

Adaptive Systems

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Lecture 9: Perception and adaptation: development, plasticity and substitution

Spring 2010

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This lecture

- Perception as a central aspect of adaptive systems: *visual* and *body* perception
- How perceptual systems *develop* by an adaptive process that creates sensorimotor invariants.
- How perception is about specific modes of sensorimotor engagement and not a passive sensory input.
- How perception and sensory modalities can re-adapted or re-created

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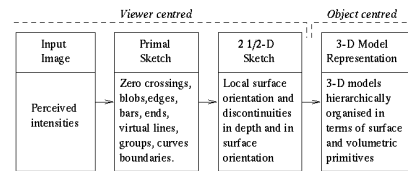
What is "to see"?

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Standard view

- To see is to create accurate internal representations (3D models) inside the brain
- David Marr (1982). "Vision: A Computational Investigation into the Human Representation and Processing of Visual Information". New York: Freeman.

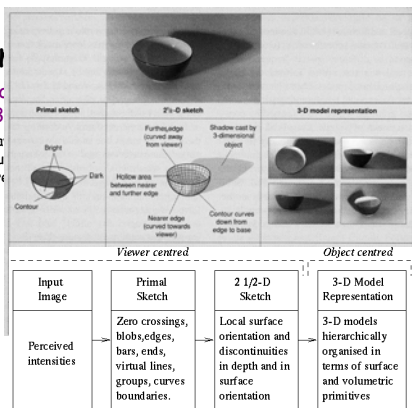


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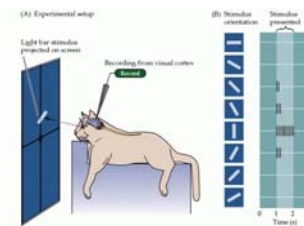


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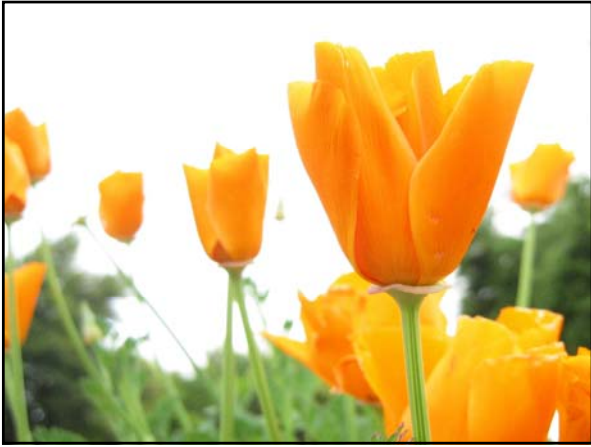
Standard view

- To see is to create accurate internal representations (3D models) inside the brain
- Hubel & Wiesel: Nobel Prize 1981



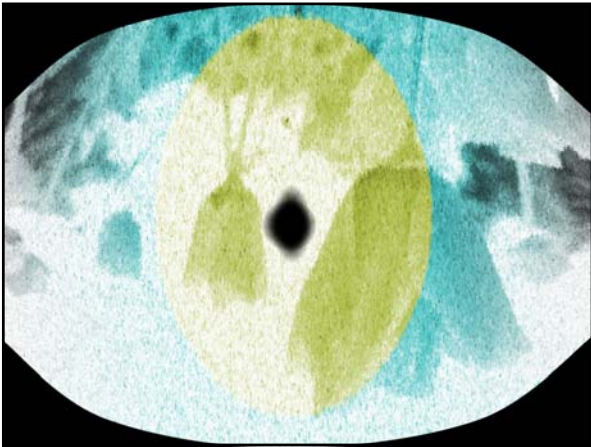
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However ...

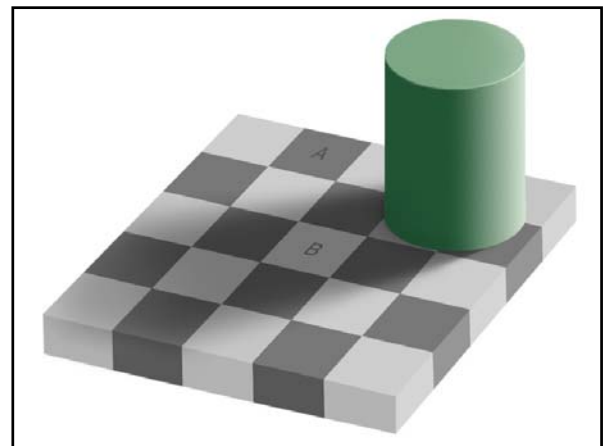
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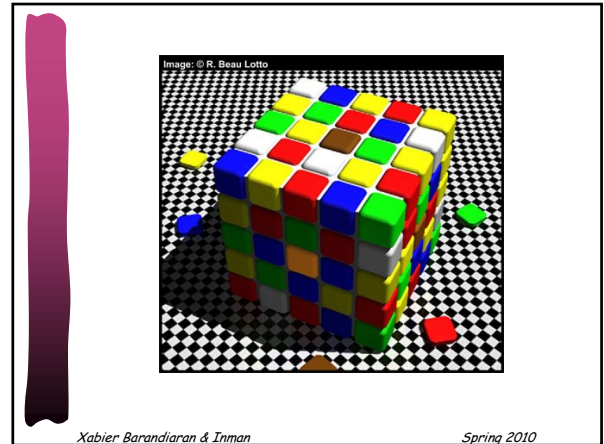
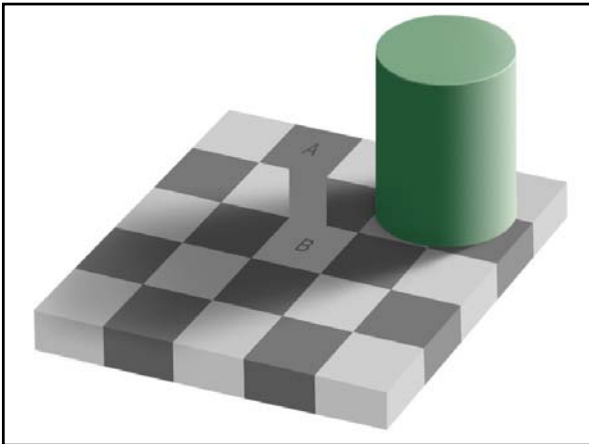


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Context dependency

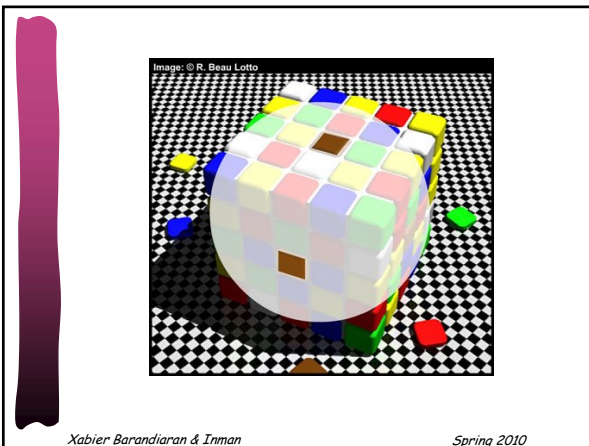
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Attention dependency

video!

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Sensorimotor dependency

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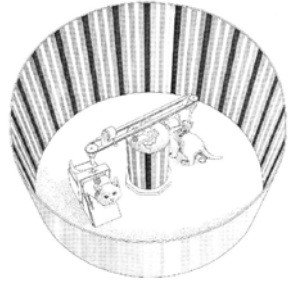
Sensorimotor development

- ✦ Experiment by Held and Hein (1963). Development of visually guided behaviour in kittens. Two kittens (previously reared in darkness) subject to roughly the same visual experience. One of them can move relatively freely but the other follows symmetric (non-voluntary) movements.
- ✦ The experiments decouples proprioceptive and visual inputs, and it shows the importance of the first to distinguish self-generated movement

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Active kitten developed normal sensorimotor coordination. Passive kitten failed to show blinking response to approaching hands, did not retreat from visual cliff, failed to anticipate contact with surface by placing its paws accordingly. (Normal behaviour recovered after freed for several days.)



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Not only during development!

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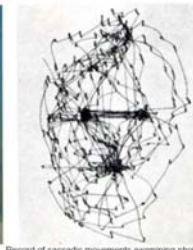
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Active Perception

✦ Saccadic eye movements: continuous scanning, like a blind-stick movements



Examine this photograph



Record of saccadic movements examining phot

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Active Perception

✦ Saccadic eye movements: continuous scanning, like a blind-stick movements



- ✦ MacKay, D.M. (1967). Ways of looking at perception. In W. Wathan-Dunn (Ed.), *Models for the perception of speech and visual form* (pp. 25-43)
- ✦ Powers, W. (1973). *Behavior: The Control of Perception*. Aldine Transaction.
- ✦ Ballard, D. H. (1991). Animate vision. *Artificial Intelligence*, 48(1), 57-86.

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Experiment

- ✦ Visual perception vanishes without saccadic movements.
- ✦ Try it yourself!

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So what is to see?

✦ MacKay (1965):

"[T]o perceive something (say an object in one's path) is to respond by internal adaptation to it (setting up conditional readinensses to avoid it, grasp it, describe it, etc., in case of need); and the unity or 'wholeness' of an object as perceived reflects the integration of the 'state of conditional readinenss' to match the stimuli from it."

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Substituting vision: projects

- ✦ **Using tactile stimuli:** Bach-y-Rita pioneering work (from late 60s on). Some current devices commercially available. A camera sends data to an array of skin stimulators.
- ✦ **Using auditory stimuli:** Use different frequency/volume patterns to provide information about an image picked by a camera or distance sensors.
- ✦ **Echolocation:** Ultrasonic devices. Anne De Volder (Louvain), Tom Bower (Edinburgh) 70s.

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Bach-y-Rita

Paul Bach-y-Rita (Neuroscientist, University of Wisconsin). Has worked on neural rehabilitation, volume brain plasticity and haptic sensory substitution.



- ✦ First project published in *Nature*, 1969, improved through the 70s. Tactile-vision sensory substitution (TVSS) system. Tried successfully on 100s of blind people (including congenitally blind).

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TVSS

- ✦ An array (20x20) of vibrating elements (10-inch-square) is located on the subject thorax, abdomen or back. The pattern of vibration follows the input from a camera according to brightness (no colour discrimination). Camera can be mounted on spectacle frames or moved by hand.



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TVSS



Two blind subjects wearing the TVSS system (Bach-y-Rita 1972, *Brain mechanisms of sensory substitution*, Academic Press).

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A personal account

- ✦ G. Guarniero (1974), Experience in tactile vision, *Perception*, 3, 101-104. Congenitally blind subject relates his experience using the device.
- ✦ No perception without voluntary camera movement
- ✦ Skin sensation only felt on first use.
- ✦ Soon "images" appeared located in a 2-D space outside the body.
- ✦ Self-produced sensation due to camera movement quickly discriminated from moving objects.

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A personal account

- ✦ After 1-2 days object discrimination was possible.
- ✦ Addition of zoom lens introduced complication, but soon was adapted to.
- ✦ Distance discrimination from cues.
- ✦ Adaptation to shifting 2-D image of 3-D objects.
- ✦ Experiments with mirrors, candles, "hand-camera" coordination.

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‡ Array can be moved from one position to another (back to abdomen) and cameras may be hand-held or mounted on frames. Either change is adapted to very quickly. The array can even be divided in halves without perceptual impairment.



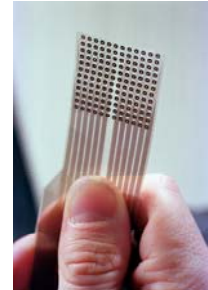
Congenitally blind child using TVSS system

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Current versions

- ‡ The tongue is ideal in its density and quality of sensors.
- ‡ Development hoping to reach miniaturization state (tooth size implant)
- ‡ Also useful for divers for getting radar information.



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Enactive torch

- ‡ A current project at Sussex (Froese, Di Paolo, Seth).
- ‡ Ultrasound transformed into pitch.
- ‡ Aim: reintroduce phenomenology to enactive perception.

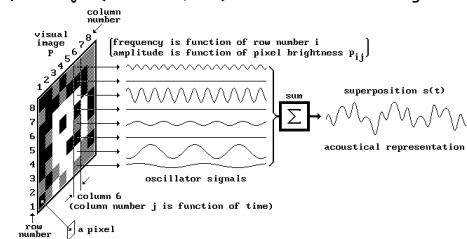


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The vOICe system

‡ P. Meijer (Eindhoven, 90s) Transforms camera image into



8x8 pixel, 3 grey-tone example of image-to-sound conversion

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vOICe system



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vOICe system

video!

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Echolocation

✦ T. Bower (1974)

✦ Using ultrasound. Pitch coding for distance, volume for size and distorted sound for texture. Plus stereo effect for spatial orientation.

✦ 4-month baby started to locate objects on first use. Two-handed reaches at 6 months, searches for a hidden object at 8.

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Echolocation



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Some implications

✦ "Seeing" is **not** about having functional eyes. To perceive is to create sensorimotor invariants. No perception by just sitting still, or if someone else moves the camera. Same thing with normally sighted people. You cannot perceive visually if you do not move (head, eye movements, focus, etc.)

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Some implications

✦ Perceived objects **not** felt on the skin. (Same as with normally sighted people!) A trained subject whose camera zoom setting was changed without warning moved backwards to avoid an incoming object.

✦ Adaptation is parallel to visual inversion experiments, revealing power of brain plastic re-organisation.

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Body Perception

✦ Perception of self and body is an essential aspect of adaptive systems

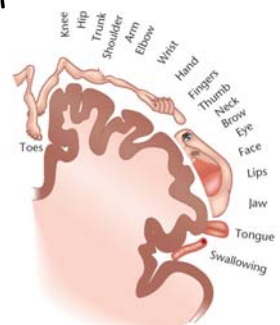
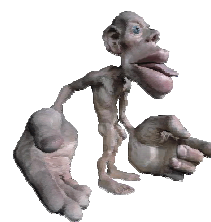
✦ Even more... perceiving the body is also a process of adaptation

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Body Perception

✦ Standard view



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Body Perception

- # But...
- # The somatosensory map is *created, sustained and modified* through sensorimotor experience
- # **Development:** Érdi, P., & Barna, G. (1984). Self-organizing mechanism for the formation of ordered neural mappings. *Biological Cybernetics*, 51(2) & Stafford, T., & Wilson, S. P. (2007). Self-organisation can generate the discontinuities in the somatosensory map. *Neurocomputing*, 70(10-12), 1932-1937.
- # **Examples:** pianist hands, amputations, attached fingers, ...
- # **Most research on mouse whiskers:** Feldman, D. E., & Brecht, M. (2005). Map Plasticity in Somatosensory Cortex. *Science*, 310(5749), 1024-1027.

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SO Kohonen Maps

Algorithm

1. Randomize the map's nodes' weight vectors
2. Grab an input vector
3. Traverse each node in the map
 - a) Use Euclidean distance formula to find similarity between the input vector and the map's node's weight vector
 - b) Track the node that produces the smallest distance (this node is the best matching unit, BMU)
4. Update the nodes in the neighbourhood of BMU by pulling them closer to the input vector

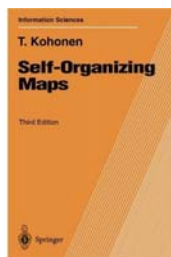
$$Wv(t + 1) = Wv(t) + \theta(t)\alpha(t)(D(t) - Wv(t))$$
5. GO TO 2.

Wv = current weight vector
 D = target input
 $\theta(t)$ = restraint due to distance from BMU - usually called the neighbourhood function
 $\alpha(t)$ = learning restraint due to time

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SO Kohonen Maps



video!

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SO Kohonen Maps

- # But...
- # This is not a passive process where body perception matches skin sensory surface
- # **Movement matters:** body perception is the result of action, and action is the result of body perception (specially in the fetus)
 - Kuniyoshi, Y., & Sangawa, S. (2006). Early motor development from partially ordered neural-body dynamics: experiments with a cortico-spinal-musculo-skeletal model. *Biological Cybernetics*, 95(6), 589-605.

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But there is much more to body perception...

- # Visual perception and sensory correlations also affects body perception
- # As the following experiments show

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Rubber hands that feel



- # Experiments by Botvinick and Cohen (1998), (extended by Ramachandran and colleagues).
- # Subject sits with left arm resting on table. A screen prevents direct visual contact with the arm. A rubber hand is placed in front of the subject.
- # Experimenter uses paintbrushes to simultaneously stimulate both the rubber hand and the subject's

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- ✦ After a few minutes subjects feel that the rubber hand "belongs" to their body.
- ✦ The "location" of the touched sensation appears to be on the rubber hand.
- ✦ In extended versions the same experiment was performed with a *shoe* instead of a rubber hand. Same effect.
- ✦ When experimenter brought a hammer and struck the shoe down, the subject reacted defensively. Measures of skin resistance showed startling reaction.

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Extended noses

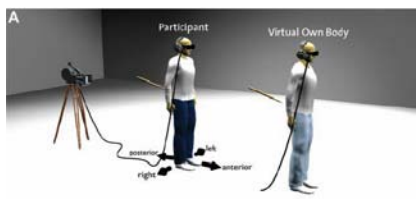
- ✦ On a similar vein, Ramachandran and colleagues experimented with illusions of distorted body image.
- ✦ A blindfolded subject seats on a chair. An accomplice seats in front of subject facing in the same direction.
- ✦ The experimenter takes the subject's hand and uses its finger to repeatedly and randomly stroke the accomplice's nose. *Synchronously* the experimenter strokes the subject's own nose.
- ✦ Subject experiences after a few seconds the illusion of having a dislocated or stretched nose.

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Out of Body experiences

- ✦ Out-of-body experiences can be induced by a combination of tactile stimulation and virtual reality.
- ✦ Lenggenhager et al., *Science*, 2007



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'Whole body' illusions

- ✦ Correlated multisensory signals and visual perspective shifts can engender (i) ownership of an artificial body and (ii) body swapping.
- ✦ Petkova & Ehrsson., *Plos-One*, 2008



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Other related theories

Sensorimotor theory of consciousness

- ✦ Alva Noë and Kevin O'Regan (a philosopher and a visual psychophysicist)
- ✦ Sensory experience results from "cognitive access to the fact of currently exercising mastery of a sensorimotor skill"
- ✦ The phenomenal differences between the experiences of seeing and hearing can be accounted for by the different things we "do" when we see and when we hear.
- ✦ A conscious experience is **something that is done**.

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Many more...

- ✦ **Poincaré (1800)**: Is it possible to perceive in a 4-5-6 dimensional world? The 3D world is a result of sensorimotor invariances and conditionals.
- ✦ **Interactivism**: Piaget (40-50's) perception is about assimilation into sensorimotor schema.
- ✦ **Ecological approach to visual perception**: Gibson (1979). Perception is not perception of objects but of affordances: i.e. possibilities for actions, "activation" of skills related to the object.
- ✦ **Enactive cognitive science**: Varela, Rosch & Thompson (1991). Perception is *enacting sensorimotor invariants*, NO input of information, but IN-formation, formation

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Conclusions

- ✦ Perception is about *stabilizing sensorimotor invariants through development and enacting them through experience*.
- ✦ Experiments that distort those invariants show the adaptive process behind their creation. Plasticity triggers changes in behaviour which modifies plastic mechanisms, and so on, until an invariant state is achieved.
- ✦ Research on sensory substitution supports this conclusion.

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- ✦ **Adaptation** occurs only through the subject's own activity. So does **development** of perceptual capabilities.

✦ The idea that perception has an associated spatial location or neural pathway is not obvious. Sensory apparatus and perceptual objects need not be physically correlated in terms of location. The lack of perception of the skin stimulation by the TVSS subjects and the experiments with rubber hands confirm this.

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Seminar

- ✦ Ivo Kohler, "Experiments with goggles", *Scientific American*, May, 1962. [PG]
- ✦ Richard Held, "Plasticity in sensory-motor systems", *Scientific American*, November, 1965 [PG]
- ✦ Myin, E., & O'Regan, J.K. (2008). Situated perception and sensation in vision and other modalities: from an active to a sensorimotor account. In P. Robbins & A. Aydede (Eds.) *Cambridge Handbook of Situated Cognition*. (pp. 185-200). [UG & PG]

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Next week

- ✦ Behaviour Based Robotics

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