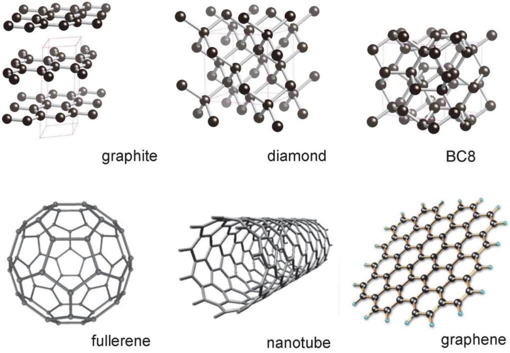
NBICS Technologies

Alexander Aksentyev

National Research Nuclear University "MEPhI"

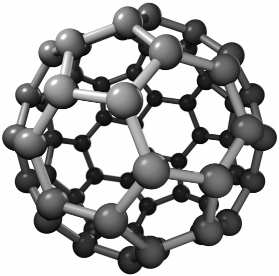
Carbon allotropes

Allotropy is the property of some chemical elements to exist in several different geometries (known as *allotropes*) in the same physical phase



The Buckyball

- The Buckminsterfullerene (named after inventor Richard Buckminster Fuller) was one of the first nanoparticles to be discovered (1985)
- Number of atoms: 20 to over 100; the most common type (C60) contains 60 carbon atoms
- Modifying a buckyball by adding or replacing an atom in order to change the properties of the buckyball is called **functionalization**



Uses

- **Armor**. Hard as diamonds, buckyballs are potentially useful within armor
- **Medicine**. Functionalized buckyballs can be made soluble by body cells, and hence find the following medical applications:
  - As antioxidants, because of their ability to absorb electrons in free radicals
  - In targeted drug delivery. The buckyball encases a minute dose of a particular drug. By controlling the functionalization of the buckyball the drug is absorbed only by the necessary cells
- **Fiber optics**. Because of their perfect spherical shape, buckyballs are able to transmit light

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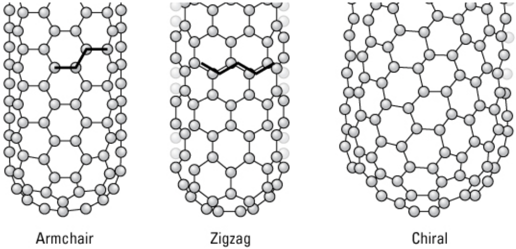
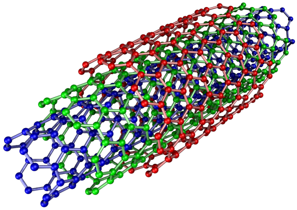
The nanotube

- Diameter < 1 nm
- A few nano- up to a millimeter in length
- Symmetry: armchair, zig-zag, chiral
- Single/multiple wall CNTs
- Compared to steel:
    - 100 $\times$ more difficult to tear apart
    - 5 $\times$ as elastic
    - a quarter density
- High thermal conductivity
- Metallic/semi-conductive contingent on symmetry





Uses

- **Medicine**: functionalization, as well as their natural fluorescence, enable the use of CNTs as chemical sensors; they have also been shown to fuse well with bone, which could be used to diminish the implant rejection rate
- **Conductive plastics**: CNTs are the best known conductive fillers because of their high aspect ratio
- **Energy storage**: good battery electrodes due to high surface area ($\sim$ 1000 m^2/g), good electrical conductivity, and linear geometry; the high surface area and thermal conductivity also make them useful as electrode catalysts in fuel cells
- **Molecular electronics**: their geometry, electrical conductivity, and the ability to be precisely derived, make CNTs invaluable connectors between switches at the nanoscale; their properties as semiconductors also make them usable as switches themselves

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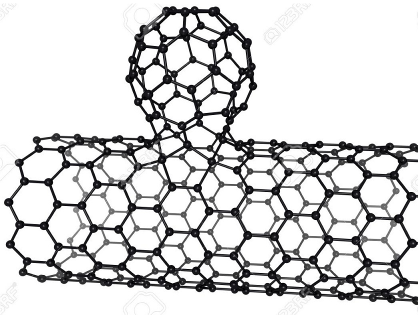
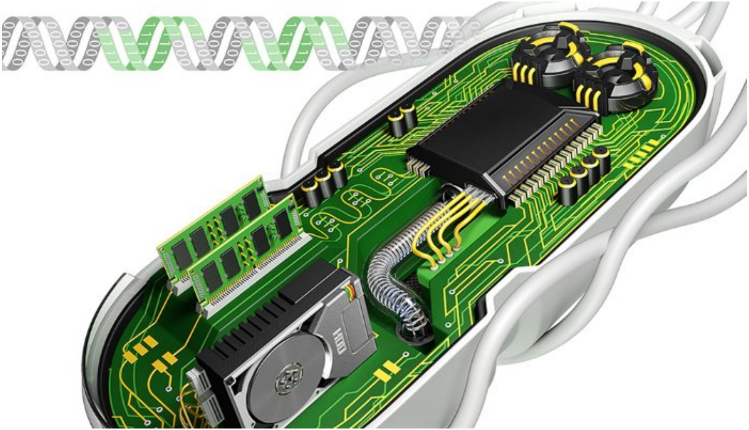
The nanobud

- A nanotube with a fullerene ball attached to it
- As chemically reactive as the fullerenes, as electrically conductive as the nanotubes
- The fullerene buds serve as additional anchors, modifying the mechanical properties of the whole structure
- Efficient field emitters, with the emission threshold 0.65 V/μm (a third of that of the nanotubes)
- Highly scalable production processes, therefore applications of industrial importance

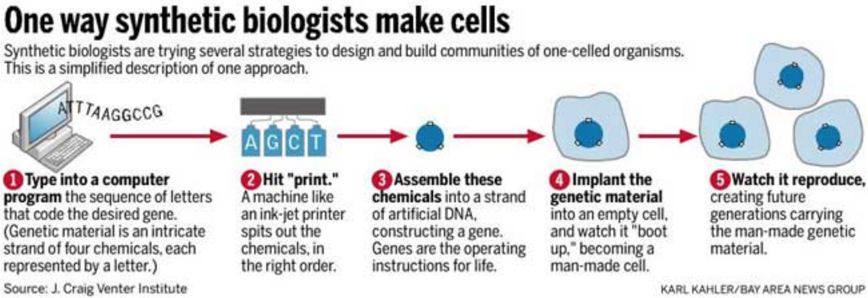


Synthetic biology



A set of technologies to construct living organisms with desired phenotypes

- Systems biology studies complex biological systems as integrated wholes
- Synthetic biology studies how to build such systems for engineering applications
- Living systems provide a rich medium for controlling and processing
  - information
  - materials
  - energy
- Bacteria are the simplest known natural objects capable of replicating



Enabling technologies:

- Standardization of DNA parts (BioBrick plasmids)
- DNA Synthesis
- DNA Sequencing
- Modular protein assembly

Uses

- **Materials**. DNA synthesis and DNA sequencing have enabled the construction of microorganisms with specially engineered metabolic cycles. This is used in a variety of production processes: BioIsoprene, BioAcrylic, "Green Chemicals"
- **Vaccines**. Bio Technologies provide tools to formulate vaccines via molecular engineering and DNA sequencing
- **Fuel**. Sugars from non-food biomass can be used to manufacture biofuels and renewable chemicals that are currently produced from expensive and price-volatile petroleum feedstocks
- **Waste disposal**. Bioplastics made from fermented sugars can be biodegraded by microbes already existing in soil and water environments

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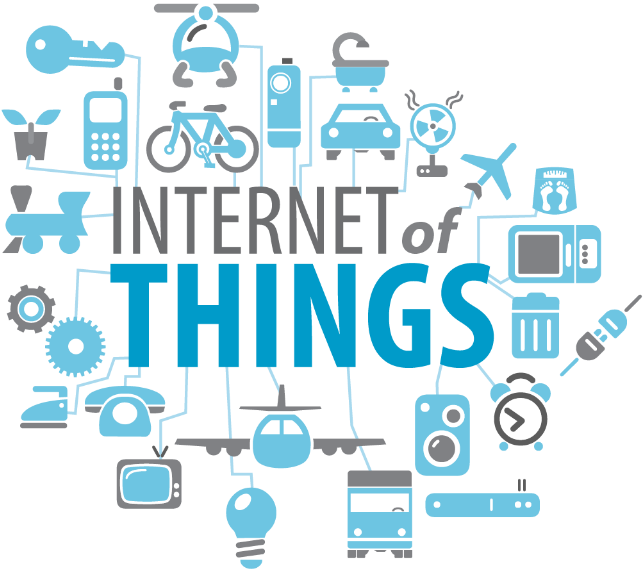
INTERNET of
THINGS

- The internetworking of physical devices to allow collection and exchange of information
- An instance of the more general class of *cyber-physical systems*:
  - smart grids
  - smart homes
  - smart cities
  - intelligent transportation
- Made by equipping all physical objects with identifying devices
- By 2020 there expected to be 20 billion connected devices
- The Internet of Things will therefore depend on the adoption of IPv6 to accommodate for the large address space

Enabling technologies

Some of the top 10 IoT-enabling technologies Gartner (IT research and advisory firm) identifies as most in-demand in 2017–2018:

- **IoT security**: IoT devices are open to both information and physical attacks, and many of them lack the processors and OS to afford sophisticated security approaches
- **IoT analytics**: IoT business models require new algorithms, data structures, machine learning approaches to profit from the data that will become available
- **IoT device management**: as the devices comprising the IoT will find themselves in a variety of contexts, locations, physical states, the challenge is to develop data structures capable of learning and adapting to circumstances

- **IoT processors**: processor architecture defines the device capabilities, such as security, firmware updatability, ability to support device management agents, etc.
- **IoT OS**: traditional OS consume too much power, need fast processors, lack guaranteed real-time response, require too much memory. A range of specialized IoT OS has been developing
- **Event stream processing**: distributed stream computing platforms (DSCPs) have emerged to address the need to analyze the extremely high data rates generated by some IoT applications (telecom, telemetry) on-line
- **IoT standards**: IoT devices need to interoperate, and IoT business models rely on sharing data between multiple devices and organizations

Uses

The employment of the IoT leads to the following benefits:

- In manufacturing:
  - **Connected factory**: reduce downtime, increase productivity, maintain industry compliance
  - **Connected machines**: optimize processes, improve overall equipment effectiveness, secure operations
  - **Connected supply chain**: drive faster decision-making, reduce risk, improve supply chain visibility
- In the energy field, **smart grids** enable pervasive monitoring and control of energy distribution networks to enhance energy delivery and reduce carbon emission
- In transportation:
  - **on-line traffic analysis** improves logistics (smart infrastructure, smarter personal choices)
  - **on-board wi-fi**, **real-time video**, **smart ticketing**, **centralized operations** enhance mass transit and passenger experience

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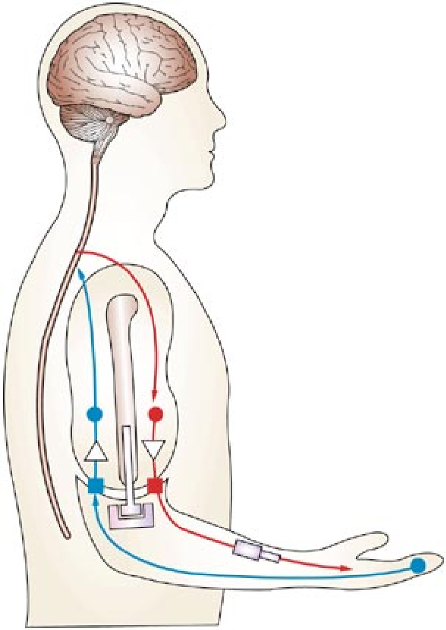
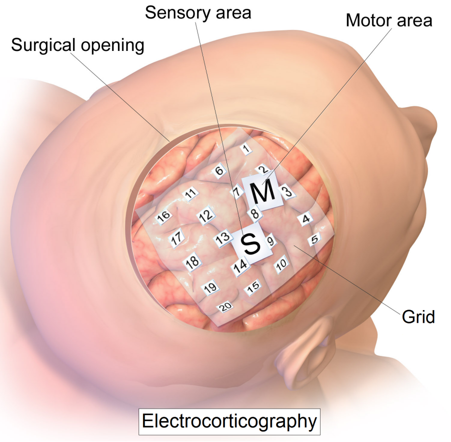
Neural interfaces



- A brain-computer interface (BCI) is a direct communication pathway between a wired brain and an external device
- Research and development are focused primarily on neuroprosthetics applications
- Was made possible by the development of *electroencephalography* (EEG)

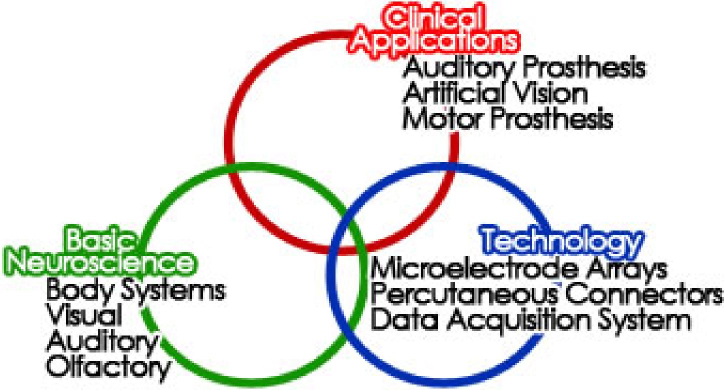
Types of interfaces

- EEG-based:
  - Electrocorticography: electrodes embedded in a plastic pad are placed above the cortex, beneath the cranium
- Non-EEG-based:
  - Pupil-size oscillation: an eye's pupil contracts according to the brightness of the looked at object

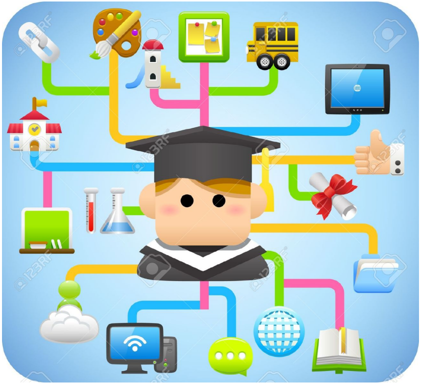


Electrocorticography

BCI applications



Educational technology



- Learning theory
  - Behaviorism
  - Cognitivism
  - Constructivism
- Computer-based training
- Online learning
- Mobile learning

Top technologies: AI, VR, VW

AI
: Customized learning-experience is already a reality. An intelligent tutoring system consists of:

  learner model
  : to assess how the student is doing

  tutoring model
  : to determine what material to present next

  domain model
  : to represent it appropriately

VR
: Learn by doing. One can now explore and interact with molecules and galaxies, thanks to virtual reality

VW
: Socialization is a vital part in a person's development, and as it turns out, introverted kids don't feel anxious interacting online

Top technologies: AR

Use the user's context to specify information

Top technologies: ARG

Enabling the use of communication tools typically used in the workspace, provides learning opportunities by situating important decisions in a thematic story

References I

Synthetic biology.
http://syntheticbiology.org/FAQ.html.

CISCO.
http://www.cisco.com/c/en/us/solutions/internet-of-things/overview.html.

Crel.
http://www.renders-graphiques.fr/galerie/Jeux-video-3/Adam-Jensen-Deus-Ex--91655.htm.

Gartner.
http://www.gartner.com/newsroom/id/3221818.

Mathôt.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4743834/pdf/pone.0148805.pdf.

References II

Understanding Nano.
http://www.understandingnano.com.

Gomez-Gil Nicolas-Alonso.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3304110/pdf/sensors-12-01211.pdf.

Biology Innovation Organization.
https://www.bio.org/articles/current-uses-synthetic-biology.

Clark Quinn.
http://www.litmos.com/blog/hi-tech/10-new-learning-technologies-by-dr-clark-quinn.

Cheap Tubes.
https://www.cheaptubes.com/carbon-nanotubes-applications/#CNTs%20Conductive%20Plastics.