Semantics comes from *Experience*

E103

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"NEURAL WORDS" AS A SUBSTRATE FOR BOTH FLASH MEMORY AND THE EVOLUTION OF LANGUAGE

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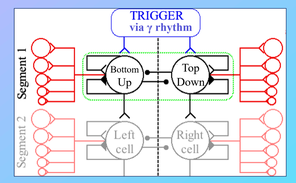
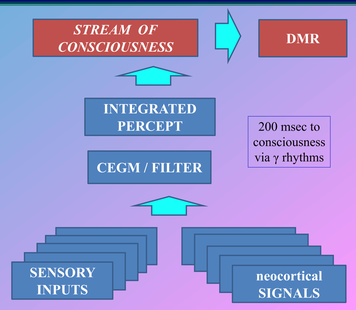
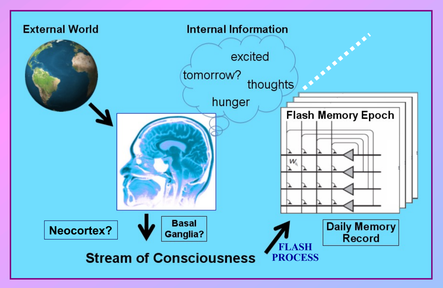


FLASH MEMORY / DMRs

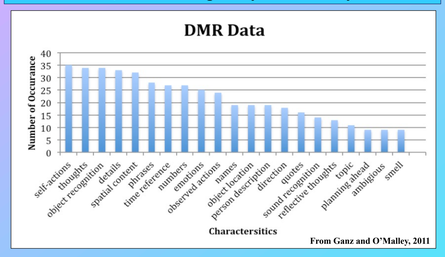
1. Utilizes Stored Representations
2. Has a Capacity that is Proportional to Related Prior Experience
3. is Likely Stored in Neocortex
4. is Largely Non-Linguistic
5. is an Excerpt of Conscious Experience



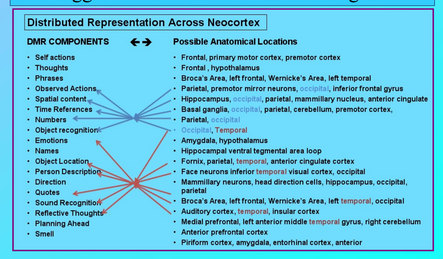
"Flash Memory" is just a descriptor used to emphasize the effortless, one-trial writing of day long memory records (**DMRs**). **FM** differs from list-learning in regards to absence of any rehearsal or intent to store information. The size of the DMR store vastly exceeds **Working Memory** stores.



Analysis of **DMRs written by students,** instructed to record the finest recollected details over a short time interval, shows frequency of memory items.



The nature of different DMR memory items can be associated with distinct cortical processes and thus suggests a neocortical locus of storage.



From *Neural Words* to Daily Memory Records

Self-interrogation of our **Daily Memory Records** (DMRs) reveals extensive, salient constructs selected from our sub-conscious information processors. DMRs indicate a powerful symbol-processing system distinct from **Language**. From an evolutionary perspective, DMRs precede and may link to the origins of words and grammar. We suggest that DMRs are derived from compact, non-linguistic **"neural words"** that help streamline the vast, ongoing computations of neocortex.

Were *Invariant Representations* the forerunners of Neuronal Symbols?

Invariant Representations (of objects, places etc.) **are phylogenetically ancient**

From zebrafish to primates, the brain possesses compact representations of important real-world entities (RWEs), including learned items, concepts, and innate knowledge of objects and physical laws. In the human **episodic memory** system each RWE is vastly interconnected with other RWEs and new items are often created via analogical processes.

A **representation** of a maze is NOT a **maze**. See discussion of: Penn, Holyoak, Povinelli, 2008

Symbolic Neuronal Operations (SNOPs)

- emerge from **Invariant Representations**
- are phylogenetically ancient — McElligott & O'Malley, 2005 & rat "time" cells, MacDonald et al. 2011
- derive from both in-life & evolutionary learning
- use Auto Associative Networks (AANs)
- are built over repeated experiences
- become increasingly iconic for internal use
- ultimately emerge as **arbitrary symbols** for purposes of animal communications

Neural Words, like other symbols, might be digital in nature. This might help with DMR storage and retrieval and reply of these the FM written, DMR records.

Are Flash Memory/DMRs SYMBOLIC?

- Synthetic construction of percepts requires manipulation of multiple items.
- Speed of CGM requires compact algorithms and presumably neocortical prediction, iaw Jeff Hawkins, 2006.
- DMRs are spatially & functionally orgnzd.
- DMR capacity is a f (prior experience)
- DMRs are saved as f (novelty, salience)
- These operations are performed on iconic items
- Manipulation of items = SNOPs-NL
- SNOPs-Non-Linguistic = precursor to language

SNOPS, DMRs and LANGUAGE: an essay for the curious

available at zfhindbrain.com Don O'Malley © 2014

The issue of **Representation** is central to most neural coding and memory. In the case of human flash memory, it appears that a symbol-encoding system is used to efficiently store chronological records of our conscious experiences. The experience of replaying these memories (termed autonoetic consciousness by Tulving) reveals that this record consists of largely non-linguistic items (places, people, objects, actions, etc.) while the exact wording of linguistic events (seminars, discussions, readings) are generally not so retrievable (Ganz and O'Malley, 2012, CSHL Neuronal Circuits meeting). Whether or not the endless stream of non-linguistic items in our Daily Memory Records (DMRs) are "symbols" is debatable.

From the standpoint of linguistics, a neural representation of an *red circle* or a *moving shape* would not generally count as a "symbol". Language is system for manipulating fully arbitrary symbols; its infinite compositionality is impressive. But we do not have to linguistically "tag" every visible or heard item in the physical world in order to perceive them. These items appear in cortex as **sub-linguistic representations** and it is these lower-level constructs that are operated upon in our minds/brains so as to be effortlessly and chronologically stored in our DMRs. There are myriad unanswered questions about (1) the "flash memory" process that writes these DMRs, (2) how some are selected for retention in long-term and autobiographical memory, and (3) about how it is that we can retrieve and replay these records hours and days post-writing. But all these considerations hinge on one foundational, neurobiological question: how are the items in our DMRs **represented** in our brain?

The question of the point at which a neural representation becomes "symbolic" is not a purely semantic issue. The **neural system of language** impresses because of its ability to rapidly produce and encode streams of arbitrary symbols (and to more reflectively string such symbols into written works). While most details of this processing system are unknown, it is clear that widely distributed neuronal networks in the brain give rise to the production and understanding of language. We might call such processes **Symbolic Neuronal Operations (or SNOPs).** Our claim is that DMRs are excerpted from conscious experience and stored in neocortex via a very different symbol manipulation system, i.e. **SNOPs-NL, non-linguistic** (vs. SNOPs-L for linguistic operations). Because other animals may also have DMRs, it is very likely that SNOPs-NL preceded SNOPs-L and that neural circuitry for the older system was replicated and exapted in the emergence of the newer. If so, the emergence of language stems from an older, possibly quite ancient, system of manipulating *symbols* (or *representations* at least).

LOOK LEX

The neural underpinnings, indeed existence, of animal (non-human) SNOPs is perhaps both controversial and uncertain. What is certain is that animals all along the vertebrate lineage (and likely many invertebrates as well) have rich assemblages of neural representations, a capacity that would generally increase with increasing brain size. Alex the parrot had an extensive vocabulary, while Kanzi the bonobo had prodigious tile-manipulation skills. Arguments abound as to whether these abilities might be called language, but here we are concerned specifically with the neuronal systems underlying these capabilities. Even border collies can learn up to 200 words, but neither Alex nor Kanzi could **produce** linguistic strings greater than 3 items (need to recheck on Kanzi). They did not have a SNOPs-L system equivalent to humans, but they did have neural representations AND a neuronal system that could operate on fully-arbitrary symbols. These abilities thus evidence at least a SNOPs-NL system across much of the vertebrate lineage (work on zebrafish object recognition is summarized in an article at zfhindbrain.com, DMR tab).

Our **Daily Memory Records** are not storing a wealth of entirely new items and actions, but mainly are linking pre-existing representations into unified epochs, which are then strung into day-long chronologies. Our DMRs depend upon prior experience (Gioioso and O'Malley, SFN-2009) and more specifically upon **linking retrieved representations** that are activated in the course of conscious experience, possibly with the aid of Top-Down processes. The sequencing process (which might require hippocampal assistance) constitutes a neuronal operation being applied to successive assemblages of evoked representations. Just as linguistic words can be strung into sentences, so too can evoked symbols be strung into DMR fragments. These symbols are of a higher (more abstract) nature than the lower level visual and auditory firing patterns that so extensively flow into our CEGM or conscious-experience generating machinery. We argue here that DMR items are symbolic in nature not just because such items might be more compact than more general and widely distributed representations, but also because the items being concatenated must be suitable grist for the sequence-generating mill, i.e. the SNOPs-NL.

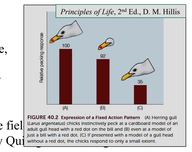


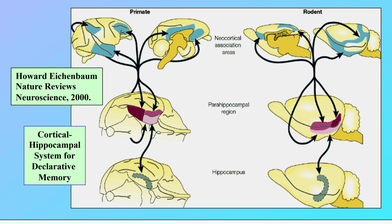
FIGURE 40.2 Expression of a Fixed Action Pattern. (A) Herring gull (Larus argentatus) chicks instinctively peck at a cardboard model of an adult gull head with a red dot on the bill and (B) even at a model of just a bill with a red dot. (C) If presented with a model of a gull head without a red dot, the chicks respond to only a small extent.

Symbols are often Digital. Words, letters, numbers, musical notes and mathematical symbols are all discrete, countable items. How are such "discrete" items represented in cortex? Retrieved? As we ascend better understood representational systems, e.g. the auditory system and the dorsal and ventral streams of visual information, we arrive at increasingly abstract receptive fiel (of sorts) being the Jennifer Anniston cells described by Qu

Red spot-pecking by gull chicks is symbol driven. The red spot has nothing to do with food, but rather evolution evolved a means to stimulate food-seeking by chicks. It is a fully arbitrary symbol since any shape or color could (in theory) suffice. **All symbolic communications are memory based.** In this case, it is an evolutionary memory process, as opposed to within-life learning, but in both cases real world knowledge is linked to arbitrary symbols (or more iconic symbols). The attraction of larval zebrafish to moving blips is not essentially different from spot-pecking. The symbol has to have certain characteristics to elicit this larval innate feeding behavior, just as the red spot must fall within particular parameters to be effective. That the gull might be said to intend the communication (whereas the swimming paramecium would prefer NOT to be communicating) is not germane: the gull may well be entirely unaware of its red spot and also has no control over this signal. Intentionality is not required to make symbols symbolic. The moving paramecium is NOT an arbitrary symbol, since size and motion are salient parameters, but the response to this "symbol" is no different than the gull chick's spot response: both were selected for as valuable stimulus-responses, both are visual, both drive feeding, both require that neural representations of incoming stimulus be analyzed, and that this stimulus be compared and comparable to a stored template in order for the (complex) behavior to be released. We argue that the stored template or representation (red spot, moving blip) is a **"neural word"**: it is a neuronal pattern that represents in a clearly symbolic way something important.

This works has been published thus far just in abstract/poster form. This chronological record is available at zfhindbrain.com under the DMRs tab. An unpublished manuscript, "*Charting an evolutionary path to syntax, semantics and consciousness*" is also available and provides key references.

Evolutionary Origins AND Neural Basis of Flash Memory



RAT FLASH MEMORY might be SYMBOLIC

1. The presence of episodic memory in rats suggests that **Flash Memory is phylogenetically ancient.**
2. Since rats lack language, FM has non-linguistic roots.
3. Rat FM is spatial-temporal, encoded using place, grid & time cells with perhaps gamma-on-theta sequencing (Jensen & Lisman, 2005) while also linking objects to places.
   See: MacDonald, Lepage, Eden & Eichenbaum, 2011, *Neuron* 71:737
4. Rat representations of objects, places, odors and feelings might be symbolically encoded for efficient flash storage.

Flash Memory to DMRs to Episodic Memory

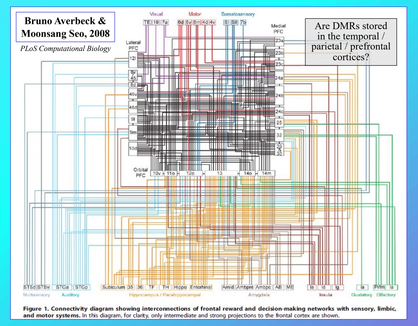


Figure 1. Connectivity diagram showing interconnections of frontal reward and decision-making networks with sensory, limbic, and motor systems. In this diagram, for clarity, only intermediate and strong projections to the frontal cortex are shown.

Complexity of Connections ➔ Complexity of Representations?

Training the Network

Evolutionary Specifications define the precise, virgin form of neocortical, hippocampal and subcortical architectures
Innate Knowledge reflects the evolutionary encoding of specific crucial memories e.g. recognition of prey items, visual cliff, etc. (Baum 2004)
Acquisition of Experience: Massively entangled, context-driven representations of the world are laid down in neocortex w/ hippo. help
Contextual Linkages: Experiences are stored as both single items and as pieces of extensively interconnected contextual memories
Ongoing Experience utilizes stored information to construct unified snapshots or epochs of the world
Flash Memory further uses pre-existing representations AND linkages.
Semantics Comes from Experience: In parallel with FM's storage of life experiences, the semantic system binds arbitrary symbols to experiences

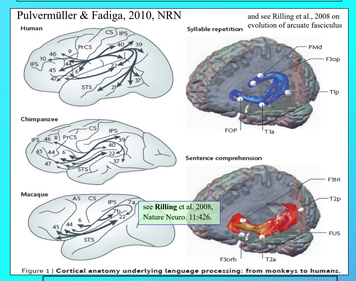
Construction of Conscious Experience

Consciousness is a highly synthetic construct (Baars and Franklin, 2005).
Neocortical Prediction (Hawkins, 2004): Contextual Prediction enables rapid interpretation and integration of incoming signals.
ThalamoCortical Arrays ➔ massively parallel WTA algorithms operate across size scales, modalities and cortical domains to resolve the world.
Invariant Representation: Autoassociative Nets (WTA operations) define / recognize objects, people, places, actions, thoughts and feelings.
Hierarchical Evaluation of Inputs: Inputs are evaluated for novelty, salience and immediacy en route to potential conscious representation.
Contextual Binding: The conjunction of WTA analyses with spatial and dynamic structure (and neocortical prediction) flows to unified experiences.
Basal Ganglia Role? Role in SoC Decision-Making? Sequences thoughts?
Consciousness-Enabling Plasticity creates quite transient yet integrated transcortical experience (which is distinct from STM/WM/LTM systems).
Flash Memory System excerpts epochs of consciousness and stores iconic replicas in our Daily Memory Record (DMR).
FM is an excerpt of Transcortical Representations and as such seems transcortical (as opposed to hippocampal) in nature.

WTA = Winner Take All

NEURAL WORDS & LANGUAGE

LANGUAGE = SYMBOL MANIPULATION on Steroids



Human STS (& MTL?) is uniquely connected with PFC.

Why only Humans?

- Language has Fast, Limitless Compositionality
- Language is entangled with non-linguistic memories
- Mammal memories are **10,000X interconnected**
- Language exhaustively accesses these memories
- "Compact" Neural Words may ***facilitate*** Language
- Manipulation of Lang. is ***more*** efficient than SNOPs-NL

Words, Symbols & Memory are ENTANGLED

- MOST animal intelligence is based upon non-linguistic processing of memory items.
- Language evolved from Animal Communication or Symbolic Systems (any role for mirror neurons?)
- Symbolic Communications are **MEMORY** based
- Mammals possess a **hyper-associative memory** system that enables ANYTHING to be associated with ANYTHING else.
- **Neural Words** are Non-Linguistic, Iconic Memory Items.

Symbolic Neuronal Operations "SNOPs" originally used Non-Linguistic *Neural Words*

1. **Linguistic Representations** (words) are the newest kinds of symbols and rely on a distinctly powerful operating system.
2. **Non-Linguistic Symbols** are communicated extensively between cortical structures: ➔ **"neural words".**
3. These older symbols are the subject of many different **rule-like manipulations or SNOPs** (non-linguistic SNOPs laid the ground work for language).
4. **Examples of symbol manipulations include:**
   - cortical prediction - analogical operations
   - imitation - memory consolidation
   - relationships (physical laws, social interactions)

   ALL OF ANIMAL IQ — What can Crows do?
5. **The (proposed) "compactness" of neural words** might enhance the efficiency of SNOP operations, including FM.

Working Theory

- **DMR content reflects trans-cortical processing and is constructed mainly from past experience**
- **DMR content is mostly non-linguistic items but they can be both *Abstract* and *Symbolic***
- **The FLASH mechanism links active representations perhaps via coupled oscillators & silent synapses** (Gioioso & O'Malley, 2009)
- **Hippocampus may help to sequence DMR content (Jensen and Lisman, 2005)**
- **DMRs are perhaps utilized for many hours post-writing via analytical & memory consolidation processes**
- **Analysis of patient DMR content might provide insight into neurological & psychiatric problems**

Poster & Refs available at: zfhindbrain.com

Selection and Delivery of Neuronal Signals to our *Mind* and *Memory*

The BRAIN uses computational methods to analyze **the outputs of its millions of neuronal processors.** We directly experience the outputs of a tiny subset of these computations via our *Stream of Consciousness*. Our internal **Consciousness Generating Machinery** (CGM) controls (selects and sequences) the flow of items from our neuronal information processors (i.e. cell assemblies) into our conscious experience.

The INPUTS to the CGM are the diverse activities of many different cell assemblies, and include a mixture of sensory percepts and higher-level **analytical results**, of which the most pressing/salient enter consciousness. While conscious experiences are quite ephemeral, a small subset are stored via a **FLASH MEMORY** mechanism in our DMRs. As such, DMRs provide a window into the output of cell assemblies, especially those higher up in our neuronal-processing hierarchies. These items seem intrinsically symbolic and largely non-linguistic.

COMPUTATIONAL VIEWS OF OBJECT RECOGNITON: PDP vs. grandmother cells: two competing views of object representation are distinguished by how winner-take-all computations digitize the outcome (Bowers, 2009, *Psychol. Rev.* **116**:220-251.)

COMPUTING CONSCIOUSNESS: 1. Basis of CGM: Baars and Franklin, 2003, 2007. 2. Mashour, 2006; Lee et al. 2010 (Anesthesiology 113:1081-1091) 3. Tononi, 2008; Rees, Kreiman, Koch, 2002.

CALCULATIONS AT 10,000X CONNECTIVITY. 1. Pulvermüller & Knoblauch, 2009; Rolls, 2010.
2. Tenenbaum et al., 2011, *Science*. 3. Goldman, 2010, *Neuron*, feed-forward. 4. Hawkins, 2004, *On Intelligence*.

DMR Analysis

Scoring Criteria for Items in DMRs

names – if a DMR included a name (mom, dad, sibling reference, or significant other included)

# of people – number of people mentioned, X = 6 or more

topic – only gives the topic of a conversation

phrases – not word-for-word dialogue

quotes – exact wording/conversation

reflective thoughts – thoughts about a time previous to the moment of the DMR

thoughts – mentions ones thoughts

time reference – references either an exact time or a time frame i.e 15 minutes

self-actions – any action conducted by oneself

observed actions – any actions that are observed done by another person

object recognition – names the object

spatial content – gives location of object

sound recognition – mentions a sound heard

planning ahead – either in thoughts or actions, one plans ahead for a point in the future

score – score of the overall DMR based on a number scale of 1-5. 1 being the lowest. Score is bias based on my overall impression of the effort and detail put into the written DMR.

numbers – mentions a number independent of time reference

emotions – mentions an emotion they felt at a particular time in their DMR

object location – a subset of spatial content. If it was an obvious location that could be from a subconscious/habit i.e "milk from the fridge"

person description – describes anything about a person i.e hair color

direction – gives a specific direction such as right, left, up, down

smell – mentions a smell in ones DMR

Neuroinformatics of the MIND: Symbols ➔ CGM ➔ DMRs

1. **DMRs** are written effortlessly & chronologically.
2. **DMRs *vastly exceed*** the short-term/working memory store capacities (i.e. ~7 unrelated items) (Gioioso & O'Malley, 2009, SFN).
3. **FM is able to write** DMRs ***because of*** our prior experiences;
   The FM mechanism *depends upon* on cortex interconnectivity.
4. **Resident** DMRs are used subconsciously throughout the day.

HUMAN MEMORY SYSTEMS

1. The term "**Flash Memory**" is used to highlight the automatic, one-trial writing of info into our DMRs.
2. Day-long **DMRs** can be interrogated at will. AND SHOULD BE!
3. Enduring **EPISODIC MEMORY** is comprised of long-lasting fragments of our succession of DMRs.

- **Neuronal Assemblies** represent things:
  bacon, kids, actions, thoughts, 3D space, location, plans, etc.
- **Neocortical Predictions** organize present items *in context*
- PFC, thalamus and/or Basal Ganglia **prioritize** items
- The CGM evaluates the output of **100,000 processors?**
- CGM assembles top-sets into *Stream of Consciousness*
- FM stores EXCERPT into DMRs
- Neocortex OPERATES on DMRs for a day or two
- Sleep consolidates & reboots brain for next DMR

via coupled oscillators
or silent synapses?

Universal Physics ➔ Shared Grammars

- some physics is innate (visual cliff)
- some physics is learned (hot, sharp, 3D)
- internal symbols (neural words)➔ **protowords**
- protowords ➔ **protogrammar**
  e.g. "deer moving" "bear behind"

QED: sub-linguistic concepts ➔ grammars

causality, spatial relationships, object properties, agent behaviors (thag hit grok), associations (mate of thag)

see Robbins Burling
& Derek Bickerton