MODELING SENSORIMOTOR HABITS WITH NEURO-ROBOTICS
A Reappraisal Of The Habit Concept In Psychology

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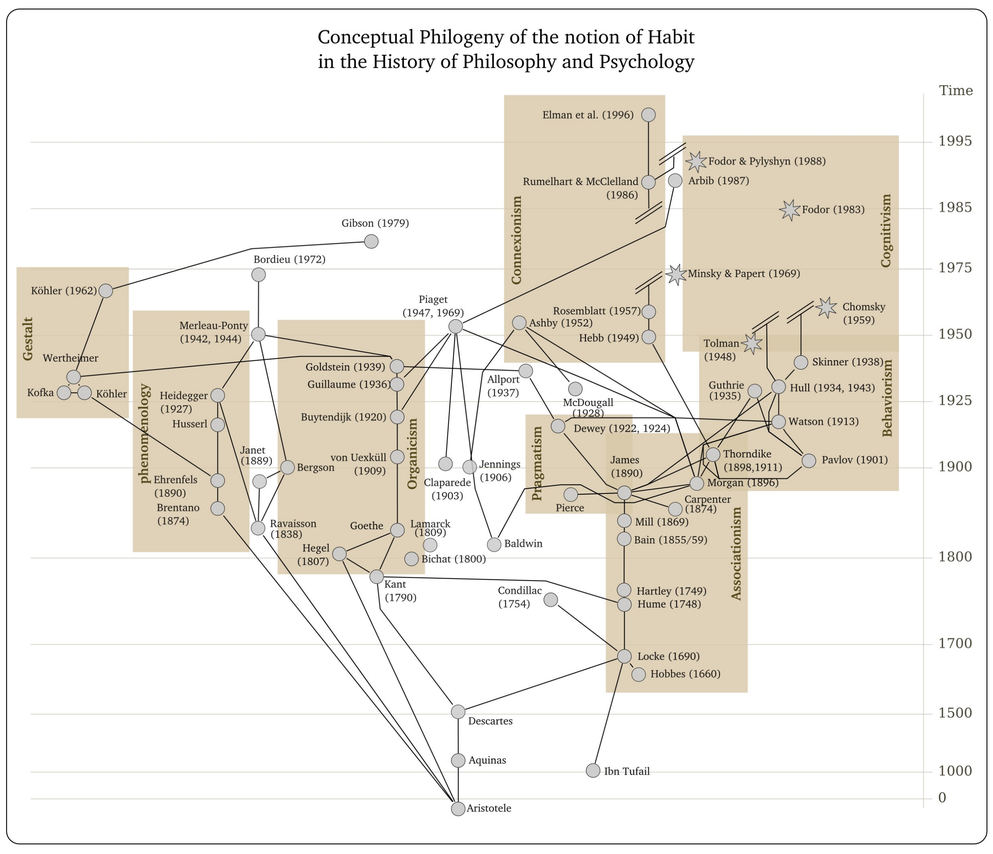
ABSTRACT

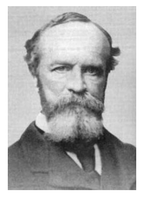
Recent trends in cognitive science have seriously undermined the notion of representation (symbolic or sub-symbolic) as a building block for theory construction and modeling in cognitive science (Stewart et al. 2011). The current lack of a clear theoretical building block for dynamical, embodied and situated cognitive approaches calls for a re-appraisal of the notion of habit as developed by early pragmatists (James, Pierce and Dewey) and continental psychologists and philosophers (Köhler, Goldstein, Merleau-Ponty). Whereas contemporary computational neuroscience and machine learning approaches (Daw et al. 2005) still sustain a behaviorist (S-R probabilistic association) conception of habit, we propose a richer notion by modeling habits as self-sustaining behavioural neurodynamic patterns where activity-dependent plasticity shows an extended temporal structure. We illustrate this point with some work on evolutionary robotics, implementing a combination of Hebbian and homeostatic plasticity (as recently supported by different neurobiological studies—Turrigiano 2000, 2007). In our robotic models, this mechanism is capable to generate sensorimotor development, reinforcement learning, spontaneous habit formation and re-habituation to sensorimotor disruptions (Di Paolo 2000, Barandiaran and Di Paolo 2010). We conclude that a richer notion of habit can significantly contribute to the foundations of cognitive science, opening up the possibility to model poorly understood psychological phenomena.

Truncated History of the Notion of Habit



"the formation of habits (...) concerns the problem of intelligence in the highest degree. (...) in so far as the organising assimilatory process, which eventually arrives at the operations peculiar to intelligence, appears from the outset in perceptual activity and in the formation of habits" J.PIAGET

"Concrete habits do all the perceiving, recognizing, imagining, recalling, judging, conceiving, and reasoning (...) 'Consciousness' expresses functions of habits, phenomena of their formation, operation, their interruption and reorganization" J.DEWEY



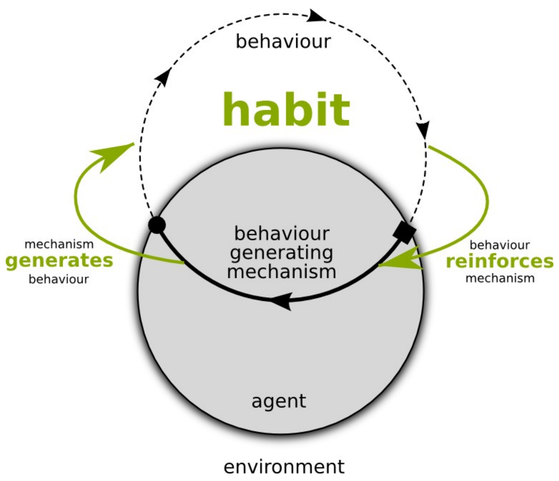
"When we look at living creatures from an outward point of view, one of the first things that strike us is that they are bundles of habits" W. JAMES

The notion of habit in contemporary cognitive psychology and neuroscience

Under the influence of behaviourism the notion of habit was *reduced* to its scientific formulation as a *probability correlation between stimulus and response*

In contemporary computational neuroscience and machine learning habits are conceived as *reactive behaviour or probabilistic associations between stimulus categories* (or measure of states in a problem domain) *and action patterns* (representing a set of motor commands that might alter the functional space of the problem environment).

What is a Habit?
A sensorimotor neurodynamic perspective



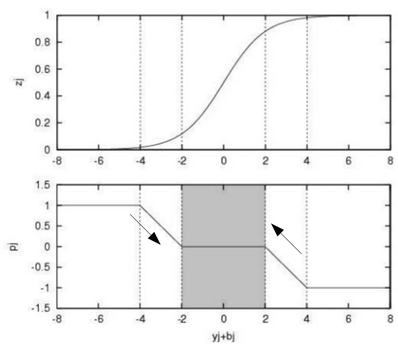
- **HABIT = *plastic and self-sustaining pattern of behaviour generated by emergent neurodynamic structures.***
- The **stability** of a habitual behaviour is coupled with the stability of the neurodynamic pattern that generates it..
- Its plasticity allows for processes of assimilation and accommodation, together with the increasing structuration.

Evolutionary robotics and re-habituation to visual inversion: a Piagetian interpretation

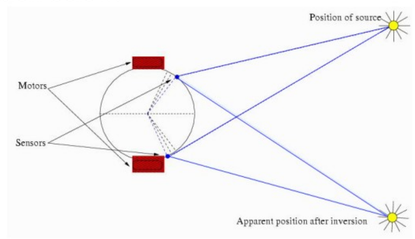
Di Paolo, E. A. (2000). Homeostatic Adaptation to Inversion of the Visual Field and Other Sensorimotor Disruptions. In J. Meyer, A. et. al (Eds.), *From animals to animats 6*. MIT Press.

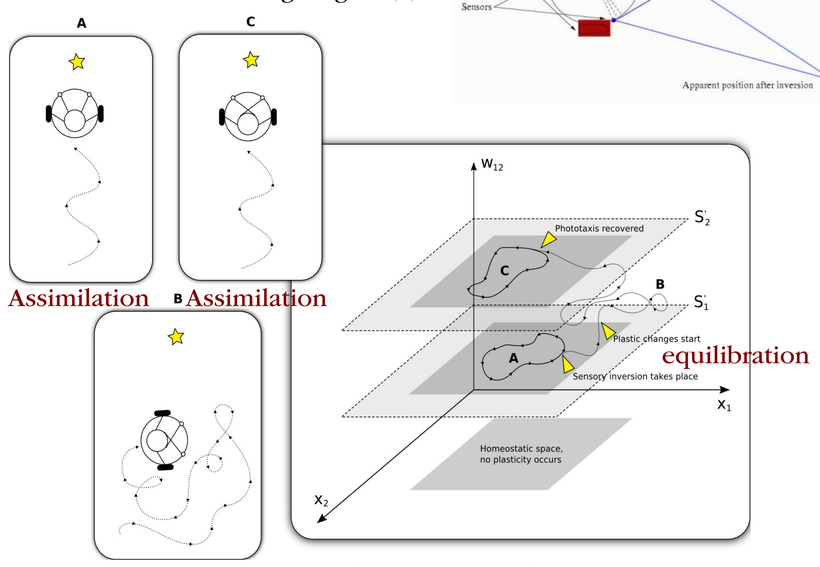
Re-habituation to visual inversion is a well documented psychological phenomenon (Kohler 1964). Whereas it would take 1bit operation to invert the visual field for a computational device it takes weeks to adapt to this condition, and free behaviour is required to achieve it. Di Paolo implemented homeostatic plasticity in a robot artificially evolved to do phototaxis and maintain synaptic stability. After optimization the robot's vision was inverted, leading to synaptic unstability as a result, until a new synaptic configuration was capable to enact photatic sensorimotor contigencies and stability was regained. See model, controllers and explanation below.

"habits exist in all areas of human personality" (p. 137) and that only when we undergo a strong process of rehabituation "do we notice what habit is, and to what extent we consist of many and strong habits" (p. 138) Kohler, I. (1964). *Formation and Transformation of the Perceptual World..*



Piagetian interpretation: the agent assimilates the light (A), visual inversion takes place and the agent acommodates (B), when reaching equilibrium it assimilates the light again (C).





x_1 and x_2 represent neural activation, w_{12} represents the synaptic weight between x_1 and x_2. Neural activation looses phototactic stable attractor A when vision is inverted, synaptic changes are activated until new attractor C is found.

The controller of the robot is a totally connected Continuous Time Recurrent Neural Network with homeostatic Hebbian plasticity: plastic changes are activated when the firing rate goes out of upper and lower bounds, increasing the strenght of incoming connections when activity is low and viceversa.

$$\tau_i \dot{y}_i = -y_i + \sum_{j=1}^{n} (w_{ij} z_j) + g_i \sum_{k=0}^{5} s_{ki} I_k \ ;$$

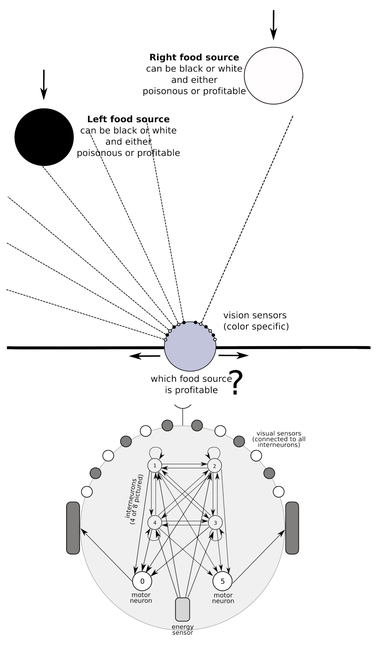
$$\text{where} \quad z_j = \frac{1}{1 + exp(-(y_j + b_j))}$$

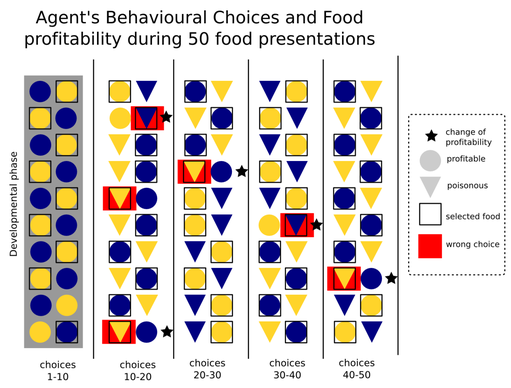
where y is the state of each neuron, τ is the time constant, w_{ij} is the connection weight between neuron i and j, z_j is the activation of neuron j, y_j is j's state and b_j a bias term; g_i is a gain (-5,5) applied to the overall sensory input to the neuron, s_{ki} (-5,5) is the input weight from sensor k to neuron i and I_k is the input value of sensor k.

$$\text{Presynaptic Hebbian: } \Delta w_{ij} = \eta_{ij} \ p_j \ (z_i - \mu_{ij}) \ z_j,$$

where p_j is the degree of plastic local facilitation explained below, μ_{ij} depends linearly on the value of w_{ij} so that $\mu_{ij} = 0$ if $w_{ij} = max$ and $\mu_{ij} = 1$ if $w_{ij} = min$, η_{ij} is the genetically specified learning rate

Operant Conditioning with homeostatic plasticity

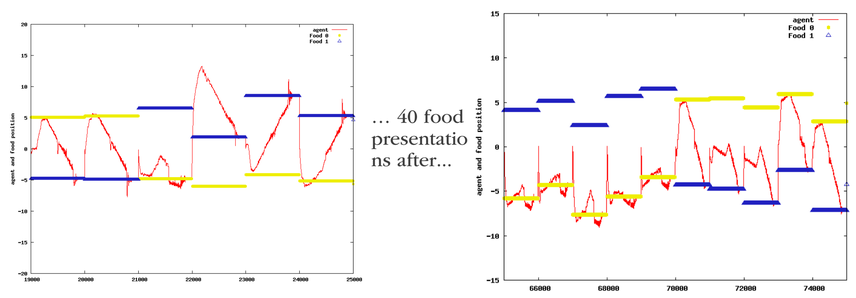




The Agent is presented with two food choices (yellow and blue), profitability of food sources (-10 or 10 energy units) changes every 6-10 presentations. The agent is capable of learning which food is beneficial and acts accordingly. The diagram on the right shows a characteristic chart of the agent's options during a 50 food presentation trial. The agent's behaviour is shown bellow. Statistical average over 20 samples of 50 trials each for food profitability change every 10, 8 and 6 presentations is shown on the bottom-right side.

Spontaneous habit formation

When both food sources are profitable the agent develops a "preference" to choose the food on its right (that this behaviour is not an innate preference can be shown on early trials not biased systematically towards the right)



Under different conditions, when no optimality criteria applies in terms of profitability, the history of interactions leads to the formation of particular preferences or habits on the agent, the exact nature of such patterns and their robustness needs to be tested and explored in more detail. Our working hypothesis is that recurrent interactions stabilize a neural configuration that sustains the interactions that generated it.

CONCLUSION

The history of the habit notion was truncated by the epistemological constraints of early behaviourism and the latter cognitivist turn. Current dynamical modeling techniques in robotics (implementing recent findings in homeostatic and activity-dependent plasticity in the brain) allow to recover a richer notion of habits: plastic sensorimotor contigencies generated-by and inducing-stability into neurodynamic structures. We have shown that phenomena of re-habituation, operant conditioning and spontaneous habit formation can be modelled within this framework. The way is open for more complex cognitive tasks that build, from the bottom-up, increasingly organized networks of habits through a process of equilibration between assimilation and accommodation of sensorimotor patterns.