Remembrance of Things to Come

The restless brain between memory and (self-fulfilling) prophesy

Giuseppe Pagnoni

Nijmegen, May 2014
“[...] his golden-bronze sunflowers are painted; they are painted as sunflowers and nothing more, but to understand a sunflower in nature now, we have to resort to Van Gogh”

Antonin Artaud

*Van Gogh, Le Suicidé de la Société* (1947)
Perception as an inference problem
World to senses: many-to-one
World to senses: one-to-many
Perception as an inference problem

Hp 1: A burglar broke in!

Hp 2: A branch fell on the roof

How well does the evidence match the hypothesis?

How probable is the hypothesis per se?
Perception as an inference problem

Bayes’ Rule

\[
P(h|e) = P(e|h) P(h)
\]
Courtroom case analogy

• Attempt to reach a verdict among different hypothesis (*guilty* or *innocent*)
• Evidence is *noisy*, uncertain
• *Active* querying of witnesses and evidence
• A successful hypothesis:
  – is best supported by the evidence
  – can be used effectively to interrogate the evidence
• There needs to be some degree of *insulation* among the different sources of evidence and query to reach a fair verdict
The human adult brain contains 80-90 billion of neurons for a total of $10^{14}$ synapses.
Prediction error minimization

LOW LEVEL

MIDDLE LEVEL

HIGH LEVEL

prediction

 prediction error

 precision expectation

 self-inhibition

prediction

 prediction error

 precision expectation

 self-inhibition

 WORDLY CAUSES
Perception turned on its head

Classical view
• bottom-up massive flow of sensory input
• top-down processing has only the role of feedback on the sensory data

Predictive coding view
• top-down hypotheses querying the world
• the predicted portion of sensory input is dampened down (“explained away”)
• only the unexplained portion of sensory data is propagated upstream as prediction error
• prediction error aids in revising the original hypothesis
Binocular rivalry

Zhou et al, Curr Biol 2010
Perceptual grouping

occhio sinistro  occhio destro
Perceptual grouping

Hohwy 2013
'Virgin Mary' toast fetches $28,000

A decade-old toasted cheese sandwich said to bear an image of the Virgin Mary has sold on the eBay auction website for $28,000.

An internet casino confirmed it had purchased the sandwich, saying it had become a "part of pop culture".

Goldenpalace.com says it will take the sandwich on world tour before selling it and donating the money to charity.
Two ways of minimizing prediction error

- **perceptual inference** is the *passive* process of updating one's internal beliefs to best explain away the sensory signal

- **active inference** takes the prediction for granted and minimizes prediction error by acting in the world so to make the actual sensory input fit the prediction better
Two ways of minimizing prediction error

• There needs to be an alternation of perceptual and active inference for the long-term optimization of prediction error minimization

• This is determined by the expected precisions of actual sensory input and predicted sensory input

• Precision is the gain of prediction error mediated by attention
The free-energy principle (K. Friston)

- A self-organizing biological system in order to conserve its form must minimize surprise through exchanges with the environment

- Surprise is *conditioned on a generative model of the world*

- To minimize surprise it is sufficient for the system to minimize free-energy

- Under reasonable assumptions free-energy is simply prediction error
Minimization of free-energy across timescales

\[ \mu_x^{(i)} = \arg \min F(\bar{s}(a), \mu^{(i)} | m^{(i)}) \]
\[ \mu_a^{(i)} = \arg \min F(\bar{s}(a), \mu^{(i)} | m^{(i)}) \]
\[ \mu_y^{(i)} = \arg \min \int dt F(\bar{s}^{(i)}, \mu^{(i)} | m^{(i)}) \]
\[ \mu_o^{(i)} = \arg \min \int dt F(\bar{s}^{(i)}, \mu^{(i)} | m^{(i)}) \]
\[ m^{(i)} = \arg \min \int dt F(\bar{s}^{(i)}, \mu^{(i)} | m^{(i)}) \]
\[ m = \arg \min \sum_i \int dt F(\bar{s}^{(i)}, \mu^{(i)} | m^{(i)}) \]

**Perception and Action:** The optimization of neuronal and neuromuscular activity to suppress prediction errors (or free-energy) based on generative models of sensory data.

**Learning and attention:** The optimization of synaptic gain and efficacy over seconds to hours, to encode the precisions of prediction errors and causal structure in the sensorium. This entails suppression of free-energy over time.

**Neurodevelopment:** Model optimization through activity-dependent pruning and maintenance of neuronal connections that are specified epigenetically.

**Evolution:** Optimization of the average free-energy (free-fitness) over time and individuals of a given class (e.g., conspecifics) by selective pressure on the epigenetic specification of their generative models.

Friston, TICS 2010
A self-organizing system (organism, brain) IS a model of its world
Percepts and Concepts

• Both are representations of state of affairs in the world
• Percepts are about shorter-term, detail-rich regularities
• Concepts are about longer-term, detail-poor regularities
The restless brain

A default mode of brain function

Raichle et al, PNAS 2001
Semantic processing and the default mode network

Binder et al, Cereb Cortex 2009
The default mode network  
(hypothesis)

A continuous prediction of sensory data on the basis of autobiographical experience that...

... biases us towards a subspace of the sensorium that fits our model best (minimizing prediction error)

The self-confirmation of our model of the world based on autobiographical experience is also a confirmation of the narrative Self
Alzheimer’s disease

Buckner et al, J Neurosci 2005
Meditation

- maintain a steady posture
- minimize variability of sensory input
- keep a vigilant but broad attention
- refrain from acting out spontaneous thoughts or even following them
Action and attention

- A hypothesis is cast out by the internal model which *predicts* a certain proprioceptive signal
- but when less *attention* is allocated to the *actual* proprioceptive signal
- the mismatch between the two is minimized by eliciting an *action* that brings the actual proprioceptive signal closer to the predicted one
Our usual state

- Attentional allocation biased towards the internal hypotheses
- **high precision** (weight) of *expected* sensory and proprioceptive signals
- **low precision** (weight) of *actual* sensory and proprioceptive signals
- behavior is biased towards making us actively search for the situations that confirm our prior beliefs

The mindful state

- Attentional allocation biased towards the actual sensory/proprioceptive/interoceptive signals
- **low precision** (weight) of *expected* sensory and proprioceptive signals
- **high precision** (weight) of *actual* sensory and interoceptive signals
- there is a bias towards changing the internal model to fit the actual sensory and interoceptive signal
Meditation: a hypothesis

Meditation practice may rebalance our mental activity by introducing periods where the self-confirmation mode is dampened down in favor or a revision of the model.

Our beliefs about the world (priors), as well as our sense of the Self, become more malleable.

We may become more flexible in our behavior and mental states.
Nonlinear dynamics
Meditation and creativity

Meditation, mindfulness and cognitive flexibility
Adam Moore, Peter Malinowski *
Consciousness and Cognition, 2009

Stepping out of history: Mindfulness improves insight problem solving
Brian D. Ostafin a,*, Kyle T. Kassman b
Consciousness and Cognition, 2012

“Mind the Trap”: Mindfulness Practice Reduces Cognitive Rigidity
Jonathan Greenberg*, Keren Reiner, Nachshon Meiran
PLoS One, 2012

Meditate to create: the impact of focused-attention and open-monitoring training on convergent and divergent thinking
Lorenza S. Colzato *, Ayca Ozturk and Bernhard Hommel
Frontiers in Psychology, 2012
Depression and mindfulness

MBCT significantly decreases risk of relapse
  • *mindfulness makes the system regain degrees of freedom*

Sad music can easily tip depressed people into worsening of mood
  • *with strong attractors a little nudge is sufficient to make the system fall back into their orbit*

Problem-solving ability is inversely related to risk of relapse
  • *higher creativity reflects a greater freedom of the system’s itinerant dynamics among the basins of attraction*
Problem solving capacity collapses after sad mood induction

- when the system falls into a strong attractor it exhibits an abnormal rigidity

Patients with high child trauma scores benefited most from MBCT

- attractors with a longer history of self-confirmation have the strongest pull
- that’s were mindfulness may be more efficacious
Illusory flowers in an empty sky

“Never foolishly misconstrue dim-sightedness as falsehood and thereby look for truth outside it. That is a short-sighted view.

Because enlightenment is rooted in dim-sightedness, all things that constitute enlightenment are invariably the ones adorned with the dim-sightedness. Because delusion is also rooted in dim-sightedness, all things that constitute delusion are invariably adorned with the dim-sightedness as well”

Dōgen on Meditation and Thinking
Hee-Jin Kim, 2007