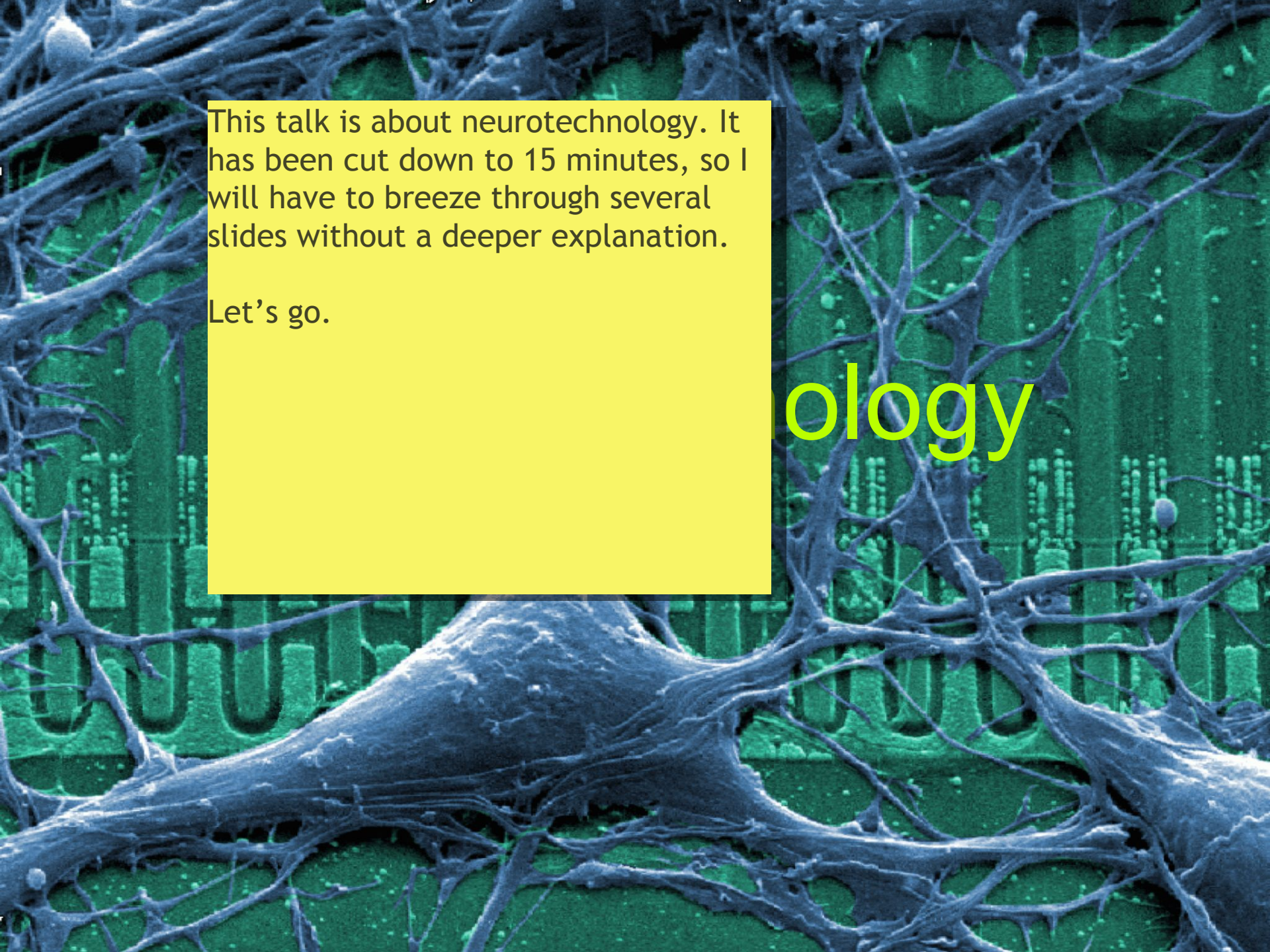
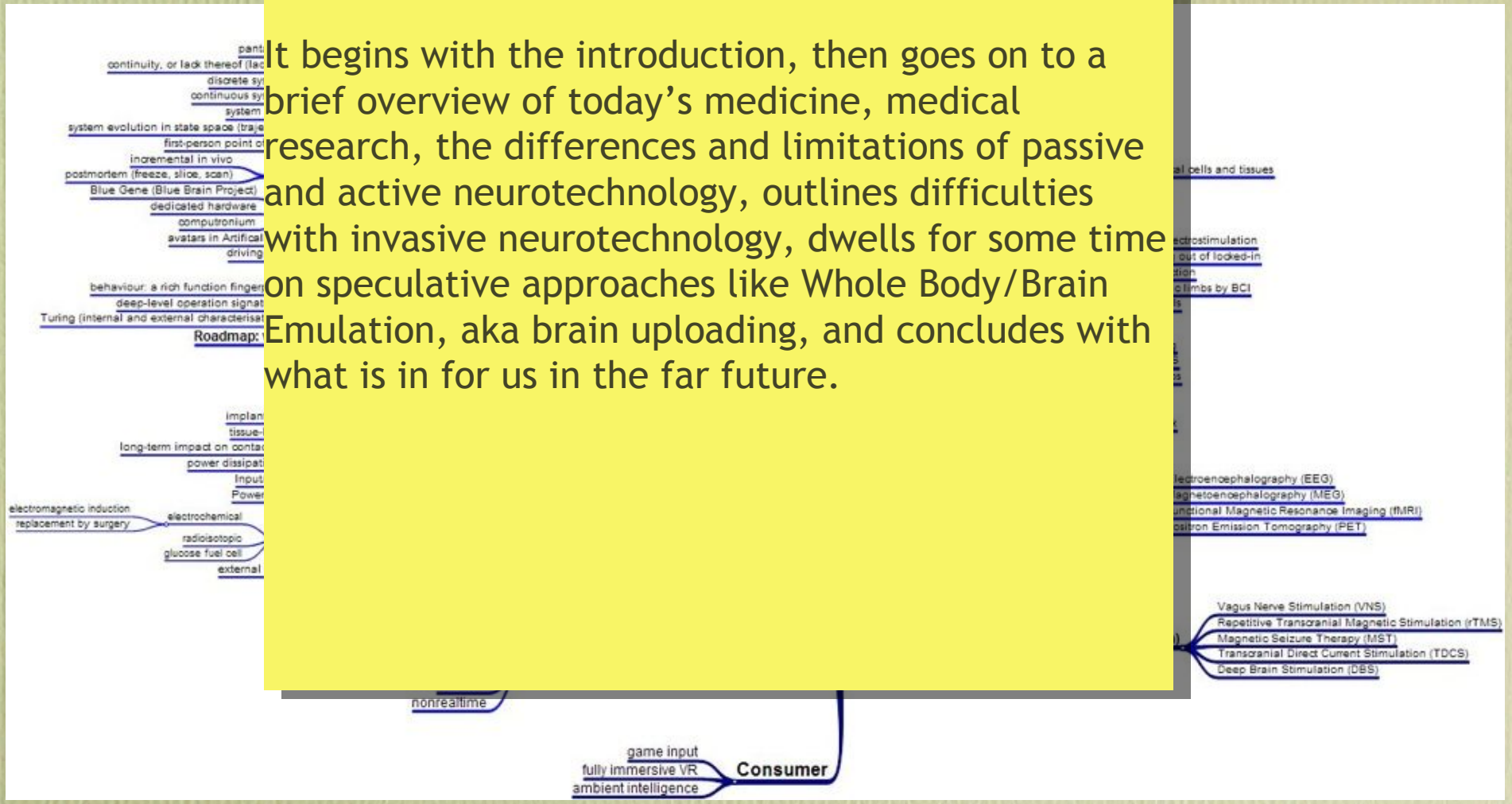


This talk is about neurotechnology. It has been cut down to 15 minutes, so I will have to breeze through several slides without a deeper explanation.

Let’s go.

Here's the overview of the talk as a mind map.
<SKIP TO NEXT SLIDE>

It begins with the introduction, then goes on to a brief overview of today's medicine, medical research, the differences and limitations of passive and active neurotechnology, outlines difficulties with invasive neurotechnology, dwells for some time on speculative approaches like Whole Body/Brain Emulation, aka brain uploading, and concludes with what is in for us in the far future.



What is neurotechnology?

It's *any* technology to manipulate the Central Nervous System, especially the brain, to an desired effect.

Information processing in cells and tissues is not something new. Already single-cell organisms use genetic networks to represent and process information about themselves and their environment.

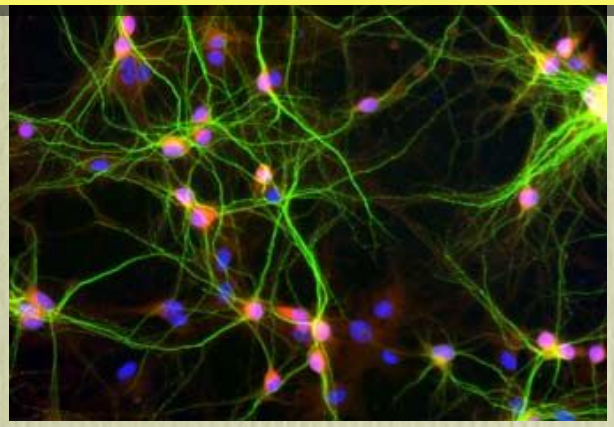
Assemblies of single cells are capable of rudimentary communal processing like quorum sensing and chemical signals to initiate and navigate spatial aggregation (called chemotaxis), such as cyclic adenosine monophosphate (cAMP) spiral waves with the slime mould Dictyostelium discoideum.

Such early capabilities have been honed and refined in the course of co-evolution, ultimately resulting in mammals and especially higher primates, the pinnacle of evolution's achievement on this planet. (Or so they say).

Which tools has today's medicine at its disposal?

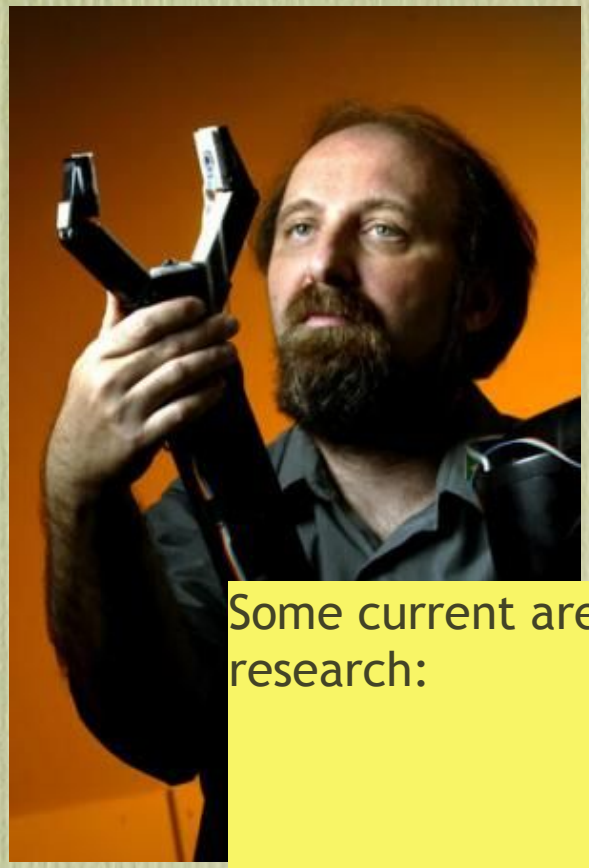
Today's M

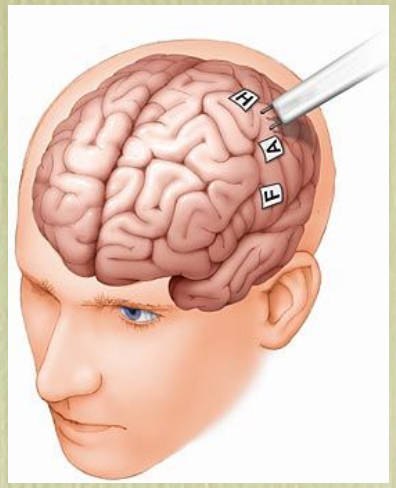
- brain imaging (passive)
- brain electrostimulation (
- breaking the ice of locke
- prosthetic limbs by BCI
- drugs
- stem cells contra degeneration
- genetic modification (GM)



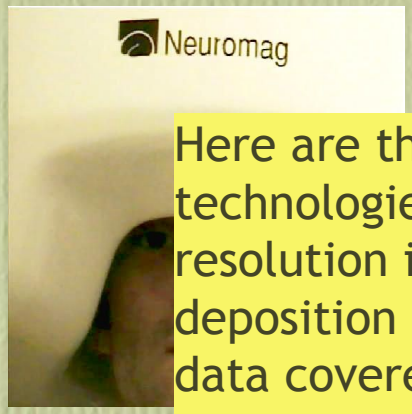
Research

- brain mapping
- disruptive TMS
- prosthetic limbs
- smart drugs
- smart food
- neurofeedback





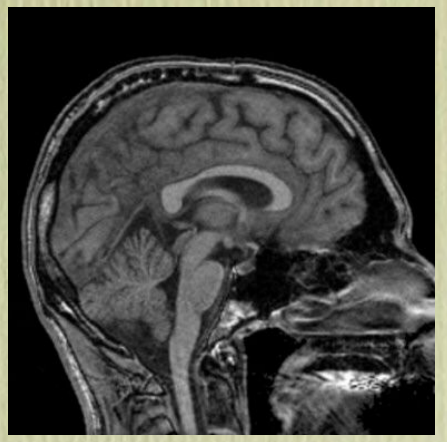
Some current areas of research:



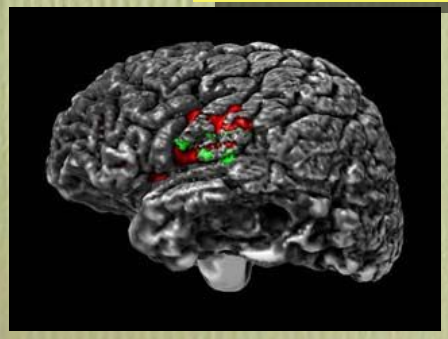
Imaging (Imaging)

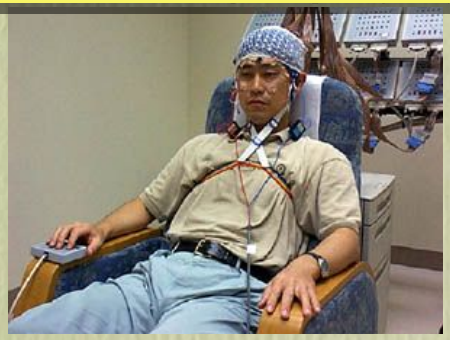
Here are the most important current imaging technologies. They all have limits, such as resolution in time and/or in space, energy deposition limits in tissue, and the type of data covered.

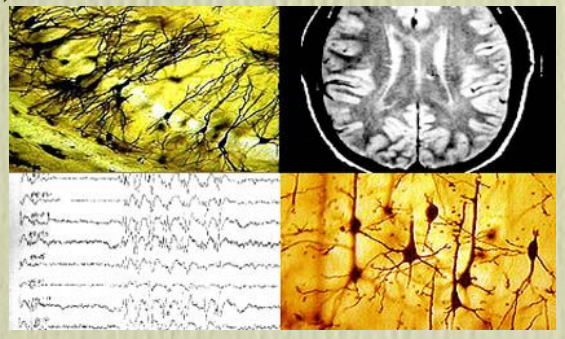
EEG is a galvanic approach to gather electric potentials, MEG measures magnetic fields from brain's own electrical activity, fMRI pinpoints areas of high metabolism with correlate with high brain activity, and PET does the same using radioactive isotope labels.

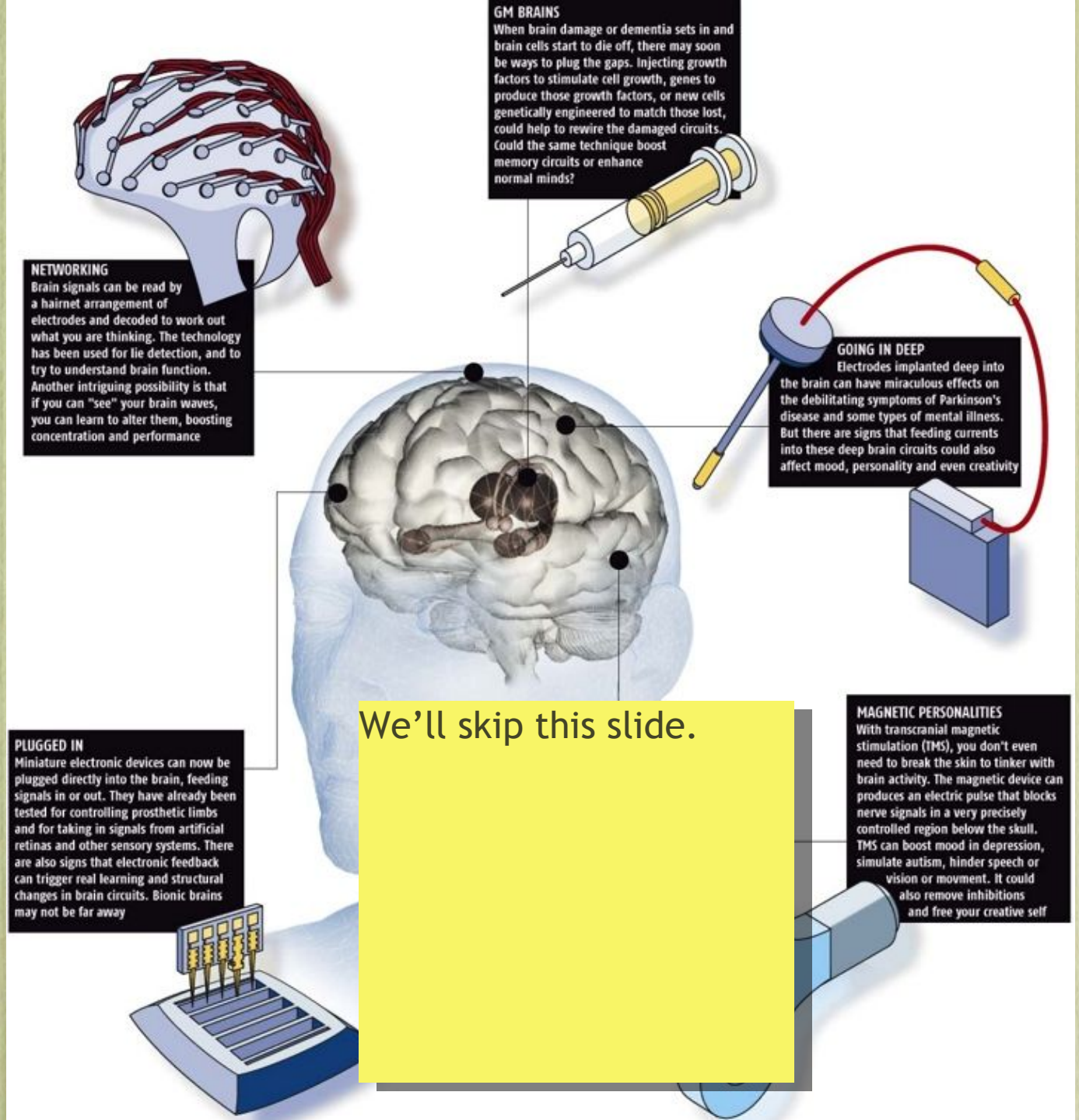


- aging (fMRI)
- T)









We'll skip this slide.

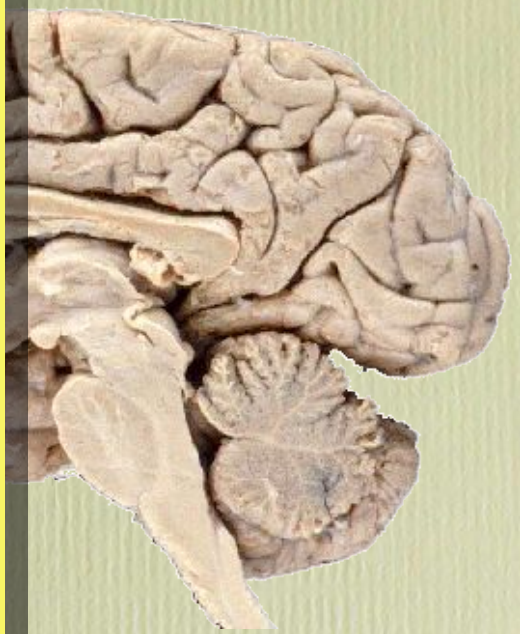
Neurotechnology

We can classify neurotechnology by the following properties:

invasive versus noninvasive (i.e., does it cross the skin?)

passive or active (imaging and manipulation)

realtime versus nonrealtime - are we seeing each individual process or averaging over time and space?



Here are the active electrostimulation approaches currently in therapeutical use or as future candidates.

ive (Manipulation)

- Vagus Nerve Stimulation (VNS)
- repetitive Transcranial Magnetic Stimulation (rTMS)
- Magnetic Seizure Therapy (MST)
- Transcranial Direct Current Stimulation (TCDS)
- Deep Brain Stimulation (DBS)

mulation

120 million people world-wide are depressed. Every year about 850 000 people commit suicide, 9 out of 10 of them are depressed. A considerable fraction of severe depression cases resist drug treatment. The only other alternative - electroconvulsive therapy is frequently rejected because of frightening side effects such as amnesia.

Electrostimulation therapies are showing promise to be effective against severe depression, bipolar disorder, obsessive-compulsive disorder, and bulimia.

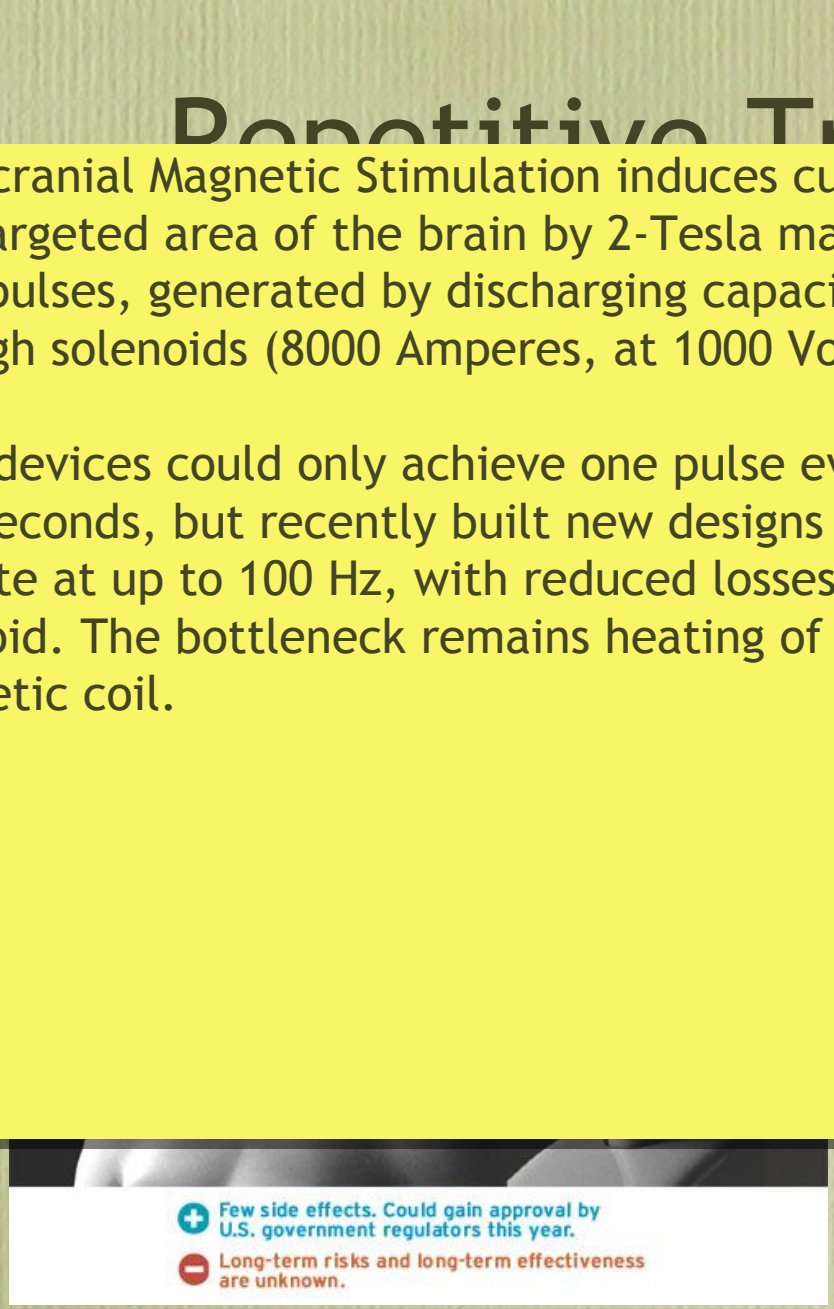
enerator implanted in a patient's chest
ctric pulses to the vagus nerve, one of 12
at radiate from your brain rather than
al cord. The pulses send signals into the
t may reduce or eliminate severe chronic
n.

IEEE Spectrum/Bryan Christie

Repetitive Transcranial ...on (rTMS)

Transcranial Magnetic Stimulation induces currents in a targeted area of the brain by 2-Tesla magnetic field pulses, generated by discharging capacitors through solenoids (8000 Amperes, at 1000 Volt).

Early devices could only achieve one pulse every four seconds, but recently built new designs can operate at up to 100 Hz, with reduced losses in the solenoid. The bottleneck remains heating of the magnetic coil.

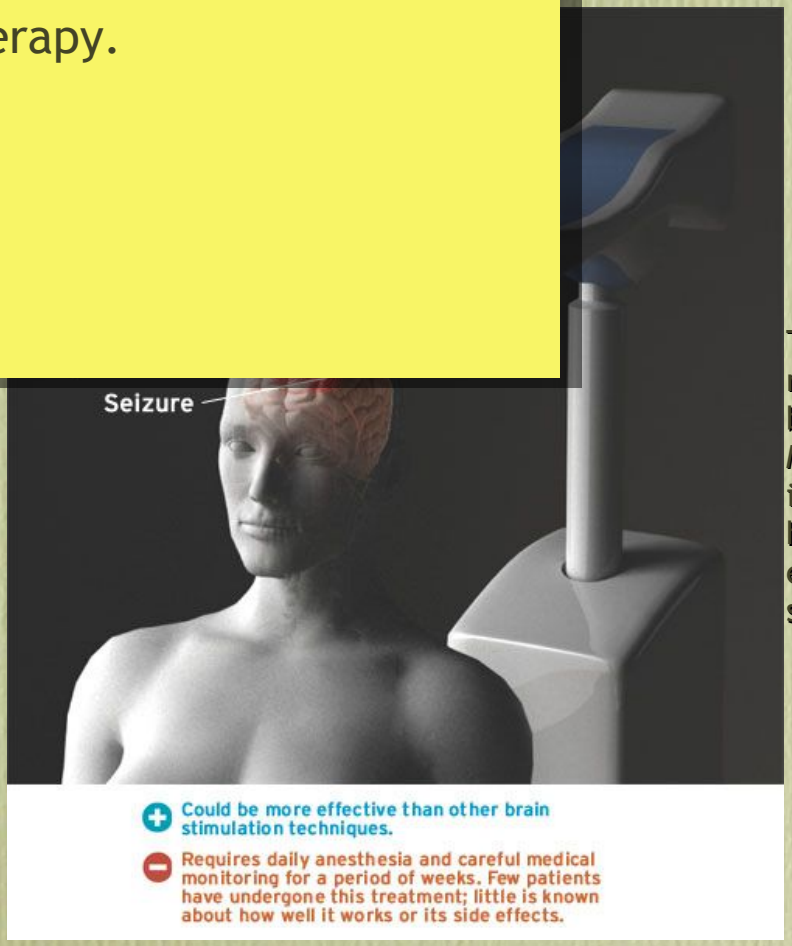


...pulsed electromagnet positioned over a ...brain implicated in depression induces ...current in neurons locally. Though the ...is done only for minutes a day over a ...eeks, it alters the activity of the ...g-term.

IEEE Spectrum/Bryan Christie

Magnetic Seizure Therapy (MST)

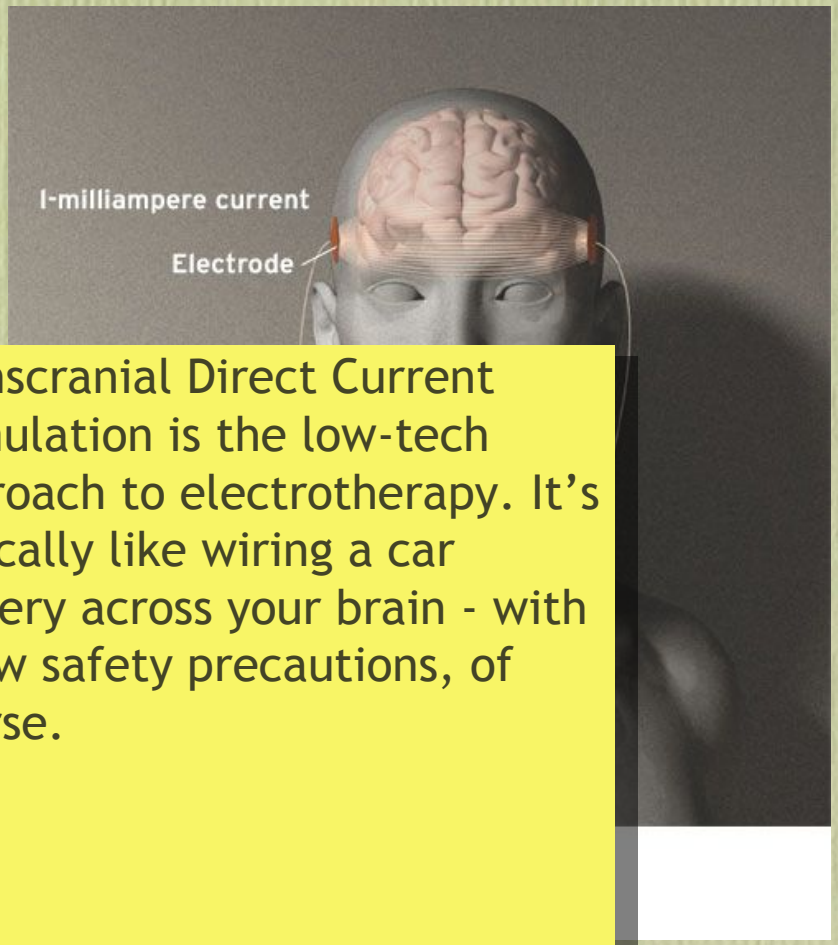
Magnetic Seizure Therapy is the magnetic, contactless variant of electroconvulsive therapy.



This therapy uses a more powerful electromagnet than repetitive transcranial magnetic stimulation does; it is basically a magnetic version of electroconvulsive therapy. Magnetic seizure therapy induces a high-frequency current in a small portion of the brain until it sparks a seizure. The hope is that a magnetically induced seizure will be as effective at treating depression as an electrically induced seizure while causing less memory loss.

IEEE Spectrum/Bryan Christie

Transcranial Direct Current Stimulation (TDCS)



Transcranial Direct Current Stimulation is the low-tech approach to electrotherapy. It's basically like wiring a car battery across your brain - with a few safety precautions, of course.

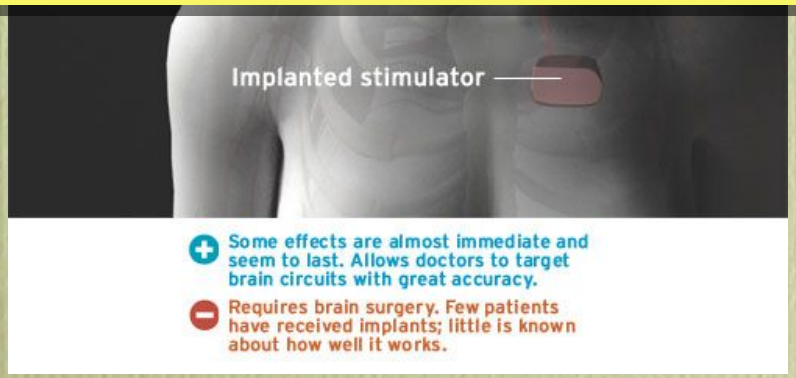
A device drives a small direct current through the front part of a patient's brain. Though the stimulation is done only for minutes a day over a period of weeks, it appears to alter the activity of neurons in the long term.

IEEE Spectrum/Bryan Christie

ulation (DBS)

Deep Brain Stimulation is the most invasive approach, for those few cases which resist electroconvulsive therapy. It involves implanting electrodes deeply into the brain for electrostimulation to break malfunctioning neuronal circuits implicated in the disease.

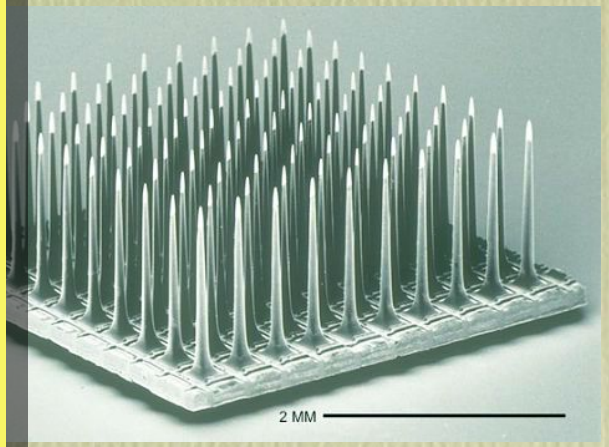
timulator implanted in a patient's chest sends
ses of electricity to electrodes embedded deep
hin the brain. The stimulation switches off
rons within a few millimeters of the electrodes.
an cure severe depression by interrupting
lfunctioning brain circuits implicated in the disease.



IEEE Spectrum/Bryan Christie

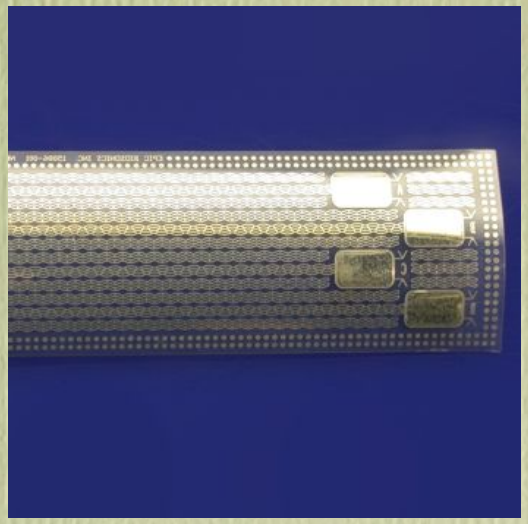
otechnology

Here we see an assortment of multielectrode implants, it's the BrainGate device to enable quadruplegic and locked-in patients to communicate by means of controlling a computer cursor on screen mentally.

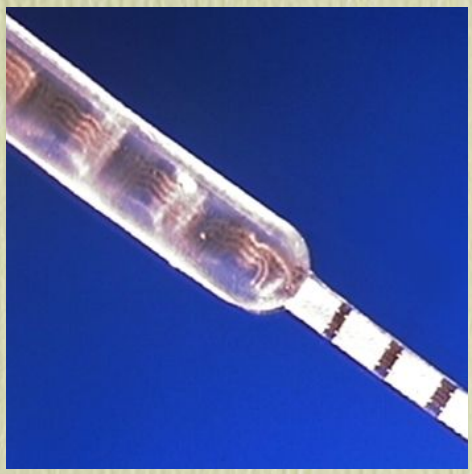


This slide illustrates the issues with implants:

ocompatibility



- implant durability
- tissue-like flexure
- long-term impact on contacting tissue
- power dissipation density

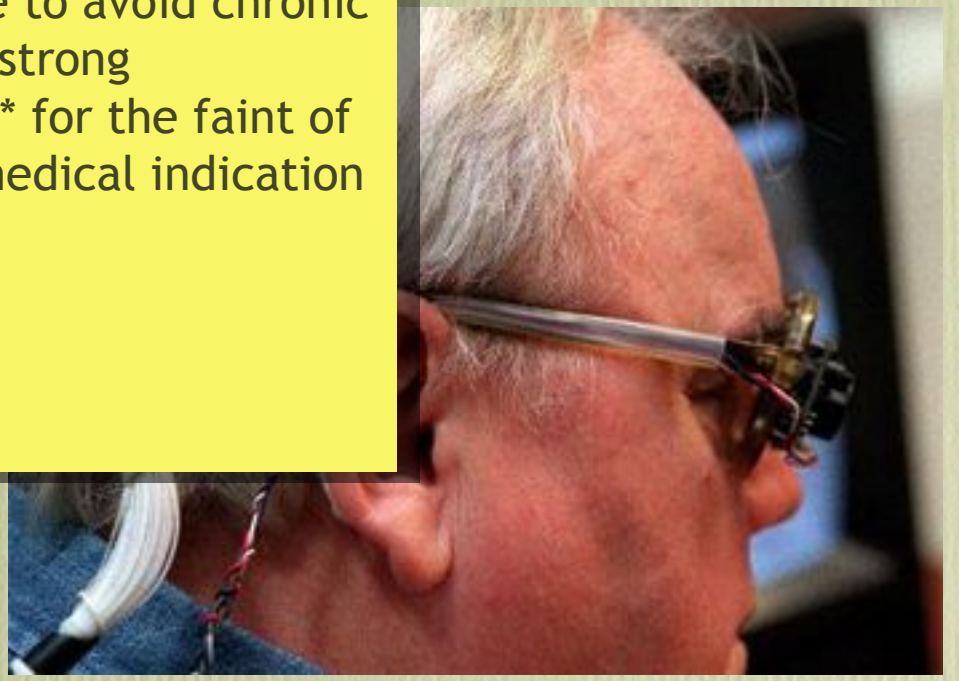


portal

Do we have to cross the skin, or not? Crossing the skin is necessary to get the signals out and in, and to provide power to the implanted device.

This has a high threshold, since involving surgery, needs proper care to avoid chronic infections, and has a very strong Frankenstein Factor. *NOT* for the faint of heart. Needs a powerful medical indication to at all to contemplate.

- infections
- Frankenstein F.

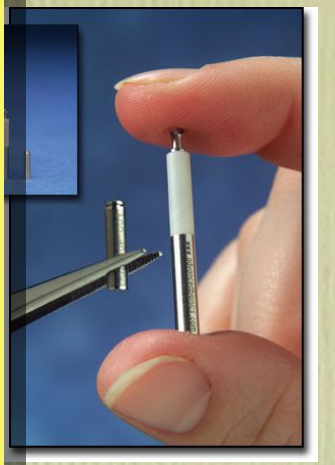


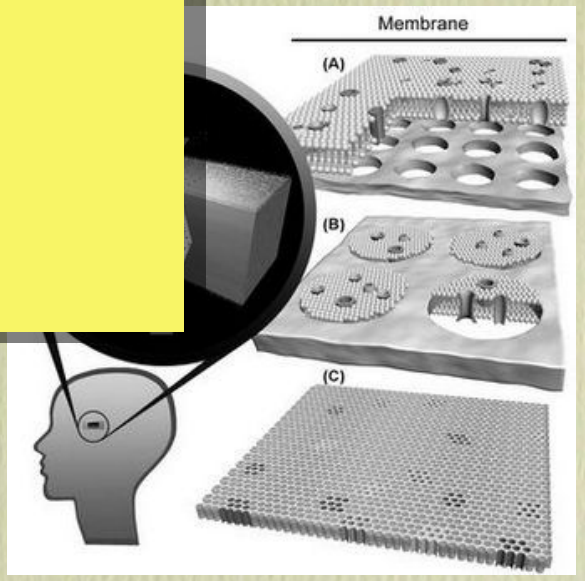
Powering the implant is a difficult problem.

Conventional electrochemical energy sources (batteries) can be recharged via induction e.g. overnight, periodically replaced by surgery -- radioisotope batteries are very long-lived, but have issues of their own.

- A new approach is trying to build glucose/oxygen fuel cells, thus leeching on locally available resources.

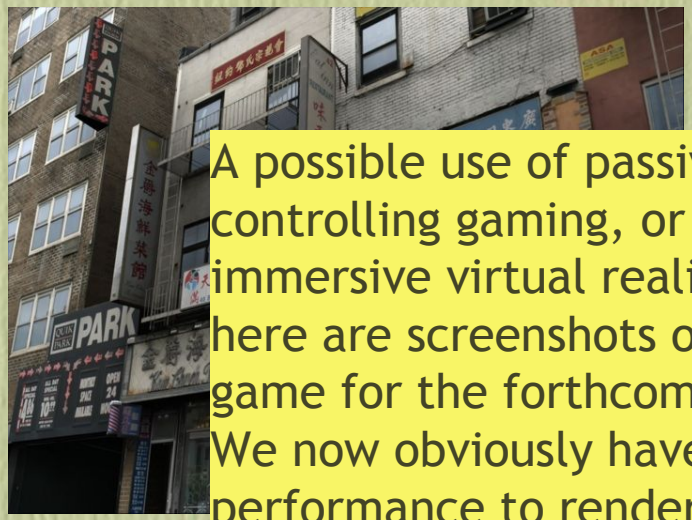
A simple approach, especially for high-power devices is to use an external battery with a transdermal portal to power the implant.





- glucose fuel cell

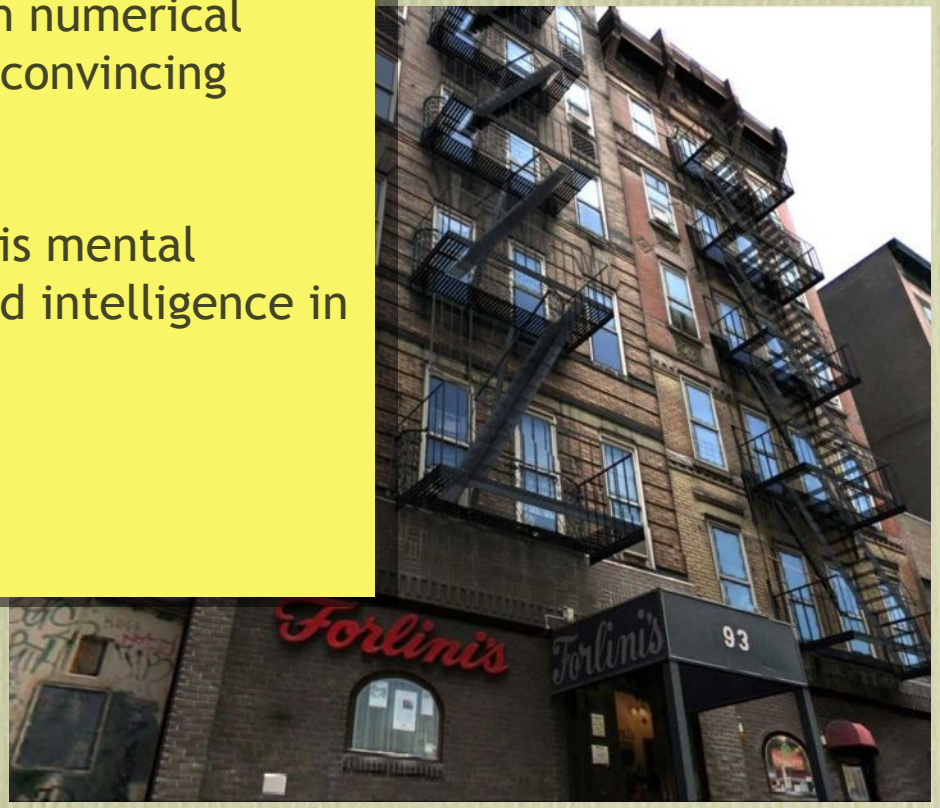
- external (transdermal)



Consumer

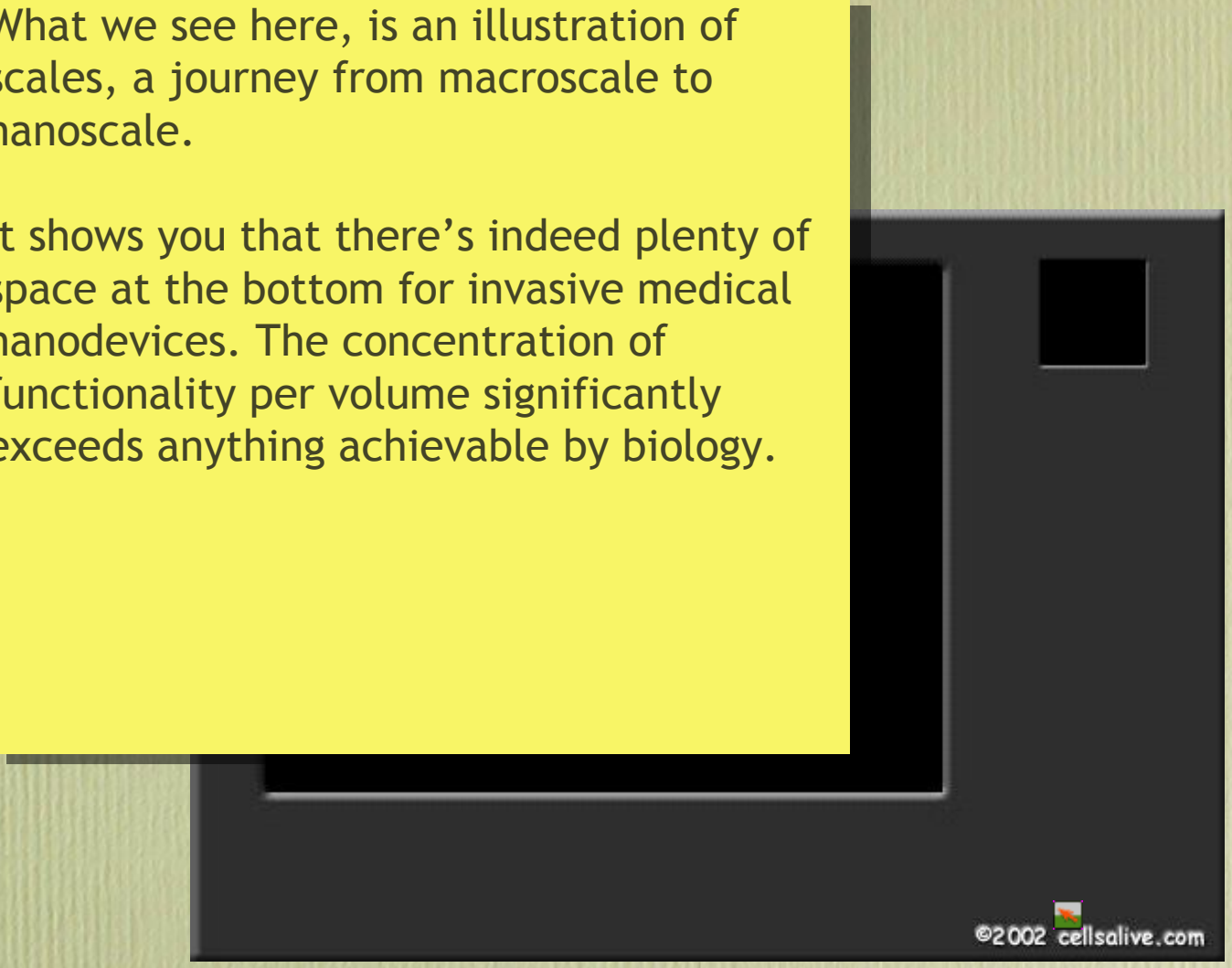
A possible use of passive neurotechnology is controlling gaming, or navigation in fully immersive virtual reality -- the images you see here are screenshots of a next-generation game for the forthcoming PS3 game console. We now obviously have enough numerical performance to render pretty convincing virtual reality.

- Another futuristic application is mental communication with embedded intelligence in the environment around you.
-
-
- ambient intelligence



What we see here, is an illustration of scales, a journey from macroscale to nanoscale.

It shows you that there's indeed plenty of space at the bottom for invasive medical nanodevices. The concentration of functionality per volume significantly exceeds anything achievable by biology.

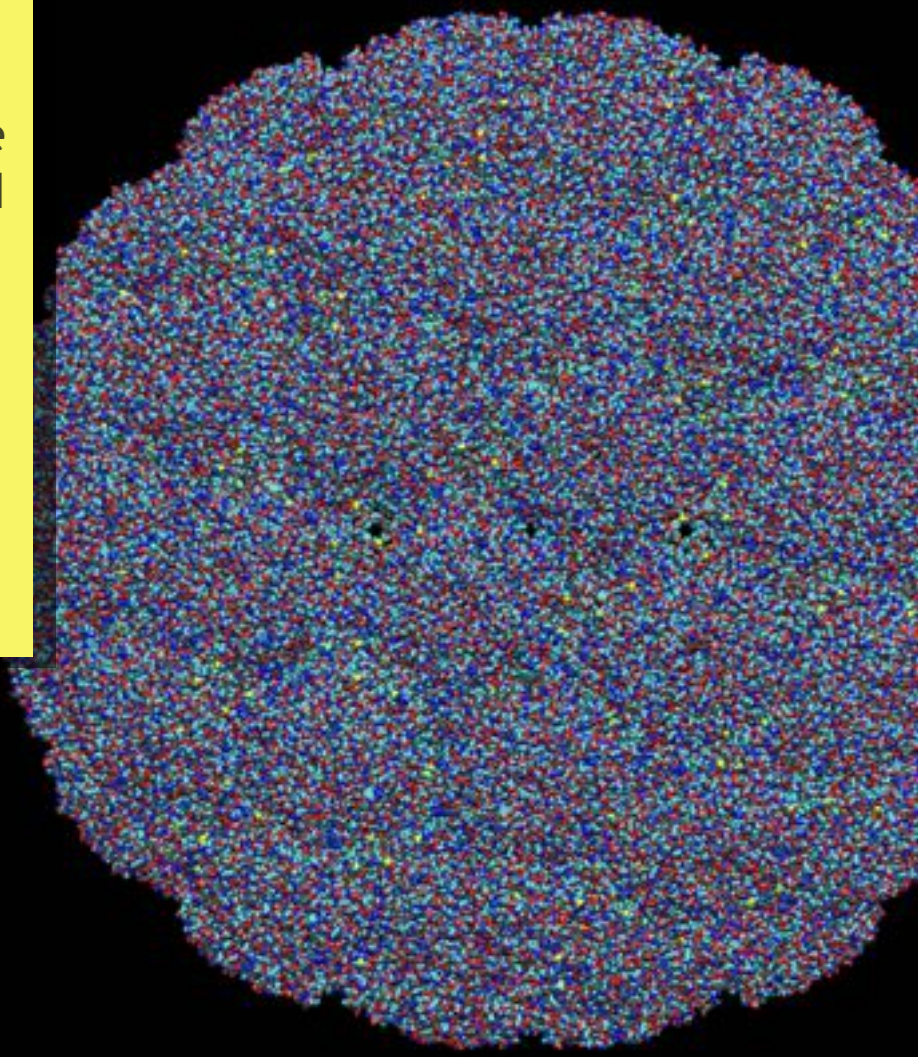


(A working interactive version of the above illustrative flash animation can be found at http://leitl.org/docs/nano/howbig.htm)

To the right we see a virus of about the same size as the rhinovirus in the slide before. It is roughly 20 nm across.

Next is a pump selective to neon, then a piece of hydrated bilayer (basically a piece of a cell membrane), a planetary gear, and a fine-motion controller.

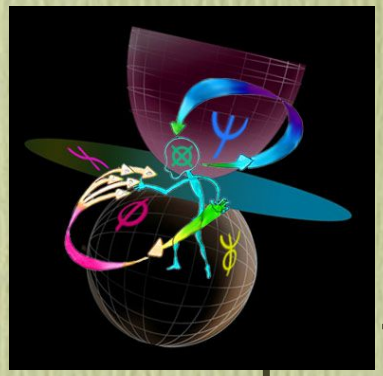
The devices are speculative, and are here merely for a size illustration.



Whole Body-Brain Emulation

We’re addressing on how to translate and transplant the identity of a an animal (human primates included) to a very different substrate.

An accurate simulation obviously requires modelling the CNS, a reasonably accurate body phantom, and the virtual environment, called Artificial Reality.



Personal Identity

- ta rh
- continui
- continou
- discrete
- nonlinea
- system e
  (traject
- first-person point of view

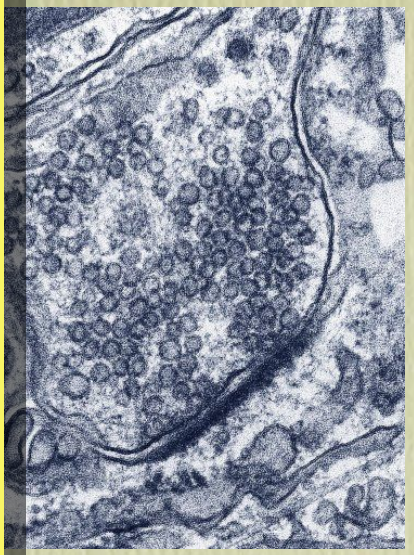
One of most misunderstood issues in animal modeling is personal identity. It is not something fixed, as Heraclitus already observed, the neuronal circuits are in the state of rapid, albeit homeostated flux. The pattern is important, not its components. These have no own identity, it is their arrangement which creates the pattern - you.
Pattern continuity is routinely violated through flat EEG lacunes, which occur at hypothermia, medication, and stopped blood flow (ischemia). People are routinely recovered from such transient, electrically silent states, without being considered zombies.

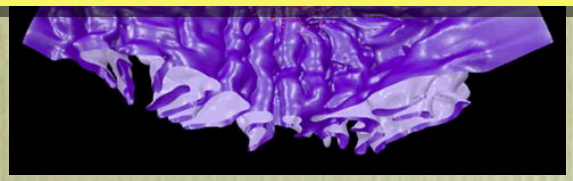
<SEE SLIDE FOR MORE>

omy

We have two fundamental choices: we can incrementally substitute isofunctional, artificial machinery in vivo, or we can extract the pattern, and build a computational model of it by abstracting salient features.

How do we extract the pattern? The living system is far too dynamic. We have to stop the time in order to read everything out. Freezing a biological system stops the movement, and fixes everything in place. But it creates artifacts, and destroys information. Vitrification is a more gentle methods, turning live tissues into cryogenic glass. Now we can slice it up, and imagine everything by successive abrasion from the surface. Time is no longer an issue. Arguably, assembling a TEM image stack into a volumetric data set might be enough for simple systems.

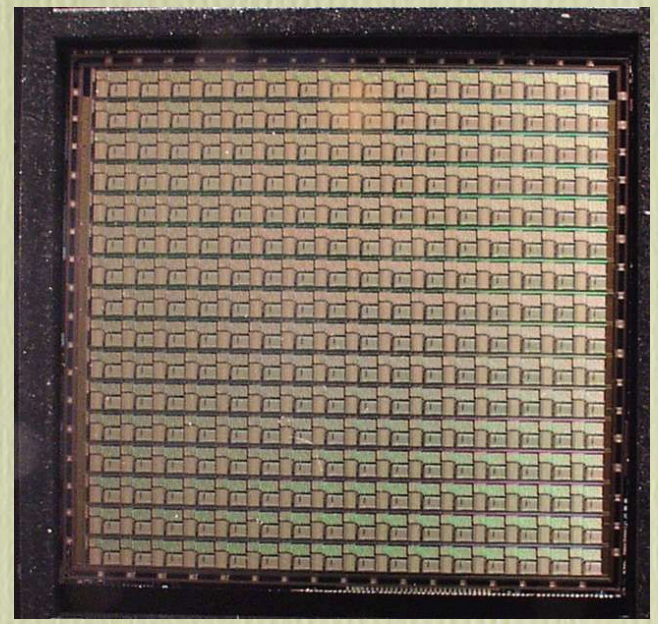




If we have a data set, where do we load it to run?
Here are our options:

tion hardware

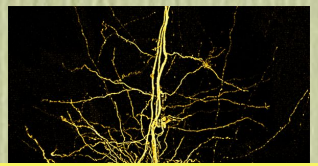
- Blue Gene (Blue Brain Project)
- dedicated hardware
- computronium



embodiment

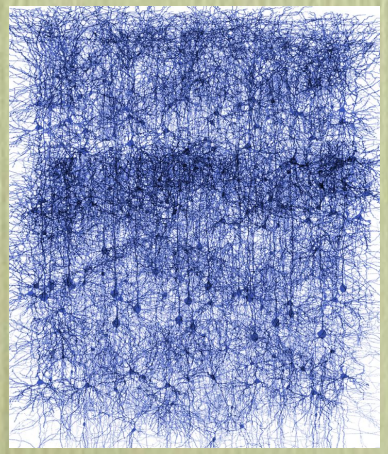
ty

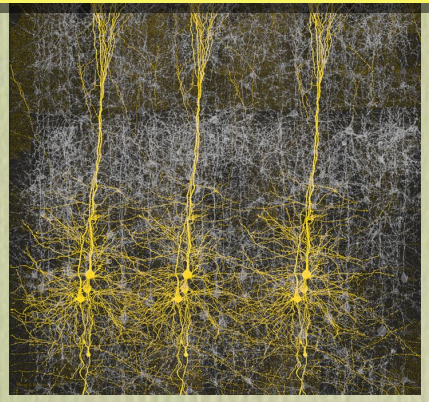
state of the art



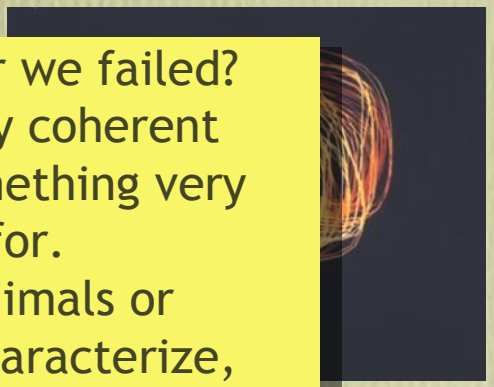
What is the state of the art in neuronal emulation?

- Blue Brain Pro





Henry Markram, EPFL



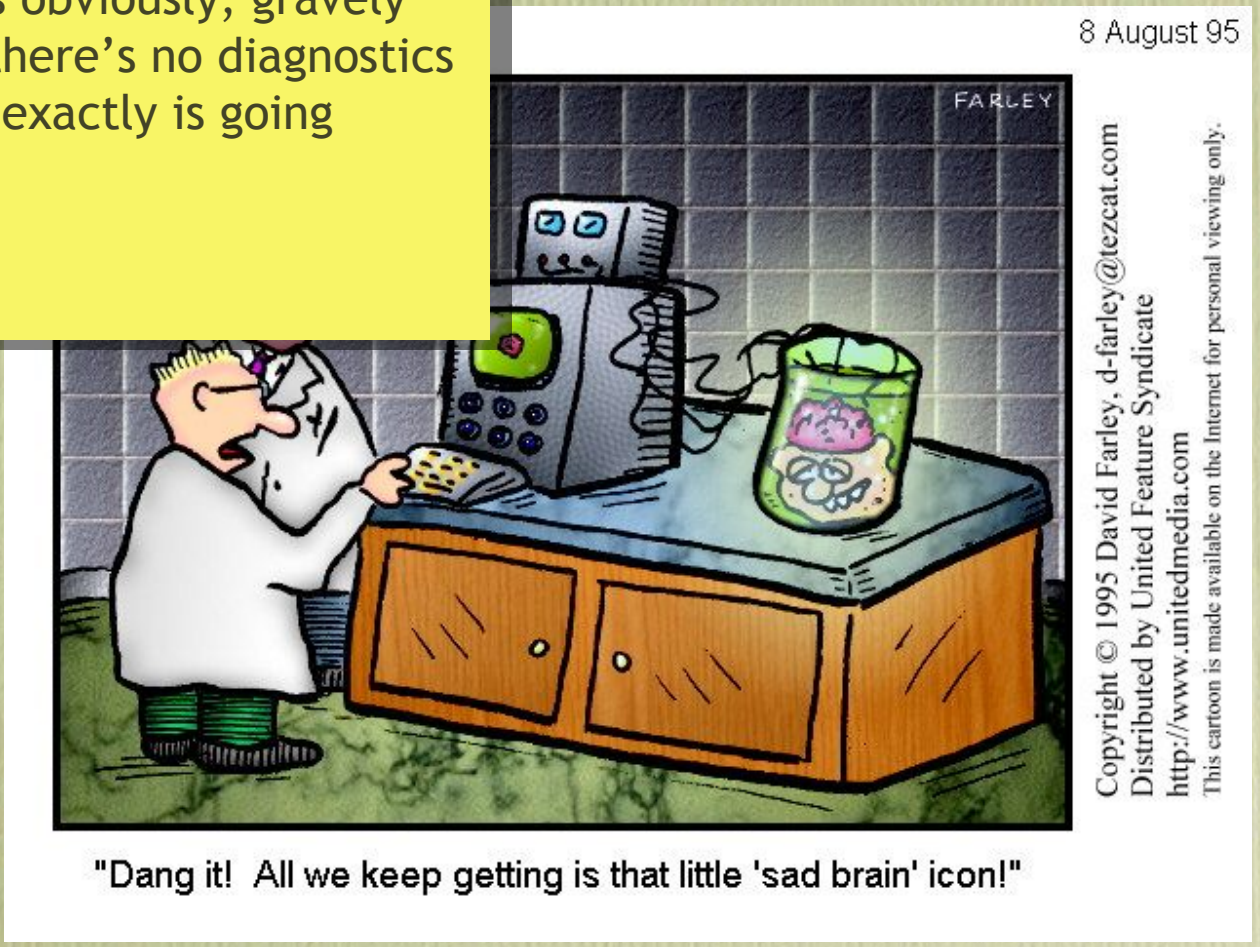
How can we figure out whether we succeeded, or whether we failed?
If our model is completely wrong we fail to regenerate any coherent activity pattern whatsoever. The system will be doing something very gravely, very obviously wrong. That's an easy one to test for.
With simple organisms, we can observe freely behaving animals or animals in a scenario designed to evoke a learned task, characterize, and then euthanize and digitize them.
If the numerical model reproduces the behavior learned previously, that's a validation. For all practical purposes we can consider behavior a rich functional fingerprint of the internal state. We humans have evolved fine antennas for gauging animal behavior.
For people, we can apply a variant of the Turing test - we can simply ask questions, and compare them with our previous record.
This however, is not sufficient for such complex systems as us.
Instrumenting the central nervous system of a behaving human with a very large number of monitoring channels (hundreds of thousands to hundreds of millions) and extracting some activity invariant will be required. We can't do this right now. A closest analogy would be a multichannel FFT EEG.

Arguably it would take invasive medical nanotechnology to deploy that many probes, and a very large supercomputer to mine the data for

nportance of QA

Here is an example of terrible importance of a proper quality control metric in organism modeling.

Something is obviously, gravely wrong, but there's no diagnostics to tell what exactly is going wrong.



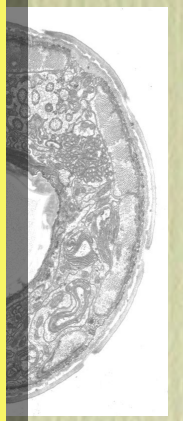
Where do we go from here? Arguably, we already can produce individually accurate numerical models of nematodes from structural data. It's just nobody has bothered to do all the work, especially since it would involve no new science.

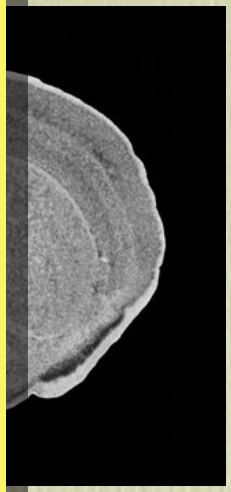
The adult Caenorhabditis elegans nematode is 1 mm in length, and 70 um in diameter. It is transparent, and consists of less than 1000 cells, about one third of them neurons.

A natural next step up in complexity is Drosophila melanogaster, the common fruit fly.

A mouse has about 100 million, and a human some 85-100 billion neurons.

All of the three are common model organisms in biology, extremely well characterized, and hence natural milestones towards the primates, especially humans.

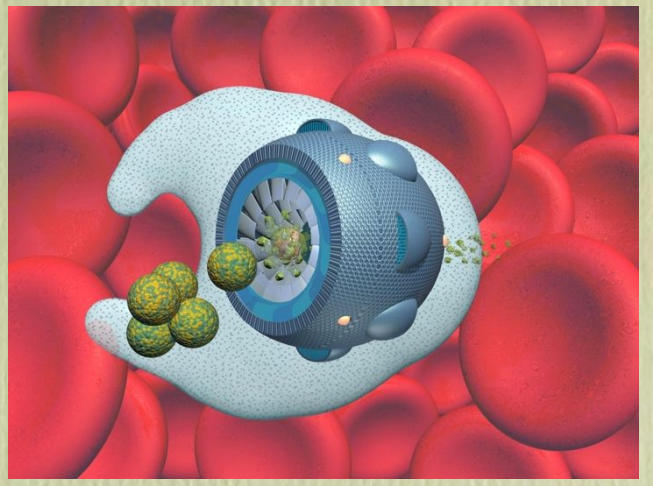




I'll conclude the talk with the obligatory expedition to the lunatic fringe.

What can we expect from neurotechnology of the future?

Future



- ogy
- human augmentation
- Whole Body/Brain Emulation
- speciation and radiation of postbiology
- expansion into space