



Learning to perceive in the sensorimotor approach: Piaget's theory of equilibration interpreted dynamically

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Overview

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*The goal of the current paper is to proceed along similar lines of theoretical development and examine another central, and heretofore neglected, aspect of the sensorimotor approach: **perceptual learning**.*

”

1. Perceptual experience involves sensory inputs and active motor actions.
2. They proposed a theory of how the perceptual learning work in a sensorimotor manner.

THE ROLE OF UNDERSTANDING IN SENSORIMOTOR THEORY

... the practical, engaged, sensorimotor skills of the whole subject are required, for perception. **This is the practical sense of the word understanding**, which we will adopt throughout this paper.

Perceptual experience involves practical understanding.

- Consider Kohler's (1951 [1964]) work, involving long-term adaptation to *vision-inverting prisms and lenses*.
- ... for subjects who actively engaged with the world, after a long period of using such devices, the world slowly righted itself.
- ... actions became more and more correct, and eventually perception itself became more and more correct.
 - (a) the adaptations, both behavioral and perceptual, were partial; and
 - (b) they were very situation-dependent: subjects came to perceive correctly only in those situations where they had practice.



https://www.youtube.com/watch?app=desktop&v=OJTC_E2Nlgg

THE ROLE OF UNDERSTANDING IN SENSORIMOTOR THEORY

Perceptual experience involves practical understanding.

- ... Kohler's subjects often used explicit strategies to react correctly in the initial stages of habituation, but that these strategies eventually became implicit, and automatic; and concomitantly, the visual world itself came to look more and more normal.

1. Subjects perceive the world consciously/autonomously;
2. "Skills" are acquired;
3. Subjects perceive the world unconsciously/automatically.

THE PARADOX OF PERCEPTUAL LEARNING

If understanding is required for perception, how can a subject learn to perceive something new, which they do not yet understand?

- To resolve this paradox, we need a worked out theory of perceptual learning that builds on the above suggestions.
- ... although SMC theory relies on the possibility of perceptual learning, it currently lacks such a worked out theory.

1. To perceive, sensorimotor skills (i.e., *understanding*) are needed.

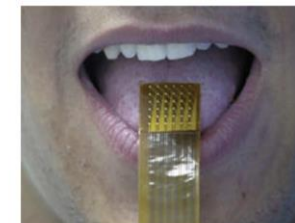
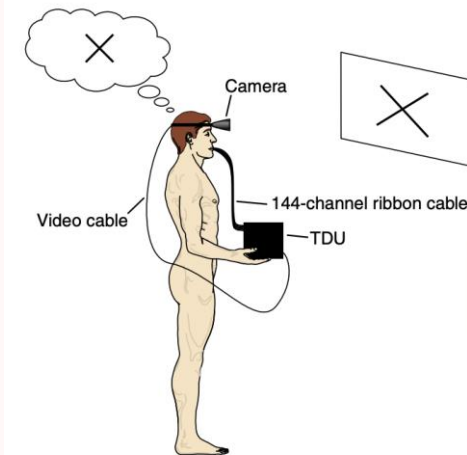
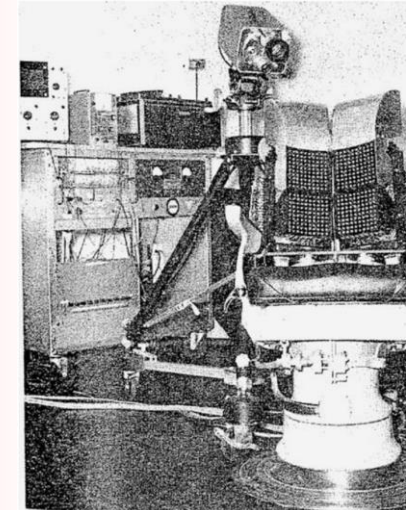
2. To perceive something new, such skills are lacking, so it cannot perceive it.

PARADOX!

Solution: Learning!

THE PARADOX OF PERCEPTUAL LEARNING

- Learning is also important in the discussion of cortical deference vs. cortical dominance given by Hurley and Noë (2003).
- ... Another example of cortical deference occurs in **tactile-visual sensory substitution** (TVSS). Here, the image from a camera is fed to a 2D array of vibrating touch actuators on the body. In early experiments (Bach-y-Rita, 1967) this was a relatively large array, placed on the subject's back. In more recent experiments (Sampaio et al., 2001), smaller arrays are situated on the subject's tongue. Strikingly, subjects who are passively "shown" the world via this system do not learn to perceive anything new. In contrast, those who are allowed to use the camera to actively explore the world can begin to get a sense that the system is providing visual-style access to the world within only a small number of days of training (Guarniero, 1974).



Visell, Y. (2009). Tactile sensory substitution: Models for enaction in HCI. *Interacting with Computers*, 21(1-2), 38-53.

PIAGET'S THEORY OF EQUILIBRATION

... adaptation, which itself is seen as a process of *equilibration* between *assimilation* and *accommodation* processes

- ... by **assimilation** we refer to a process by which an environmental aspect (a perturbation, a new object, or a novel situation, etc.) is integrated, coupled or absorbed into an existing physiological (metabolic, muscular, etc.) or cognitive/behavioral (sensorimotor, perceptual, reflexive) scheme or structure.
- By **accommodation** Piaget refers to the process by which the physiological or cognitive scheme or structure is modulated or transformed to facilitate or encompass a not-yet-assimilated aspect of the environment.
- **Equilibration** is the process by which a given cognitive or biological organization, as a result of a maturational process or in the presence of an ever changing environment or any internal sources of tension, reaches a new form of organizational stability.

1. To assimilate means to match input to a prototype/pattern/schema.
2. To accommodate means to create or revise new prototypes.
3. To equilibrate means to become stable between the two procedures.

PIAGET'S THEORY OF EQUILIBRATION

For example,

1. ... a baby assimilates the mother's nipple into a suckling reflex;
 - A assimilates an environmental aspect A' , that in turn leads to the coordination B that demands and assimilates B' in a sequence scheme, or organization, expressed as " $A \times A' \rightarrow B; B \times B' \rightarrow C; C \times C' \rightarrow \dots$ ". In terms of the example, A can denote **suckling** and A' **the mother's breast**, B **swallowing** and B' **the milk**, C **breathing** and C' **air**, etc.
2. ... the suckling sensorimotor coordination of the baby gets progressively attuned to the size, texture and shape of the nipple.
3. Piaget denotes the stability of the organization as the closure of a cycle of sensorimotor engagements: $A \times A' \rightarrow B; B \times B' \rightarrow C; C \times C' \rightarrow \dots \rightarrow Z; Z \times Z' \rightarrow A$.

PIAGET'S THEORY OF EQUILIBRATION

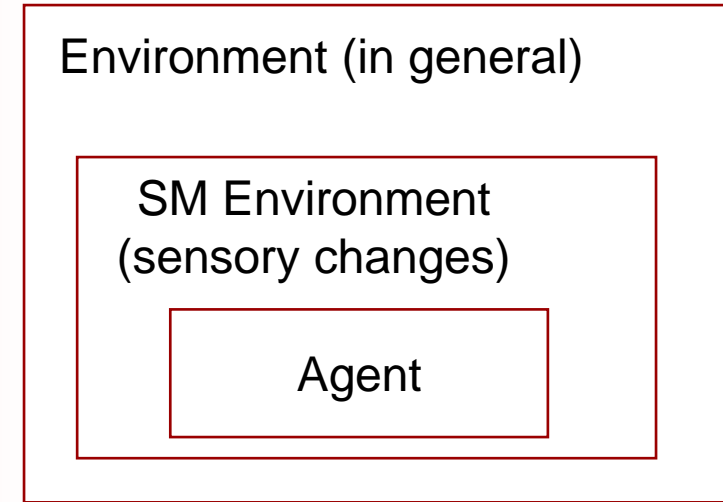
Piaget's development of the theory, particularly along its notation system, lacks a detailed dynamical systems formalization that can make justice to the microgenetic learning and equilibration processes he conceptualized.

A DYNAMICAL APPROACH TO EQUILIBRATION

... our strategy is to describe Piaget's ideas in modern dynamical systems terms and relate those with our previous dynamical definitions of SMCs (Buhrmann et al., 2013).

Buhrmann et al. (2013) propose four formal concepts of SMCs, and describe them in dynamical systems terms.

1. **sensorimotor environment:** the set of possible *sensory changes* induced by arbitrary (open-loop) *motor activity*.
2. **sensorimotor habitat:** ... is again a general mapping, but taking into account the closed-loop situated agent, i.e., how the agent itself induces motor changes and how these changes affect sensory activity.
3. **sensorimotor coordination:** ... describes particular sensorimotor patterns that are reliably used in performing a task.
4. **sensorimotor strategy:** A sequence of SM coordination classes (and their corresponding environmental projections)

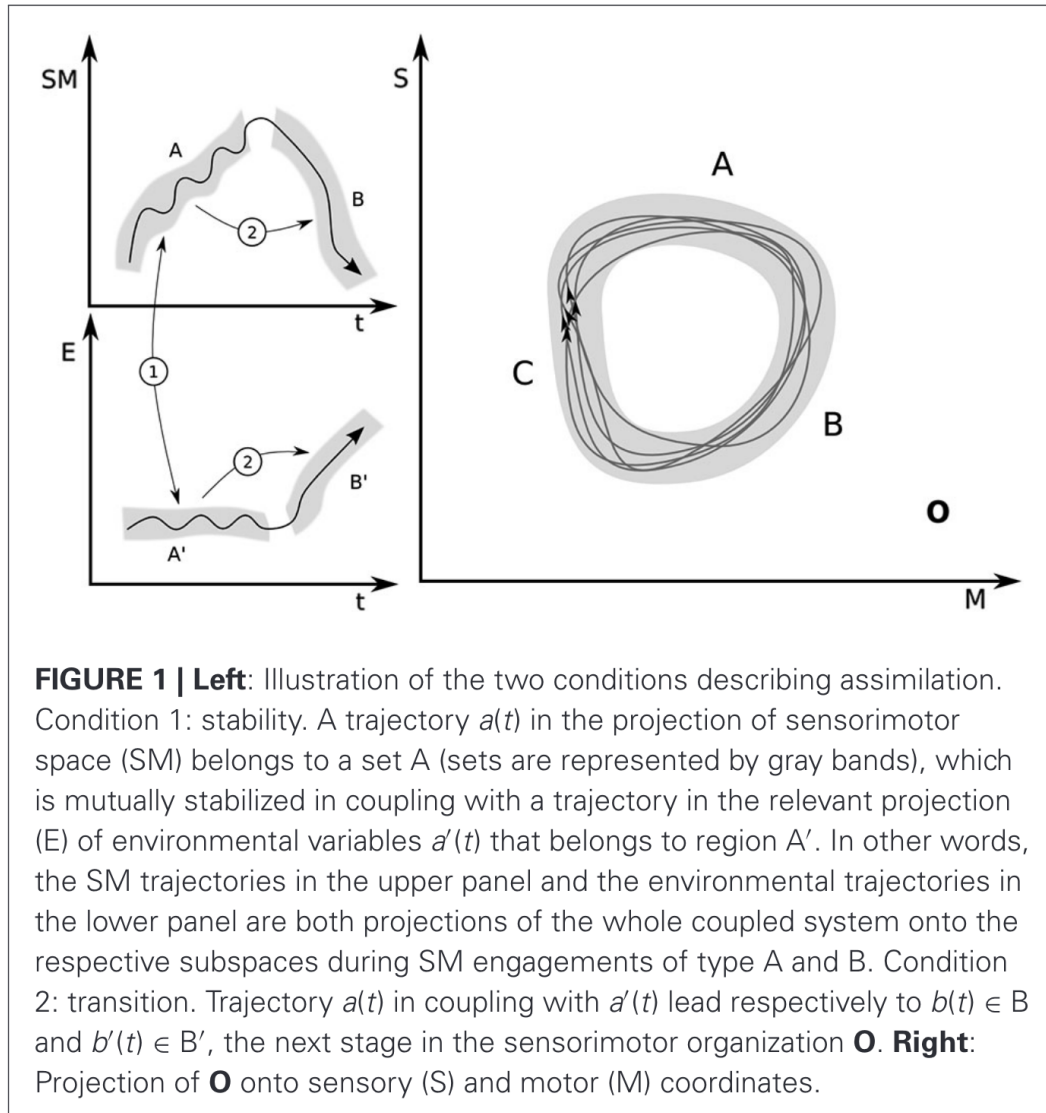


SM habitat=SM env. + agent

SM strategy: prototype; or
sensorimotor organization or
sequence scheme

SM coordination: instance

A DYNAMICAL APPROACH TO EQUILIBRATION



The authors assume a set (or class) of states in the environment can be mapped into a set of states in the agent's mind (the gray areas). For example, A' and A .

A sensorimotor coordination in class A assimilates an environmental feature A' if and only if

1. An SM coordination $a(t)$, ($a(t) \in A$), and $a'(t)$, ($a'(t) \in A'$), are mutually *stabilized* (i.e., they are *matched*). This procedure is denoted as, $A \times A'$. – *Stability Condition*
2. “ $A \times A'$ ” leads to any further “ $B \times B'$ ”. This procedure is denoted as “ $A \times A' \rightarrow B \times B' \rightarrow$ ”. – *Transition Condition*

Eventually, an *SM coordination* (i.e., trajectory) matches an *SM organization* $\mathbf{O} = A \times A' \rightarrow B \times B' \rightarrow C \times C' \rightarrow A \times A'$.

A DYNAMICAL APPROACH TO EQUILIBRATION

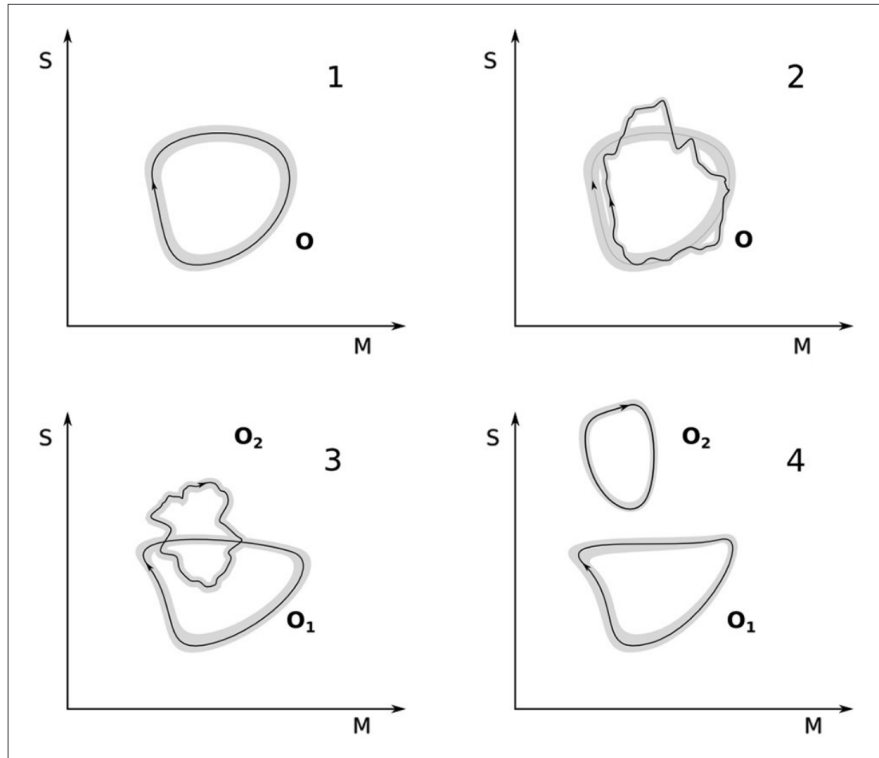


FIGURE 2 | Accommodation and equilibration. Top left: a maximally equilibrated sensorimotor organization \mathbf{O} ; a trajectory in sensorimotor space is shown within the gray band defined by \mathbf{O} . Top right: a perturbation brings the sensorimotor trajectory outside the gray band, however, due to plastic changes, **the trajectory is accommodated and a cycle restored.** Bottom left: through repeated perturbations and re-equilibrations, the organization \mathbf{O} has been turned into \mathbf{O}_1 and another organization \mathbf{O}_2 has been equilibrated, they correspond now to two different kinds of sensorimotor engagements. Bottom right: \mathbf{O}_2 attains maximal equilibration (represented graphically as a smoother trajectory that does not leave the gray band) and \mathbf{O}_1 has been re-shaped due to a mutual accommodation between the two clearly distinct sensorimotor schemes.

Any violation of either the stability condition or the transition condition leads to forming new *SM strategy* and *SM organization*.

1. Assume there has been an *SM organization* \mathbf{O} .
2. A new *SM coordination* (i.e., trajectory) occurs that does not match \mathbf{O} , thus a new *SM organization* is formed; the old *SM organization* is revised simultaneously.
3. Thus, multiple *SM organizations* are formed (e.g., \mathbf{O}_1 and \mathbf{O}_2).
4. They are revised and reach new *equilibration* given, according to existing schemes (or prototypes), e.g., to revise \mathbf{O}_2 given \mathbf{O}_1 .

PRINCIPLES FOR SENSORIMOTOR EQUILIBRATION

What kind of cognitive organizational principles can help sustain SMCs in a flexible, open-ended manner? At least these principles:

- (1) The organization of SM coordinations in equivalence classes;
- (2) the meta-stability of SM coordination;
- (3) the existence of selection mechanisms to choosing SM schemes;
- (4) an intrinsic normative evaluation of the equilibration process;
- (5) the existence of sufficiently rich adaptive mechanisms for altering SM coordinations; and
- (6) a higher-order re-equilibration mechanism to organize the relation between various SM schemes.

(1) What is meant by “equivalence classes”?
There is no interpretation in the paper...

- A correspondence between environment states and mental states (like A and A').
- *SM strategies*, i.e., prototypes.

(2) Prototypes can be revised.

(3) Given current observation, where to see for the next step? It is determined by selecting next possible *SM schemes*.

(4) We need a normative theory for organizing the experience.

(5) There should be some algorithms or approaches for learning from the input ...

(6) Some mechanisms can be applied to existing prototypes, instead of direct input.

Comments

They gave some interesting examples in psychology, illustrating why motor action is necessary in human perception. Is it true for any intelligent system? What is the rationale behind it?

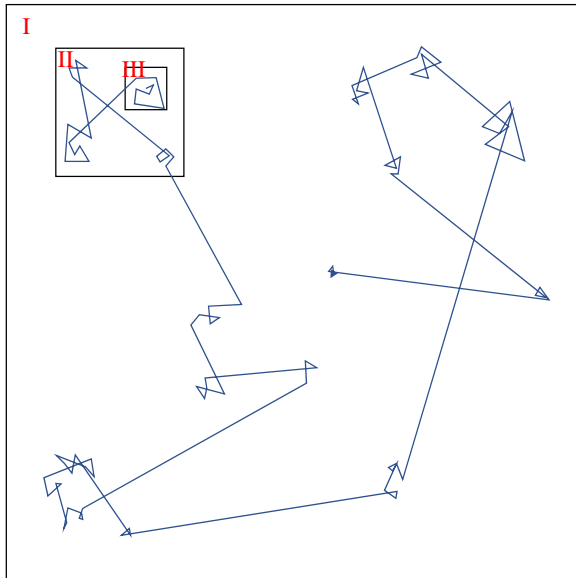
I agree with the general principles they proposed, but their theory is not elaborate enough to design a model that can be implemented in computers.

I disagree that there are some standard, existing classes/sets which can be projected to mental states. “To say such classes are infinite” is no better than “to say there are no predetermined classes”.

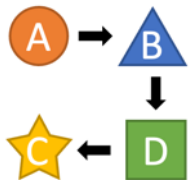
A Model of Sensorimotor Learning

Goal:

- To develop a *Conceptual Network* (based on NAL), which is capable of perception in a sensorimotor manner.



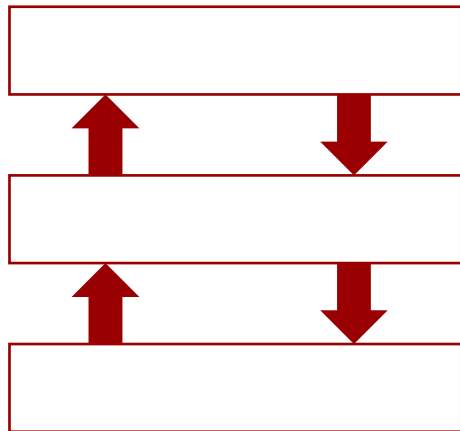
- Top-Down and Bottom-Up interaction
- Invariances
 - Translation Invariance
 - Distortion Invariance
 - Scale Invariance
 - Rotation Invariance



(A, ^right, B, ^down, D, ^left, C)
{(A;L1), (B;L2), (D;L3), (C;L4)}

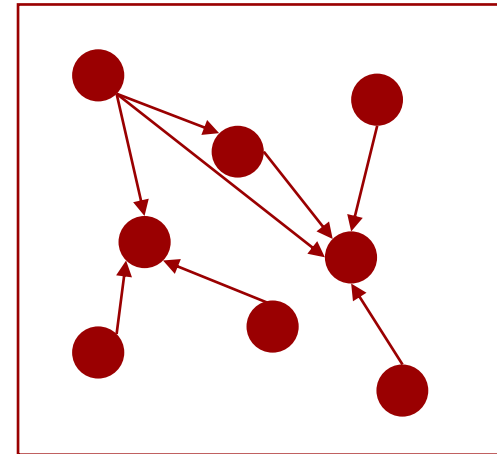
A Model of Sensorimotor Learning

Explicit Hierarchy vs. Implicit Hierarchy?



Explicit Hierarchy.

- Concepts are organized into layers.
- A concept in a higher layer is the combination or compound of concepts in the lower layer.
- Control mechanisms vary in inter-layer interaction and intra-layer interaction.

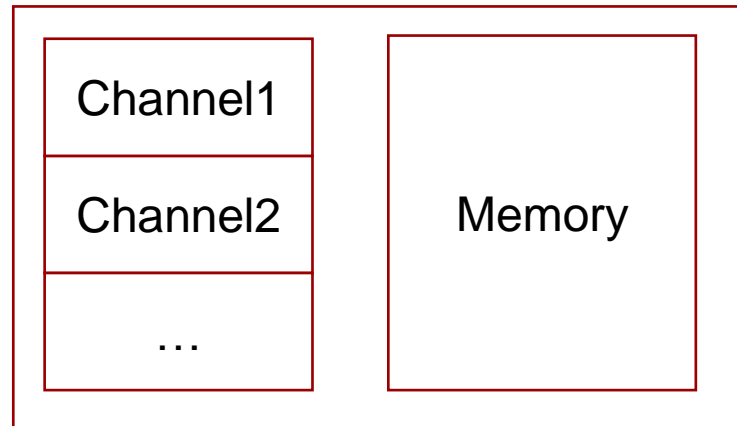


Implicit Hierarchy.

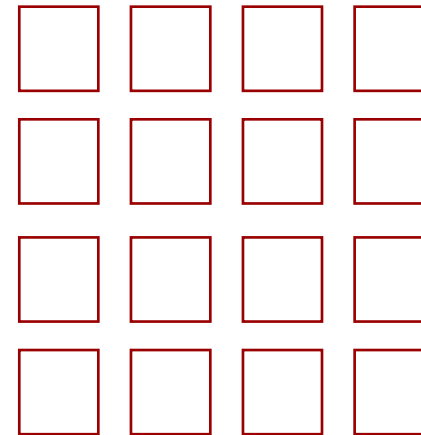
- Concepts are organized into a Graph.
- Concepts are combined into compound, forming a hierarchy implicitly.
- Control mechanisms are applied through the whole graph.

A Model of Sensorimotor Learning

Centralized Architecture vs. Distributed Architecture ?



Centralized Architecture.



Distributed Architecture.

- There are many units following the same mechanisms.
- Different units connect to different channels and specialize to different functions.