Where's the Action in Cognitive Science?

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- Pure vision - a caricature of current paradigms
- Critique of key assumptions
  - Perception as representation
  - Atomistic ontology
  - Methodological atomism
  - Neuro-chauvinism
- Alternative intuitions
  - Action-centered theory
  - Minimal representation
  - Situatedness
  - Embodiment
  - Holistic stance
- Supportive evidence from cognitive neuroscience

INTRODUCTION

- **Paradigm shift in cognitive science:**
  - **Cognitivist paradigm: cognition as algorithmic computation over symbolic representations; processing substrate-neutral; computational results localized, context-independent**
  - **Connectionist paradigm: cognition emergent from global states in networks of simple elements; computation intimately linked to biological architecture; representations distributed, context-dependent**
  - **Discussion has focussed on the differences: style of computation; spatial scale and microstructure of representational states; role of plasticity and learning; view on system dynamics**

- **Goal of the talk:**
  - **Describe assumptions common to both cognitivism and connectionism**
  - **Use these as starting point for a critique of dominant concepts in cognitive neuroscience**
  - **Argue that current views are insufficient for an adequate theory of cognition**
  - **Do all this using visual perception (visual neuroscience) as an example**
  - **Note: I will just highlight intuitions, and not give detailed arguments**

PURE VISION - A CARICATURE (1)

- **Representational account of perception:**
  - "Brains are world-modelers .." *(Churchland & Sejnowski, 1992)*
  - Vision: recovering features of a pre-given world, and construction of an internal image of the world
  - World-model: "database" containing general-purpose knowledge about external world; is explicit (contains descriptions of object structures); is invariant (object descriptions independent of situational context)
  - "Regarding the central goal of vision as scene recovery makes sense. If we are able to create, using vision, an accurate representation of the three-dimensional world and its properties, then using this information we can perform any visual task." *(Aloimonos & Rosenfeld, 1991)*

- **View of the world:**
  - Ontological realism: relevant structures of external world are observer-independent and defined irrespectively of any cognitive activity
  - "Object ontology": world conceived as a universe of indepedent and context-free physical entities; perception primarily directed at "objects"

- **Computationalism:**
  - Sensory systems compute external features from energy distributions on the respective sensory surface; thus, reconstruct object structure

PURE VISION - A CARICATURE (2)

- **Computationalism (ctd.):**
  - Computation hierarchical: linear-sequential extraction (filtering) of features; bottom-up - each new percept synthesized de novo from elementary bits of information
  - Visual system considered as a parallel computer: numerous visual areas dedicated to the analysis of different object features; data type: distributed neural activation patterns (assemblies) carrying object descriptions

- **Methodological atomism:**
  - Modularity: assumption of independent processing pathways within vision
  - Visual modality operates independently of other sensory modalities, of previous learning, goals, motor planning or motor execution; vision builds a "complete" eidetic world model, supplied to other subsystems only late
  - Typical research strategy: studying effects of context-free stimuli on neuronal responses

- **Reductionism / individualism:**
  - Explanations of perceptual (cognitive) processes can adequately be achieved only at the "neural level"; neurobiology offers privileged access to cognition
  - Focus on inner states of a single subject

QUESTIONS

- Does this "theory of pure vision" suffice to establish an adequate account of perception?
- Do the basic conceptual and methodological premises provide an adequate background?
- Note: the "theory of pure vision" is paradigmatic for the current status of cognitive neuroscience!

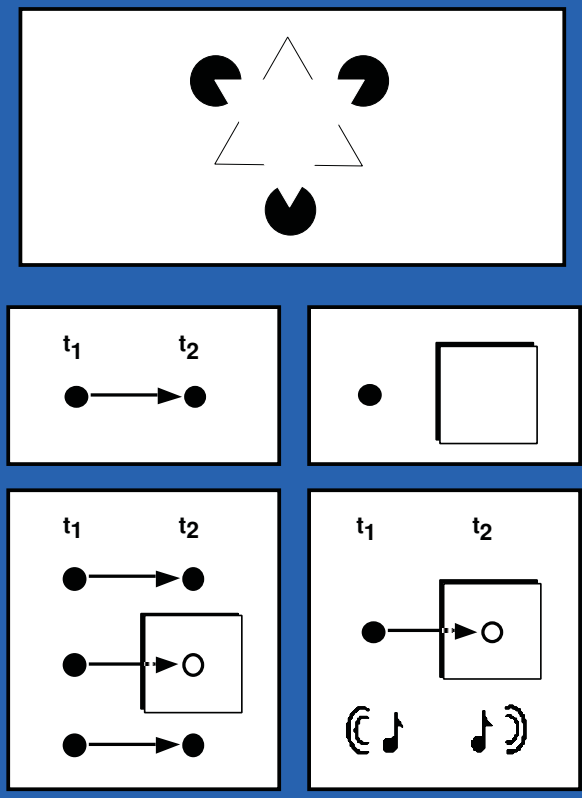
REPRESENTATIONAL THEORY (1)

- **Does the representational account adequately describe the role of cognition, and the relation between cognitive system and world?**
  - **Implies realism: perceptually relevant distinctions are "fixed" and observer-independent**
  - **Implies separation of cognitive system and world: subject conceived as detached observer, who is not "engaged in" the world**
  - **Implies passiveness: cognitive systems behave in a merely receptive way, they just "re"-act, and take copies of pre-specified information**
  - **Implies description: contents of representational states corresponds to context-invariant, explicit, purpose-free internal images**

- **Perception is not a passive event:**
  - **"The organism cannot properly be compared to a keyboard on which the external stimuli would play .. Since all the movements of the organism are always conditioned by external influences, on can, if one wishes, readily treat behaviour as an effect of the milieu. But in the same way, since all the stimulations which the organism receives have in turn been possible only by its preceding movements which have culminated in exposing the receptor organ to external influences, one could also say that *behavior is the first cause of all stimulations*. Thus the form of the excitant is *created by* the organism itself .." *(Merleau-Ponty, 1942)***

REPRESENTATIONAL THEORY (2)

- Intuition *(cf. Dewey, Maturana & Varela, Edelman)*: perception is an active process whose operations are highly selective; is constructive: perceptual acts define, first of all, relevant distinctions in the field of sensory experience (by virtue of the cognitive system's structural organization, as well as previous learning, expectation)
- Perception not neutral with respect to action, but always part of sensorimotor couplings by which the cognitive agent engages in the world



• Perceived world not observer-independent:

- Features such as edges, textures, colours etc. always specified relative to an observer for whom they provide relevant distinctions
- Examples: colour, "illusory contours", "apparent motion"
- Perceptual "objects" not distinguishable as physical entities, but individuated according to observer-dependent context (usage)

• Thus:

- Representational account seems to misconstrue the relation between cognitive system and world
- *If* "representation" refers to the construction of passive mirror-image, *then* representation cannot be the core function of cognition

ATOMISTIC ONTOLOGY (1)

- **Assumptions about domain structure:**
  - "Object-oriented" ontology: both realistic and atomistic
  - Environment has pre-given observer-independent structures
  - World considered as a contingent array of objects; these are isolated, context-invariant entities
  - Perception primarily directed at recognizing and identifying such isolated units ("object recognition", "object representation")
  - Since the environment has pre-defined structures, there is only one "correct" solution to every scene segmentation problem
  - Criterion for successful cognition: finding the correct solution, "correct" reconstruction of object properties
  - Theories implying these assumptions: *Marr, Biederman* ("recognition-by-components"), many connectionist models

- **Counter-intuition:**
  - Perception does not target isolated objects, but objects embedded-in-situational-contexts which derive their meaning (significance) from previous action (*Dreyfus; cf. Heidegger*: "referential nexus" - "Verweisungszusammenhang", "involvement whole" - "Bewandtnisganzheit")
  - These contexts can only be defined by reference to the needs and concerns of the cognitive agent

ATOMISTIC ONTOLOGY (2)

- "A normal person experiences the objects of the world as already interrelated and full of meaning. There is no justification for the assumption that we first experience isolated facts, .. and *then* give them significance." ***(Dreyfus, 1992)***
- ".. the situation is organized from the start in terms of human needs and propensities which give the facts meaning, make the facts what they are, so there is never a question of storing and sorting through an enormous list of *meaning-less, isolated data*." ***(ibid.)***
- **Objects never invariant, but individuated according to situational context and demands of current action; thus, there is more than one way of "correctly" segmenting a scene and perceiving its constituents**

METHODOLOGICAL ATOMISM (1)

- **Atomistic stance at a variety of levels:**
  - Classic: idea that single neurons are the relevant level of description for cognitive neuroscience; ".. it no longer seems completely unrealistic to attempt to understand perception at the atomic single-unit level." *(Barlow, 1972)*
  - Level of functional subsystems: concept of modularity, i.e., independence of processing pathways; "the assumption is that the visual system consists of a number of modules that can be studied more or less independently. .. The integration of modules is assumed to be primarily 'late' in nature." *(Ullman, 1991)*
  - Visual modality as a whole considered in isolation: most classical and connectionist pattern recognition models treat visual processing independently of other domains
  - Assumption: scene segmentation and object recognition could be achieved purely based on visual information; object representations can be purely visual ("eidetic world model")

- **Empirical counter-arguments:**
  - Physiological and anatomical data suggest: populations, rather than single neurons appropriate descriptive level; subsystems by no means independent

METHODOLOGICAL ATOMISM (2)

- **Vision cannot be treated in isolation:**
  - **Developmental argument - learning of adequate object perception and categorization presupposes sensorimotor coupling and active exploration**
  - **Functional argument - vision occurs never isolated from motor activity; intimate physiological and anatomical relations between vision and other systems; vision ceases in a completely passive organism**
  - **Selectionist argument - "seeing" an object does not mean to extract visual features for computing a "full" structural description; rather, it corresponds to the selective and goal-directed usage of visible aspects in the context of ongoing action (seeing is not contemplation, but visually guided action)**
  - **Knowledge argument - knowledge of cognitive systems about "real" environments is not based on general, explicit, invariant descriptions, but corresponds to implicit, context-dependent sensorimotor couplings (no basic difference between "procedural" and "declarative" knowledge)**

NEURO-CHAUVINISM

- **Does looking into the brain suffice for understanding cognition?**
  - **Assumption: complete description of brain function would fully account for cognition (reductionism, eliminativism; sub-personal, dis-embodied)**
  - **"Thinking is brought about by neurons, and we should not use phrases like 'unit activity reflects, reveals, or monitors thought processes', because the activities of neurons, quite simply *are* thought processes." *(Barlow, 1972)***
  - **".. we believe that the problem of consciousness can, in the long run, be solved only by explanations at the neural level." *(Crick & Koch, 1990)***

- **Possibly, the neurobiological approach alone is insufficient:**
  - **Context-problem: looking into brains would not suffice to individuate the contents of mental states; the latter is always defined only with respect to the environment and relative to situational context; brain states *per se* have no meaning; thus, an individualistic approach must fail**
  - **Homunculus-problem: cognitive processes cannot fully be described at the neural level because exclusive reference to "sub-personal" states means comitting a "homunculus fallacy" (Kenny); ascribing cognitive acts to *parts of persons* amount to category mistakes**
  - **Qualia-problem: just having a description of the neural correlates of pain does not imply knowledge of *how it feels* to have pain**
  - **Observer-problem: neurobiology - as a form of scientific activity - always *presupposes* intentionality and, thus, cannot *completely* explain it**

PUTTING MORE ACTION INTO COGNITIVE SCIENCE

"Pragmatic turn" from a representation-centered towards an action-oriented paradigm:

- **Selection**
  - Cognition as active process
- **"Minimal representationism"**
  - Implicit, partial, context-dependent encoding of contents
- **Self-organization - nonlinear dynamics**
  - replaces classical notions of computation
- **Decentralized cognition**
  - Emergence in distributed systems
- **Holism**
  - Interaction (binding) of local processes/subsystems
- **Situatedness**
  - Focus on embodiment and embeddedness into environment

SOURCES

Authors of the "pragmatic turn":

- "Classics"
  - *Dreyfus* (1972) What computers can't do
  - *Winograd & Flores* (1986) Understanding computers and cognition
- In the current discussion
  - *Brooks* (1991) Intelligence without representation
  - *Varela, Thompson & Rosch* (1991) The embodied mind
  - *Kurthen* (1992) Neurosemantik
  - *Kurthen* (1994) Hermeneutische Kognitionswissenschaft
  - *McClamrock* (1995) Existential cognition
  - *Kelso* (1995) Dynamic patterns
  - *Port & van Gelder* (1995) Mind as motion
  - *Hendriks-Jansen* (1996) Catching ourselves in the act
  - *Agre* (1997) Computation and human experience
  - *Clancey* (1997) Situated cognition
  - *Clark* (1997) Being there
  - *Pfeifer & Scheier* (1999) Understanding intelligence
  - *Rowlands* (1999) The body in mind
  - Note: primary motivation from robotics, neuroscience, theory of nonlinear dynamical systems
- Sources of inspiration
  - *Mead, Dewey* (american pragmatism)
  - *Merleau-Ponty, Heidegger* (phenomenol.-hermeneutic tradition)

SITUATEDNESS AS AN ALTERNATIVE (1)

- **Cognitive science as "theory of action" *(Varela, Clark, Kurthen)*:**
  - **Cognition should be considered from the viewpoint of action; not detached contemplation, but a set of processes that determine possible actions; perceiving a world is distinguishing possibilities for action;**
  - **Cognition rooted in concrete sensorimotor activity, in a pre-rational practical understanding of the world**
  - **Motivation for this "pragmatic turn" (from a representation-centered to an action-centered notion of cognition): explanation of real-world-cognition; the only way to attribute meaning (significance) to internal states *(Kurthen)***

- **Captured by the concept of "situatedness" *(Dreyfus, Clancey)*:**
  - **Refers to more than the trivial statement of environmental relationships**
  - **Inherits some characteristics of the phenomenological notion of "situation" *(Heidegger, Merleau-Ponty)*: basic context set by ongoing action (of multiple agents);**
  - **Characterized by a holistic structure, i.e. a "referential nexus" across all components, and a merging or "intertwinement" of cognitive system and world *(cf. Kurthen)***
  - **This means, first, that the situation cannot be decomposed into neutral objects and, second, that situations can only be defined with respect to the needs and goals of the cognitive agent *(cf. Dreyfus)***

SITUATEDNESS AS AN ALTERNATIVE (2)

Embodiment

Reference to the physical (biological) organisation of the system; explanation by instantiation of agents with real-world interactions (robotics)

Embeddedness

Relation to the environment, which is not only task domain, but also a resource that "scaffolds" (Clark) cognitive acts

Minimal Representation

No "complete" description, but local and context-dependent coupling by indexical internal states; always comprising sensory and motor aspects

- **Concept of situatedness might help to:**
  - overcome the misconstrual of agent-world relationship
  - modify ontological assumptions (i.e. those concerning the relevant entities in the domain of cognitive science)
  - modify current views on the significance of internal states
  - change general view of the brain's functional architecture
  - overcome the limitations of a individualistic-reductionistic approach

SITUATEDNESS AS AN ALTERNATIVE (3)

- **System-world relation:**
  - Relation of cognitive subject to the world: active, selective, constructive; perception as a process of defining relevant boundaries, not of grasping pre-existing features
  - The brain not a device for world-mirroring, but a "vehicle for world-making"
  - Main task of cognition: guidance of action; criterion for success of cognitive operations: not "correct" representation of environmental features, but appropriate (adaptive) action in a given situation

- **Ontological assumption:**
  - Phenomenal world does not have a pre-specified structure that exists prior to and independent of any cognitive activity; (a-priori) unlabelled "field of experience" where cognition (as embodied action) draws relevant distinctions
  - Phenomenal structure is organized in "referential wholes" that can only be characterized with respect to a class of agents; "situation" should replace the context-invariant "object" as a basic domain descriptor

- **Significance of internal states:**
  - If anything, internal states "represent" the capacity of structuring situational contexts; do not correspond to images of the external world
  - Do not carry complete descriptions, but partial, context-dependent contents
  - Not purely sensory, but cross-system (sensori-motor) couplings

SITUATEDNESS AS AN ALTERNATIVE (4)

- **Significance of internal states (ctd.):**
  - "Representation" of the environment is mainly "implicit" in the (partly learned) architecture of the system
  - ".. the brain should not be seen as primarily a locus of inner descriptions of external states of affairs; rather, it should be seen as a locus of inner structures that act as operators upon the world via their role in determining actions" *(Clark, 1997)*

- **Functional architecture:**
  - Holistic stance: since integrated sensorimotor activity is constitutive for perception, vision can only be understood properly with reference to other subsystems and the action of the whole cognitive system
  - Enhanced emphasis on top-down processing (contextual influences)
  - No principal difference between "lower" neural functions (e.g. sensorimotor transformations) and "higher" cognitive processes (problem solving, thinking)

- **Individualistic-reductionist approach:**
  - Embodiment: brings cognitive theory back to the personal level (i.e., a level where the acting system as a whole is described); situatedness: also means placing the cognitive system into social context
  - Embodiment, embeddedness, "external scaffolding": imply that the cognitive system consists of the brain *and* its environment (anti-individualistic)

NEUROBIOLOGICAL EVIDENCE

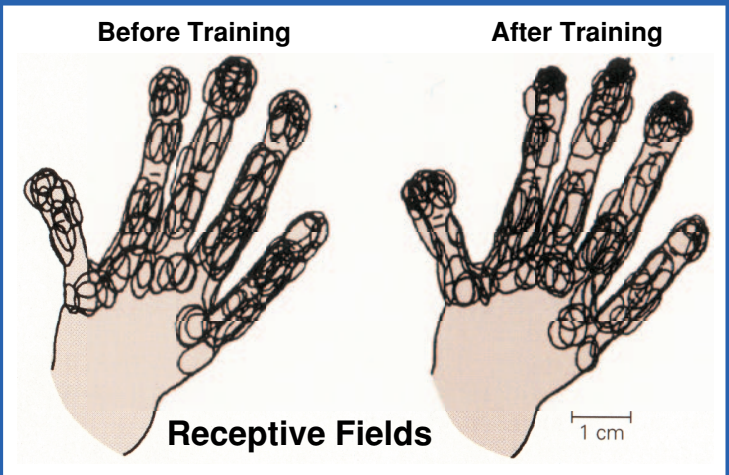
Evidence for a fundamental role of action:

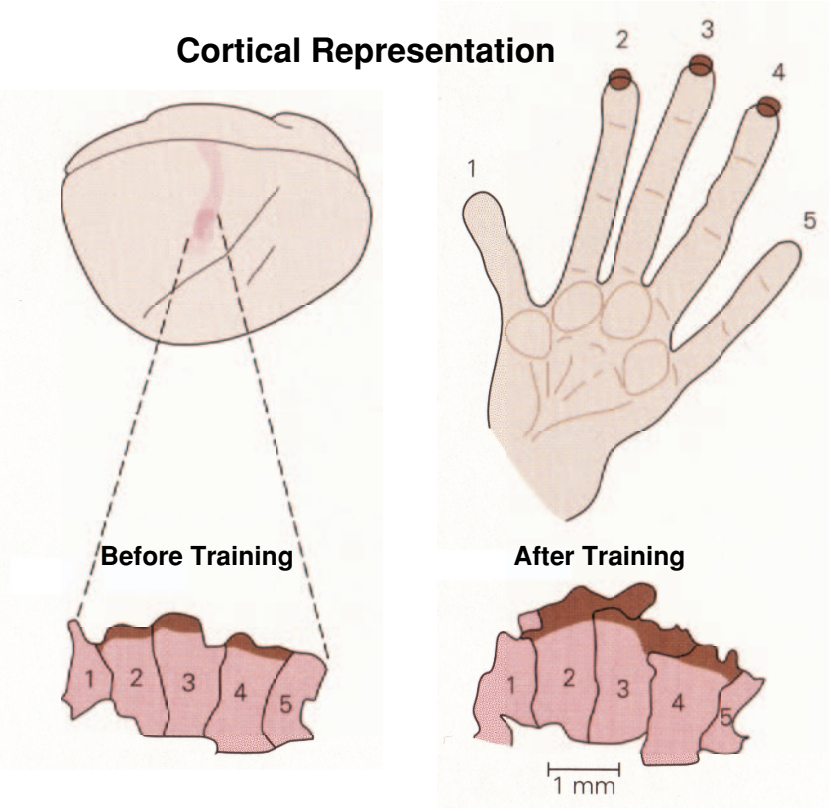
- Perceptual learning dependent on sensorimotor interactions and active exploration of the environment *(Held & Hein, 1963)*
- Stability of topographic maps in cortical areas is activity-dependent *(Merzenich et al., 1983)*
- Corollary discharge (reafference): Relation to action (prediction about the sensory outcome of movement) critical for the basic interpretation of sensory data
- Neuronal response profiles dependent on action context
  - Activation of visual neurons weaker if unrestrained, self-induced eye movements are permitted *(Gallant, Connor & Van Essen, 1998)*
  - Multimodal receptive fields dependent on body and limb position *(Graziano & Gross, 1995)*
- "Object representations" are always action-centered - "know-how"
  - Parietal and premotor neurons have combined visual-motor activation profiles
  - Intense anatomical linkage of sensory and motor areas
  - Evidence for dynamic sensorimotor binding
- Importance of "virtual action"
  - Neglect under visual imagery influenced by virtual action context *(Bisiach & Luzzati, 1978)*
  - Motor systems active during "mental rotation" of objects *(Georgopoulos et al., 1989)*; generally, motor imagery involves motor and premotor areas

SHAPE OF SENSORY MAPS IS ACTIVITY-DEPENDENT

(Jenkins, Merzenich, Ochs, Allard & Guic-Robles 1990)

- After extensive practise with fingers 2, 3 and 4, monkeys acquire an increased number of tactile receptive fields on the respective fingertips
- In the somatosensory cortex, the area representing the trained fingers is enlarged



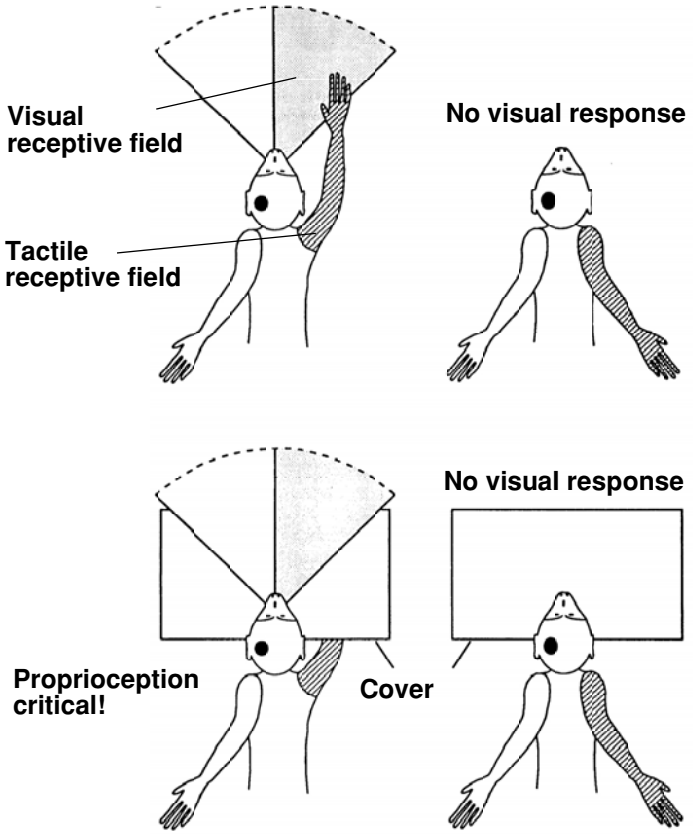


PROPERTIES OF PREMOTOR NEURONS DEPEND ON ACTION CONTEXT

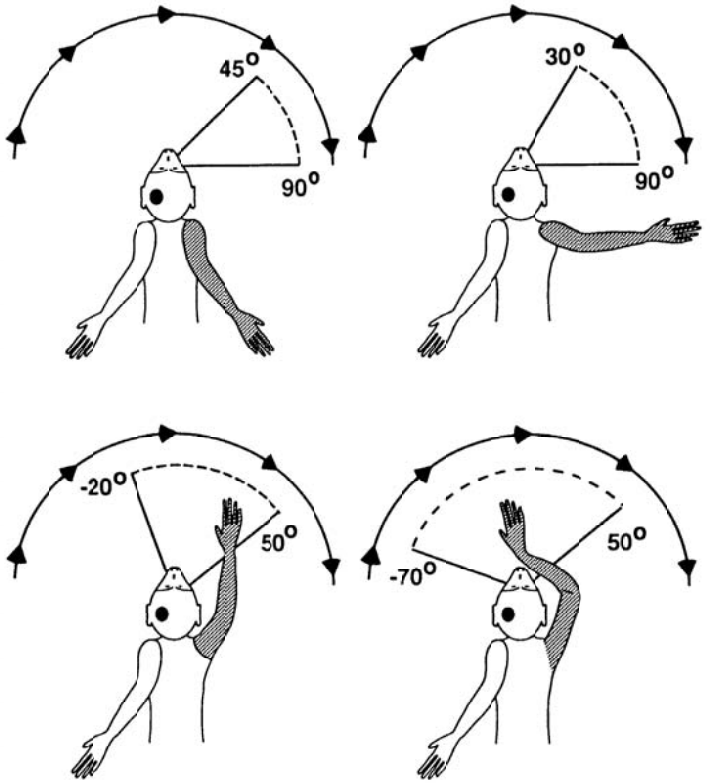
(Graziano & Gross 1995)

- Tactile and visual receptive fields of premotor neurons are in dynamic register
- Sensory activation profiles are strongly dependent on motor context
- Polymodal fields allow predictions about expected changes on the sensory side

Example 1



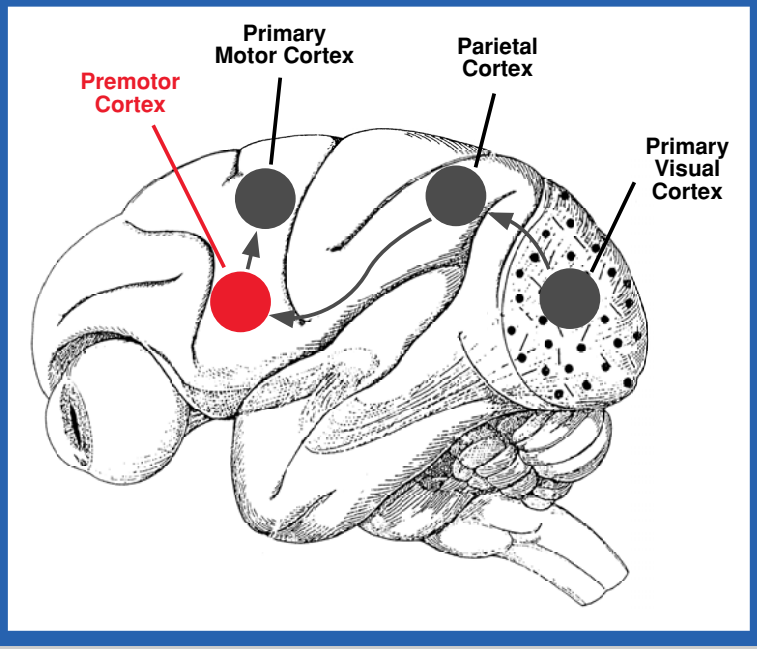
Example 2

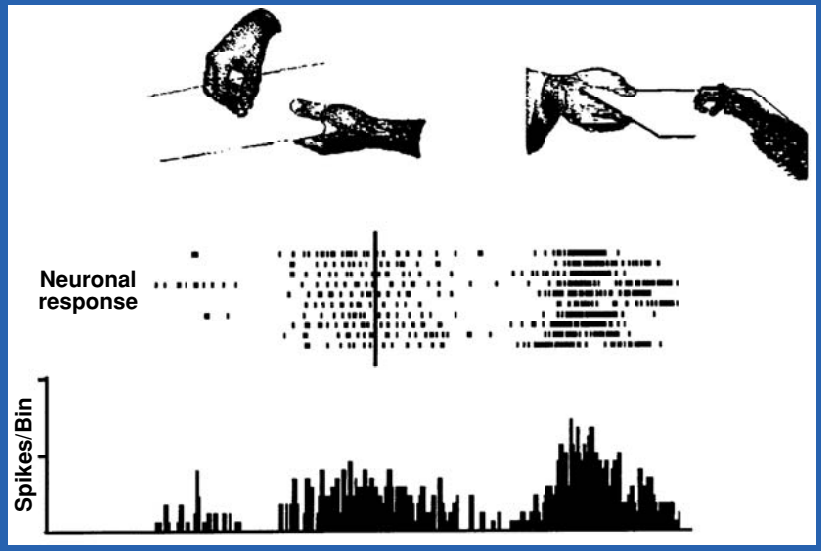


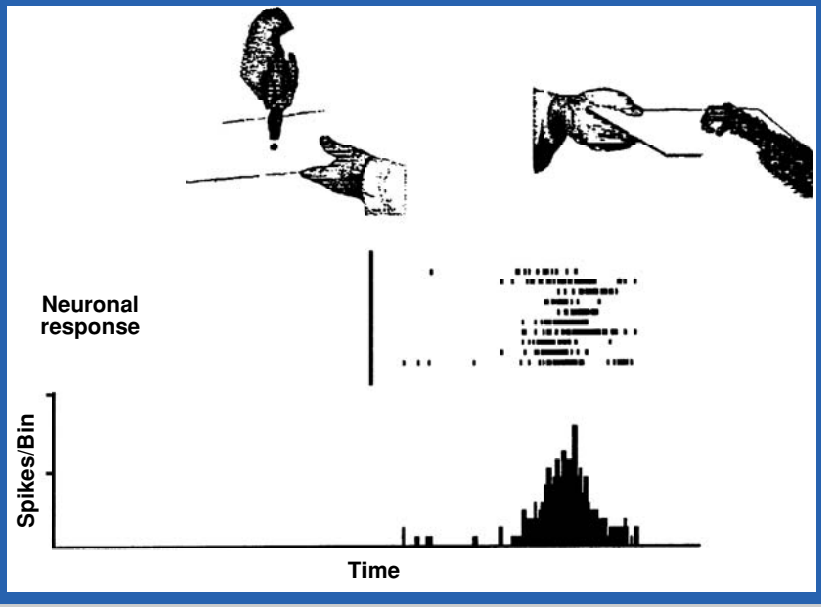
MIRROR NEURONS SHOW EQUIVALENCE OF PERCEPTION AND ACTION

(Rizzolatti & Arbib 1998)

- Neurons in premotor cortex fire during perception of a particular act and during execution of the same act
- Activation profile is unique: the neuron does not fire if the observed action does not match the cell's specificity
- Perception of alien action and self-executed action have to "mirror" each other



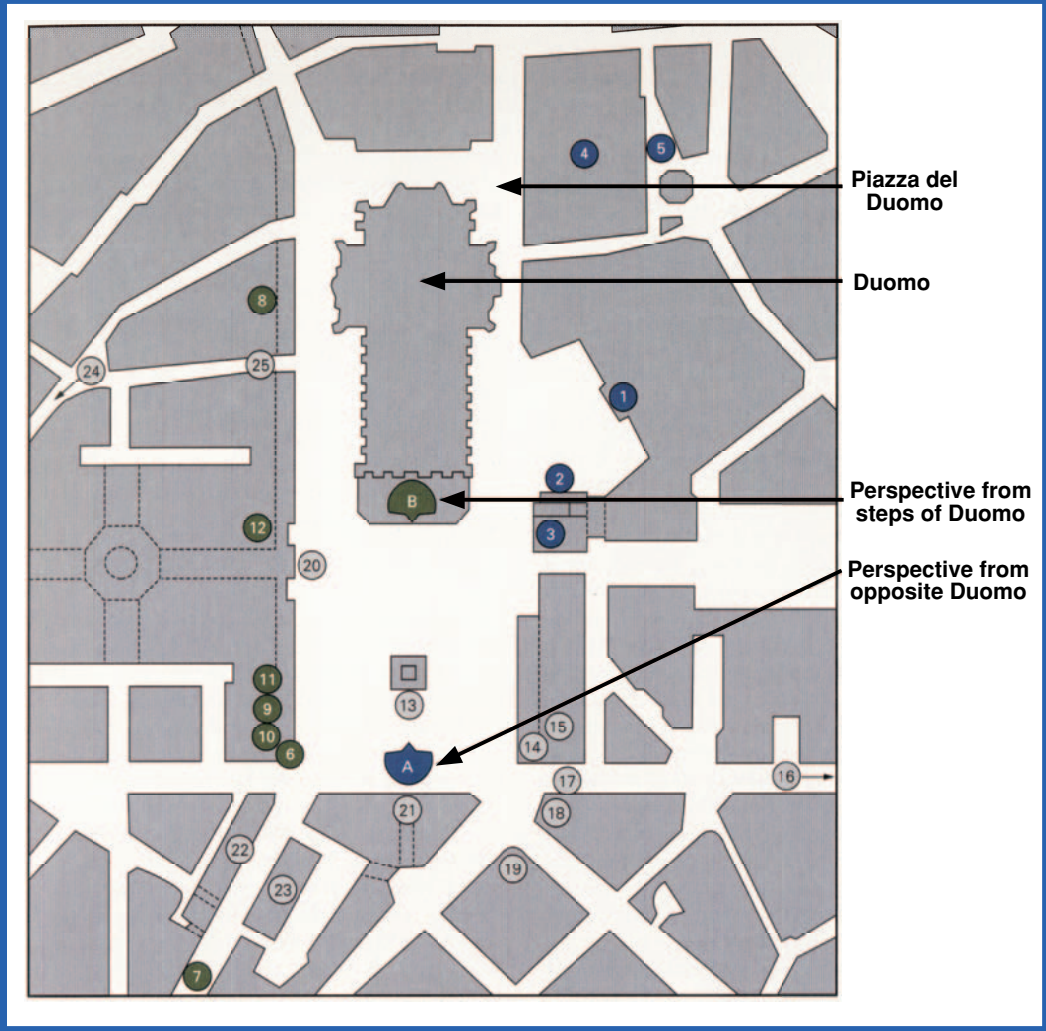




NEGLECT INFLUENCED BY VIRTUAL ACTION

(Bisiach & Luzzati 1978)

- Neglect occurs also under mere imagination of known spatial settings
- If the subject imagines turning by 180 deg, he suddenly sees the objects on the formerly neglected side



AGENDA FOR COGNITIVE NEUROSCIENCE

- **Goals**
  - Investigate sensory activity not as a function of isolated stimuli but, rather as a function of contexts of action
  - Role of top-down mechanisms
  - Cross-system-, cross-modal interactions
  - Compare "complex" with "basic" processing (e.g. language processing with preattentive visual segmentation)
  - Investigate "real-world cognition"
- **Strategy of experimental approaches**
  - Use realistic stimuli, complex sensorimotor paradigms
  - Go beyond mere simulation of experimental data: hypothesis testing by physical implementation
  - Interact with robotics, artificial-life-research
- **Methodological profile**
  - Observation and quantification of complex behaviours
  - Massively parallel recording techniques
  - Observation of neuronal dynamics during complex action, for extended periods of time
  - Analysis of high-dimensional datasets