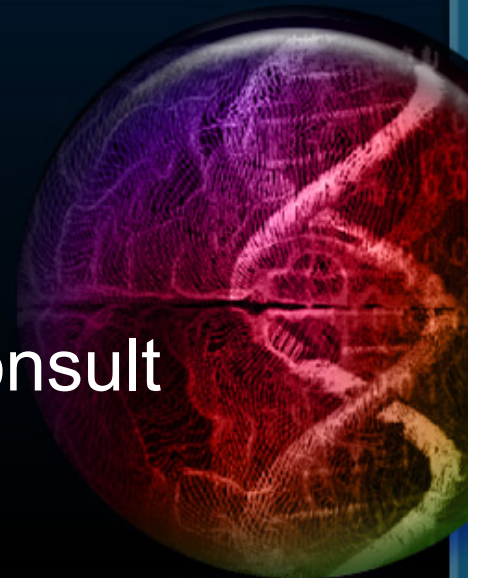


Consciousness and Computing - an exploration of the issues

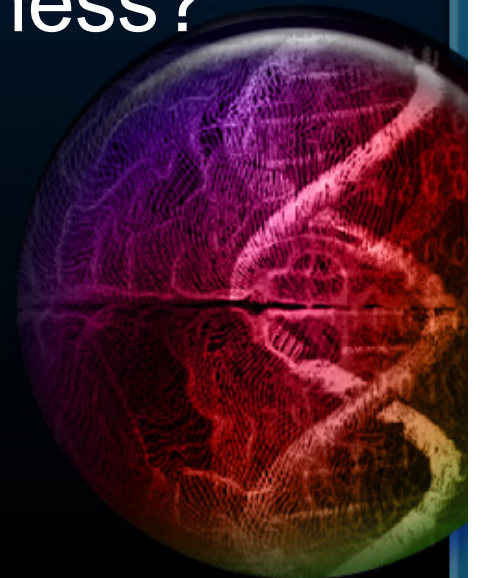
- **Queensland Brain Institute**
29 August 2006 Brisbane, Australia
- **Howard Florey Institute**
21 August 2006 Melbourne, Australia
- **Cajal Centenary Conference**
24-29 April 2006 Barcelona, Spain

• Bob Bishop Founder BBWORLD Consult



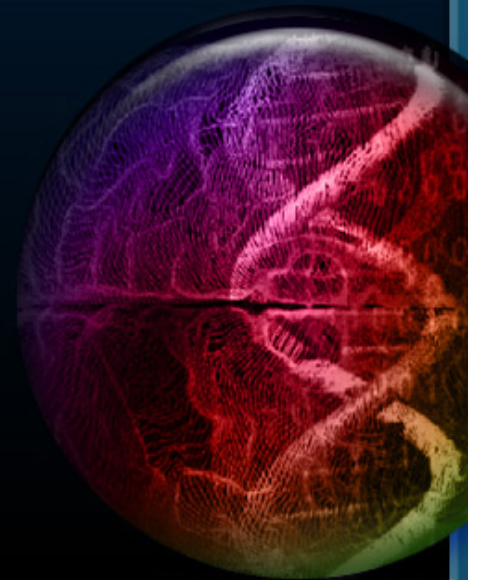
The Mystery of Consciousness

- What is the **function** of consciousness?
- Is it **only humans** that have consciousness?
- Do **animals** have consciousness?
- Can **other entities** have consciousness?



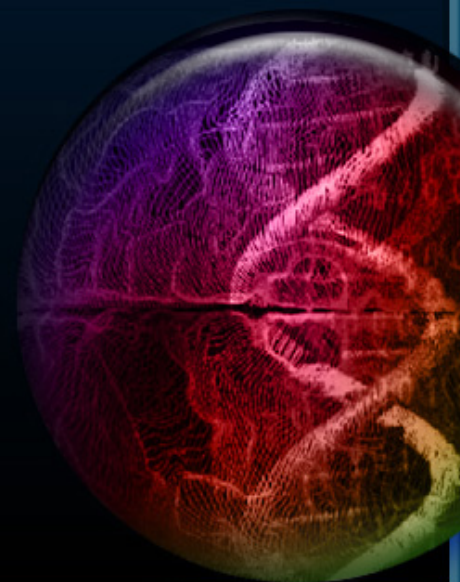
The Mystery of Consciousness

- **How** did consciousness evolve?
- **Why** did consciousness evolve?
- **When** did consciousness evolve?



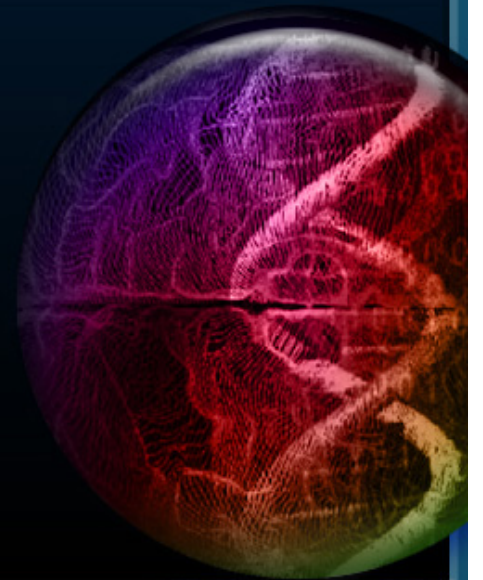
The Mystery of Consciousness

- Is consciousness **localised** or **ubiquitous**?
- Is there a **collective** consciousness?
- Is there a **cosmic** consciousness?



The Mystery of Consciousness

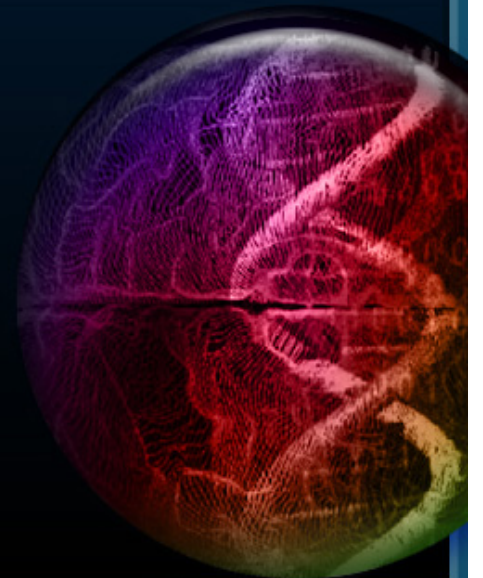
- Is there **continuity** of consciousness after **death** and **disintegration** of the body?



The Mystery of Consciousness

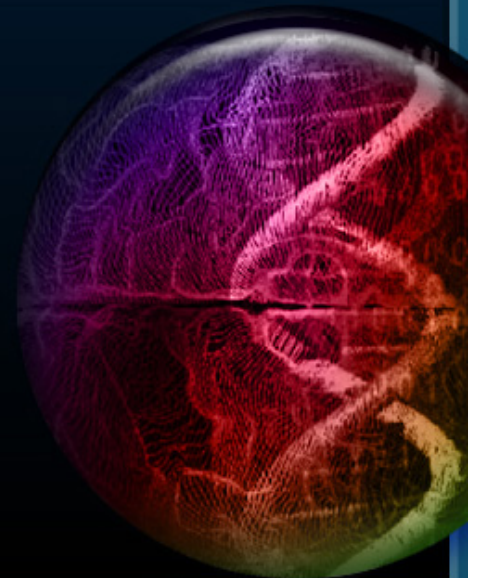
Is consciousness part of a **larger concept**:

self, spirit or soul, for example?



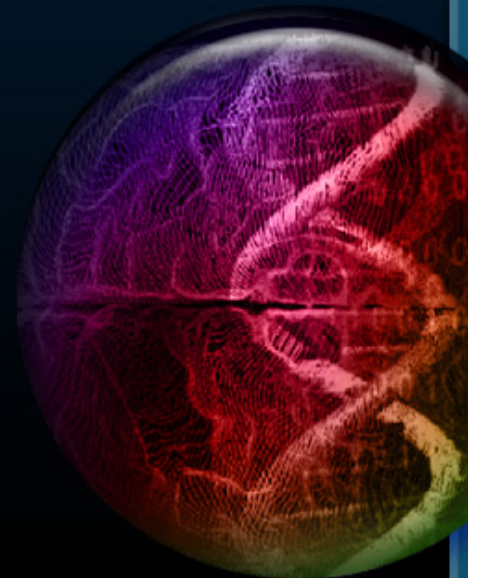
Consciousness **reigns**, but doesn't **govern**

- Paul Valery



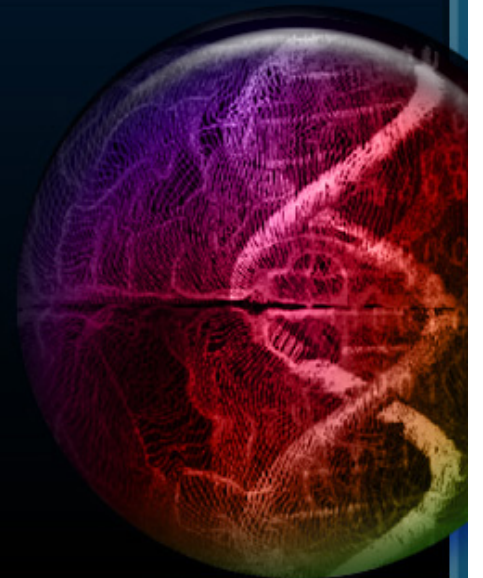
The Character of Consciousness

- Consciousness refers to the **moment-to-moment awareness** we have of **ourselves** and our **environment**
- Consciousness arises when we are **attentive to our emotions and perceptions**, or when we are **thinking and reasoning**
- Consciousness is a **unitary process**, not a thing.

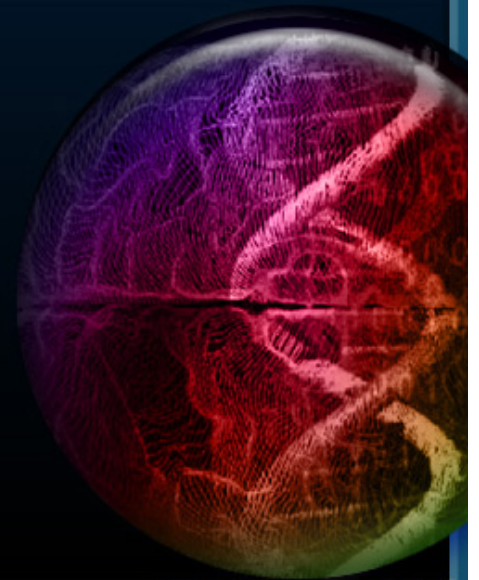
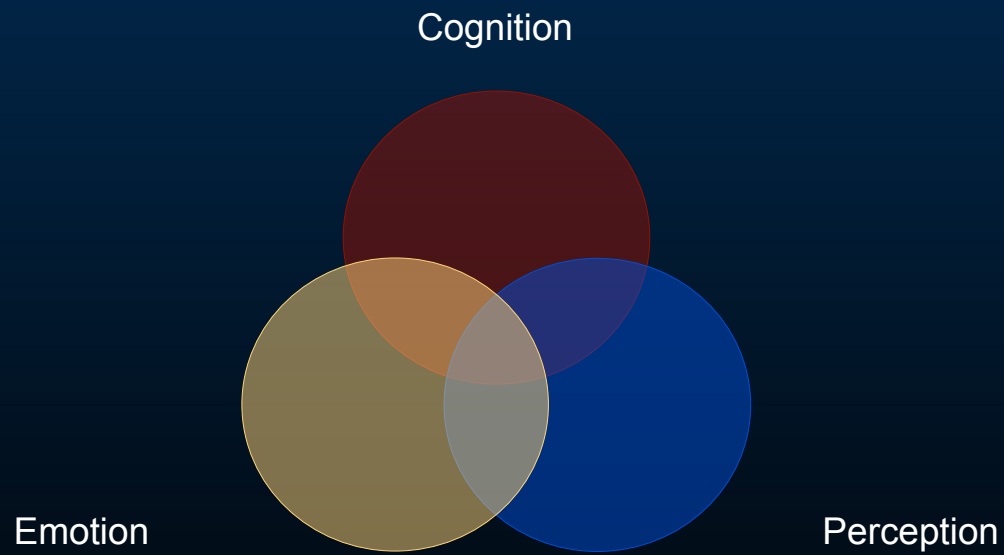


Consciousness is a process whose function
is **knowing**

- Gerald Edelman

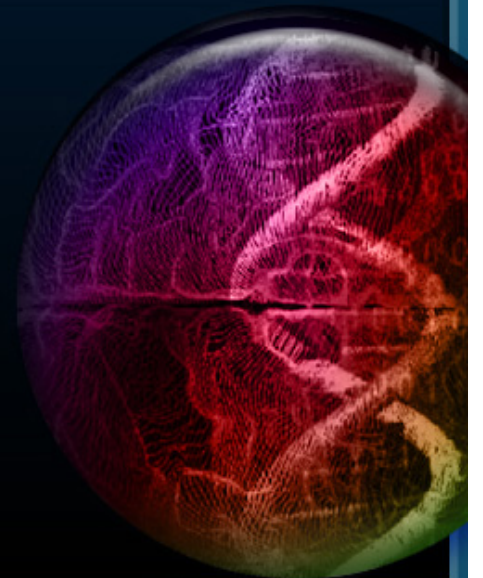


The **Modes** of Consciousness



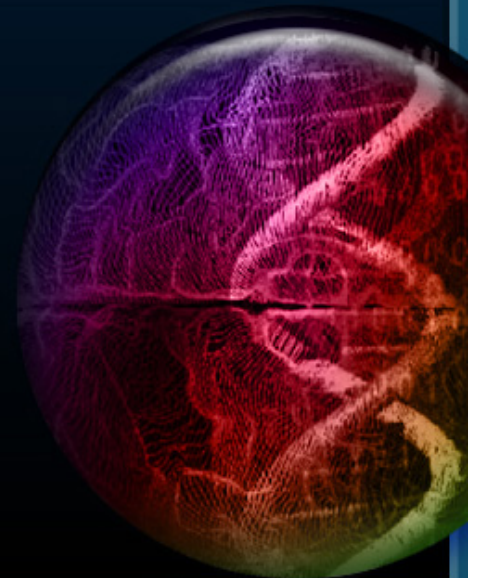
The Continuum of Consciousness

- Conscious
- Semiconscious
- Preconscious
- Subconscious
- Unconscious
- Concussed
- Comatose



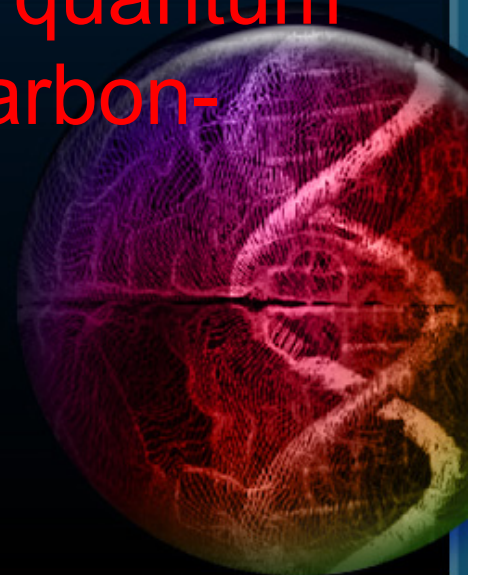
The Calibration of Consciousness

- No calibration is available to measure consciousness as it **waxes** and **wanes** in **intensity, richness and vividness**
- There is no **Index of Consciousness** !
 - no thermometer
 - no Richter scale
 - no pH level



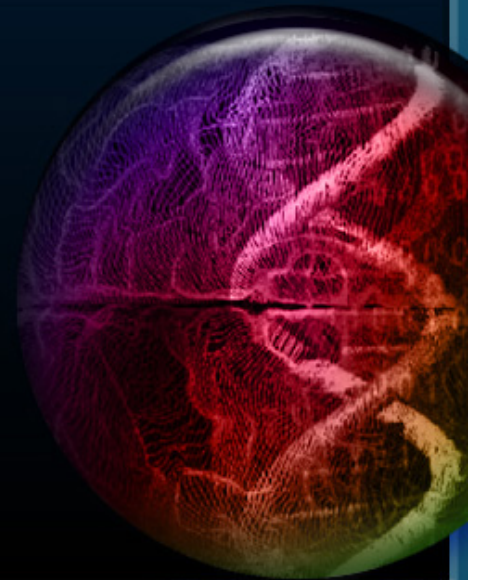
Can Computers have Consciousness?

- Alan Turing defined the mathematical notion of what a computer is (the **Turing Machine**)
- This set a **limit** on **what a computers can do**
- Maybe something **other** than a computer can be built with consciousness: a **quantum device**, a **virtual reality device**, a **carbon-silicon hybrid device** perhaps?



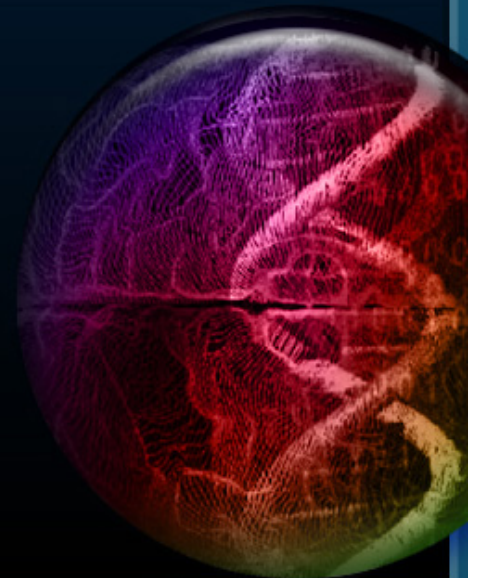
The challenge of the 21st Century

- Can we build **Artificial Consciousness**?
- Can we **reverse engineer** the human brain?
- Can we build **artifacts** with attributes that **mirror our humanity** and become **companions to mankind**?
- Should we?

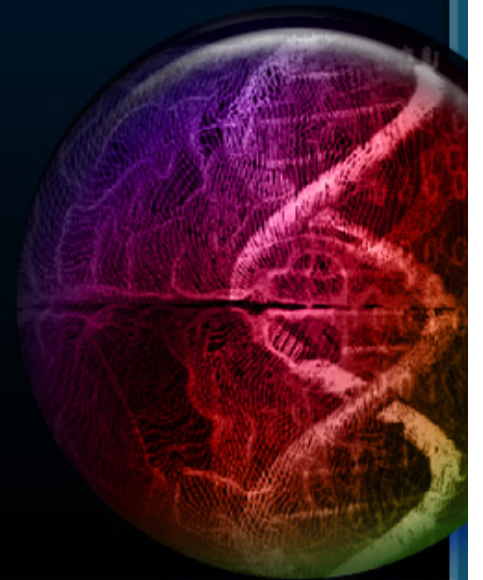


Many underlying moral questions

- For **good** or for **evil**?
- Mental disorders?
- How to educate?
- What religion?
- Legal rights?
- Voting rights?
- **Who can pull the plug?**

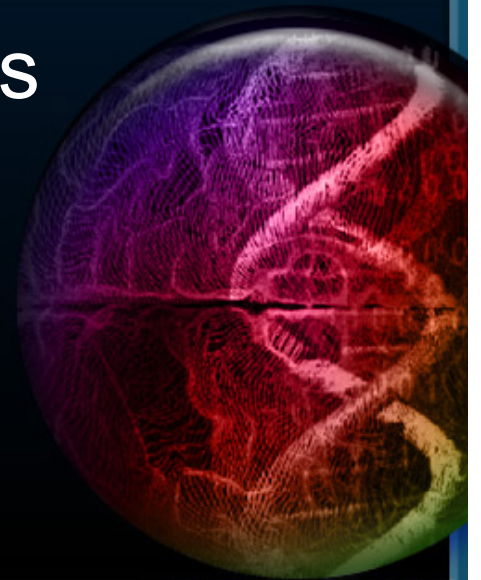


Would a Conscious Artifact have to be **alive**?

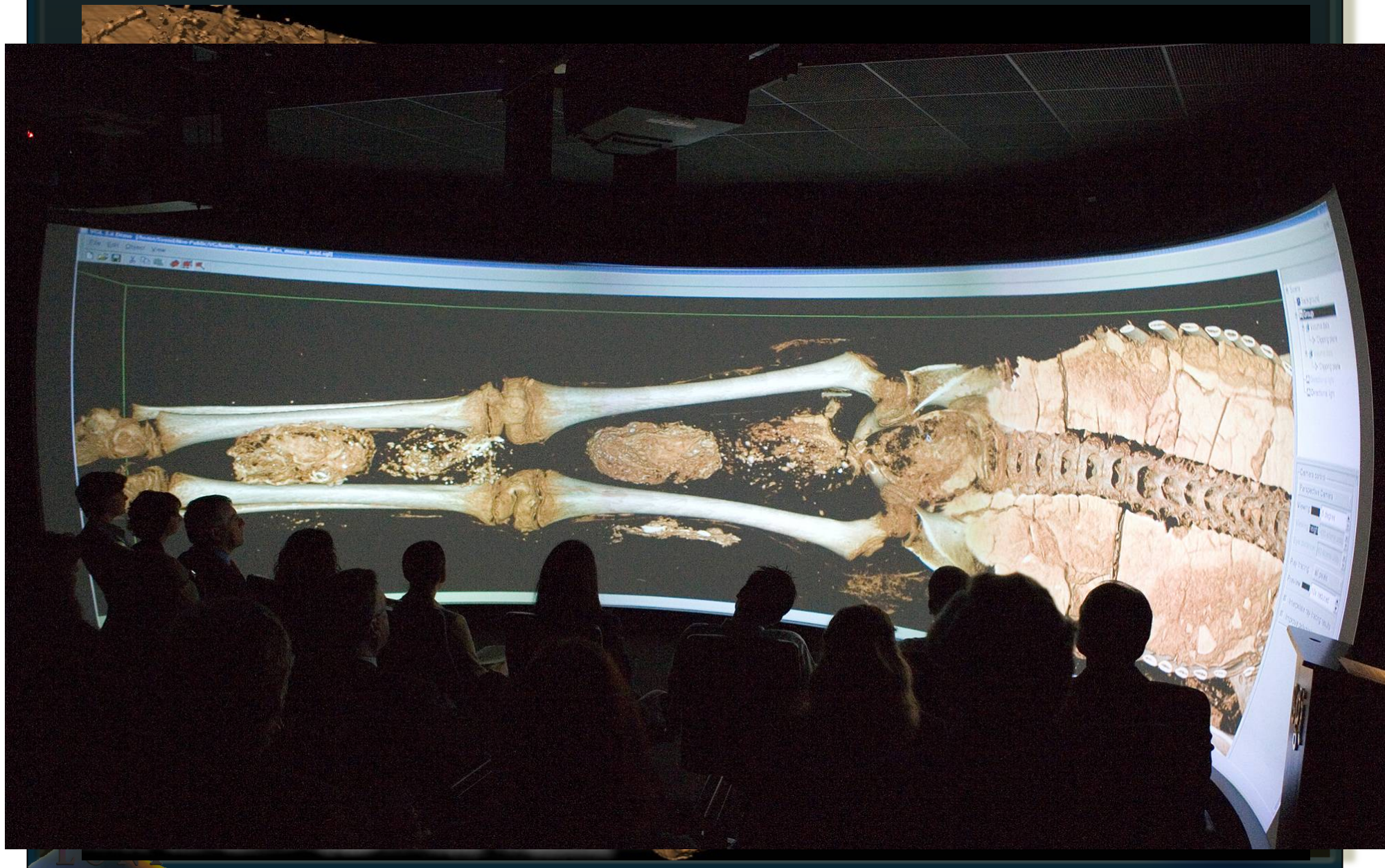


Ancient Egyptians

- Believed the **heart** was the seat of consciousness and that the brain was only a '**cooling device**'
- In the mummification process, the **heart** was **carefully preserved** within the body, whereas the brain was pulled out through the nose and **disposed** of.

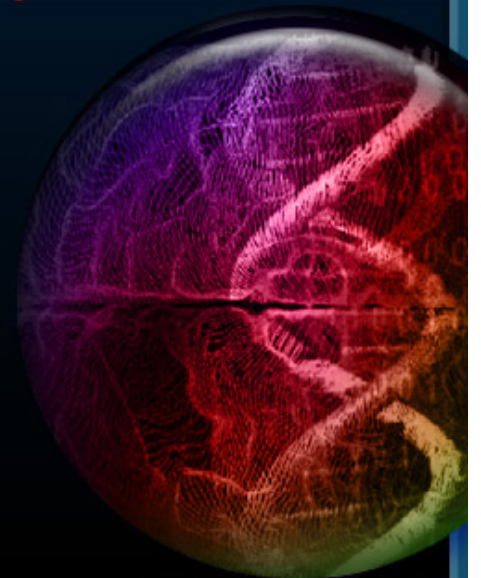


Sherit



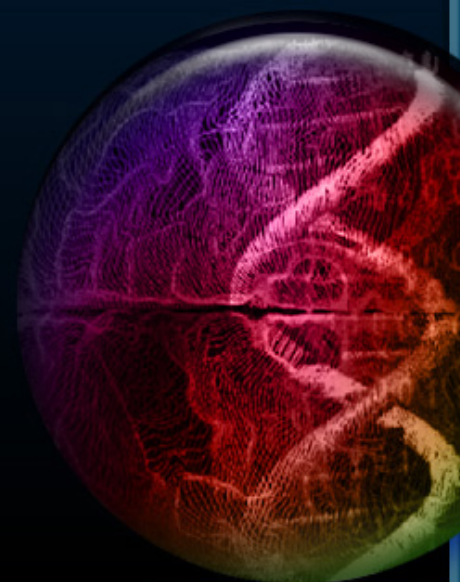
Indian Mystics

- Yoga taps into **universal** consciousness
- One does a cosmic **download** into the **tailbone**
- The spine is the **conduit** of consciousness
- The brain is the '**flower**' of the **spine**



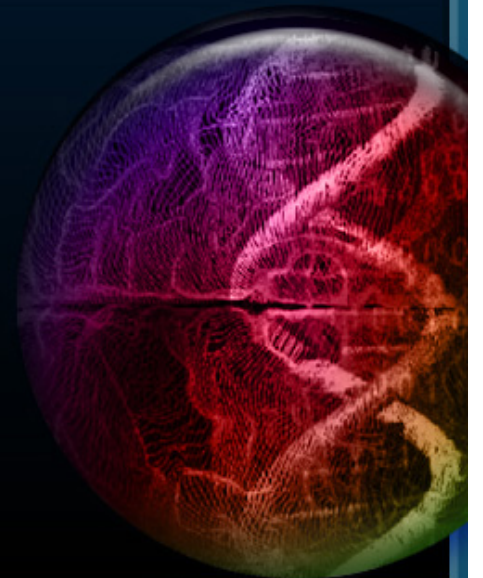
Chinese Sages

- **Time** is consciousness, permeating everything
- The '**past**' and the '**future**' are false concepts
- We all exist within the '**endless now**'
- We are subject to **endless change**
- Part of us can **know everything**
- The **I Ching** divines everything



Australian Aborigines

- **Earth** is the source of consciousness
- Humans play a **nurturing** role
- The landscape is their **church**
- **'Dreamtime'** integrates it all

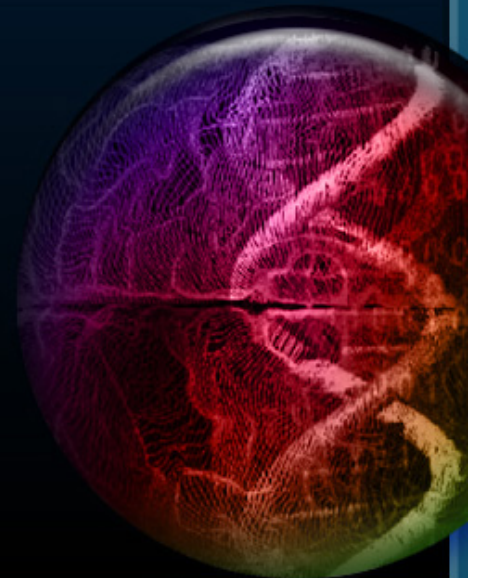


The Religious Viewpoint:

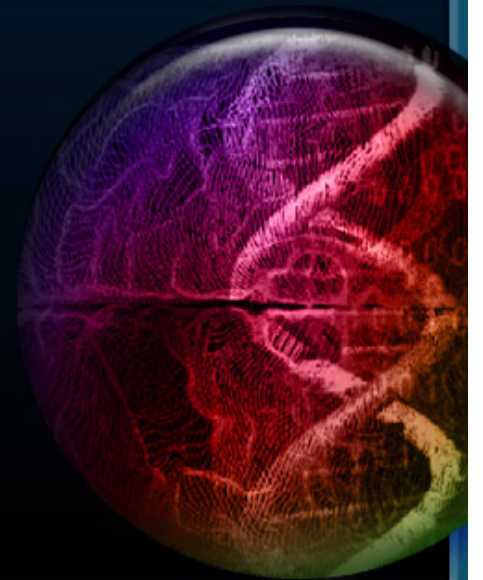
Human consciousness is simply 'ordained'

The brain is just the **weight of God**

... Emily Dickerson

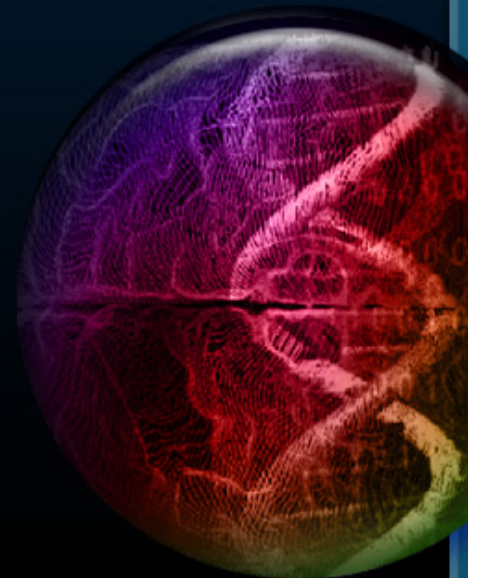


Can **Spirituality** and **Science** be reconciled?



In the view of our modern scientific society

- The **brain** is the **seat** of consciousness
- The **brain** is the **headquarters of our conscious selves**
- Even though the majority of neurosurgeons today spend the majority of their time **operating on the spine** rather than the brain!

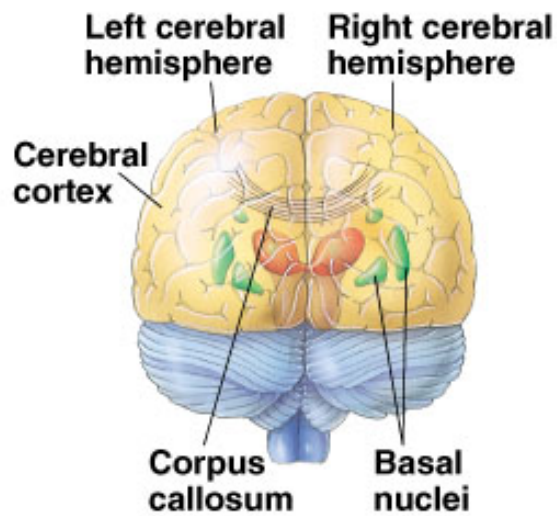


How did the Brain emerge?

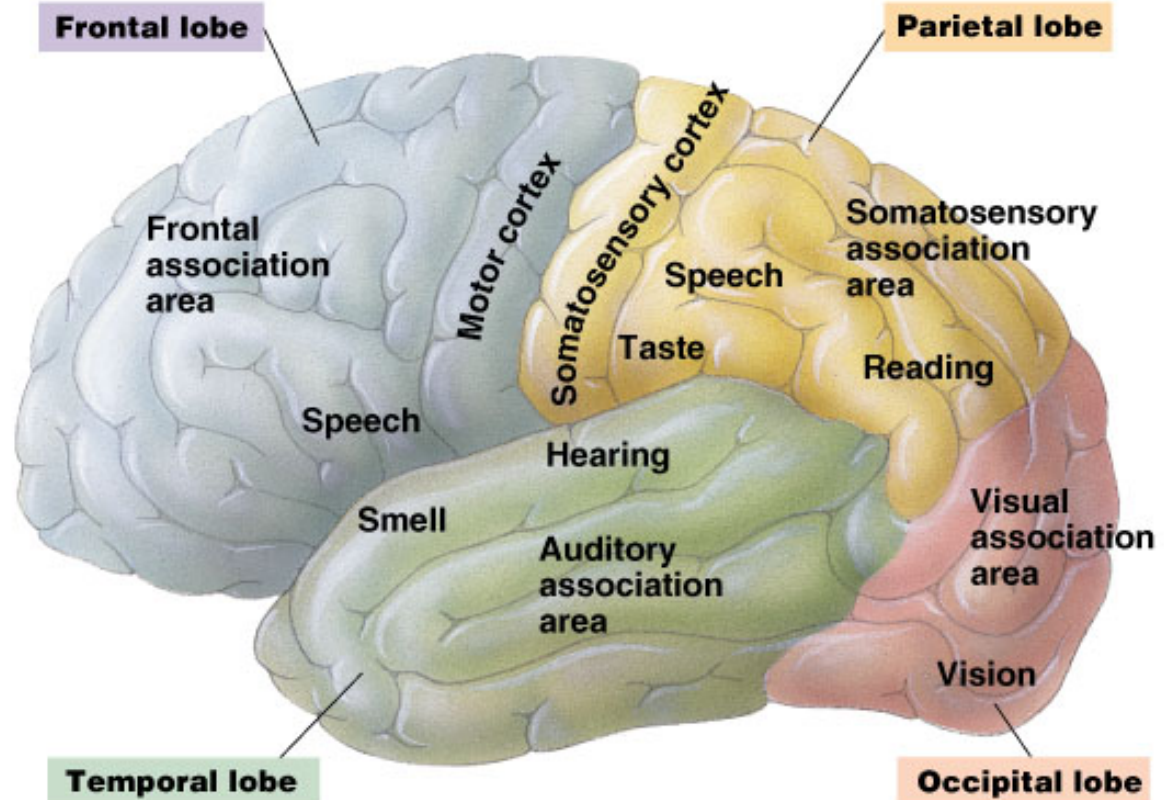
- **Evolution** is the universal force that forged the brain in **all species**
- Cultural evolution is the force that fine-tuned the **human brain**
- The **neo-cortex** increased in size rapidly in the **transition from primate to human** – perhaps due to the HAR1F gene.



The Neo-Cortex of the Human Brain



(a) Back of brain



(b) Left side of brain

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How did Consciousness emerge?

- Any brain, **however rudimentary**, will have a **degree of consciousness**
- Consciousness grows as the brain **grows in complexity**
- Between Homo erectus and Homo sapiens the brain **crossed a critical threshold** whereby **true language** developed, and ultimately, **consciousness of consciousness** !



Two developmental stages of consciousness

- **Primary** consciousness – for survival
- **Higher-order** consciousness:
 - closely associated with **speech & language**
 - encouraged by **advanced socialisation**
 - leading to **moral & ethical sensitivities**
 - separating the **past, present & future**
 - able to be **conscious of consciousness**
 - enabled by the **FOX2P** gene?

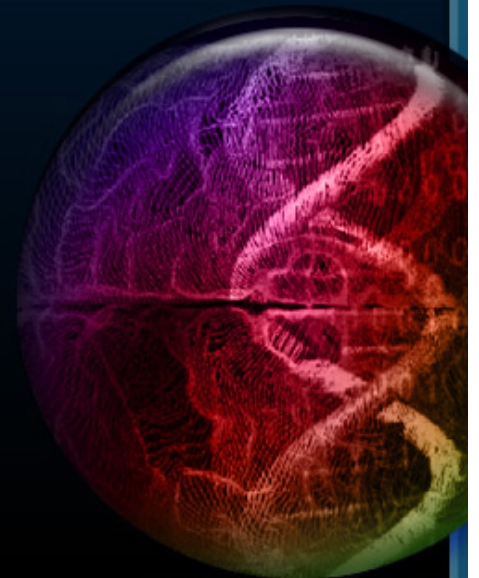


Primary consciousness emerged to:

- **Integrate** visual, tactile, auditory, olfactory and memory into **a single field of perception**
- **Discriminate** prey from predator and **survive**
- **Socialize** and develop **communities**

Higher-order consciousness emerged to:

- Distinguish the **past, present & future**
- Perceive what is **relevant** and **plan**
- Build **tools** for **competitive advantage**
- Build **models** of the real world that help **predict the future**

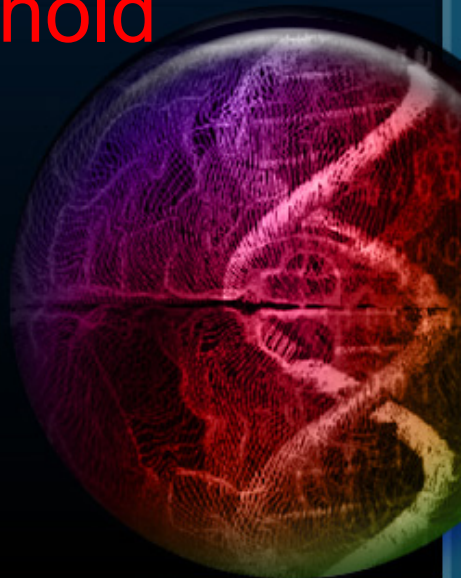


How does the Brain create Consciousness?

- Through the **synchronous and coherent** firing of neuron networks in the **Pre Frontal Cortex**? (largely a **digital** phenomenon).

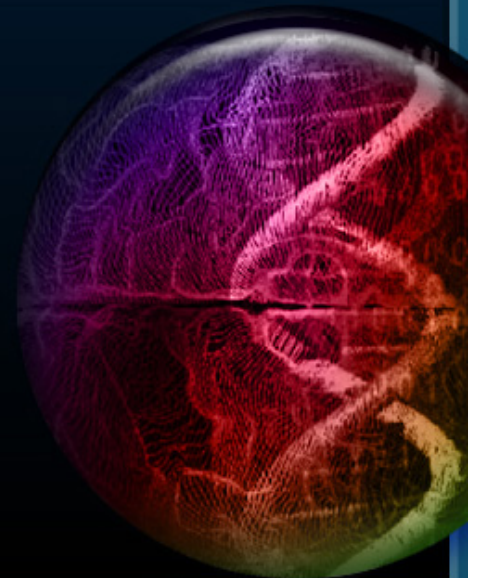
or

- Through the build up of **sub-threshold voltage patterns** in the dendritic fabric? (an **analog** phenomenon).



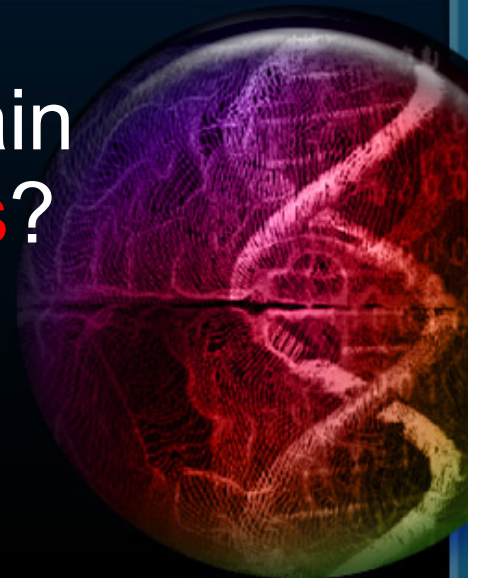
Neurons are the butterflies of the Soul

- Santiago Ramon y Cajal



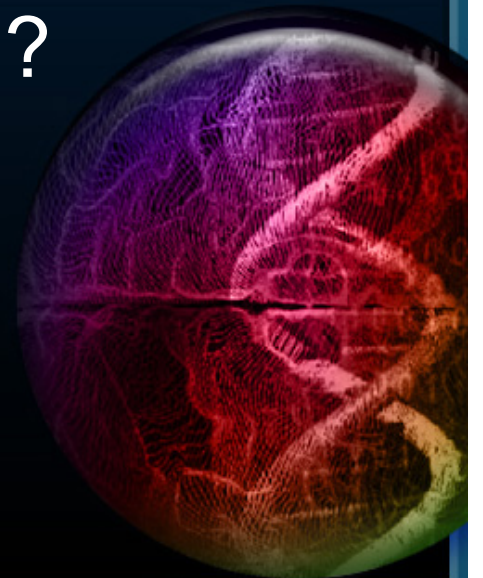
Either way, a wide explanatory gap

- Is consciousness something **apart** from the brain's physical activity, but **correlated** with the brain's activity?
- Is consciousness something **apart** from the brain's activity, but **caused** by the brain's activity?
- Is consciousness **identical** with brain activity; **nothing more, nothing less**?



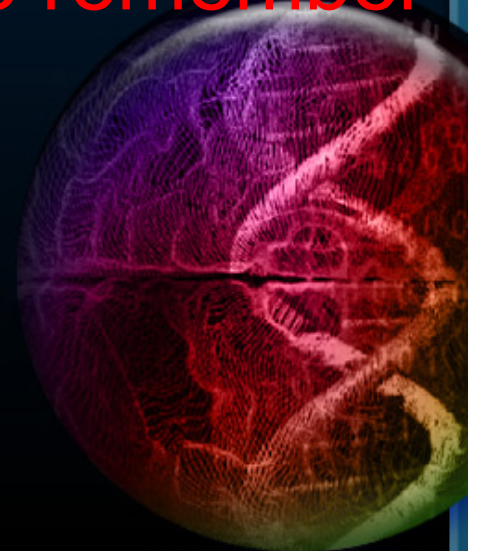
Determinism vs Free-Will

- If the **mind** can be reduced solely to **molecular physical processes** in the brain, what is the scope for **free-will**?
- Is indeterminacy at the **psychological level** matched by an exactly isomorphic indeterminacy at the **neurobiological level**?



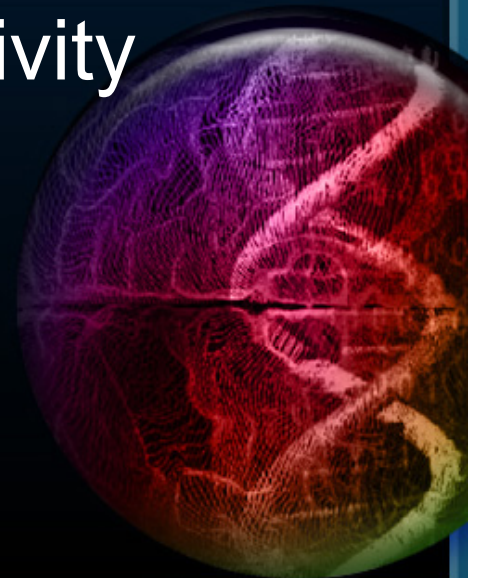
The role of Memory and Recall

- This is the brain **speaking to itself!**
- Key to our **identity and functioning**
- Integral to **our being**
- Life without memory & recall is **no life at all**
- In order to be yourself, **you have to remember who you are!**



The Mechanics of Memory are becoming clear

- Memory has a **short & long term** aspect
- Memory is **embedded** and **distributed** in multiple regions of the brain
- Memory entails the **creation** and **maintenance** of synaptic connectivity



Memories can be Classified

Episodic

Semantic

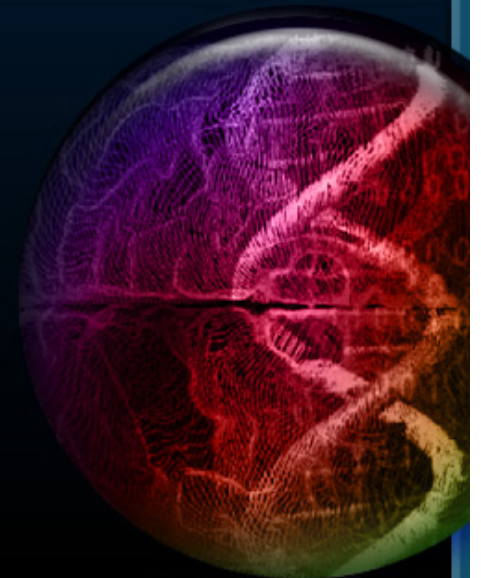
Explicit

experiences

facts

Implicit

reactions

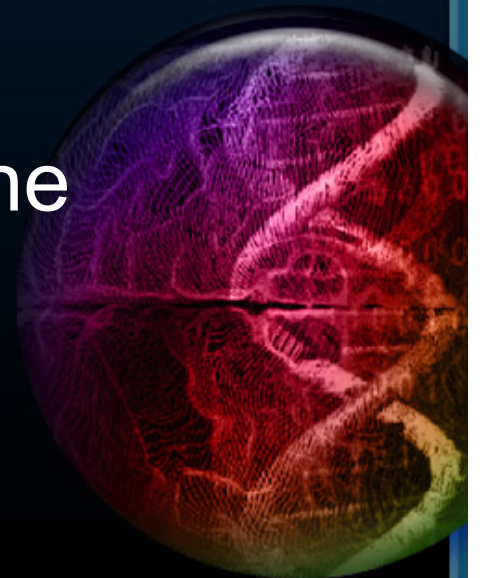


Memory is the key to Learning

- The brain is a **sponge** for knowledge
- Its disposition is to **learn** and **adapt**
- The brain **rewires** itself as it **learns**
- Neurons that **fire** together **wire** together
- Learning also entails the **elimination** of certain synaptic connections
- Together these processes form the basis of the brain's **plasticity**

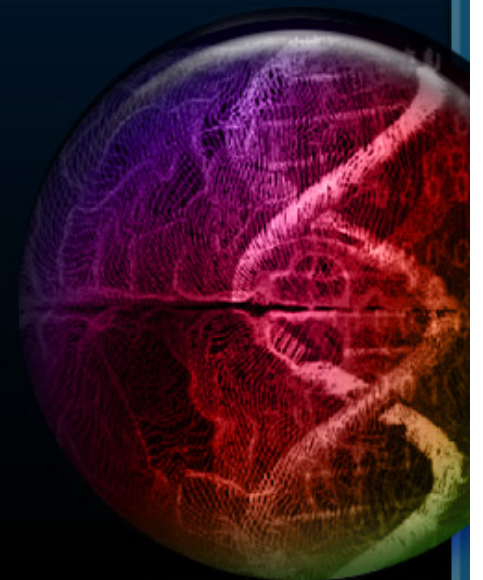


LONI



The **Resiliency** of the Brain is Legendary

- Every **perception** is an act of **creation**
- Every **recall** is an act of **imagination**
- Memory is not perfect and many **things can go wrong!**

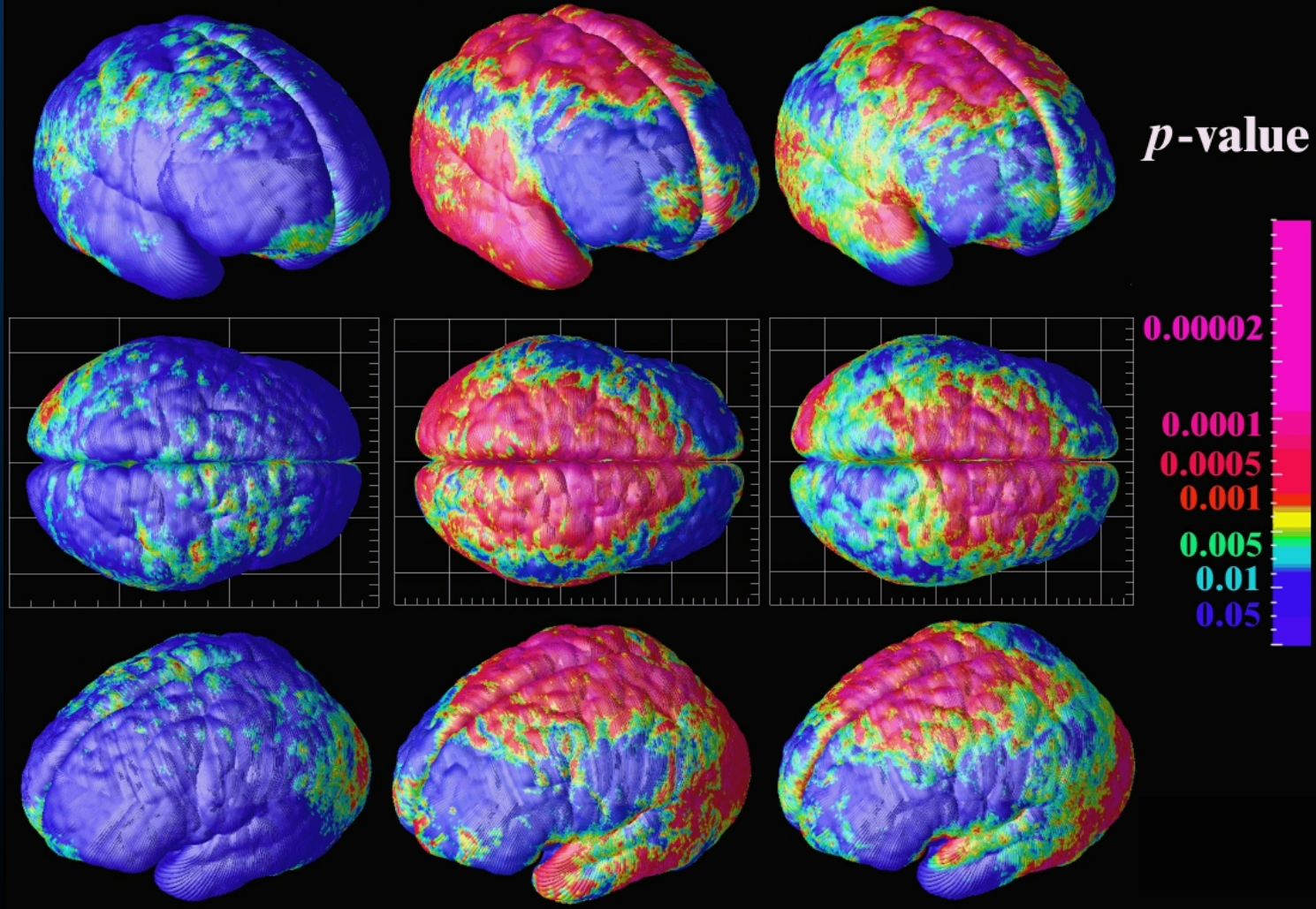


Significant Progressive Gray Matter Loss in Schizophrenia

NORMAL

SCHIZOPHRENIC

DIFFERENCE



LONI

But also effects other systems, eg temporal

gray matter loss

Cortical Mapping Challenges

Anatomical
Models

3D MRI,
CT

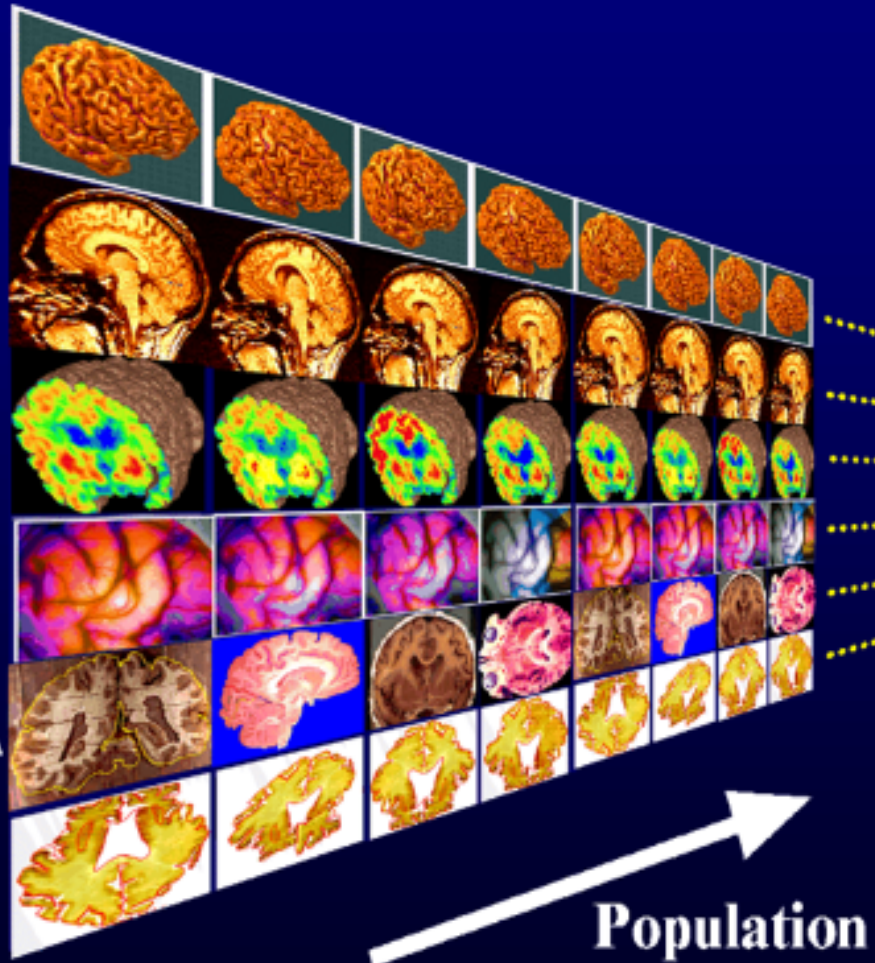
PET, SPECT,
fMRI, MRS

OIS, EEG,
MEG

Cryo
(Archit)

Histo

• Integration

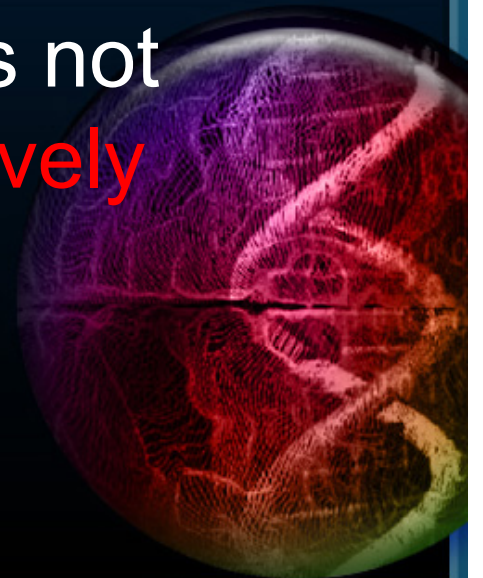


Population
Variability



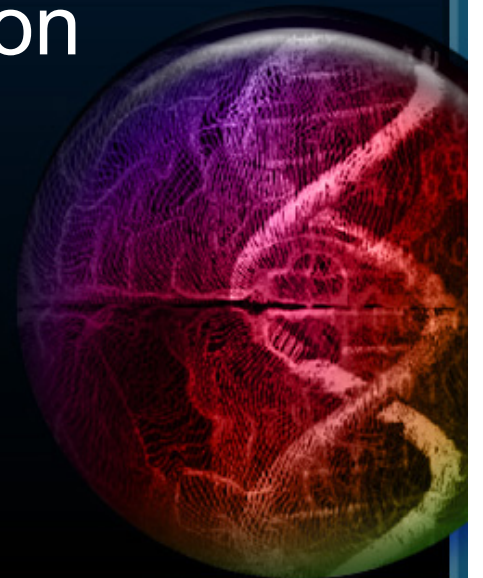
The Tsunami of Data

- Tagging methods, microscopy scanning speeds and resolution improvements are rapidly adding **clarity** and **insights**
- Multi-modal data is being ‘**fused**’ into **real-time high-definition images**
- Nevertheless, such data still does not tell us what the patient is **subjectively experiencing**, at least not yet !



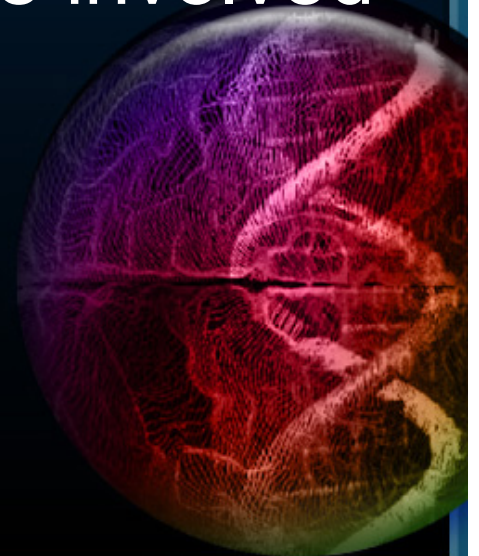
Navigating through volumes of Data

- Data-mining
- Conceptual mapping
- Knowledge discovery tools
- Modeling, simulation & visualisation
- Bayesian hypotheses generation
- **Asking the right questions!**



The **Scientific Consensus** of today:

- The mind is an **holistic** phenomenon
- Consciousness entails the integration of **multiple fields** and **mental modeling** of the physical world
- Both **analog & digital** processes are involved
- The mind is **not** a Turing Machine



Contrast the **Brain** to Digital Computing

- **Wet** – Dry
- **A+D** - Digital
- **Plastic** – Rigid
- **Resilient** - Fragile
- **Intuitive** – Logical
- **Creative** – Deterministic
- **Self organised** - Designed
- **Self assembled** - Manufactured
- **Synchronous** – Mostly asynchronous
- **Embedded memory** – Segregated memory
- **Variable neural network** – Fixed instruction set



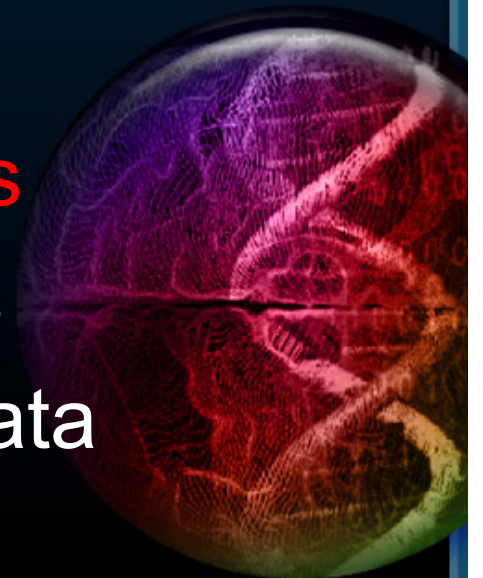
Clawing our way towards Consciousness (with the **convergence** of multiple technologies)

Nanotech and **biotech**

- **Silicon-Carbon** hybrids
- **Artificial** neuron networks
- **Extraordinary** compute power
- **Virtual Reality** methodologies
- **Avatars, robotics** and **humanoids**
- **Non-linear** mathematical models
- **Multi-modal** high-def **real-time** data

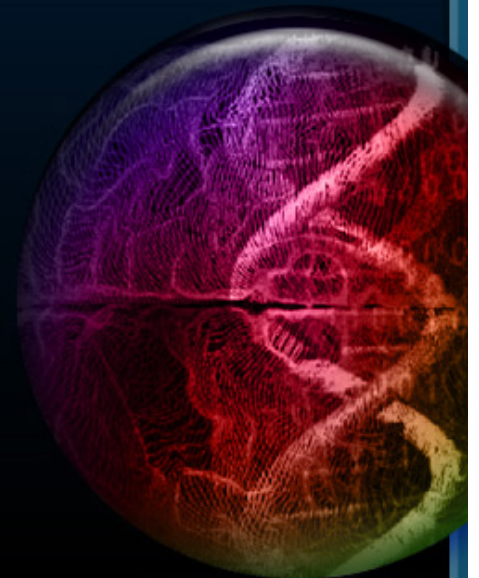


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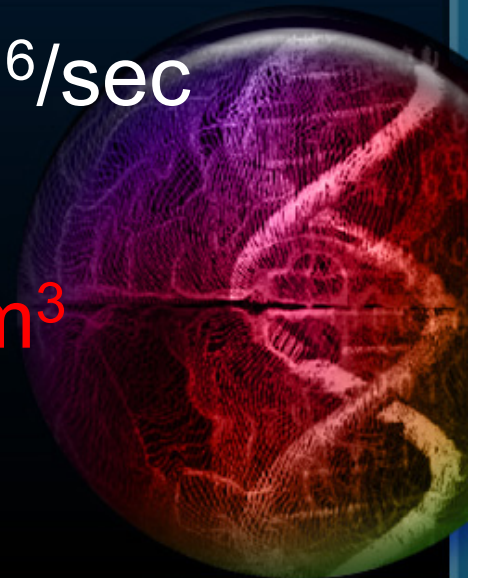
Architecture of the Brain

- Massively **complex**
- Massively **parallel**
- Massively **redundant**
- A synthesis of **multiple nested evolutionary processes**



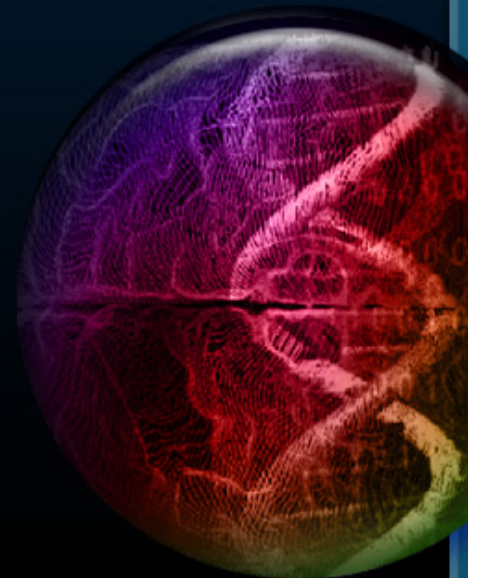
Micro-architecture of the Brain

- ~100 B neurons (100×10^9)
- ~12000 synapses/neuron
- = 1200 T synapses (120×10^{13})
- Synapse firing rate ~ 500 Hz
- Combined firing rate: $\sim 60 \times 10^{16}/\text{sec}$
- Brain volume: 1500 cm^3
- Firing density: $40 \times 10^{13} / \text{sec}/\text{cm}^3$



Supercomputing at NASA: Project Columbia

- Fastest **full production** machine in the world
- Installed **October 2004**, NASA–Ames California
- Main purpose – **return to flight** of NASA's three Space Shuttles, Earth & Space Sciences, Cosmology.



NASA



Project Columbia Overview

- 10,240 processors x 410M transistors/pr
~4.2T transistors (4.2×10^{12})
- + 20 Terabytes memory x 8 bits/byte
~ 160 Terabits @ 1 transistor/bit
~ 160T transistors (160×10^{12})
- Total transistors ~ 164T (163×10^{12})
Switching rate = 1.6 Gigahertz (1.6×10^9 /sec)
- Total Switch rate ~ 260×10^{21} switches/
sec

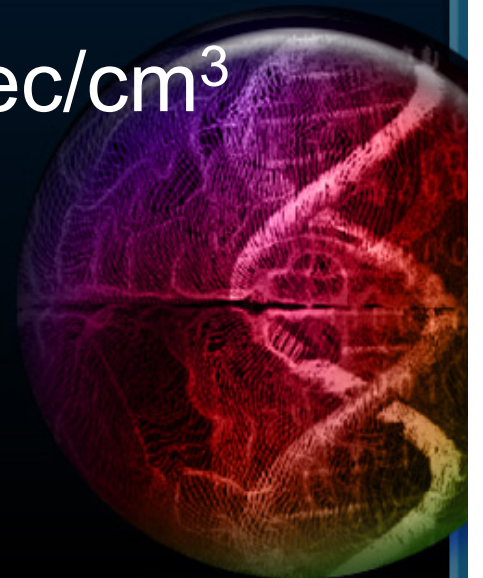
Volume ~ 6,000 m³

Switching density ~ 43×10^{12} sw/sec/cm³



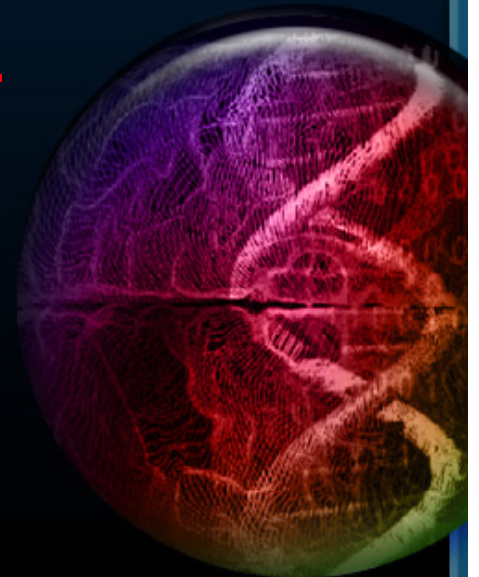
Signaling Density Comparisons

- Human Brain:
 $\sim 40 \times 10^{13}$ synapse firings/sec/cm³
- Project Columbia:
 $\sim 43 \times 10^{12}$ transistor switches/sec/cm³



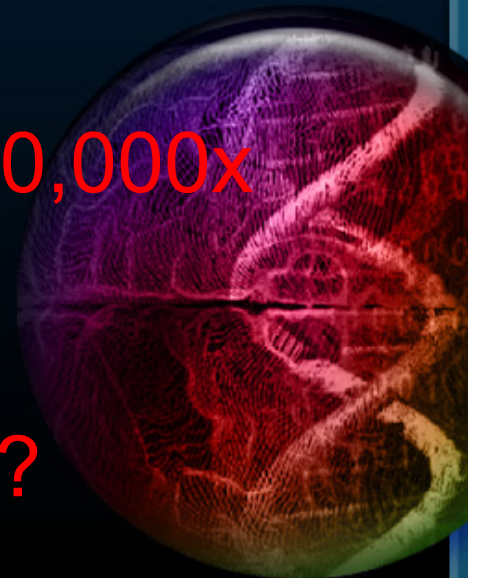
Supply Comparisons

- Human Brain: ~20% of the brain's volume is occupied by blood vessels which supply oxygen and glucose
- Project Columbia: ~20% of the space is occupied by power plant and air-conditioning



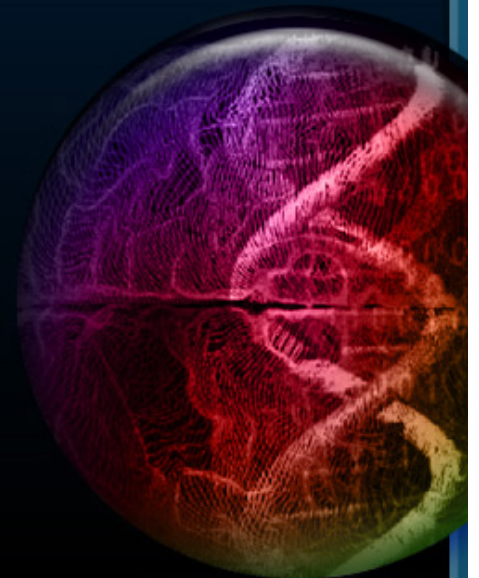
Additional Performance Considerations

- Assume the number of **neurons** in the human brain is underestimated by **10x**
- Assume the **glial cells** contribute to human brain performance by an **additional 10x**
- Assume the sub-threshold **dendritic** analog voltages **contribute by 1000x**
- Then we need to find **another 1,000,000x** in digital switching performance to match the human brain's firing density. **Where will this come from?**



Moore's Law predicts that

Digital switching density will **equalise** the additional performance factors of the human brain in **20 years**. This is the time that it takes a **supercomputer to evolve down to a laptop!**

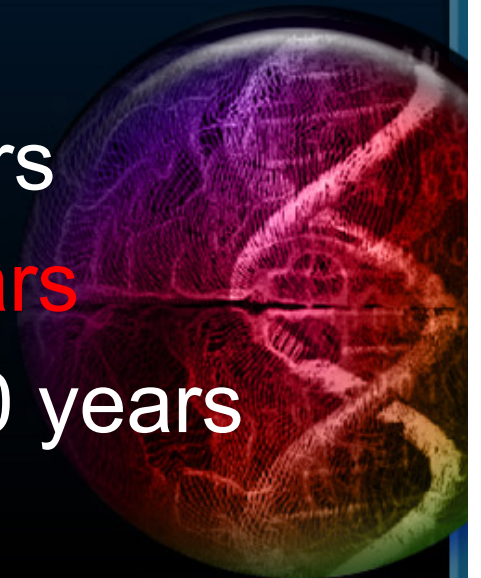
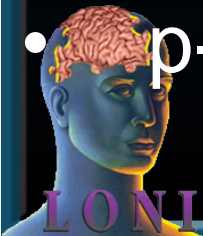


Moore's Law for Semi-Conductors

- 2x performance and $\frac{1}{2}$ price every 2 years, ie price-performance improves **4x every 2 years**

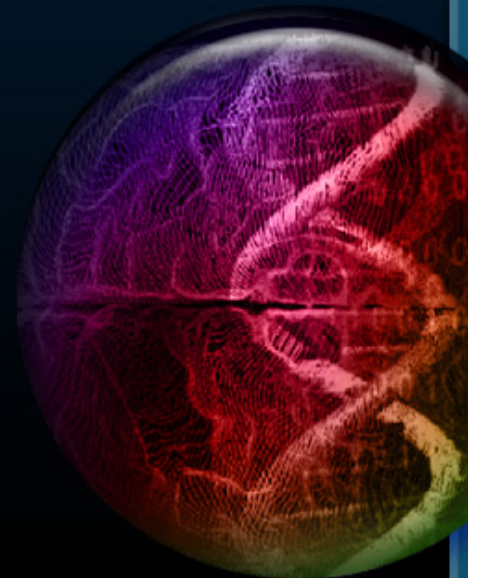
Therefore:

- p-p improves 1,000x every 10 years
- p-p improves **1,000,000x in 20 years**
- p-p improves 1,000,000,000x in 30 years



More than Moore!

- Parallelisation
- Intelligent memory
- Global shared memory
- On-the-fly reconfigurability
- New processor technologies
- Quantum computing
- New algorithms
- The Internet

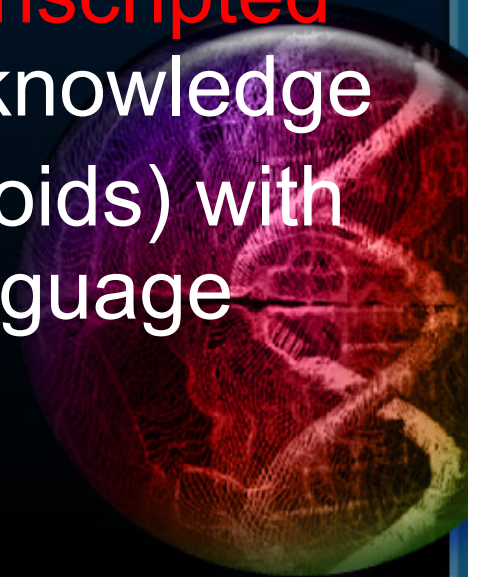


One path to Artificial Consciousness

- Continue to **measure, model & simulate** the human brain
- Extract **algorithms that mimic emotion, intelligence and consciousness** from the analog+digital activity of neuron networks
- Explore within the safety of VR, **unscripted virtual humans** created from this knowledge
- Build **autonomous robots** (humanoids) with lifelike natural language, body language and facial expressions.

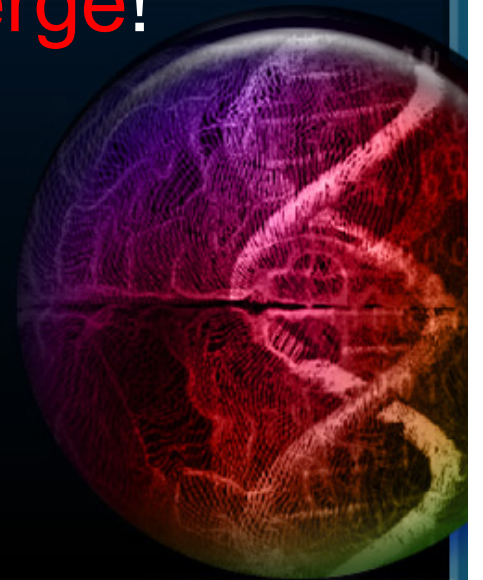


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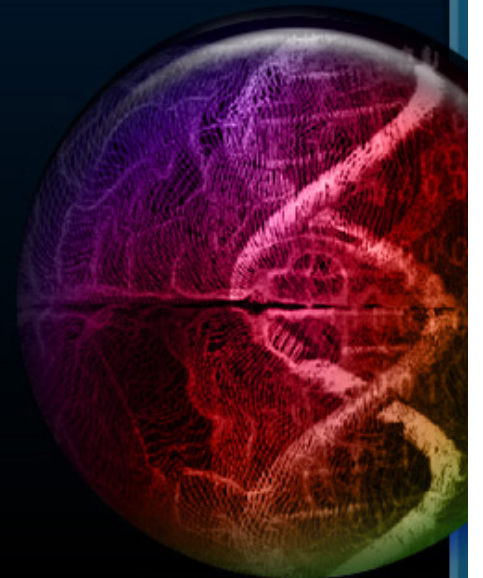


The **Global Brain** Alternative

- Take 1 billion Internet users
- Connect with broadband
- Add sophisticated software agents
- Wait for consciousness to **emerge!**

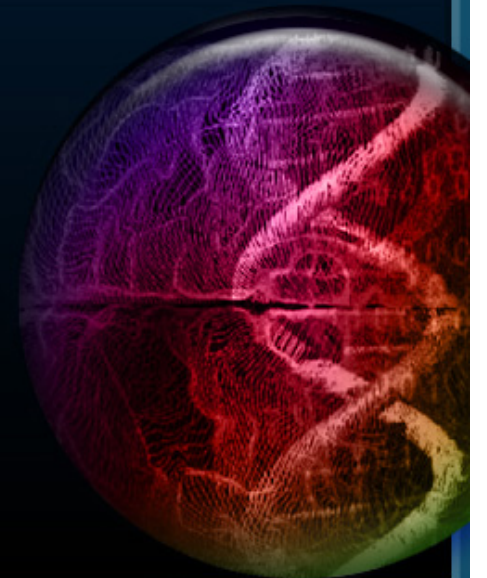


Can we mimic Consciousness when we don't yet understand it ?



First we build tools, then they build us

- Marshall McLuhan



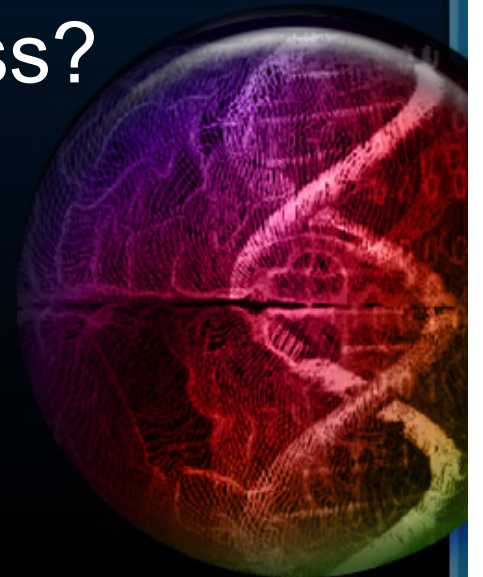
There is a wide range of Theories of Mind!

- Mind is an 'emergent property' of complex dynamic interacting physical phenomenon
- Mind is a 'fundamental property' of the universe as are 'mass' & 'charge'
- Mind arises from the 40Hz collapse of the brain's 'quantum wave-function'
- Mind and matter are equally valid descriptions of the same phenomenon (a la the wave and particle theory of light)



String Theory - M Theory

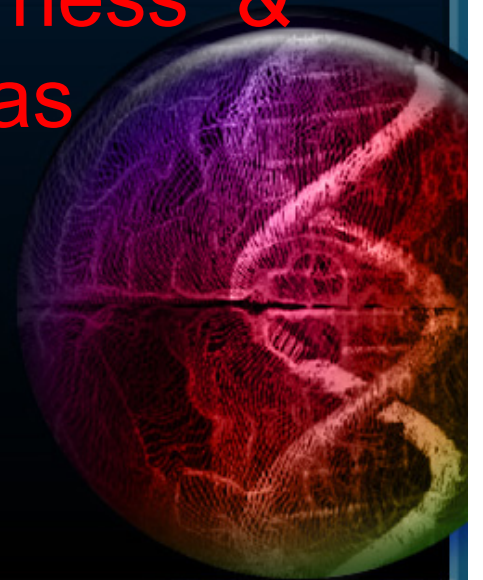
- The universe has **11** dimensions
- 4 are occupied by **space-time**
- The remaining 7 create **parallel universes**
- Parallel universes somewhat explain the **big bang, dark matter, gravity, worm holes**
- Do they also explain consciousness?
- The conscious **brain** =
The conscious **brane**?



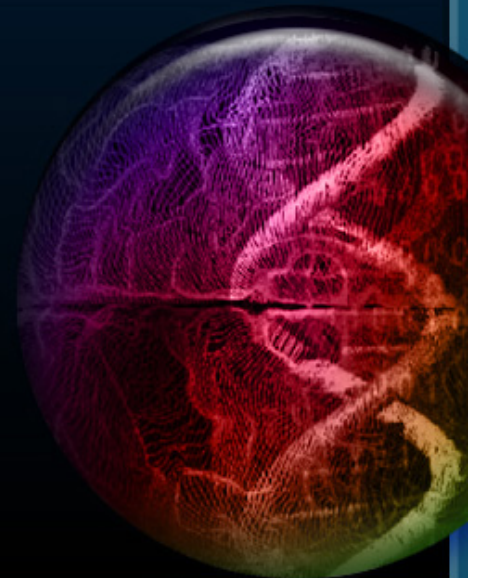
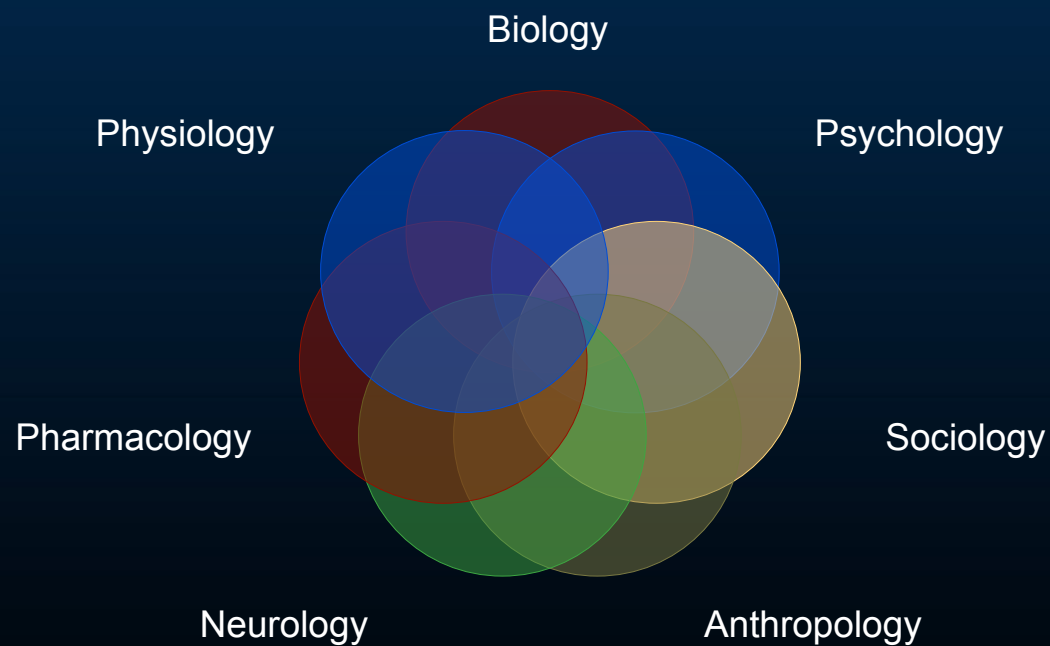
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The Limits of Science

- Today, science is **reductionist & specialised**
- This is a **strength and a weakness**:
 - how do we get a **holistic view**?
 - how do we **reintegrate the pieces**?
- In the 21st Century, we need to **harness & synthesise** knowledge from **all areas**
- Brain Science (like Earth Science) is a true **interdisciplinary** science



Resynthesising our Knowledge Pools



Towards a Metascience

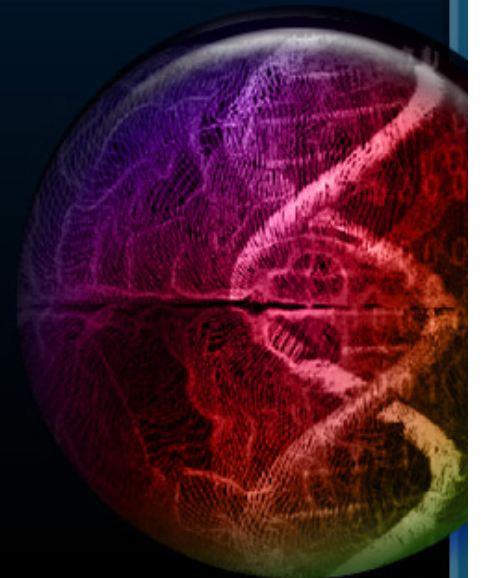
- Do we need a **new science** that addresses the **immediate holistic apprehension of things**?
- Why? Because the problem of consciousness is **different than every other problem**:

subjective vs objective

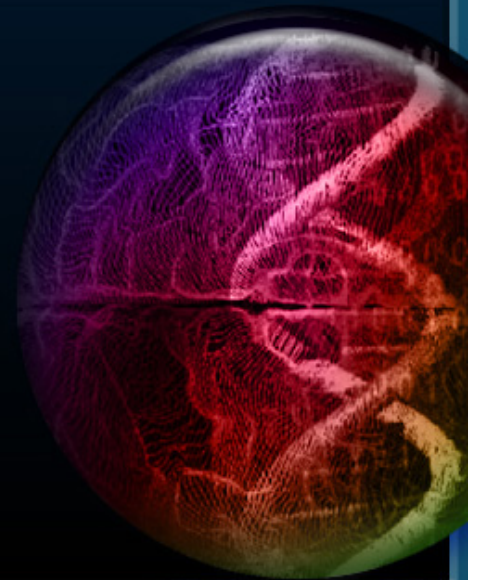
first person vs third person

inner vs outer

me vs them



A God's Eye View ...



The Brain: object of its own inquiry?

- Do we have the ability to **understand our own intelligence?**
- The human brain is the only organ in the known universe that seeks to **understand itself**
- The human brain made other revolutions possible – now we need a **revolution in the understanding of the brain itself.**



There are **no finish lines** in Evolution

- For humans, the size of the brain is limited by the dangers of **childbirth** – already 30% of US and 70% of Brazilian childbirths involve C-sections
- A far greater percentage of the human brain's final development takes place **post-natal** for humans than for other mammals
- Can consciousness affect **future evolution**?
- Will our future transcend biology with the aid of '**neuro-technology**' ?

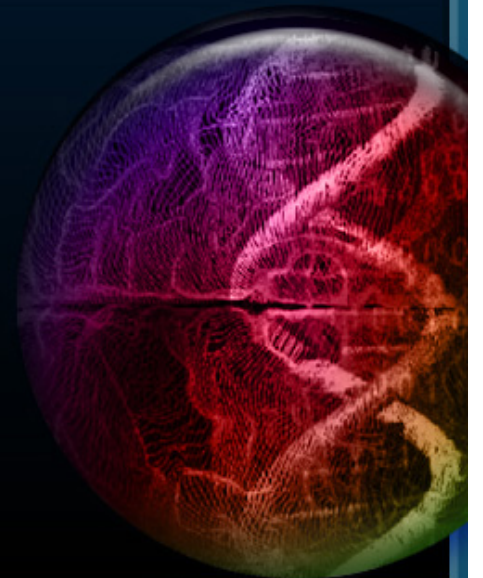


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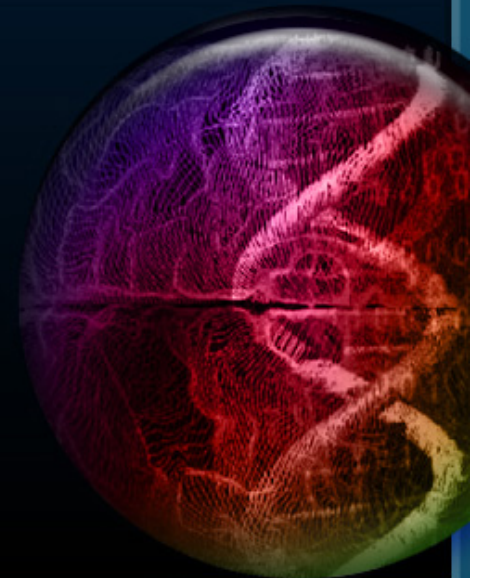
The quest for Artificial Consciousness
will drive human beings to more closely
examine and understand themselves

At some time in the future we will have to
decide **how human we wish to remain!**



Consciousness is the **very essence** of what it is to be human

In a word, Consciousness is our **Life!**



Thanks for contributions from ...

- Dr. Henry Markram, EPFL
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- Dr. Klaus Scherer, SCAS
- Dr. Allan Basbaum, UCSF
- Dr. Scott Hubbard, SETI

