The Copernican Revolution of Neuroscience

Traditional view: the Brain gathers sensation and assembles it into a model of the world directly.

Contemporary View: the Brain generates and maintains a model of the world using sensation as feedback about the accuracy of its model. Knowledge of the world is indirect.

Perception is an active probe the brain uses to test its model. An experiment to test a hypothesis.

The Brain runs a simulation of reality, a parallel world that gets updated when sensation doesn’t match predictions.

Daniel Kish - “Bat Man”

“Blind as a Bat: seeing without eyesight.” YouTube

Very sparse sensory data (echoes), therefore “seeing” the world in 3-D only possible if the brain provides the model which is then fine tuned by the sparse sensory data from the world.
The Brain as Crime Artist

Crime artist (police sketch artist) sits in a room, like the brain in the skull.

No direct access to the real world.

Access to the real world is through witnesses who come in, like sensation coming into the brain.

Witnesses are imprecise and inaccurate, like sensations.

Crime artist using “generic” memories of faces draws a model, a prediction of what the suspect looks and tests it with the witnesses- How is this?

Witnesses respond by saying what's wrong with particular details, and the crime artist updates the model.

The more times this cycle is repeated, the closer the drawing is to the suspect in the real world, despite lack of direct access and imperfect data.

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Drawing what you’ve never seen.

The Brain Internal Model

PBS “The Brain” with David Eagleman
- What is Reality?

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The Rotating Mask Illusion

YouTube “The Rotating Mask Illusion”

The brain’s model of the “most likely explanation of the sensory data” dominates our experience.

In this illusion we see a convex face, even when we are looking at the back of the mask which is concave.

Concave faces are such an unlikely occurrence in nature that our brain won’t let us see it, even when it is there.

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The Predictive Brain

The brain is a sophisticated hypothesis testing mechanism that is constantly trying to minimize prediction errors using sensation as feedback.

Minimizing prediction errors can account for perception, learning, action, attention, goal directed behavior, functional specialization in a statistically based, rigorous methodology.

Only interested in prediction error. Predicted stimuli ignored.

The brain predicts by generating models based primarily on experience i.e. memory.

Friston 2012, Friston 2009, Bar 2009, Strelnikov 2010
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Predictive Brain in action

Police entering apt. in rough neighborhood at night…
“When a gun is not a gun”  NYT  4/19/15

tennis serve- predicting bounce

Insulin rise before a meal.

Glucose rise before competition.

Cortisol increase before rising in the morning.

Generating hypotheses in psychotherapy.

Predictions are based on memories.

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Memory Updating

Mismatch between what the brain predicts and what it senses (a prediction error) opens a window of 4-6 hours during which memory can be updated. Learning.

Memories are refined to enhance their efficiency and utility over time. Automatic and non-conscious.

Changes mediating updating span intracellular gene induction to system level reorganization.

Memories are balanced between stability vs. flexibility to be updated. Accuracy vs. complexity. Specific vs. general.

Memories are like a sketch that captures some features better than others, and evolves with experience over time. Not a video.


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“Good Memory”

Is accurate allowing predictions to guide behavior.

Is consistent with other memories in the system.

Can be combined with other memories to extrapolate and predict things we haven’t directly experienced.

Is capable of being updated. Dynamic.

Optimized?


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Mismatch Negativity

Brain's response to stimulation that deviates from what is predicted - marker of prediction error.

EEG wave with a negative deflection that occurs after an unexpected stimulation e.g. series of the same auditory tone followed by a different tone.

Auditory, visual, somatosensory stimulation, violation of an abstract rule, grammatical rule etc.

“When the power went out, the house became ....”

Naatanen 2007, Strelnikov 2007

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Summary-Predictive Brain

Brain makes a model.

Runs experiments using sensation to test its model.

Only interested in “prediction error”, when sensation doesn’t match the prediction. (when the model gets it wrong)

Mismatch Negativity marks the error.

Mismatch opens the window for memory updating.

Memory and Model get updated improving predictive accuracy.

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The Triune Brain- Paul MacLean

(3) Neocortex
“thinking brain”-flexible responses

(2) Limbic brain
“emotional brain”-learned responses

(1) Brainstem
“Reptile brain” Hard-wired responses.

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**Back to Basics Principle**

When function of the newest brain (3) is compromised, the older brain (2) takes control.

What worked before.

Less flexible but more reliable.

Hughlings Jackson MD  
“Dissolution” 1870.

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**Trauma Induced Imbalance**

Acute-Newer brain function (3) compromised, lower brain (2) takes control—often adaptive. Usually reverses when event is over.

Trauma-lower brain remains in control with ongoing imbalance of whole brain.

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**Stress Induced Brain Imbalance**

High Nor-epinephrine (NE) decreases Pre-frontal cortex (PFC) neuronal firing and therefore “top-down” control.

High NE enhances amygdala function and therefore “bottom up” control.

High NE “gives the microphone” to the lower brain.

(Moderate NE has the opposite effects thereby enhancing PFC “top-down” control when safe.)

Arnsten et al. 2015
Extreme Stress shuts down prefrontal cortex turning control of behavior over to lower, older brain structures. Faster, more reliable, pre-programmed, survival driven behavior.

PFC Hypo-function
- Loss of PFC mediated inhibition of amygdala
- Poor habituation to novel neutral stimuli
- Pre-attentive bias for threat information
- Deficits in working memory and executive function
- Poor affective information processing
- Poor affective regulation
- Indexed by Heart Rate Variability (HRV)

Working with Memory
- “Working memory” more precisely conceptualized as “Working with Memory” (a problem solving function)
  - the selection of task relevant information and activation of the corresponding circuits in the brain
  - repeated cycles of selection and activation necessary for different stages of solving a problem
  - “goal” must be held online, over time, with constantly changing particulars. Dynamic.
  - Dorsolateral PFC - critical node in “Working with Memory”
Consciousness-Dehaene

“Global Neuronal Workspace”-Consciousness is global information broadcasting to distant cortical regions.

When processing crosses a threshold there is “ignition” of a temporary network with synchronization of distant, specific brain regions in bi-directional communication.

 Allows information to be processed flexibly by a variety of different systems in different ways, for an arbitrarily long duration. Processing no longer reflexive.

 “Signatures of Consciousness” - patterns of brain activity that occur only if person having conscious experience.

Dorsolateral PFC and FEF are anchor nodes in the GNW

Dehaene 2014

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Consciousness-Workspace ignition

A Visible word Invisible word

B Detected sound Non-detected sound

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Global Neuronal Workspace

Reverberating global neuronal workspace (conscious access)

Dehaene 2009

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When Stress turns off the PFC there is no “Working with Memory”!

Summary-Trauma induced imbalance

Brain shifts control to more primitive structures as an adaptive response in extreme circumstances.

High levels of nor-epinephrine turn off PFC.

“Working with memory” is not available so information is not broadcast and diverse regions are not able to share information and integrate into a coherent representation. (Left with fragments.)

When triggered, emotionally charged fragments stimulate high levels of nor-epi and imbalance persists.

Restoring PFC Function

Returning to “window of tolerance”

Safety, control

Increase Heart Rate Variability (e.g. using emWave)

Eye Movements

alpha 1 antagonist (prazosin)

alpha 2A agonist (guanfacine, clonidine)

Executive fxn. tests- e.g. simple calculations

Thayer 2007, Arntsen 2015
Resting State Networks

Brain networks identified using a variety of imaging techniques. Most common- functional MRI (fMRI).

Analogy to social networks e.g. “Pool club network” is “at rest” during the winter, but evidence can be seen in sporadic activity (emails) between members (nodes). In summer, network becomes activated with lots of activity between members. Membership may overlap with “Ski club network”. Some functions e.g. town-wide celebration may activate both networks.

Patterns, but also flexibility in membership and activation.

Not like a computer with fixed wiring and functions.

3 Principal Networks

Me Network - my past, my future, my relationships.

Deal Network-deal with the external world. Direct the eyes.

Feel Network-feeling and regulating the body and emotions.

Me Network

Nodes in network: medial prefrontal cortex, posterior cingulate, inferior parietal lobule, medial and lateral temporal lobe

Functions: my past, my future, my relationships. Prediction.

Formally known as the Default Mode Network in the literature.
Deal Network

Nodes in network: Dorsolateral prefrontal cortex, frontal eye fields, intraparietal sulcus, superior parietal lobule, posterior parietal cortex, middle temporal area.

Function: Deal with the world. (Directed attention/cognition.) Working With Memory. Directing eye movements.

Formally known as the Central Executive Network in the literature.

Buschman 2009, Bressler 2010

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Deal vs. Me Network

Nodes in network:

Feel Network

Nodes in network: orbitofrontal cortices/anterior insula, anterior cingulate, extensive connections to subcortical nuclei- amygdala, hypothalamus, ventral striatum periaqueductal grey.

Functions: visceral sensation, autonomic and emotional regulation, reward processing. Mediates interactions between Me and Deal networks.

Formally known as the Salience Network in the literature.

Menon et al. 2010, Menon 2011, Seeley 2007

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Me-Deal Network see-saw

When the Deal network increases in activity, the Me network decreases in activity and vice versa. Mediated by the Feel network.

Attention demanding tasks (Deal network) decrease "rumination" (Me network).

Distraction takes mind off of problems.


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The Feel Network Switch

Me Feel Deal

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3 Principle Networks

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Core of Network Balance

Feel network sits between the Me and Deal networks having a panoramic view of the external and internal environments where it integrates external sensation with internal visceral sensation, emotion, and cognition.

Feel network selectively and flexibly recruits the Me and Deal networks, thus allocating functional resources depending on circumstances.

“deficits in engagement and disengagement of these three core neuro-cognitive networks play a significant role in many psychiatric disorders”

Barbas et al. 2010, Menon 2011

Role of Eye Movements

Eye movements turn on the “explore mode” by activation of the Frontal eye fields, and the Deal network. This turns down the Me network thus redirecting processing resources to the external world. Sampling of sensation increases facilitating updating with new information e.g. “it’s over”.

“saccades are optimal experiments in which data are gathered to test hypotheses or beliefs”


How EMDR works: Network Balance Model

Assessment activates Me and Feel networks with the poorly encoded memory.

Eye movements activate Deal network, turning down Me network by the seesaw effect. Deal network has minimal connection to the limbic system therefore anxiety abruptly decreases.

Eye movements increase sensory sampling of the present which triggers Mismatch Negativity prediction error as current sensation does not match the prediction of the poorly encoded memory.

Memory becomes labile for updating and optimization to reduce prediction error and enhance predictive accuracy for the future.

Repetition of procedural steps sequentially activates Me, Feel and Deal networks “manually” re-establishing dynamic network balance and fluid Dual Attention. “Network Balance Training”
Role of Bilateral Tactile Stimulation

Surprising (=unpredicted) somatic sensation heralds significant events e.g. threat of a snake bite or presence of a loving caress.

Insula (part of Feel network) coordinates prediction error minimization of somatic sensation e.g. tactile

Insula anchors a Global Neuronal Workspace enabling re-entrant communication between PFC and somatosensory cortex.

Bilateral Tactile Stimulation creates a mismatch in the somatic memory that triggers memory updating.

Fine tuning network balance.

Dual Attention - balance Me and Deal networks (in bounded oscillation).

“Stay off the tracks” - avoid unnecessary activation of Deal network when networks balanced and processing.

“Let whatever happens, happen” - encourage “surrender” to reduce Deal network activation.

“Watch a movie” - decrease Feel network, increase Deal network. (“Detached observer”)

Focus on Attachment - increase Feel network and interpersonal regulation via Social Vagus activation.

“Looping” and Network Balance

Stuck on the same informational plateau. High distress, same emotions, sensations, images etc.

Not processing because networks not balanced.

Change eye movements- speed or direction. Attempt to activate Deal network. Motion captures attention. ( Habituation?)

Focus on body sensation. All, most pronounced, tension from thwarted movement. Attempt to activate Feel network.

Scan incident for more distressing element-visual, auditory. Activate Me Network.

Cognitive interweave-information activation of Deal network.
**EMDR and Me/Deal Network See-saw**

Single case report - subsyndromal PTSD in Bipolar patient.

Baseline-poor Me network deactivation in response to attention demanding task (Deal network).

After 14 EMDR sessions - significantly improved Me network deactivation.

Conclusion “...EMDR is capable of modulating the function of the Me Network”.

Network Balance Model: “exercising” the Me/Deal network seesaw improves its flexibility and network balance.

*Landín-Romero et al. 2013*

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**Neurobiology in Trauma**

decreased activity in frontal lobe, anterior cingulate, thalamus

increased activity in medial temporal lobe, limbic nuclei e.g. amygdala

frontal lobe activation post EMDR - most common finding, dorsolateral prefrontal cortex

difficulty engaging Deal network and disengaging Me network in a Working Memory task

*Bergmann 2010, Daniels 2010, Blair 2013*

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**Borderline PD Network Balance**

(Purple-Feel network, Green-Deal network. Control group on Left, Borderline PD on right)

Balance shifted in Borderline patients towards the Feel network away from Deal network relative to controls.

*Doll 2013*
What do eye movements do?

Eye movements activate the Frontal eye fields and the Central Executive Network (Deal Network) thus restoring PFC function and balance in the three resting state networks allowing conscious updating of the traumatic memory with new information e.g. “it's over”.

The Brain Internal Model

PBS “The Brain” with David Eagleman - What is Reality? (3:58)

Prediction from cortex in blue.

Sensation from world in white.

Prediction error (=difference between prediction and sensation) sent back to cortex in green driving updating of the model.
How does EMDR work?

EMDR works by creating a state of increased prediction error in the brain.

(Driven by Thermodynamics, the brain quickly updates and reorganizes the memory to minimize the increased prediction error.)

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That's just my theory, but I think it's correct.

-Woody Allen

Chamberlin applied Neuroscience

eric@ChamberlinNeuroscience.com
Further Reading

PBS The Brain with David Eagleman. DVD
Making up the Mind: How the Brain creates our Mental world. Chris Frith
Consciousness and the Brain. Stanislaw Dehaene
The Invisible Gorilla: How our intuitions deceive us. Christopher Chablis
The New Executive Brain: Frontal Lobes in a Complex World. Elkhonen Goldberg
Wider than the Sky: The Phenomenal gift of Consciousness. Gerald Edelman
Surfing Uncertainty. Andy Clark
The Predictive Mind. Jakob Hohwy

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