Live Long and Prosper

2015 NURDS Conference
University of New England
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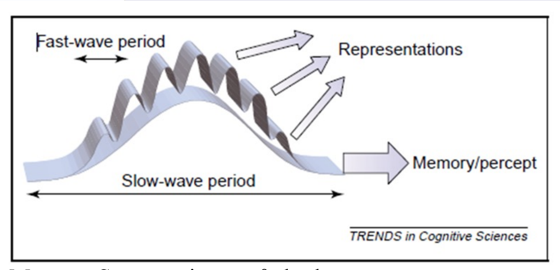

Memory Storage via γ on θ rhythms, Lisman & Idiart, 1995

Knowledge Acquisition, Integration and Reward: a Neuronal / Synaptic Perspective of STEM Learning

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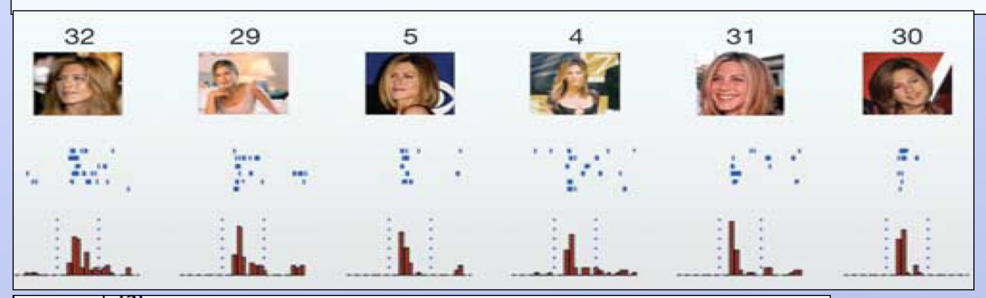
In education, Big Data is all about finding multivariate correlations and using that to improve learning and teaching outcomes: this is called *evidence-based* teaching or learning. But this does not explain how we learn. In our extension of Synaptic Learning Theory (SLT), we seek a path to a more principled understanding of the neural processes that acquire and integrate knowledge, as well as the nature of mammalian knowledge architectures. Advancing learning science without these principles might be akin to advancing molecular biology without knowing what codons are or what restriction enzymes do. Linking KA's to synaptic events could take 100 years or more, but could have far-reaching ramifications. Coming soon: *Synthetic Neuroscience Institute:* d.omalley@neu.edu

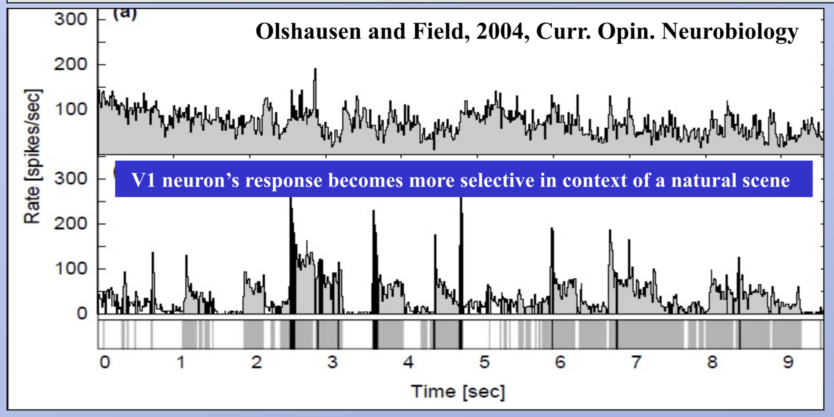
1. Why is there no *Flow Chart* from Neural Representation to Knowledge Integration?

Details on Neural Representation are presently sketchy, so it is difficult to chart a path whereby new items become integrated into our still mysterious knowledge architectures. We highlight here some key obstacles along with thoughts on how they might be addressed.

2. WHAT do Neural Representations Look Like?

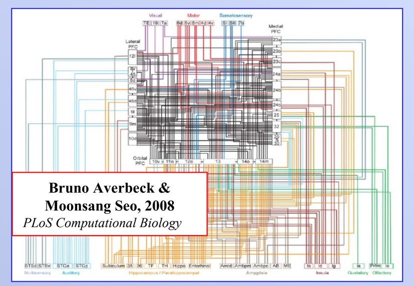
- more likely *distributed* than *grandmother-cell like*
- flexible, reliable and multi-sensory
- associated with gamma, theta and alpha rhythms
  i.e. associated with synchronous neural activity
- "sparse" perhaps, but might actually be quite dense
- human temporal lobe neuron responded only to pictures of Jennifer Aniston (Quian Quiroga et al., 2005, Nature)





3. WHERE are Neural Representations Located?

- working memory strongly involves prefrontal cortex (PFC) but PFC-hippocampal connections are also prominent
- **one trial learning** in hippocampus-amygdalar complex shown for "novel" and "familiar" cells (Rutishauser et al. 2006)
- **locations** are best guesses based upon sparse information
- both **locus & nature** of most neural codes are largely unknown



PFC is a massive hub. Are DMRs stored in the temporal / parietal / prefrontal cortices?

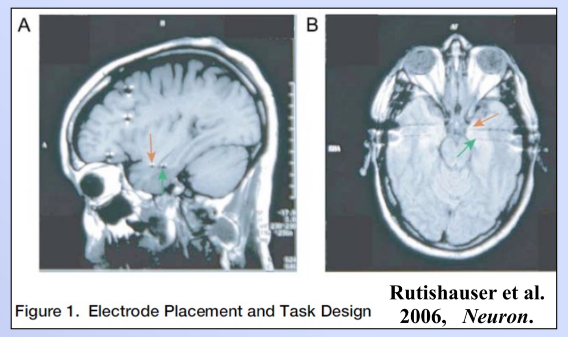
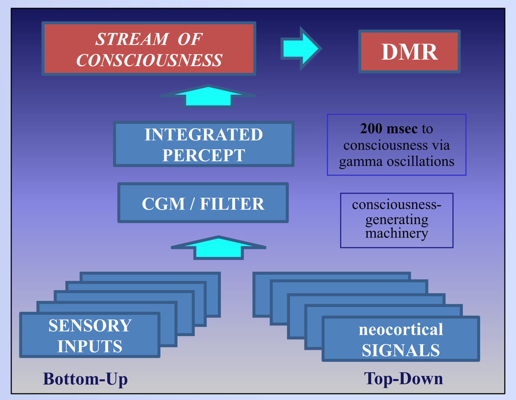


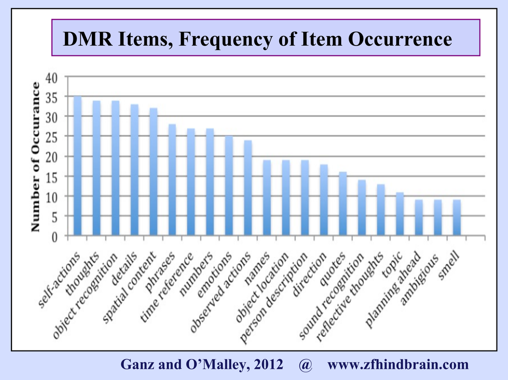
Figure 1. Electrode Placement and Task Design
Rutishauser et al. 2006, *Neuron.*

4. HOW does NEW knowledge enter our brains?


Rat Hippocampus
Santiago Ramon y Cajal

- *some* enters via Working Memory in Prefrontal Cortex
- but *most* is Long Term Memory, requires hippocampus
  see e.g. LTP, patient HM; but location of EM buffer is uncertain
- all **Declarative Knowledge** passes through *Conscious Experience* and Daily Memory Records (DMRs)





see *On Intelligence* (Hawkins) and Baars & Franklin (2003, 2005, 2007)

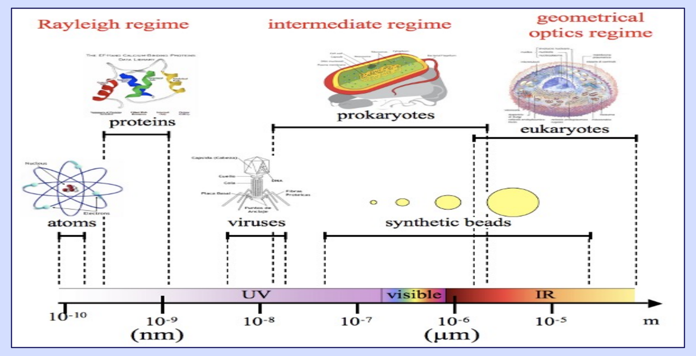
5. How do WM contributions differ from DMRs?

- WM holds 7 +/- 2 items (see Lisman & Idiart γ on θ model)
- DMRs are largely non-linguistic in nature: "knowledge tokens" WM is repetitive and effortful vs. the 1-trial, no effort DMR writing mechanism that might store thousands of items. Both entail conscious states, but they seem rather different!

Consc. Epochs see VanRullen & Koch (2003); **Alpha/Gamma** see Ward (2003) in Trends in Cogn. Sciences

6. Atoms to Organisms: *Learning by Analogy*

- Exemplar STEM **Knowledge Architecture** (KA): *Biology* atoms, molecules, DNA, cells, organisms, clades … LIFE
- KAs are often analogous to other KAs (network duplication?)
- Universal Physics (objects, actions, properties) shaped the evolution of CNS, neocortical architectures
- Theoretical model of Knowledge Integration (e.g. Hinton, 1986) has no clear correlate in neocortical systems



The number of possible sentences vastly exceeds the number of words. By analogy, the number of knowledge architecture constructs vastly exceeds the number of "stored" working memory tokens.

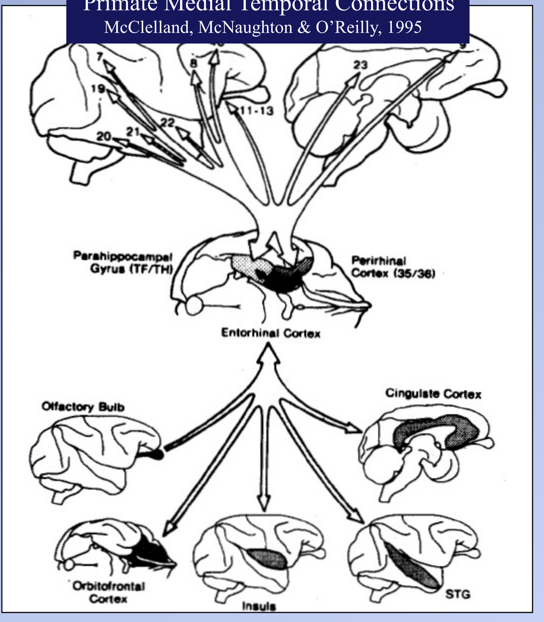
7. How do α, θ and γ Rhythms Contribute?

- γ (gamma) rhythms underlie **conscious experience**
- γ on θ rhythms enable **working memory** (WM)
- synchrony amplifies signals, LTP & STDP (plasticity)
- **coupled oscillators** might link DMR items
- memory recall depends more on θ than on α-rhythm
- rhythms intensify upon learning, decision making

see e.g. Benchenane et al. 2010, Kendrick et al. 2011, Watrous et al. 2015.

- From *Stream of Consciousness* (SoC) we **RECORD** into DMRs
- Excerpts of DMRs are **SAVED** into Long Term Memory (LTMs)
- Most learning/memory is **Hebbian**, which requires coincident firing
- Multiplexing/concurrent rhythms is a computational multiplier, BUT …
- ARE rhythms computations? [as opposed to mere carrier bands]

Complementary Learning Systems:
Primate Medial Temporal Connections
McClelland, McNaughton & O'Reilly, 1995



We WANT a PATH!

8. How is NEW Knowledge Integrated?

- role of **SCIP** ϟ Sub-Conscious Information Processing
- valuation of connections in trans-neuronal representations
- expansion and enrichment of Knowledge Architectures
- how are new CONCEPTS created?
- role for Symbolic Neuronal Operations (SNOPs)?
- percolation for Pavlovian-connections & processing?

HOCs Rock! *Higher Order Correlations*

- within DMRs (correlations between DMR epochs)
- SCIP scanning of knowledge architectures for best fits
- roles for hippocampus, Bayesian inference? J. Tenenbaum
- percolation theory and Auto Associative Networks
- cortical proofreading mechanisms (www.syndar.org)

Bound items in DMRs relate to diverse, trans-cortical representations involving many parts of neocortex. Hippocampus might sequence DMR epochs via γ on Φ rhythms.

9. How does Language relate to Knowledge?

- words, by themselves, mean nothing
- words and phrases: just "tags" for non-linguistic items?
- universal grammar is built upon universal physics
  aka evolutionarily deep objects, actions, relationships
- language offers fully symbolic operations, BUT
- sub-linguistic SNOPs might entail massive SCIPs

Pulvermüller & Fadiga, 2010, NRN

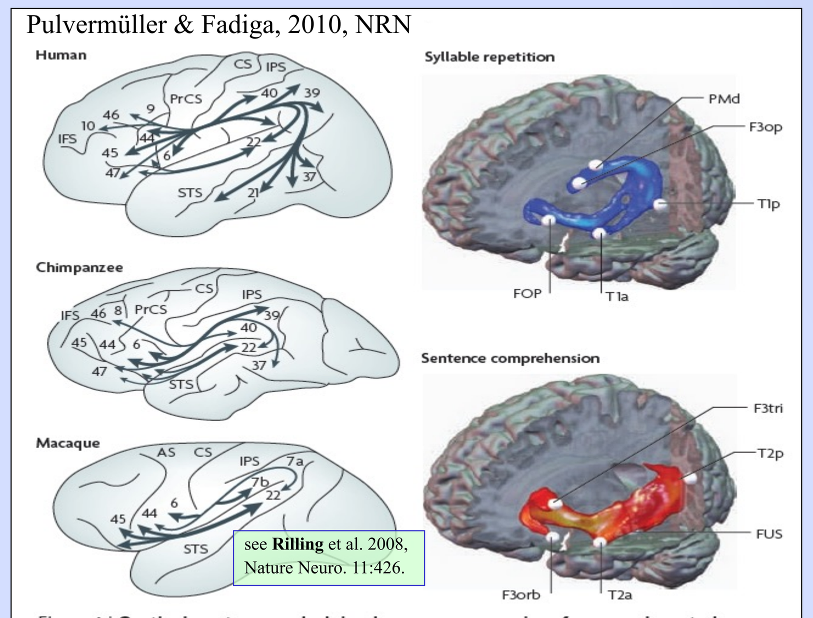
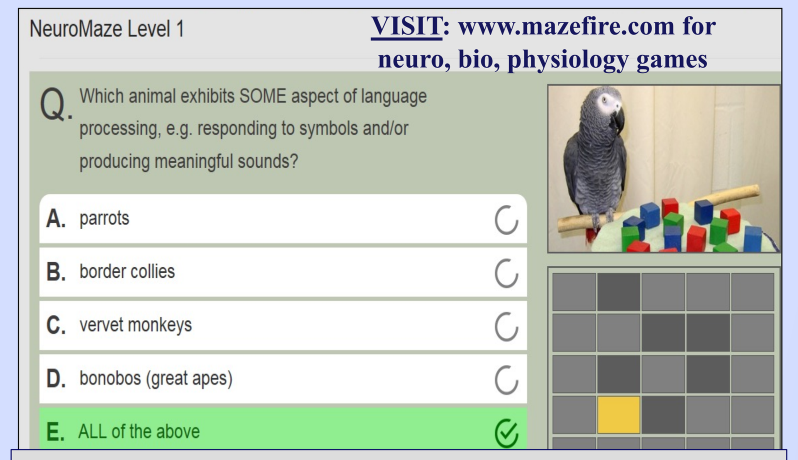


Figure 1 | Cortical anatomy underlying language processing: from monkeys to humans.

Rilling showed, in humans, enhanced trans-cortical STS connectivity which might facilitate fully symbolic neuronal operations (SNOPs) aka Language.

10. Can Active Learning Help?

- **extrinsic motivation** boosts synaptic activation
- amplified by **intrinsic motivation** of games, case studies
- neuronal summation (multisensory, connections) ➔ LTP
- **active learning facilitates** *knowledge integration*
- SLT framework might inspire new A.L. approaches?



Digital Maze Games use *Intrinsic Motivation* to boost synaptic learning

MEDscience cases are *Active* and *Multi-Sensory*

Suggested Readings

Adcock RA, Thangavel A, Whitfield-Gabrieli S, Knutson B, Gabrieli JDE (2006). Reward-motivated learning: Mesolimbic activation precedes memory formation. Neuron 50:507-517.

Baddeley A (1992) Working Memory. Science, 255:556-559.

Baars BJ, Franklin S (2003) How conscious experience and working memory interact. Trends Cogn. Sci. 7:166-172.

Bowers JS (2009) On the biological plausibility of grandmother cells: implications for neural network theories in psychology and neuroscience. *Psychol. Rev.* **116**:220-251.

Brady TF, Konkle T, Alvarez GA and Oliva A (2008). Visual long-term memory has a massive storage capacity for object details. PNAS 105:14325-14329.

Eichenbaum H (2014) Time cells in the hippocampus: A new dimension for mapping memories. Nature Reviews Neuroscience 15:732-744.

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Mashour GA (2006) Integrating the science of consciousness and anesthesia. Anesth. Analg. 103:975-982.

O'Keefe J, Dostrovsky J (1971) The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely-moving rat. Brain Res. 34:171–175.

Parker ES, Cahill L, McGaugh JL (2006) A case of unusual autobiographical remembering. Neurocase 12:35-49.

Quiroga RQ, Reddy L, Kreiman G, Koch C, Fried I (2005) Invariant visual representation by single neurons in the human brain. Nature 435:1102-1107.

Song S, Miller KD, Abbott LF (2000) Competitive Hebbian learning through spike-timing-dependent synaptic plasticity. Nature Neuroscience, 3, 919-926. Doi:10.1038/78829

Tononi G (2008) Consciousness as integrated information: a provisional manifesto. Biol. Bull. 215:216-242.

VanRullen R, Koch C. (2003) Is perception discrete or continuous? Trends Cog. Sci. 7:207-213.

Ward, LM. (2003) Synchronous neural oscillations and cognitive processes. Trends Cog. Sci. 7:553-559.

AVAILABLE RESOURCES

Origins of Syntax & Semantics (2011)
Neural Words (technical report)
Synaptic Learning Theory white paper
ongoing-work: Motivation & Reward Systems

10. HOCs Rock! [Higher Order Correlations]

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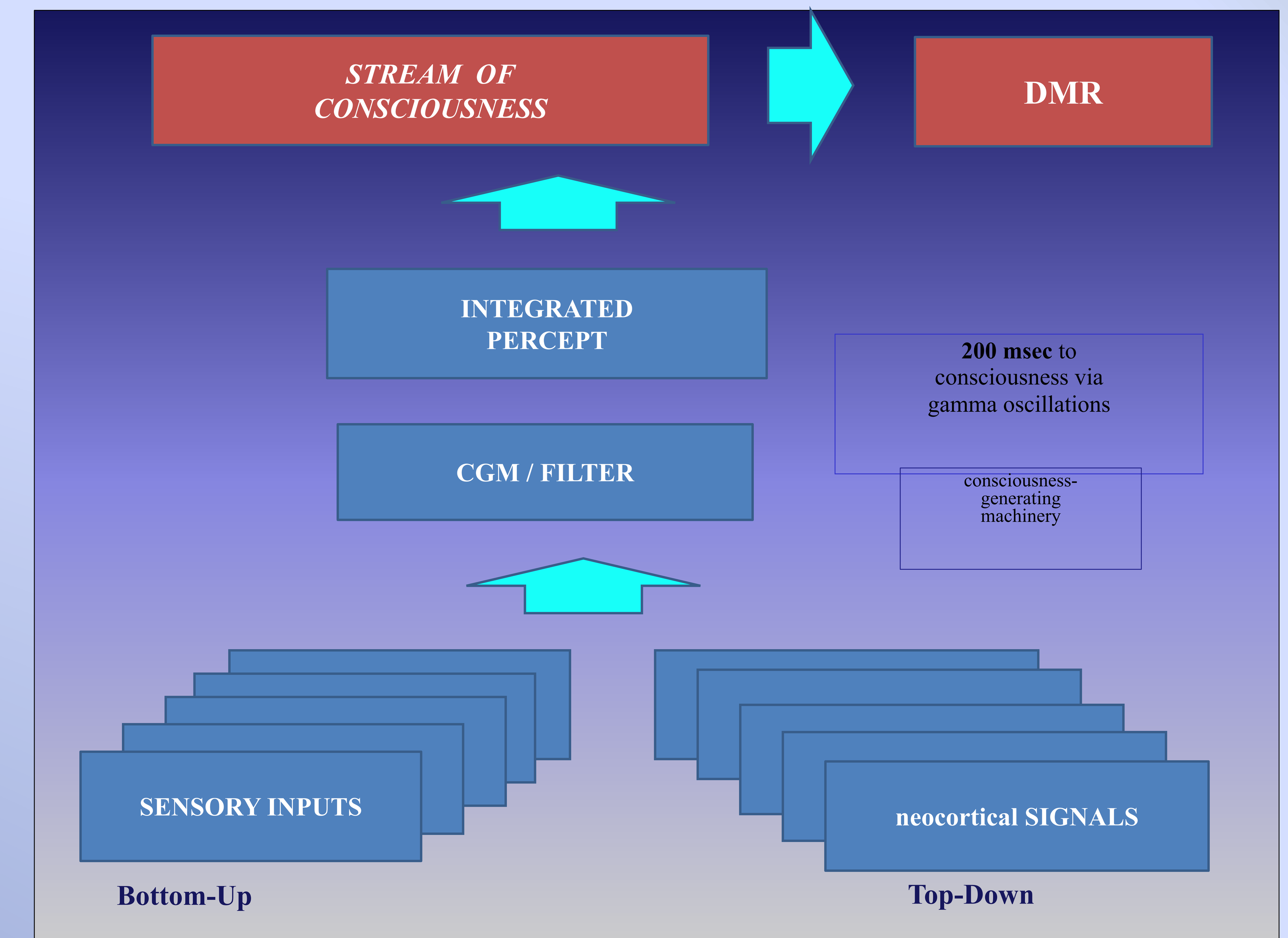

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Ganz & O'Malley, 2012

4. What do DMR epochs look like?

- trans-cortical representations (see items #6, #8)
- binding depends on alpha & gamma-band oscillations?
- largely non-linguistic in nature: "knowledge tokens"

Distributed Representation Across Neocortex

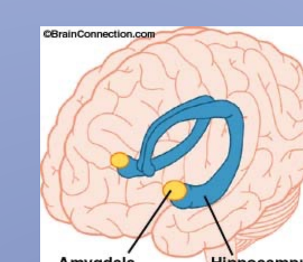
DMR COMPONENTS ←→ **Possible Anatomical Locations**

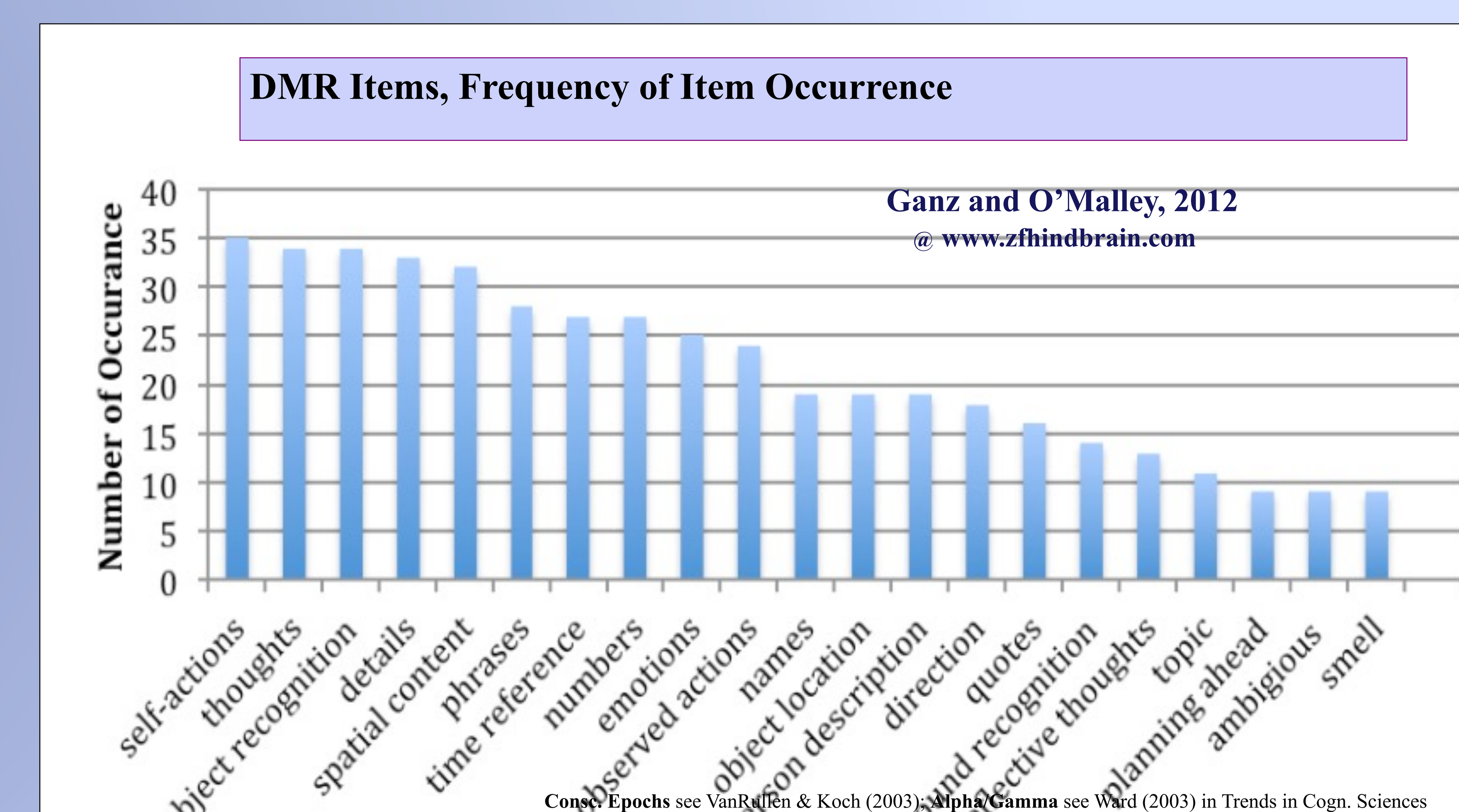
DMR COMPONENTS:

- Self actions
- Thoughts
- Phrases
- Observed Actions
- Spatial content
- Time References
- Numbers
- Object recognition
- Emotions
- Names
- Object Location
- Person Description
- Direction
- Quotes
- Sound Recognition
- Reflective Thoughts
- Planning Ahead
- Smell

Possible Anatomical Locations:

- Frontal, primary motor cortex, premotor cortex
- Frontal , hypothalamus
- Broca's Area, left frontal, Wernicke's Area, left temporal
- Parietal, premotor mirror neurons, occipital, inferior frontal gyrus
- Hippocampus, occipital, parietal, mammillary nucleus, anterior cingulate
- Basal ganglia, occipital, parietal, cerebellum, premotor cortex,
- Parietal, occipital
- Occipital, Temporal
- Amygdala, hypothalamus
- Hippocampal ventral tegmental area loop
- Fornix, parietal, temporal, anterior cingulate cortex
- Face neurons inferior temporal visual cortex, occipital
- Mammillary neurons, head direction cells, hippocampus, occipital, parietal
- Broca's Area, left frontal, Wernicke's Area, left temporal, occipital
- Auditory cortex, temporal, insular cortex
- Medial prefrontal, left anterior middle temporal gyrus, right cerebellum
- Anterior prefrontal cortex
- Piriform cortex, amygdala, entorhinal cortex, anterior





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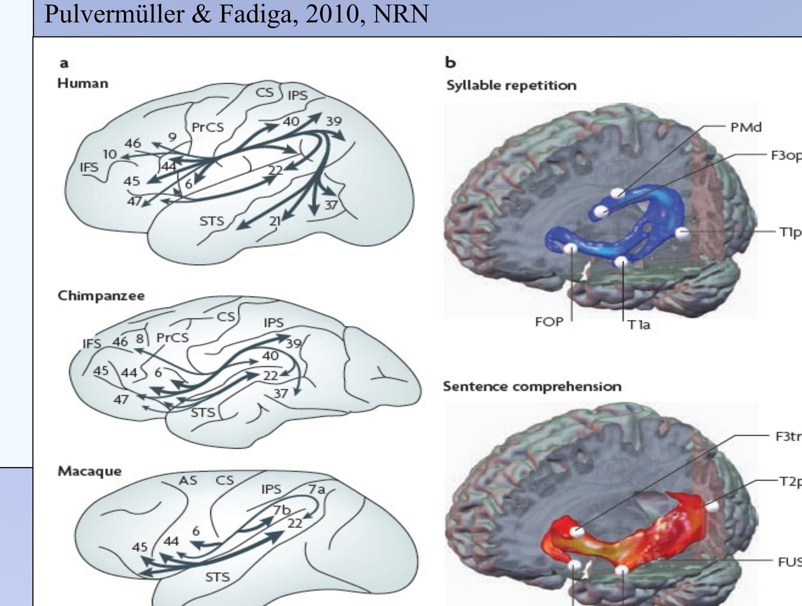


Figure 1 | Cortical anatomy underlying language processing: from monkeys to humans.

see **Rilling** et al. 2008, Nature Neuro. 11:426.

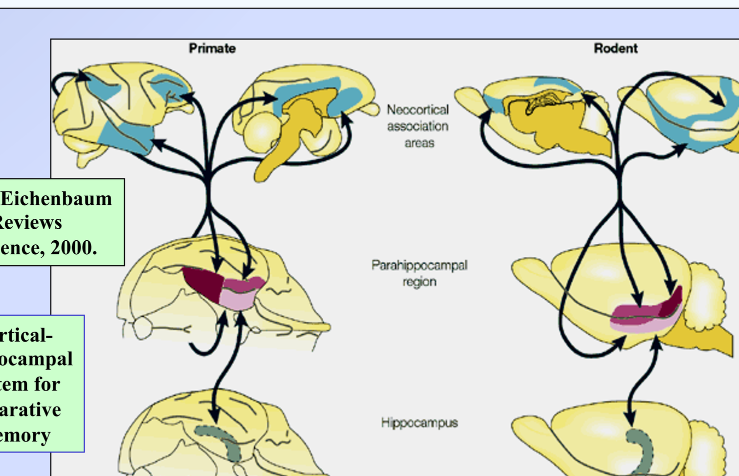
Rilling showed, in humans, enhanced trans-cortical STS connectivity which might facilitate fully symbolic neuronal operations (SNOPs) aka Language.

5. What exactly DO we RECORD and SAVE?

- "salience / novelty" = <u>first pass "filter"</u> into SoC
- from SoC, <u>2nd filter</u> evaluates and stores epochs
- of ~ 15,000 epochs per day (= 1 DMR) only a small subset are consolidated into long-term memory
- epochs might be assigned value by comparison to stored, related items <u>= 3rd filter</u>
- subconscious IP, sleep & hippocampus all contribute

Howard Eichenbaum Nature Reviews Neuroscience, 2000.

Cortical-Hippocampal System for Declarative Memory



- From *Stream of Consciousness* (SoC) we **RECORD** into DMRs
- Excerpts of DMRs are **SAVED** into Long Term Memory (LTMs)
- Rats store contextual LTMs that require an intact hippocampus
- Do rats have DMRs? Just ask one! or see Eichenbaum and Fortin, 2003
  Most learning/memory is **Hebbian**, but this requires coincident firing