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An Artificial Neural Network Approach for Brain Emulation - Analysis of the Blue Brain Project

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ABSTRACT: A human being is called intelligent because of the brain. The knowledge of a human brain is retained till the existence of the human being's life; but few brains of extraordinary humans may be required to be used for the development of the human society. Hence, there is a need to emulate the human brain and develop a virtual brain using asupercomputer for the sole purpose of preserving the intelligence, knowledge, memory and skill of a person forever. A virtual brain is a machine that can function as a human brain - it can take decisions, it can think, it can respond, and also it can keep things in memory. Neural network theory revolves around the idea that certain key properties of biological neurons can be extracted and applied to simulations, thus creating a simulated brain. An Artificial Neural Network approach is used to simulate and construct sizeable networks of artificial neurons with the ultimate goal to emulate the biological neurons in the entire human brain. This paper analyses one such brain emulation project called the "BLUE BRAIN"- the name of the world's first virtual brain.

KEYWORDS: Neuron, Synapse, Neocortical Column, Cortical microcircuit, Nanobots, Blue Gene

I. INTRODUCTION

The brain essentially serves as the body's information processing centre. The brain consists of about 10^{10} basic units, called **neurons**; each is connected to about 10^4 others. The brain receives signals from sensory neuronsin the central and peripheral nervous systems, and in response it generates and sends new signals that instruct the corresponding parts of the body to move or react in some way. It also integrates signals received from the body with signals from adjacent areas of the brain, giving rise to perception and consciousness. There are three functions that the human brain puts into action: sensory input, integration, motor output.

- Sensory Input: Receiving input such assound, image, etc through sensory cells.
- Interpretation: Interpretation of the received input by the brain by defining states of neurons in the brain.
- Motor Output: Receiving of electricresponses from the brain to perform any action.

In the human brain, a typical neuron collects signals from others through a host of fine structures called **dendrites**. The neuron sends out spikes of electrical activity through a long, thin stand known as an **axon**, which splits into thousands of branches. At the end of each branch, a structure called a **synapse** converts the activity from the axon into electrical effects that inhibit/ excite activity from the axon into electrical effects that inhibit/excite activity in the connected neurons. When a neuron receives excitatory input that is sufficiently large compared with its inhibitory input, it sends a spike of electrical activity down its axon. Learning occurs by changing the effectiveness of the synapses so that the influence of one neuron on another changes.

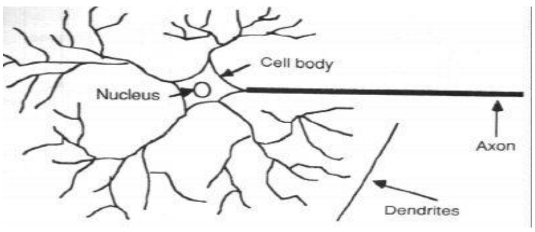

Fig 1: Components of a Neuron

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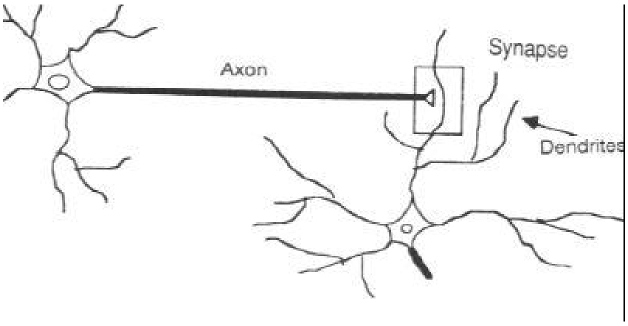

Fig 2: The Synapse

An **artificial neural network (ANN)** is an interconnected group of processing elements called **artificial neurons** that uses a mathematical or computational model for information processing. The inspiration for an ANN came from biological neural network - the brain. In an ANN, simple artificial nodes, called "neurons", "neurodes", "processing elements" or"units", are connected together to form a network of nodes, which mimics the vastnetwork of neurons in the living brain.

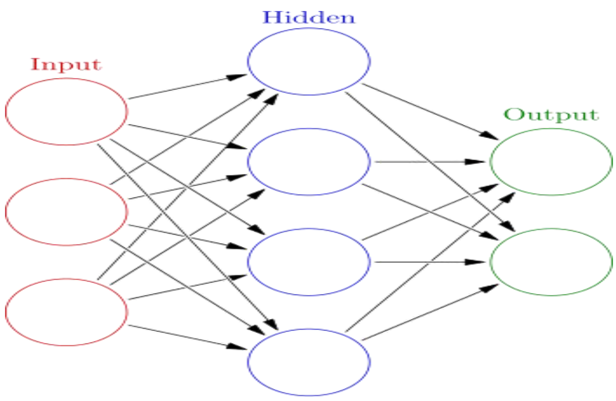

Fig 3: An Artificial Neural Network

An ANN learns by example–a neural network is an adaptive system that changes its structure during a learning phase. ANNs are used to model complex relationships between inputs and outputs or to find patterns in data. Learning in ANNs involves adjustments to the synaptic connections that exist between the neurons. The components of an artificial neural network are an attempt to recreate the computing potential of the human brain. Essential elements of neural network connectivity are:

1. **Connection strengths** - It tells howstrongly one neuron influences those neurons connected to it. They are the real information holders in the brain.
2. **Excitation/Inhibition distinction** - In human brains, each neuron is either excitatory or inhibitory, that is, its activation will either increase the firing rates of connected neurons, or decrease the rate, respectively. The amount of excitation or inhibition produced is dependent on the connection strength - a stronger connection means more inhibition or excitation, a weaker connection means less.
3. **Transfer Function**- This component is used for determining a neuron's response. The transfer function describes how a neuron's firing rate varies with theinput it receives. A very sensitive neuronmay fire with very little input, forexample. A neuron may have athreshold, and fire rarely below threshold, and vigorously above it. Using these three concepts, artificial neural networks are constructed. An artificial neuron captures all the important elements of a biological one. Nodes are connected to each other and the strength of that connection is normally given a numeric value between -1.0 for maximum inhibition, to +1.0 for maximum excitation. The transfer function in artificial neurons whether in a computer simulation, or actual microchips wired together is typically built right into the nodes' design.

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II. TRANSITION FROM LIVING BRAINTO VIRTUAL BRAIN

The human brain is very difficult to study, both from a technical perspective, and a moral one. A virtual model, however, makes direct observations possible. Researchers hope to gaina better understanding of how the brain works (and malfunctions) by creating simulations. A model can provide insight at all levels, from the biochemistry and neurochemical behavior of individual cells to the behavior of networks of neurons in the cortex and other parts of the brain.

level of biological accuracy and, ultimately, to study the steps involved in the emergence of biological intelligence. The Blue Brain Project is mainly an attempt to create a physiological simulation of a mammalian brain for biomedical applications, and then to enhance the same principles on a human brain. Goals of the project are to provide the scientific community with a simulation tool:

To gain a complete understanding of thebrain for developing basic and clinical research into its structure and function.
To enable better and faster development of brain disease treatments.
To be able to understand and reproduce human consciousness.

How the Blue Brain Project works?
The research involves studying data about the geometrical and electrical properties of differentneuron types, obtained from experimentation on slices of living brain tissue using microscopes and patch clamp electrodes. The project identifies key principles that determine synapse-scale connectivity by virtually reconstructing a cortical microcircuit. These principles make it possible to predict the locations of synapses or neural connections in the cerebral cortex. Each neuron in the circuit is reconstructed into a 3D model on a powerful Blue Gene supercomputer. About 10,000 of virtual neurons are packed into a 3D space in random positions according to the density and ratio of morphological types found in the corresponding living tissue. The researchers will then compare the model back to an equivalent brain circuit from a real mammalian brain.

Uploading Human Brain
The blue brain project is an attempt to create a virtual brain that is a physiological simulation ofthe human brain. For this, the human brain needs to be uploaded using very small robots known as the **nanobots** or **nanoids.** Nanobots are incredibly tiny robots, down at a microscopic scale. The name comes from a combination of the nanometer (the scale the devices are built at) and a robot. These devices are equipped with a variety of sensors and stimulators and communicate wirelessly with computers outside of the body. These robots are small enough to travel throughout our circulatory system. Nanobots are introduced intothe human brain noninvasively through the capillaries. Traveling into the spine and brain, they will be able to monitor the activity and structure of our central nervous system. Nanobots carefully scan the structure of our brain, providing a complete readout of the connections between each neuron, and also record the current state of the brain. This information, when entered into a computer, could then continue to function as a human brain. Thus the data stored in the entire brain will be uploaded into the computer.

Fig 4: Images of Nanobots

Creation of a virtual brain
There are three main steps required for building a virtual brain:
Data Acquisition Simulation Visualization of Results

i. Data Acquisition
Data acquisition involves taking brain slices (i.e. synapses or neural circuits), placing them under a microscope, and

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measuring the shape and electrical activity of individual neurons. The neurons are typed by morphology (i.e. their shape), electrophysiological behavior, locationwithin the cortex, and their population density. These observations are translated into mathematical algorithms that describe the form, function, and positioning of neurons. The algorithms are then used to generatebiologically-realistic virtual neurons ready forsimulation.

ii. Simulation and Simulation Workflow

The primary software used by the Blue Brain Project for neural simulations is a package called NEURON, a simulation environment for modeling individual neurons and networks of neurons. The simulation process involves synthesizing virtual cells using simulation algorithms. The algorithms and parameters are adjusted for the age, species, and disease stage of the brain being simulated. All the processors of the Blue Gene supercomputer are pressed into service, in a massively parallel computation solving the complex mathematical equations that govern the electrical activity in each neuron when a stimulus is applied. As the electricalimpulse travels from neuron to neuron, the results are communicated via inter-processor communication. The simulation workflow is as follows:

First a network skeleton is built from all the different kinds of synthesizedneurons.

Then the cells are connected together according to the rules that have been found experimentally.

Finally the neurons are functionalized and the simulation brought to life.

iii. Visualization of Results

The patterns of emergent behavior are viewed with visualization software.RTNeuron is the primary software used for visualization of neural simulations. This allows researchers to watch as activation potentials propagate through a neuron and between neurons. The animations can be stopped, started and zoomed, thus letting researchers interact with the model. The visualizations are multi-scale that is they canrender individual neurons or a whole corticalcolumn.

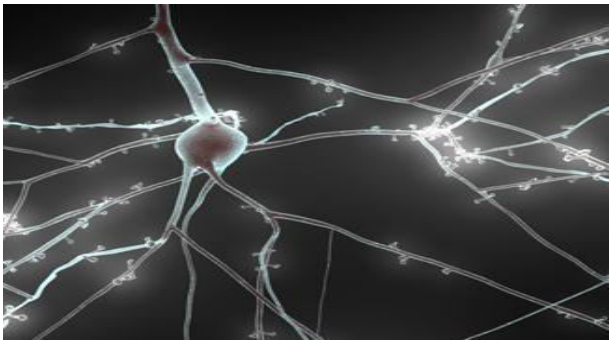

Fig 5: RTNeuron- Visualization of a NeuronHardware and Software Requirements

The motivation to model the entire human brainin all its intelligent, emotional complexity is supported by supercomputers of hitherto unseen power, and also by highly efficient and robust simulation software. The main hardware and software requirement specifications forimplementing this project are discussed below.

Blue Gene Supercomputer

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". In June 2010 thismachine was upgraded to a Blue Gene/P. It is a supercomputer of hitherto unseen power, havingmemory with a very large storing capacity, and a very high power processor.

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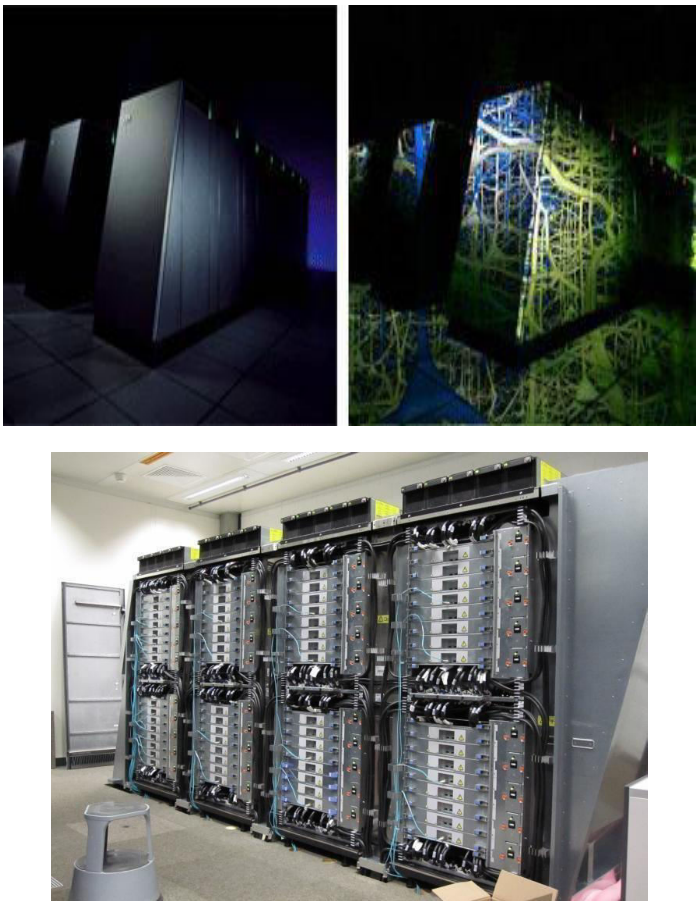

Fig 6: The EPFL Blue Gene supercomputer

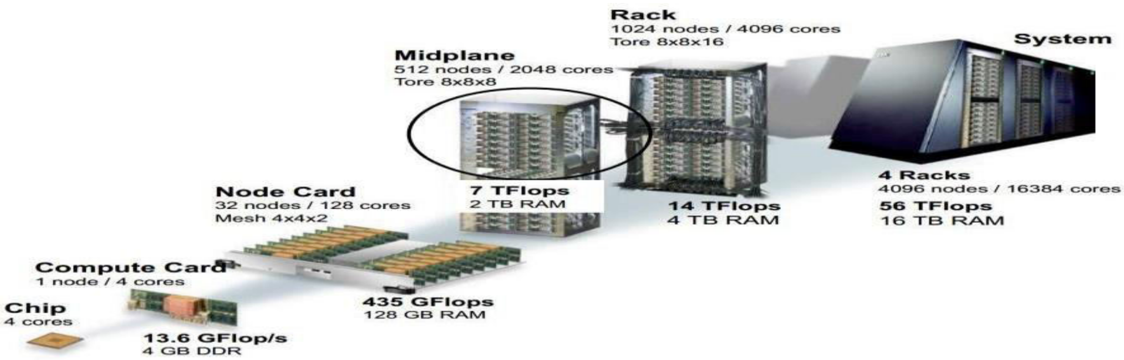

Fig 7: Architecture of the Blue Gene/PSupercomputer

Blue Gene/P technical specifications:
4,096 quad-core nodes (16,384 cores intotal)
Each core is a PowerPC 450, 850 MHzTotal: 56 teraflops, 16 terabytes of memory

Fig 8: The Blue Gene/P CabinetSilicon Graphics
A 32-processor Silicon Graphics Inc. (SGI)
system with 300 GB of shared memory is used for visualization of results.

Nanobots

Very powerful Nanobots act as the interface between the natural brain and the computer. Nanobots are typically devices ranging in size from 0.1-10 micrometers and constructed of nanoscale or molecular components.

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NEURON Software

NEURON is a program to convert the electric impulses from the brain to input signal, which isto be received by the computer, and vice versa.It was developed by Michael Hines at Yale University and John Moore at Duke University. It is written in C, C++, and FORTRAN. It is free and open source software, currently available in version7.2. The BBP-SDK (Blue Brain Project - Software Development Kit) is a set of classes that allows researchers to utilize and inspect models and simulations. The SDK isa C++ library wrapped in Java and Python.

RTNeuron Software

RTNeuron is the primary software used by the Blue Brain Project team to visualize, navigate and interact with cortical neuron circuit models and corresponding simulation results. The software was developed internally by the Blue Brain Project team. It is written in C++ and OpenGL. Detailed and statistically varying shapes of the neurons are used to layout a cortical circuit and establish synapses, the connections between neurons. Eventually, thesimulation is run in a super computer and different variables, such as membrane voltage and currents, spike times are reported. The outcome of these simulations is analyzed in several ways, including direct visualization of the simulator output.

III. FUTURE ENHANCEMENTS

In future, the Blue Brain Project could be used to study the effect of new pharmaceutical compounds on virtual brains of any species, irrespective of their age, and stage of brain diseases. The project aims to provide a centrally coordinated resource for the neuroscientists all over the world by building a bigger, better platform for them to experiment on. The project is becoming a brain simulation facility that will be accessible to all. It is expected to achieve high performance computing through remote interactive simulation, visualization and analytics on supercomputers. The Brain Simulation Platform will extend the scope of simulation to multiple levels of biological organization such as effects on cell morphology, Synaptic transmission, the electrical dynamics of neuronal microcircuits, effects on the functionality of brain systems, thus, makes it possible to map the brain's critical vulnerabilities.

IV. CONCLUSION

The Blue Brain Project is not an attempt to create a brain. This is a visionary project grounded in experimental analysis andcomputational synthesis of neural properties andconnectivity at the scale of a cortical column, in which a neural network is generated from stored data and simulations run to investigate systematically the performance of the network. The Blue Brain will provide a huge leap in our understanding of the brain's function and dysfunction and help us understand the root causes of intractable problems in mental health and neurological diseases and hence, could provide a new foundation for a new generation of information-based, customized medicines. The project will also throw new light on frequently asked questions - What does it mean to perceive, to think, to remember, to learn, to know, to decide? What does it mean to be conscious? In summary, the Blue Brain Project has the potential to revolutionize technology, medicine, neuroscience, and society.

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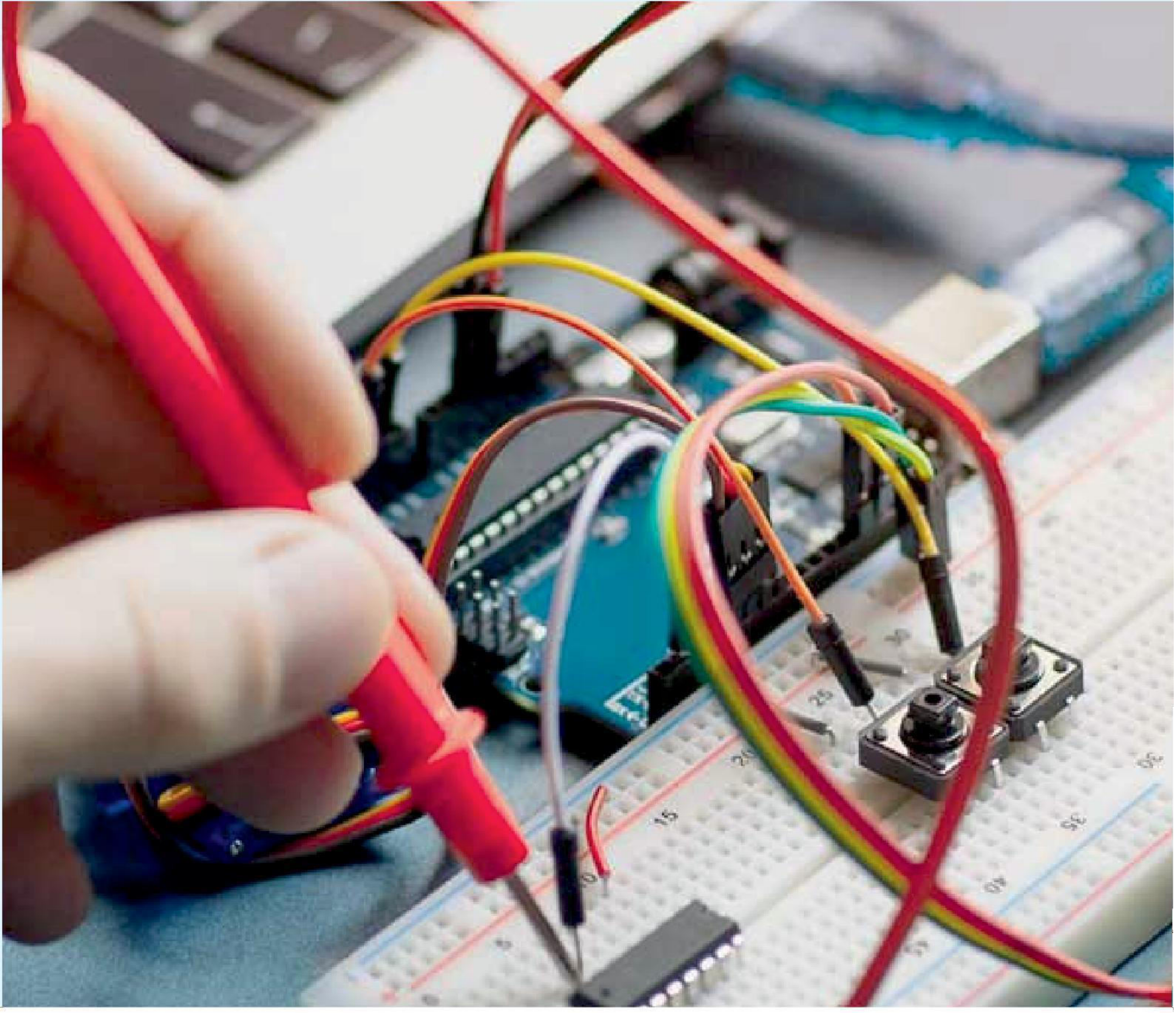

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