Artificial Brains
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Blue Brain Project

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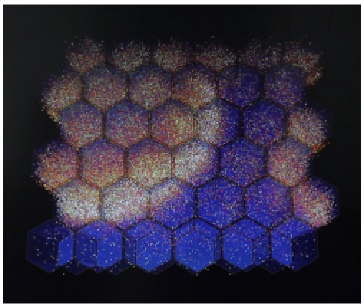

Cortical mesocircuit simulation

The **Blue Brain Project** is an attempt to reverse engineer the human brain and recreate it at the cellular level inside a computer simulation. The project was founded in May 2005 by Henry Markram at the EPFL in Lausanne, Switzerland. Goals of the project are to gain a complete understanding of the brain and to enable better and faster development of brain disease treatments.

The research involves studying slices of living brain tissue using microscopes and patch clamp electrodes. Data is collected about all the many different neuron types. This data is used to build biologically realistic models of neurons and networks of neurons in the cerebral cortex. The simulations are carried out on a Blue Gene supercomputer built by IBM. Hence the name "Blue Brain". The simulation software is based around Michael Hines's NEURON, together with other custom-built components.

As of August 2012 the largest simulations are of mesocircuits containing around 100 cortical columns (image above right). Such simulations involve approximately 1 million neurons and 1 billion synapses. This is about the same scale as that of a honey bee brain. It is hoped that a rat brain neocortical simulation (~21 million neurons) will be achieved by the end of 2014. A full human brain simulation (86 billion neurons) should be possible by 2023 provided sufficient funding is received.

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Latest news

July 9, 2012 - The FET Flagship Pilots final conference took place in Brussels today. Results of the recently-completed one-year pilot phase of the Human Brain Project (HBP) were presented. See the 108-page HBP report, as well as the conference statement by EC vice-president Neelie Kroes. During autumn 2012 the EU will consider the HBP and five other candidate science projects. In February 2013 a decision will be made on which of the two candidates will each receive €1 billion in funding over ten years. The chosen two projects will then run from 2013 to 2023. If the HBP is chosen, the Blue Brain Project will become a central part of it.

Jun 20, 2012 - Two newly published video talks which share lots of detail about the Blue Brain Project simulations and visualisations. The talks were given at the INCF Multiscale Modeling Program Workshop in Stockholm on May 31 and June 1, 2012.
- Juan Hernando - Challenges in visual analysis of multi-scale tissue simulations
- Daniel Keller - A Multiscalar Approach to Subcellular Modeling in the Cortical Column

Jun 11, 2012 - Scientific American has published a featured article by Henry Markram. Available online behind a $6 paywall: A countdown to a digital simulation of every last neuron in the human brain. See also the associated video animation: Neuron to cortical column.

May 24, 2012 - New video of Henry Markram talking about the Blue Brain Project. Includes Markram's thoughts on consciousness, autism, and the Human Brain Project. Recorded in Barcelona on May 22, 2012.

Mar 30, 2012 - The ETH Board has requested CHF 85 million (€70 m) from the Swiss government to fund the Blue Brain Project during 2013 to 2016.

Jan 3, 2012 - FET Flagships mid-term conference presentation is now available online: Introducing the Human Brain Project

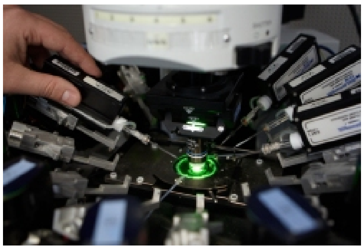
Data acquisition

There are three main steps to building the virtual brain: 1) data acquisition, 2) simulation, 3) visualisation of results.

Data acquisition involves taking brain slices, placing them under a microscope, and measuring the shape and electrical activity of individual neurons. This is how the different types of neuron are studied and catalogued. The neurons are typed by morphology (i.e. their shape), electrophysiological behaviour, location within the cortex, and their population density. These observations are translated into mathematical algorithms which describe the form, function, and positioning of neurons. The algorithms are then used to generate biologically-realistic virtual neurons ready for simulation.

One of the methods is to take 300 µm-thick sagittal brain slices from the somatosensory cortex (SA1) of juvenile Wistar rats (aged 14 to 16 days). The tissue is stained with biocytin and viewed through a bright field microscope. Neuronal 3D morphologies are then reconstructed using the Neurolucida software package (pictured below, far right) which runs on Windows workstations. Staining leads to a shrinkage of 25% in thickness and 10% in length, so the reconstruction process corrects for this. Slicing also severs 20% to 40% of axonal and dendritic arbors, so these are regrown algorithmically.

The electrophysiological behaviour of neurons is studied using a 12 patch clamp instrument (pictured below left). This tool was developed for the Blue Brain Project and it forms a foundation of the research. It enables twelve living neurons to be concurrently patched and their electrical activity recorded. The Nomarski microscope enhances the contrast of the unstained samples of living neural tissue. Carbon nanotube-coated electrodes can be used to improve recording.


The 12 patch-clamp, close-up view

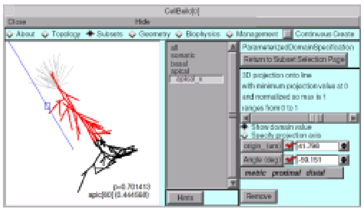

12 patch-clamp at the Blue Brain lab


3D neuron morphology reconstruction

Around 200 different types of ion channel are found in the cell membranes of cortical neurons. Different types of neuron have different mixes of channels - and this contributes to differences in their electrical behaviour. The genes for these channels are cloned at the lab, overexpressed in cultured cells, and their electrical behaviour recorded. Over 270 genes are known to be associated with voltage-gated ion channels in the rat. The results of this work are publicly available online at Channelpedia.

Simulation

NEURON


Example NEURON cell builder window

The primary software used by the BBP for neural simulations is a package called NEURON. This was developed starting in the 1990s by Michael Hines at Yale University and John Moore at Duke University. It is written in C, C++, and FORTRAN. The software continues to be under active development and, as of July 2012, is currently at version 7.2. It is free and open source software, both the code and the binaries are freely available on the website. Michael Hines and the BBP team collaborated in 2005 to port the package to the massively parallel Blue Gene supercomputer.

- Website: www.neuron.yale.edu
- Scholarpedia: NEURON simulation environment

Simulation speed

In 2012 simulations of one cortical column (~10,000 neurons) run at approximately 300 x slower than real time. So one second of simulated time takes about five minutes to complete. The simulations show approximately linear scaling - that is, doubling the size of the neural network doubles the time it takes to simulate. Currently the primary goal is biological validity rather than performance. Once it's understood which factors are biologically important for a given effect it might be possible to trim components that don't contibute in order to improve performance.

The simulation timestep for the numerical integrations is 0.025 ms and the timestep for writing the output to disk is 0.1 ms.

Workflow

The simulation step involves synthesising virtual cells using the algorithms that were found to describe real neurons. The algorthims and parameters are adjusted for the age, species, and disease stage of the animal being simulated. Every single protein is simulated, and there are about a billion of these in one cell. First a network skeleton is built from all the different kinds of synthesised neurons. Then the cells are connected together according to the rules that have been found experimentally. Finally the neurons are functionalised and the simulation brought to life. The patterns of emergent behaviour are viewed with visualisation software.

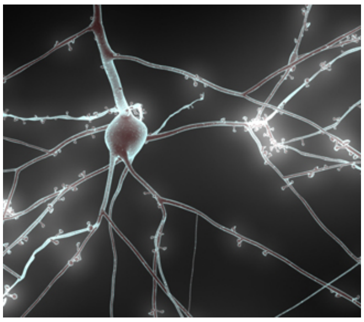
A basic unit of the cerebral cortex is the cortical column. Each column can be mapped to one function, e.g. in rats one column is devoted to each whisker. A rat cortical column has about 10,000 neurons and is about the size of a pinhead. The latest simulations, as of November 2011, contain about 100 columns, 1 million neurons, and 1 billion synapses. A real life rat has about 100,000 columns in total, and humans have around 2 million. Techniques are being developed for multiscale simulation whereby active parts of the brain are simulated in great detail while quiescent parts are not so detailed.

Every two weeks a column model is run. The simulations reproduce observations that are seen in living neurons. Emergent properties are seen that require larger and larger networks. The plan is to build a generalised simulation tool, one that makes it easy to build circuits. There are also plans to couple the brain simulations to avatars living in a virtual environment, and eventually also to robots interacting with the real world. The ultimate aim is to be able to understand and reproduce human consciousness.

BBP-SDK

The BBP-SDK (Blue Brain Project - Software Development Kit) is a set of software classes (APIs) that allows researchers to utilize and inspect models and simulations. The SDK is a C++ library wrapped in Java and Python.

Visualisation of results



RTNeuron visualisation of a neuron

RTNeuron

RTNeuron is the primary application used by the BBP for visualisation of neural simulations. The software was developed internally by the BBP team. It is written in C++ and OpenGL. RTNeuron is ad-hoc software written specifically for neural simulations, i.e. it is not generalisable to other types of simulation. RTNeuron takes the output from Hodgkin-Huxley simulations in NEURON and renders them in 3D. This allows researchers to watch as activation potentials propogate through a neuron and between neurons. The animations can be stopped, started and zoomed, thus letting researchers interact with the model. The visualisations are multi-scale, that is they can render individual neurons or a whole cortical column. The image right was rendered in RTNeuron, as was the video seen here.

Computer hardware / Supercomputers

Blue Gene/P

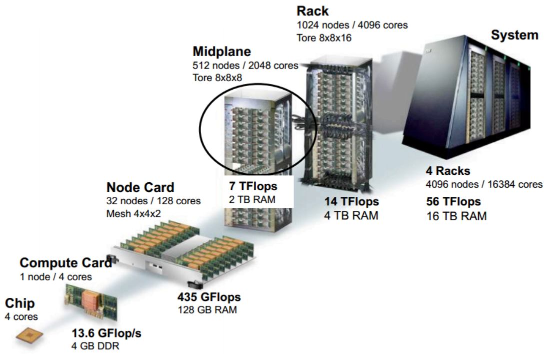
The primary machine used by the Blue Brain Project is a Blue Gene supercomputer built by IBM. This is where the name "Blue Brain" originates from. IBM agreed in June 2005 to supply EPFL with a Blue Gene/L as a "technology demonstrator". The IBM press release did not disclose the terms of the deal. In June 2010 this machine was upgraded to a Blue Gene/P. The machine is installed on the EPFL campus in Lausanne (Google map) and is managed by CADMOS (Center for Advanced Modelling Science).

The computer is used by a number of different research groups, not exclusively by the Blue Brain Project. In mid-2012 the BBP was consuming about 20% of the compute time. The brain simulations generally run all day, and one day per week (usually Thursdays). The rest of the week is used to prepare simulations and to analyze the resulting data. The supercomputer usage statistics and job history are publicly available online - look for the jobs labelled "C-BPP".

Blue Gene/P technical specifications:

- 4,096 quad-core nodes (16,384 cores in total)
- Each core is a PowerPC 450, 850 MHz
- Total: 56 teraflops, 16 terabytes of memory
- 4 racks, one row, wired as a 16x16x16 3D torus
- 1 PB of disk space, GPFS parallel file system
- Operating system: Linux SuSE SLES 10
- Public front end: bluegene.epfl.ch and processing log

This machine peaked at 99th fastest supercomputer in the world in November 2009. By June 2011 it had dropped to 343th in the world. It has since dropped out of the top 500. See the Blue Gene/P ranking on the TOP500 list. More details and photos: CADMOS Blue Gene/P presentation (PDF).



Silicon Graphics

A 32-processor Silicon Graphics Inc. (SGI) system with 300 Gb of shared memory is used for visualisation of results.

Commodity PC clusters

Clusters of commodity PCs have been used for visualisation tasks with the RTNeuron software. A research paper published by the BBP team in 2012 describes the following setup:

- 11 node cluster, 3.47 GHz processors (Intel Xeon X5690)
- 24 GB RAM, 3 Nvidia GeForce GTX 580 GPUs
- Full-HD passive stereo display connected to two GPUs on head node
- 1 Gbit/s, 10 Gbit/s ethernet, 40 Gbit/s QDR InfiniBand

It's not known where this cluster is physically located - either in the BBP lab itself, in an EPFL data center, or elsewhere.

JuQUEEN

JuQUEEN supercomputer in Germany

JuQUEEN is an IBM Blue Gene/Q supercomputer that was installed at the Jülich Research Center in Germany in May 2012. It currently performs at 1.6 petaflops and was ranked the world's 8th fastest supercomputer in June 2012. It's likely that this machine will be used for BBP simulations starting in 2013, provided funding is granted via the Human Brain Project.

In October 2012 the supercomputer is due to be expanded with additional racks. It is not known exactly how many racks or what the final processing speed will be.

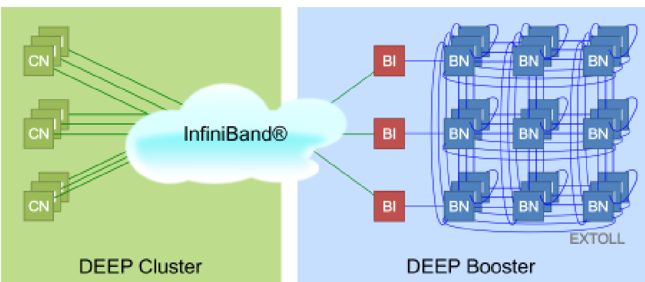
The JuQUEEN machine is also to be used by the JuBrain (Jülich Brain Model) research initiative. This aims to develop a three-dimensional, realistic model of the human brain. This is currently separate from the Blue Brain Project but it will become part of the Human Brain Project if the latter is chosen for EU funding in late 2012.

DEEP - Dynamical Exascale Entry Platform

DEEP (deep-project.eu) is an exascale supercomputer to be built at the Jülich Research Center in Germany. The project started in December 2011 and is funded by the European Union's 7th framework programme. The three-year protoype phase of the project has received €8.5 million. A prototype supercomputer that will perform at 100 petaflops is hoped to be built by the end of 2014.

The Blue Brain Project simulations will be ported to the DEEP prototype to help test the system's performance. If successful, a future exascale version of this machine could provide the 1 exaflops of performance required for a complete human brain simulation by the 2020s.

The DEEP prototype will be built using Intel MIC (Many Integrated Cores) processors, each of which contains over 50 cores fabricated with a 22 nm process. These processors were codenamed *Knights Corner* during development and subsequently rebranded as *Xeon Phi* in June 2012. The processors will be publicly available in late 2012 or early 2013 and will offer just over 1 teraflop of performance each.



DEEP cluster-booster architecture

Videos

Year Two:
August 2011

Year One:
January 2010

16:48

HD

More videos

- Henry Markram talk at TEDxCHUV - June 2012
- Visual analysis - Juan Hernando, June 2012
- Subcellular modeling - Daniel Keller, June 2012
- Neuron to cortical column animation - June 2012
- Henry Markram interview - May 2012
- Eagleman-Markram discussion - November 2011
- Markram talk at ISC11: pt1, pt2, pt3 - June 2011
- TED talk by Henry Markram - July 2009

Funding

The project is funded primarily by EPFL, which in turn is funded by the Swiss government. EPFL is one of only two federally-funded universities in Switzerland, the other being ETH in Zurich. The BBP has additionally received funding from EU research grants, foundations, other entities, and individuals. Henry Markram mentioned in an interview in 2009 that there was "one special visionary donor" but he didn't specify exactly who.

In March 2012 the ETH Board requested CHF 85 million (€70 m) from the Swiss government to fund the Blue Brain Project during 2013 to 2016.

IBM has not funded the project, but they sold their Blue Gene supercomputer to EPFL at a reduced cost. This was because at the time the computer was a prototype and IBM was interested in testing the machine on different applications.

An application has been made for an EU FET Flagship grant for the Human Brain Project. This would provide €1 billion in funding over ten years. If the grant is awarded then the BBP will become a key part of the Human Brain Project and will share some of the funding. A decision on this award is expected in February 2013.

Collaborators

The Polytechnic University of Madrid (UPM) and Instituto Cajal (IC) from the Higher Council for Scientific Research (CSIC) are Involved in the Blue Brain Project (BBP) With An initiative named Cajal Blue Brain. Different research groups and laboratories from Spanish Institutions take part in esta initiative, grouping together a large number of scientist, engineers and practitioners.

- Idan Segev and team at Hebrew University in Jerusalem, Israel
- Phil Goodman of the University of Reno, Nevada
- Michael Hines of Yale University, author of NEURON simulator, MP enhancements
- Alex Thomson, School of Pharmacy, University of London
- Yun Wang, St. Elizabeth's Medical Center, Boston (MA)

Project timeline

2002	Henry Markram founds the Brain Mind Institute (BMI) at EPFL
2005	**June** - EPFL and IBM agree to launch Blue Brain Project, IBM installs Blue Gene Basic simulation of single neurons achieved
2006	Basic parallelization of simulation code achieved **December** - auto-generated cortical column simulated, shown to be biologically valid
2007	**November** - modeling and simulation of first rat cortical column
2008	Cortical column construction and simulations Neocortical column (10,000 cells) Research on determining position and size of functional cortical columns
2009	**June** - BlueGene/L replaced by BlueGene/P, doubling of processors Simulations of cortical construction continue

2010 **December** - apply for FP7 grant
2011 Designing the FP7 project
Simulation of multiple columns, cellular mesocircuit of 100 columns
September - move into larger dedicated office space in 3rd floor of the building
2012 **April** - completion of the FET Flagships one-year pilot phase.
2013 **February** - decision expected on Human Brain Project funding of €1 billion over 10 years from the EU
Simulations using NEURON software ported to the Blue Gene/Q system in Jülich
2014 Cellular-level simulation of the entire rat brain neocortex, ~100 mesocircuits
NEURON simulation software ported to the DEEP Cluster-Booster prototype system in Jülich
2020 Exascale simulations start on the DEEP Cluster-Booster production system in Jülich
2023 Cellular-level simulation of the entire human brain, equivalent to 1,000x the size of the rat brain

Motivation

Four broad motivations behind the Blue Brain Project are:

- Brain disease treatments
- Scientific curiosity about consciousness and the human mind
- Integration of all neuroscientific research results worldwide
- Progress towards building thinking machines (bottom up approach)

One in four people will suffer from one of around 560 brain diseases during their lifetime. Therefore it is important to have a good strategy for understanding these diseases and finding suitable treatments. The living brain is very difficult to study. Both from a technical perspective, and a moral one. A virtual model, however, makes direct observations possible. Experiments on models are also more efficient and limit the need for laboratory animals. The Blue Brain Project, by including molecular-level simulations, could be used to study the effect of new pharmaceutical compounds on virtual brains of any species, age, and stage of disease.

Another aim of the Blue Brain Project is to provide a centrally coordinated resource for the 200,000 active neuroscientists in the world. Previously each researcher has focused on their own specialist field without the results being shared and easily available to all. The BBP hopes to build a bigger, better platform for neuroscientists to experiment on. The project is becoming a brain simulation facility that is accessible to all.

People involved

Abdeladim Elhamdani
Neural and microcircuitry lab manager (LNMC)

Ahmet Bilgili
Computer graphics, large-scale volume rendering

Alejandro Schiliuk
Operations manager, logistics, staffing

Alvaro Martinez
Cajal Blue Brain, software developer

Bruno Magalhaes
Software engineer, parallel multi-core HPC

Daniel Keller
Molecular and subcellular neuronal simulation

Daniel Nachbaur

Deborah La Mendola
Autism research using rat brains

Dimitri Christodoulou
Morphological reconstruction of neurons

Eilif Muller
Development of neocortical tissue model

Emmanuelle Logette
Electrophysiology of ~200 membrane channels

Farhan Tauheed
Spatial data, indexing, data mining

Felix Schürmann
Blue Brain General Project Manager

Gabriel Mateescu
Senior HPC architect, large-scale simulation

Georges Khazen
Molecular composition of neocortical neurons

Henry Markram W
Project director

James King
Supercomputer libraries/tools for simulations

Jean-Denis Courcol
Software developer

Jean-Pierre Ghobri
Quantitative data on neurons in the brain

Jesper smoking neuron morphology, behavior, genetics

Joe Graham
Algorithmic generation of virtual neurons

Juan Hernando
Cortical circuit visualisation development

Julian Shillcock
Sub-cellular modeling group leader

Julie Meystre
Molecular biology, cell cultures, immunohistology

Kamila Markram
Autism project manager

Marc-Oliver Gewaltig
Neurorobotics group manager

Martin Telefont
Biomedical information collection, proteomics

Maurizio Pezzoli
Electrophysiology of neurons in brain slices

Melissa Cochrane
Scientific assistant

Michael Reimann
Emergent properties of simulated microcircuits

Monica Favre
Study of mesolimbic circuitry in autism

Nenad Buncic
Senior project manager, technology vision

Rajnish Ranjan Ion channel database, channelpedia.net

Richard Walker
Science writer, funding proposals and papers

Robert Bishop
Chairman advisory board

Rodrigo Perin
Patch-clamp recording of neurons

Sean Hill
Project Manager for Computational Neuroscience

Sebastien Lasserre
Software engineering, real-time visualization

Shruti Muralidhar
Characterisation of rat neocortex layer 1

Srikanth Ramaswamy
Synapse recording and modeling

Stefan Eilemann
Visualisation architect for exascale simulations

Valentin Haenel computational neuroscientist

Vincent Delattre
In vitro recording of neurons using microchips

Werner Van Geit
Software development, automated neuron modeling

Yihwa Kim
Cell morphologies, artificial generation

Ying Shi
Software development, neural morphology algorithms

Research papers

- List of research papers on the Blue Brain Project website
- Emergent properties of in silico synaptic transmission in a model of the rat neocortical column - December 2011

Web Links

- Blue Brain Project - Homepage
- Cajal Blue Brain Project - Spanish homepage, and Twitter feed
- Wikipedia article
- Google+ page
- GitHub code repository and project dependencies diagram
- FET Flagships homepage and the Facebook page

- Human Brain Project - Preparatory study report, April 2012
- Article and photos on Boing Boing - May 2011
- Evaluation of the Blue Brain Project - April 2011

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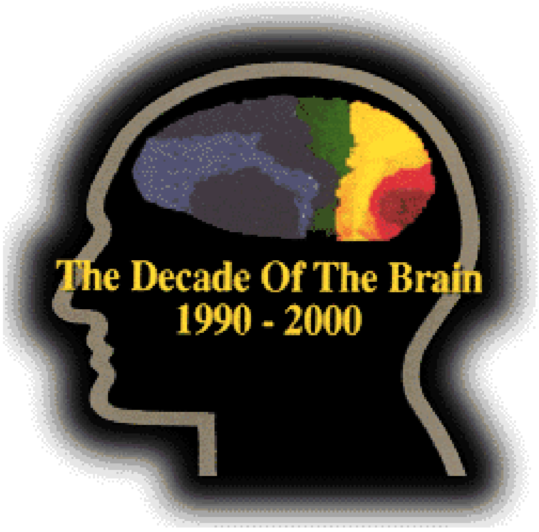
Project on the Decade of the Brain

Proclamation | Activities | Publications & Tapes | Other Links

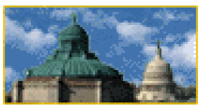


From 1990 to the end of 1999, the Library of Congress and the National Institute of Mental Health of the National Institutes of Health sponsored a unique interagency initiative to advance the goals set forth in a proclamation by President George Bush designating the 1990s as the Decade of the Brain: "to enhance public awareness of the benefits to be derived from brain research" through "appropriate programs, ceremonies, and activities." To achieve this public recognition, the LC/NIMH Project on the Decade of the Brain sponsored a variety of activities including publications and programs aimed at introducing Members of Congress, their staffs, and the general public to cutting-edge research on the brain and encouraging public dialogue on the ethical, philosophical, and humanistic implications of these emerging discoveries.

Go to:

- National Institute of Mental Health Home Page
- Library of Congress Home Page

If you have questions or comments on the LC/NIMH Decade of the Brain Project, please contact nimhinfo@nih.gov.


Library of Congress
Library of Congress Help Desk *(01/03/2000)*

Google Brain

From Wikipedia, the free encyclopedia

Google Brain is an unofficial name for a deep learning research project at Google.

Google Brain	
Commercial?	Yes
Type of project	Artificial intelligence and machine learning
Location	Mountain View, California

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History

Stanford University professor Andrew Ng who, since around 2006, became interested in using deep learning techniques to crack the problem of artificial intelligence, started Google's Deep Learning project (which would later acquire the name *Google Brain*) in 2011 as one of the Google X projects. The project's first in-depth coverage was in the *New York Times* in November 2011.[1][2]

In June 2012, the *New York Times* reported that a cluster of 16,000 computers dedicated to mimicking some aspects of human brain activity had successfully trained itself to recognize a cat based on 10 million digital images taken from YouTube videos.[3] The story was also covered by National Public Radio[4] and SmartPlanet.[5]

In March 2013, Google hired Geoffrey Hinton, a leading researcher in the deep learning field, and acquired the company DNNResearch Inc. headed by Hinton. Hinton said that he would be dividing his future time between his university research and his work at Google.[6]

On 26 January 2014, multiple news outlets stated that Google had purchased DeepMind Technologies for an undisclosed amount. Analysts later announced that the company was purchased for £400 Million ($650M USD / €486M), although later reports estimated the acquisition was valued at over £500 Million.[7][8][9][10][11][12][13] The acquisition reportedly took place after Facebook ended negotiations with DeepMind Technologies in 2013, which resulted in no agreement or purchase of the company.[14] Google has yet to comment or make an official announcement on this acquisition.

Moreover, In December 2012, futurist and inventor Ray Kurzweil, author of *The Singularity is Near*, joined Google in a full-time engineering director role, but focusing on the deep learning project.[15] It was reported that Kurzweil would have "unlimited resources" to pursue his vision at Google.[16][17][18][19] However, he is leading his own team, which is independent of Google Brain.

In Google products

The project's technology is currently used in the Android Operating System's speech recognition system[20] and photosearch for Google+.[21]

Team

Team was initially established by Andrew Ng, however he moved to lead AI group at Baidu.[22] Current team members include Jeff Dean, Geoffrey Hinton, Greg Corrado, Quoc Le, Ilya Sutskever, Alex Krizhevsky, Samy Bengio, and Vincent Vanhoucke.

Reception

Google Brain has received in-depth coverage in *Wired Magazine*,[2][8][18] the *New York Times*,[1][3] Technology Review,[7][19] National Public Radio,[4] and Big Think.[23]

See also

- Google X
- Google Research
- Quantum Artificial Intelligence Lab run by Google in collaboration with NASA and Universities Space Research Association.

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