Next Generation Brain Hacking, Security, and Interfaces

Prof. Russell Hanson

Locard Cybersecurity Summit Istanbul, Turkey

21 May 2016
21st Chaos Communication Congress

Speakers and moderators

Russell Hanson

EVENTS

Hacking The Genome
Brain Backups | Your Mind Is Your Legacy

Brain Backups, a developmental stage startup, is pursuing one of the biggest scientific and technological discoveries of our time: a map of every connection in ...

Digital Immortality and Mind Uploading

Your Brain Is Your Legacy

Prepared and Presented By:
Aamir Hussain  Arvind Lakhani

CS A, 3rd Year
Firstly, what is a Brain Backup, and what is it good for?

- Brain Backups® is a trademarked name for the *connectome*, or the network of neural connections in your brain, and some metadata about those neurons.
- We see that the *connectome* has many parallels to the human genome, which has revolutionized science and medicine down to the $1000 genome, and the $150 gene chip (23andMe). Genomic tech is a trillion USD business.
- Why would anyone want such a thing, really?
  - **Health**: Alzheimer’s, Parkinson’s, dementia, psychological disorders can be better understood and treated. “Digital immortality”/”Singularity”?
  - **Education**: Image someone’s brain before university and after university, use that info to transfer the knowledge to another brain, or selected pieces of that knowledge.
  - **Technology**: Use the brain image “Brain Backup” to inform a machine, minion, AI, robot, other person, whatever of a task that needs doing. Copy these minions, do more stuff, spend less time training/teaching/programming.
  - **Entertainment**: Pretty limitless.
  - **Business**: Truly limitless. The neural modem described below, if successful will enable telepathic-like interactions and communications. A multi-billion dollar business right there.
I don’t believe you, this sounds like science fiction.

3600 seconds/hour * 40/60 hours = 2400 the factor from real-time human brain emulation, let’s call it 2,000X (ca. 2014).

Time to increase computing power 2,000X?
Introduced by Intel on April 1, 1974, the 8080 had an 8-bit architecture, 6,000 transistors, clock speeds of 2-MHz.

In 1985, Intel 386 80386SX was available in clock speeds of 16MHz, 20MHz, 25MHz, and 33MHz.

On November 20, 2000, Intel released the Willamette-based Pentium 4 clocked at 1.4 and 1.5 GHz.
Show me a connectome

- ‘Kay.

https://github.com/openworm/CElegansNeuroML/blob/master/CElegansNeuronTables.xls

<table>
<thead>
<tr>
<th>Origin</th>
<th>Target</th>
<th>Type</th>
<th>Number of Connections</th>
<th>Neurotransmitter</th>
</tr>
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</tr>
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<tr>
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</tbody>
</table>
What do I do with a connectome? Simulate it.

The Neural Simulation Tool

current release: nest v2.10.0

>> Download Release v2.10.0 (Dec 31 2015)

NEST 2.10.0 contains 303 repository commits by 25 developers since v2.8.0. The most notable changes over v2.8.0 are:

- Support for simulations of gap junctions (see Jan Hahne et al., 2015)
- Framework for structural plasticity (see Markus Butz et al., 2013 and Markus Butz et al., 2014)
- Full support for the K computer (just in case you found one under your Christmas tree ;-))
C Elegans Neurorobotics
Timothy Busbice
interintelligence@gmail.com
http://www.connectomeengine.com
You are your connectome

Without a brain, no non-plant organism larger than a single cell would be able to respond to its environment in any way other than that dictated by physics and simple, binary responses. The entire sum of who you are resides in the activity of your brain.

Only recently have we had any ability to understand the complexity of the brain. The Human Connectome Project Consortium is elucidating neural circuits or pathways in the brain and sub-organ structure, and interconnectivity between brain regions, to understand the design and function of the connectome.

Quantifiably, a connectome is a 3 dimensional mapping of all the “wired” neural connections within a brain. Living connectomes are highly dynamic – an individual’s varies continuously throughout their lifetime. Your connectome today is different from when you were a child – and its structure is directly related to your previous connectomic configurations.
Question: How big is a connectome (in bytes)?

The human brain contains about ~100 billion nerve cells, or neurons. On average, each neuron is connected to other neurons through about 10,000 synapses. The actual figures vary greatly, depending on the local neuroanatomy.

100,000,000,000 neurons * 10,000 synapses = 1,000,000,000,000,000
1 terabyte = 1,099,511,627,760 bytes
1,000,000,000,000,000/1,099,511,627,760 = 909.49 terabytes
1 terabyte HD storage = ~$28.31 → storage for all human neurons and synapses ~$28.31 * 909.49 = ~$25,747.66

Connectivity: Assuming avg. 500 inputs per neuron, adjacency list is avg. 37•500=18,500 bits≈2kB per neuron. Neuronal type: Assume 10^3 cell types => 10 bits. Configuration: Assume each input synapse has 10^3 states => additional 5,000 bits. Total 3kB•2^37=384TB. Assume ~50% achievable compression ratio. Estimate: 200-300TB.
This is just the beginning!! Oddly.
EEG headsets: OpenBCI, eMotiv, etc.
How to make a Wifi connected brain – seems useful, right?

Should one use motor cortex? ECOG? Nanodevices like our nanoparticles?

Broadcom BCM4329 chip
that powers Wi-Fi, bluetooth on iphone 4, HTC EVO
Brain Modem: DARPA NESD $60M – read from 1,000,000 neurons stimulate 100,000 neurons

Neural Engineering System Design
Solicitation Number: DARPA-BAA-16-09
Agency: Other Defense Agencies
Office: Defense Advanced Research Projects Agency
Location: Contracts Management Office

Original Synopsis
Jan 21, 2016 11:58 am

Solicitation Number: DARPA-BAA-16-09
Notice Type: Presolicitation

Synopsis:
Added: Jan 21, 2016 11:58 am
DARPA seeks proposals to design, build, demonstrate, and validate a neural interface platform capable of recording from more than 1,000,000 neurons and stimulating more than 100,000 neurons in proposer-defined regions of the human auditory, visual and somatosensory cortex. The complete system must demonstrate high-precision detection, transduction, and encoding of neural activity.
MOTOR CORTEX and sensory cortices

Functional Areas of the Cerebral Cortex

- Primary motor cortex
- Premotor cortex
- Central sulcus
- Primary somatosensory cortex
- Somatosensory association cortex
- Parieto-occipital sulcus
- Visual association area
- Primary olfactory cortex
- Olfactory bulb
- Olfactory tract
- Uncus

Legend:
- Red: Primary motor cortex
- Pink: Motor association cortex
- Blue: Primary sensory cortex
- Light Blue: Sensory association cortex
- Purple: Multimodal association cortex
Fundamental components of a neural network system

- Synaptic weight
- Neurotransmitters
- Long term potentiation (LTP)
- Long term depotentiation (LTD)

To model a network of LT neurons, assume that their activities at time $t$ are given by the $N$ variables, $x_1(t), x_2(t), \ldots, x_N(t)$ which take on the values 0 or 1, that is, a neuron is either active (“1”) or silent (“0”). Then the activities at time $t+1$ are given by

$$x_i(t + 1) = H\left(\sum_{j=1}^{N} W_{ij} x_j(t) - \theta_i\right) \quad (E-1)$$

where $H$ is the Heaviside step function defined by $H(u) = 1$ for $u \geq 0$ and $H(u) = 0$ otherwise, $W_{ij}$ is the strength or weight of the synapse between neuron $i$ and the presynaptic neuron $j$, and $\theta_i$ is the threshold of neuron $i$. For a network of $N$ neurons, the synaptic weights $W_{ij}$ form an $N \times N$ matrix, and the thresholds $\theta_i$ an $N$-dimensional vector.
Key differences between classical ML/AI/deep learning and biological brain

• Specific networks for specific functions, significance of connectivity between these regions
• “Supervisor”/”teacher” to say when done, to move on to next task
• Highly optimized yet optimization procedure unknown
• Only 86 billion neurons, energy consumption 12 watts
• Highly integrated with peripheral nervous system (somatic nervous system and autonomic nervous system)
• Human intelligence while a general intelligence also performs many distinctly human functions
The current methodology of mapping the connectome today relies on imaging of the neurons in a brain, in one way or another. All current methods are:

**Highly Destructive**

**Highly Invasive**

*or*

**Very Low Resolution**

Don’t destroy the thing you want to image!!
Using genome sequencing for connectome sequencing

It’s still destructive!! 😞😞😞😞
Novel, non invasive, *in vivo* Imaging Methodology

*Non-destructive non-invasive* imaging of neural targets to map tissue structure and visualize dynamic biochemical processes at sub-second timescales from 1mm to 300nm. Nanoparticle imaging-agents may be “barcoded” for MRI and dual mode/spectral CT.

**Design:**
Ligand + Contrast-providing agent = Specific targeted contrast particle/agent

**AptaMark:**
Targeted RNA aptamers + gold nanoparticles = Specific targeted contrast particle/agent
Quoting Randal Koene...

Where are we now - on reconstructing brains?

We lack information to infer function from structure

We can do direct functional system identification (see hippocampal prosthesis)

Demands better recording & stimulation

evolutionary patchwork vs the ‘language’ of the brain
Decoding the auditory cortex

NeuroMorpho.Org is a centrally curated inventory of digital neurons associated with peer-reviewed publications. It contains over 100 laboratories worldwide and is continuously updated as reconstructions are collected, published, and shared. To date, it is the largest collection of publicly accessible 3D neuronal reconstructions and associated metadata.

ModelDB provides an accessible location for storing and efficiently retrieving computational neuroscience models. ModelDB is tightly coupled with NeuronDB. Models can be coded in any language for any environment. Model code can be viewed before downloading and browsers can be set to auto-launch the models. For further information, see model sharing in general and ModelDB in particular.

Browse or search through over 1000 models using the navigation on the left bar or in the menu button on a mobile device. To search papers instead of models, go here; this may be used to identify models whose paper cites or is cited by a given paper.
GlyR-a1 subunits imaged using primary antibody (mAb2b), biotinylated anti-mouse Fab fragments, and streptavidin-coated quantum dots.

**Fig. 4.** Transmission EM detection of QD-GlyRs. QD-GlyRs detected on the dendritic surface and associated with extrasynaptic membranes (arrows) (A), at the periphery of synapses (B), and within the synaptic cleft (C). d, dendrites; b, synaptic boutons. The edges of the synaptic clefts are outlined in (B) and (C). Scale bars, 500 nm.
Neurological Imaging Targets

For memory encoding:

**AMPA-R**
Exclusive glutamate, excitatory, Na+ influx ONLY, hetero OR homo-tetramer, FAST

**NMDA-R**
Glutamate and glycine receptor, inhibitory, Ca2+ and Na+ influx, GluN1 GluN2 heterotetramer -- always 2 GluN1 + either GluN2 or GluN3. Has Mg+ in core. SLOW
<table>
<thead>
<tr>
<th>Imaging method (size/time)</th>
<th>Contrast agent</th>
<th>Ligand</th>
<th>Delivery</th>
<th>Indication/application</th>
<th>Shortcoming</th>
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</thead>
<tbody>
<tr>
<td>X-ray CT (200-400nm/10 mins)</td>
<td>15 nm Au NP</td>
<td>GluR1 aptamer</td>
<td>Insulin, aptamer</td>
<td>Synaptic weights, GluR1 densities, brain mapping</td>
<td>Radiation, expense of machine</td>
</tr>
<tr>
<td>“</td>
<td>KI</td>
<td>None</td>
<td>None</td>
<td>Tissue stain</td>
<td>Non-specific</td>
</tr>
<tr>
<td>NIR (400nm/ms)</td>
<td>Upconverting NP</td>
<td>Aptamer/antibody</td>
<td>Aptamer</td>
<td>Surface receptor densities</td>
<td>Toxicity of NPs (?), slower response time</td>
</tr>
<tr>
<td>“</td>
<td>Au nanorod</td>
<td>Aptamer/antibody</td>
<td>Aptamer</td>
<td>Voltage sensitive</td>
<td>Orientation</td>
</tr>
<tr>
<td>MR</td>
<td>Paramagnetic NP</td>
<td>Aptamer/antibody</td>
<td>Aptamer</td>
<td>Region activity, blood flow, tau, synuclein</td>
<td>1-5mm voxel</td>
</tr>
<tr>
<td>Fluorescence microscopy (400nm/ms)</td>
<td>15 nm Au NP</td>
<td>GluR1 aptamer</td>
<td>None, surface accessible</td>
<td>Targeting quality control</td>
<td>Serial sectioning, shallow depth, destructive</td>
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<tr>
<td>Electron microscopy (EM) (10-40nm/∞)</td>
<td>Osmium tetroxide</td>
<td>None</td>
<td>Histological stain</td>
<td>High-res imaging</td>
<td>No biological metabolites, no protein density info</td>
</tr>
</tbody>
</table>
### Technical Specifications & Configurations

<table>
<thead>
<tr>
<th>Feature</th>
<th>phoenix nanotom s</th>
<th>phoenix nanotom m</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X-ray tube type</strong></td>
<td>Proprietary open high-power nanofocus X-ray tube, optimized for long-term stability</td>
<td>Internal X-ray tube cooling</td>
</tr>
<tr>
<td><strong>Max. voltage / power</strong></td>
<td>180kV/15W</td>
<td></td>
</tr>
<tr>
<td><strong>Target</strong></td>
<td>Tungsten on berylium (optional tungsten on CVD diamond)</td>
<td>Tungsten on CVD diamond for up to 2 times faster data acquisition at the same high image quality level</td>
</tr>
<tr>
<td></td>
<td>Transmission target type, rotatable for multiple use (other target materials, e.g. molybdenum on request)</td>
<td></td>
</tr>
<tr>
<td><strong>Filament</strong></td>
<td>Tungsten hairpin, pre-adjusted plug-in cartridges for fast and easy exchange</td>
<td></td>
</tr>
<tr>
<td><strong>Geom. magnification (3D)</strong></td>
<td>1.7x - 250x</td>
<td>1.5x - 300x</td>
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<tr>
<td><strong>Detail detectability</strong></td>
<td>Down to 200 nm (0.2 microns)</td>
<td>Down to 200 nm (0.2 microns)</td>
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<tr>
<td><strong>Min. voxel size</strong></td>
<td>Down to 500 nm (0.5 microns)</td>
<td>Down to 300 nm (0.3 microns)</td>
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<td><strong>Detector type</strong></td>
<td>High-Contrast DETECTOR HCD 120-50, 12 bit / 16 bit, 3x virtual detector enlargement (max. 6,900 pixel detector width)</td>
<td>Temperature-stabilized high dynamic GE DXR, 14 bit/16 bit, 1.5x detector enlargement (max. 4,600 pixel detector width)</td>
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<tr>
<td><strong>Pixels</strong></td>
<td>2,300×2,300</td>
<td>3,072×2,400</td>
</tr>
<tr>
<td><strong>Pixel size</strong></td>
<td>50 µm</td>
<td>100 µm</td>
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<tr>
<td><strong>Manipulation</strong></td>
<td>Granite based 5-axes manipulator with vibration insulation, precision rotation table on air bearings</td>
<td></td>
</tr>
<tr>
<td><strong>Variable focus detector distance</strong></td>
<td>from 200 mm to 500 mm</td>
<td>from 220 mm to 600 mm</td>
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<tr>
<td><strong>Max. sample diameter</strong></td>
<td>&lt;1 mm to 120 mm</td>
<td>&lt;1 mm to 240 mm</td>
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<tr>
<td><strong>Max. sample height/weight</strong></td>
<td>150 mm / 2 kg (4.4 lbs.)</td>
<td>250 mm / 3 kg (6.6 lbs.)</td>
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<tr>
<td><strong>Sample travel length Y/Z</strong></td>
<td>150 mm / 300 mm</td>
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</tr>
<tr>
<td><strong>Rotation</strong></td>
<td>0° - 360°×n</td>
<td></td>
</tr>
</tbody>
</table>
1mm x 200 μm x 200μm
0.6 μm voxel
~ 6 min scan
Nanorobots
Ex vivo EM imaging: synapses
Dvorsky’s Complaint #1: Brain functions are not computable

“Is” and “are” are complicated words, semantically…. Computability, in the sense it’s used in Dvorsky’s complaint, is a mathematical tool used for modeling certain systems. So his claim would be “brain functions cannot be effectively modeled using computable models.”

This is an interesting hypothesis, but there is certainly no scientific evidence for it. Furthermore, within the confines of current science, there is no possible way to gather solid scientific evidence for it. The problem is that all scientific data ever gathered, constitutes one large but finite set of bits (i.e a finite set of finite-precision numbers). Any finite set of bits can be modeled computationally. Of course, someone can claim a non-computable model is “better” than any computational model, for a given finite set of bits. But this then becomes a subjective claim, based on aesthetics, or intuition.

Perhaps some future discipline, going beyond the bounds of science as we know it today, will formulate some new sense in which brains fundamentally cannot be computationally modeled. But this vague possibility seems a rather threadbare excuse for rejecting mind uploading.
“My personal view about the ‘ethical implications’ is that it is unethical to NOT permit tetraplegic patients or other injured parties to receive next-generation neural interfaces. And regarding connectome imaging -- again my personal view is that it is unethical to NOT permit patients or other interested parties to image their connectome, just like withholding genetic/genomic data from an oncologist/cancer patient is presently unconscionable. If one is afraid of knowledge, one's head is truly in the sand.”
Outstanding problems, areas for outstanding contributions!

- Implanted CPU with database of neural codes
- Deep learning to improve interfaces using ephys spikes to sensorimotor cortex
- AI/ML to trace neurons/axons in image stack data
- **Neural Modem**: In the next 3-4 years DARPA wants a device that reads from 1,000,000 neurons stimulates 100,000 neurons. Cochlear implant uses only 4 electrodes.
Thanks to the Locard team!
And the kind people of Turkey! B)

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http://www.russellhanson.com/