlmann and Prof. Richard J. Warburton from the University of Basel have already shown in past publications that the indistinguishability of the photons is reduced by the fluctuating nuclear spin of the quantum dot atoms. For the first time ever, the scientists have managed to control the nuclear spin to such an extent that even photons sent out at very large intervals are the same color.

Quantum cryptography and quantum communication are two potential areas of application for single-photon sources. These technologies could make it possible to perform calculations that are far beyond the capabilities of today's computers. [10]

How to Win at Bridge Using Quantum Physics

Contract bridge is the chess of card games. You might know it as some stuffy old game your grandparents play, but it requires major brainpower, and preferably an obsession with rules and strategy. So how to make it even geekier? Throw in some quantum mechanics to try to gain a competitive advantage. The idea here is to use the quantum magic of entangled photons–which are essentially twins, sharing every property–to transmit two bits of information to your bridge partner for the price of one. Understanding how to do this is not an easy task, but it will help elucidate some basic building blocks of quantum information theory. It's also kind of fun to consider whether or not such tactics could ever be allowed in professional sports. [6]

Quantum Information

In quantum mechanics, quantum information is physical information that is held in the "state" of a quantum system. The most popular unit of quantum information is the qubit, a two-level quantum system. However, unlike classical digital states (which are discrete), a two-state quantum system can actually be in a superposition of the two states at any given time.

Quantum information differs from classical information in several respects, among which we note the following:

However, despite this, the amount of information that can be retrieved in a single qubit is equal to one bit. It is in the processing of information (quantum computation) that a difference occurs.

The ability to manipulate quantum information enables us to perform tasks that would be unachievable in a classical context, such as unconditionally secure transmission of information. Quantum information processing is the most general field that is concerned with quantum information. There are certain tasks which classical computers cannot perform "efficiently" (that is, in polynomial time) according to any known algorithm. However, a quantum computer can compute the answer to some of these problems in polynomial time; one well-known example of this is Shor's factoring algorithm. Other algorithms can speed up a task less dramatically - for example, Grover's search algorithm which gives a quadratic speed-up over the best possible classical algorithm.

Quantum information, and changes in quantum information, can be quantitatively measured by using an analogue of Shannon entropy. Given a statistical ensemble of quantum mechanical systems with the density matrix S, it is given by.

Many of the same entropy measures in classical information theory can also be generalized to the quantum case, such as the conditional quantum entropy. [7]

Heralded Qubit Transfer

Optical photons would be ideal carriers to transfer quantum information over large distances. Researchers envisage a network where information is processed in certain nodes and transferred between them via photons. However, inherent losses in long-distance networks mean that the information transfer is subject to probabilistic errors, making it hard to know whether the transfer of a qubit of information has been successful. Now Gerhard Rempe and colleagues from the Max Planck Institute for Quantum Optics in Germany have developed a new protocol that solves this problem through a strategy that "heralds" the accurate transfer of quantum information at a network node.

The method developed by the researchers involves transferring a photonic qubit to an atomic qubit trapped inside an optical cavity. The photon-atom quantum information transfer is initiated via a quantum "logic-gate" operation, performed by reflecting the photon from the atom-cavity system, which creates an entangled atom-photon state. The detection of the reflected photon then collapses the atom into a definite state. This state can be one of two possibilities, depending on the photonic state detected: Either the atom is in the initial qubit state encoded in the photon and the transfer process is complete, or the atom is in a rotated version of this state. The authors were able to show that the roles of the atom and photon could be reversed. Their method could thus be used as a quantum memory that stores (photon-to-atom state transfer) and recreates (atom-to-photon state transfer) a single-photon polarization qubit. [9]

Quantum Teleportation

Quantum teleportation is a process by which quantum information (e.g. the exact state of an atom or photon) can be transmitted (exactly, in principle) from one location to another, with the help of classical communication and previously shared quantum entanglement between the sending and receiving location. Because it depends on classical communication, which can proceed no faster than the speed of light, it cannot be used for superluminal transport or communication of classical bits. It also cannot be used to make copies of a system, as this violates the no-cloning theorem. Although the name is inspired by the teleportation commonly used in fiction, current technology provides no possibility of anything resembling the fictional form of teleportation. While it is possible to teleport one or more qubits of information between two (entangled) atoms, this has not yet been achieved between molecules or anything larger. One may think of teleportation either as a kind of transportation, or as a kind of communication; it provides a way of transporting a qubit from one location to another, without having to move a physical particle along with it.

The seminal paper first expounding the idea was published by C. H. Bennett, G. Brassard, C. Crépeau, R. Jozsa, A. Peres and W. K. Wootters in 1993. Since then, quantum teleportation has been realized in various physical systems. Presently, the record distance for quantum teleportation is 143 km (89 mi) with photons, and 21 m with material systems. In August 2013, the achievement of "fully deterministic" quantum teleportation, using a hybrid technique, was reported. On 29 May 2014, scientists announced a reliable way of transferring data by quantum teleportation. Quantum teleportation of data had been done before but with highly unreliable methods. [8]

Quantum Computing

A team of electrical engineers at UNSW Australia has observed the unique quantum behavior of a pair of spins in silicon and designed a new method to use them for "2-bit" quantum logic operations.

These milestones bring researchers a step closer to building a quantum computer, which promises dramatic data processing improvements.

Quantum bits, or qubits, are the building blocks of quantum computers. While many ways to create a qubits exist, the Australian team has focused on the use of single atoms of phosphorus, embedded inside a silicon chip similar to those used in normal computers.

The first author on the experimental work, PhD student Juan Pablo Dehollain, recalls the first time he realized what he was looking at.

"We clearly saw these two distinct quantum states, but they behaved very differently from what we were used to with a single atom. We had a real 'Eureka!' moment when we realized what was happening – we were seeing in real time the `entangled' quantum states of a pair of atoms." [5]

Quantum Entanglement

Measurements of physical properties such as position, momentum, spin, polarization, etc. performed on entangled particles are found to be appropriately correlated. For example, if a pair of particles is generated in such a way that their total spin is known to be zero, and one particle is found to have clockwise spin on a certain axis, then the spin of the other particle, measured on the same axis, will be found to be counterclockwise. Because of the nature of quantum measurement, however, this behavior gives rise to effects that can appear paradoxical: any measurement of a property of a particle can be seen as acting on that particle (e.g. by collapsing a number of superimposed states); and in the case of entangled particles, such action must be on the entangled system as a whole. It thus appears that one particle of an entangled pair "knows" what measurement has been performed on the other, and with what outcome, even though there is no known means for such information to be communicated between the particles, which at the time of measurement may be separated by arbitrarily large distances. [4]

The Bridge

The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron's spin also, building the bridge between the Classical and Quantum Theories. [1]

Accelerating charges

The moving charges are self maintain the electromagnetic field locally, causing their movement and this is the result of their acceleration under the force of this field. In the classical physics the charges will distributed along the electric current so that the electric potential lowering along the current, by linearly increasing the way they take every next time period because this accelerated motion.
The same thing happens on the atomic scale giving a dp impulse difference and a dx way difference between the different part of the not point like particles.

Relativistic effect

Another bridge between the classical and quantum mechanics in the realm of relativity is that the charge distribution is lowering in the reference frame of the accelerating charges linearly: ds/dt = at (time coordinate), but in the reference frame of the current it is parabolic: $s = a/2\ t^2$ (geometric coordinate).

Heisenberg Uncertainty Relation

In the atomic scale the Heisenberg uncertainty relation gives the same result, since the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greater proton mass.

This means that the electron and proton are not point like particles, but has a real charge distribution.

Wave – Particle Duality

The accelerating electrons explains the wave – particle duality of the electrons and photons, since the elementary charges are distributed on delta x position with delta p impulse and creating a wave packet of the electron. The photon gives the electromagnetic particle of the mediating force of the electrons electromagnetic field with the same distribution of wavelengths.

Atomic model

The constantly accelerating electron in the Hydrogen atom is moving on the equipotential line of the proton and it's kinetic and potential energy will be constant. Its energy will change only when it is changing its way to another equipotential line with another value of potential energy or getting free with enough kinetic energy. This means that the Rutherford-Bohr atomic model is right and only that changing acceleration of the electric charge causes radiation, not the steady acceleration. The steady acceleration of the charges only creates a centric parabolic steady electric field around the charge, the magnetic field. This gives the magnetic moment of the atoms, summing up the proton and electron magnetic moments caused by their circular motions and spins.

The Relativistic Bridge

Commonly accepted idea that the relativistic effect on the particle physics it is the fermions' spin - another unresolved problem in the classical concepts. If the electric charges can move only with accelerated motions in the self maintaining electromagnetic field, once upon a time they would reach the velocity of the electromagnetic field. The resolution of this problem is the spinning particle, constantly accelerating and not reaching the velocity of light because the acceleration is radial. One origin of the Quantum Physics is the Planck Distribution Law of the electromagnetic oscillators, giving equal intensity for 2 different wavelengths on any temperature. Any of these two wavelengths will give equal intensity diffraction patterns, building different asymmetric constructions, for example proton - electron structures (atoms), molecules, etc. Since the particles are centers of diffraction patterns they also have particle – wave duality as the electromagnetic waves have. [2]

The weak interaction

The weak interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and time reversal symmetry. The Electroweak Interaction shows that the Weak Interaction is basically electromagnetic in nature. The arrow of time shows the entropy grows by changing the temperature dependent diffraction patterns of the electromagnetic oscillators.

Another important issue of the quark model is when one quark changes its flavor such that a linear oscillation transforms into plane oscillation or vice versa, changing the charge value with 1 or -1. This kind of change in the oscillation mode requires not only parity change, but also charge and time changes (CPT symmetry) resulting a right handed anti-neutrino or a left handed neutrino.

The right handed anti-neutrino and the left handed neutrino exist only because changing back the quark flavor could happen only in reverse, because they are different geometrical constructions, the u is 2 dimensional and positively charged and the d is 1 dimensional and negatively charged. It needs also a time reversal, because anti particle (anti neutrino) is involved.

The neutrino is a 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

The limit of the velocity of particles as the speed of light appropriate only for electrical charged particles, since the accelerated charges are self maintaining locally the accelerating electric force. The neutrinos are CP symmetry breaking particles compensated by time in the CPT symmetry, that is the time coordinate not works as in the electromagnetic interactions, consequently the speed of neutrinos is not limited by the speed of light.

The weak interaction T-asymmetry is in conjunction with the T-asymmetry of the second law of thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes the weak interaction, for example the Hydrogen fusion.

Probably because it is a spin creating movement changing linear oscillation to 2 dimensional oscillation by changing d to u quark and creating anti neutrino going back in time relative to the proton and electron created from the neutron, it seems that the anti neutrino fastest then the velocity of the photons created also in this weak interaction?

A quark flavor changing shows that it is a reflection changes movement and the CP- and T- symmetry breaking!!! This flavor changing oscillation could prove that it could be also on higher level such as atoms, molecules, probably big biological significant molecules and responsible on the aging of the life.

Important to mention that the weak interaction is always contains particles and antiparticles, where the neutrinos (antineutrinos) present the opposite side. It means by Feynman's interpretation that these particles present the backward time and probably because this they seem to move faster than the speed of light in the reference frame of the other side.

Finally since the weak interaction is an electric dipole change with ½ spin creating; it is limited by the velocity of the electromagnetic wave, so the neutrino's velocity cannot exceed the velocity of light.

The General Weak Interaction

The Weak Interactions T-asymmetry is in conjunction with the T-asymmetry of the Second Law of Thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes for example the Hydrogen fusion. The arrow of time by the Second Law of Thermodynamics shows the increasing entropy and decreasing information by the Weak Interaction, changing the temperature dependent diffraction patterns. A good example of this is the neutron decay, creating more particles with less known information about them.

The neutrino oscillation of the Weak Interaction shows that it is a general electric dipole change and it is possible to any other temperature dependent entropy and information changing diffraction pattern of atoms, molecules and even complicated biological living structures.

We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too. This gives the limited lifetime for the biological constructions also by the arrow of time. There should be a new research space of the Quantum Information Science the 'general neutrino oscillation' for the greater then subatomic matter structures as an electric dipole change.

There is also connection between statistical physics and evolutionary biology, since the arrow of time is working in the biological evolution also.

The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction.

Fermions and Bosons

The fermions are the diffraction patterns of the bosons such a way that they are both sides of the same thing.

Van Der Waals force

Named after the Dutch scientist Johannes Diderik van der Waals – who first proposed it in 1873 to explain the behaviour of gases – it is a very weak force that only becomes relevant when atoms and molecules are very close together. Fluctuations in the electronic cloud of an atom mean that it will have an instantaneous dipole moment. This can induce a dipole moment in a nearby atom, the result being an attractive dipole–dipole interaction.

Electromagnetic inertia and mass

Electromagnetic Induction

Since the magnetic induction creates a negative electric field as a result of the changing acceleration, it works as an electromagnetic inertia, causing an electromagnetic mass. [1]

Relativistic change of mass

The increasing mass of the electric charges the result of the increasing inductive electric force acting against the accelerating force. The decreasing mass of the decreasing acceleration is the result of the inductive electric force acting against the decreasing force. This is the relativistic mass change explanation, especially importantly explaining the mass reduction in case of velocity decrease.

The frequency dependence of mass

Since $E = hv$ and $E = mc^2$, $m = hv/c^2$ that is the m depends only on the v frequency. It means that the mass of the proton and electron are electromagnetic and the result of the electromagnetic induction, caused by the changing acceleration of the spinning and moving charge! It could be that the m_o inertial mass is the result of the spin, since this is the only accelerating motion of the electric charge. Since the accelerating motion has different frequency for the electron in the atom and the proton, they masses are different, also as the wavelengths on both sides of the diffraction pattern, giving equal intensity of radiation.

Electron – Proton mass rate

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths! Also since the particles are diffraction patterns they have some closeness to each other – can be seen as a gravitational force. [2]

There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.

Gravity from the point of view of quantum physics

The Gravitational force

The gravitational attractive force is basically a magnetic force.

The same electric charges can attract one another by the magnetic force if they are moving parallel in the same direction. Since the electrically neutral matter is composed of negative and positive charges they need 2 photons to mediate this attractive force, one per charges. The Bing Bang caused parallel moving of the matter gives this magnetic force, experienced as gravitational force.

Since graviton is a tensor field, it has spin = 2, could be 2 photons with spin = 1 together.

You can think about photons as virtual electron – positron pairs, obtaining the necessary virtual mass for gravity.

The mass as seen before a result of the diffraction, for example the proton – electron mass rate Mp=1840 Me. In order to move one of these diffraction maximum (electron or proton) we need to intervene into the diffraction pattern with a force appropriate to the intensity of this diffraction maximum, means its intensity or mass.

The Big Bang caused acceleration created radial currents of the matter, and since the matter is composed of negative and positive charges, these currents are creating magnetic field and attracting forces between the parallel moving electric currents. This is the gravitational force experienced by the matter, and also the mass is result of the electromagnetic forces between the charged particles. The positive and negative charged currents attracts each other or by the magnetic forces or by the much stronger electrostatic forces!?

The gravitational force attracting the matter, causing concentration of the matter in a small space and leaving much space with low matter concentration: dark matter and energy.
There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.

The Higgs boson

By March 2013, the particle had been proven to behave, interact and decay in many of the expected ways predicted by the Standard Model, and was also tentatively confirmed to have + parity and zero spin, two fundamental criteria of a Higgs boson, making it also the first known scalar particle to be discovered in nature, although a number of other properties were not fully proven and some partial results do not yet precisely match those expected; in some cases data is also still awaited or being analyzed.

Since the Higgs boson is necessary to the W and Z bosons, the dipole change of the Weak interaction and the change in the magnetic effect caused gravitation must be conducted. The Wien law is also important to explain the Weak interaction, since it describes the T_{max} change and the diffraction patterns change. [2]

Higgs mechanism and Quantum Gravity

The magnetic induction creates a negative electric field, causing an electromagnetic inertia. Probably it is the mysterious Higgs field giving mass to the charged particles? We can think about the photon as an electron-positron pair, they have mass. The neutral particles are built from negative and positive charges, for example the neutron, decaying to proton and electron. The wave – particle duality makes sure that the particles are oscillating and creating magnetic induction as an inertial mass, explaining also the relativistic mass change. Higher frequency creates stronger magnetic induction, smaller frequency results lesser magnetic induction. It seems to me that the magnetic induction is the secret of the Higgs field.

In particle physics, the Higgs mechanism is a kind of mass generation mechanism, a process that gives mass to elementary particles. According to this theory, particles gain mass by interacting with the Higgs field that permeates all space. More precisely, the Higgs mechanism endows gauge bosons in a gauge theory with mass through absorption of Nambu–Goldstone bosons arising in spontaneous symmetry breaking.

The simplest implementation of the mechanism adds an extra Higgs field to the gauge theory. The spontaneous symmetry breaking of the underlying local symmetry triggers conversion of components of this Higgs field to Goldstone bosons which interact with (at least some of) the other fields in the theory, so as to produce mass terms for (at least some of) the gauge bosons. This mechanism may also leave behind elementary scalar (spin-0) particles, known as Higgs bosons.

In the Standard Model, the phrase "Higgs mechanism" refers specifically to the generation of masses for the $W^{\pm}$, and Z weak gauge bosons through electroweak symmetry breaking. The Large Hadron Collider at CERN announced results consistent with the Higgs particle on July 4, 2012 but stressed that further testing is needed to confirm the Standard Model.

What is the Spin?

So we know already that the new particle has spin zero or spin two and we could tell which one if we could detect the polarizations of the photons produced. Unfortunately this is difficult and neither ATLAS nor CMS are able to measure polarizations. The only direct and sure way to confirm that the particle is indeed a scalar is to plot the angular distribution of the photons in the rest frame of the centre of mass. A spin zero particles like the Higgs carries no directional information away from the original collision so the distribution will be even in all directions. This test will be possible when a much larger number of events have been observed. In the mean time we can settle for less certain indirect indicators.

The Graviton

In physics, the graviton is a hypothetical elementary particle that mediates the force of gravitation in the framework of quantum field theory. If it exists, the graviton is expected to be massless (because the gravitational force appears to have unlimited range) and must be a spin-2 boson. The spin follows from the fact that the source of gravitation is the stress-energy tensor, a second-rank tensor (compared to electromagnetism's spin-1 photon, the source of which is the four-current, a first-rank tensor). Additionally, it can be shown that any massless spin-2 field would give rise to a force indistinguishable from gravitation, because a massless spin-2 field must couple to (interact with) the stress-energy tensor in the same way that the gravitational field does. This result suggests that, if a massless spin-2 particle is discovered, it must be the graviton, so that the only experimental verification needed for the graviton may simply be the discovery of a massless spin-2 particle. [3]

Conclusions

The method developed by the researchers involves transferring a photonic qubit to an atomic qubit trapped inside an optical cavity. The photon-atom quantum information transfer is initiated via a quantum "logic-gate" operation, performed by reflecting the photon from the atom-cavity system, which creates an entangled atom-photon state. [9]
In August 2013, the achievement of "fully deterministic" quantum teleportation, using a hybrid technique, was reported. On 29 May 2014, scientists announced a reliable way of transferring data by quantum teleportation. Quantum teleportation of data had been done before but with highly unreliable methods. [8]
One of the most important conclusions is that the electric charges are moving in an accelerated way and even if their velocity is constant, they have an intrinsic acceleration anyway, the so called spin, since they need at least an intrinsic acceleration to make possible they movement .
The accelerated charges self-maintaining potential shows the locality of the relativity, working on the quantum level also. [1]
The bridge between the classical and quantum theory is based on this intrinsic acceleration of the spin, explaining also the Heisenberg Uncertainty Principle. The particle – wave duality of the electric charges and the photon makes certain that they are both sides of the same thing.
The Secret of Quantum Entanglement that the particles are diffraction patterns of the electromagnetic waves and this way their quantum states every time is the result of the quantum state of the intermediate electromagnetic waves. [2]
The key breakthrough to arrive at this new idea to build qubits was to exploit the ability to control the nuclear spin of each atom. With that insight, the team has now conceived a unique way to use the nuclei as facilitators for the quantum logic operation between the electrons. [5]
Basing the gravitational force on the accelerating Universe caused magnetic force and the Planck Distribution Law of the electromagnetic waves caused diffraction gives us the basis to build a Unified Theory of the physical interactions also.

References

[1] The Magnetic field of the Electric current and the Magnetic induction

http://academia.edu/3833335/The_Magnetic_field_of_the_Electric_current

[2] 3 Dimensional String Theory

http://academia.edu/3834454/3_Dimensional_String_Theory

[3] Graviton Production By Two Photon and Electron-Photon Processes In Kaluza-Klein Theories With Large Extra Dimensions

http://arxiv.org/abs/hep-ph/9909392

[4] Quantum Entanglement

http://en.wikipedia.org/wiki/Quantum_entanglement

[5] Pairing up single atoms in silicon for quantum computing

http://phys.org/news/2014-06-pairing-atoms-silicon-quantum.html#nwlt

[6] How to Win at Bridge Using Quantum Physics

http://www.wired.com/2014/06/bridge-quantum-mechanics/

[7] Information Entropy-Theory of Physics

https://www.academia.edu/3836084/Information_-_Entropy_Theory_of_Physics

[8] Quantum Teleportation

http://en.wikipedia.org/wiki/Quantum_teleportation

[9] Synopsis: Heralded Qubit Transfer

http://physics.aps.org/synopsis-for/10.1103/PhysRevLett.114.220501

[10] Semiconductor quantum dots as ideal single-photon source

http://www.nanowerk.com/nanotechnology-news/newsid=41243.php

[11] Single-photon source is efficient and indistinguishable

http://physicsworld.com/cws/article/news/2016/jan/29/single-photon-source-is-efficient-and-indistinguishable

[12] Superfast light source made from artificial atom

http://phys.org/news/2016-04-superfast-source-artificial-atom.html

[13] Team demonstrates large-scale technique to produce quantum dots

http://phys.org/news/2016-05-team-large-scale-technique-quantum-dots.html

[14] Precise atom implants in silicon provide a first step toward practical quantum computers

http://phys.org/news/2016-05-precise-atom-implants-silicon-quantum.html

[15] Russian physicists discover a new approach for building quantum computers

http://phys.org/news/2016-07-russian-physicists-approach-quantum.html

[16] Realizing quantum bits

http://phys.org/news/2016-07-quantum-bits.html

[17] Programmable ions set the stage for general-purpose quantum computers

http://phys.org/news/2016-08-programmable-ions-stage-general-purpose-quantum.html

[18] IBM scientists imitate the functionality of neurons with a phase-change device

http://phys.org/news/2016-08-ibm-scientists-imitate-functionality-neurons.html

[19] Neuromorphic computing mimics important brain feature

http://phys.org/news/2016-08-neuromorphic-mimics-important-brain-feature.html

[20] Network theory sheds new light on origins of consciousness

http://medicalxpress.com/news/2015-03-network-theory-consciousness.html

[21] A new study looks for the cortical conscious network

http://phys.org/news/2016-08-cortical-conscious-network.html

[22] Consciousness is tied to 'entropy', say researchers

http://physicsworld.com/cws/article/news/2016/oct/18/consciousness-is-tied-to-entropy-say-researchers

[23] Consciousness and Entropy

https://explore.scimednet.org/index.php/2016/11/02/consciousness-and-entropy/

[24] Rice, Baylor team sets new mark for 'deep learning'

http://phys.org/news/2016-12-rice-baylor-team-deep.html

[25] Researchers trace neural activity by using quantum sensors

http://phys.org/news/2016-12-neural-quantum-sensors.html

[26] A quantum case of mind over matter?

https://insidetheperimeter.ca/a-quantum-case-of-mind-over-matter/

[27] Quantum Vibrations Discovered in Brain Cells Reveal Something Thought-Provoking about Human Consciousness

http://themindunleashed.com/2017/07/quantum-vibrations-brain-consciousness.html

[28] Imagine Being Able to Explore the Brain Like a Website

http://trendintech.com/2017/07/09/imagine-being-able-to-explore-the-brain-like-a-website/