Grounding Ontologies In The External World

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The Symbol Grounding Problem

- There has been much discussion recently about the scope and limits of purely symbolic models of the mind and about the proper role of connectionism in cognitive modeling. This paper describes the "symbol grounding problem": **How can the semantic interpretation of a formal symbol system be made intrinsic to the system, rather than just parasitic on the meanings in our heads?** How can the meanings of the meaningless symbol tokens, manipulated solely on the basis of their (arbitrary) shapes, be grounded in anything but other meaningless symbols? The problem is analogous to trying to learn Chinese from a Chinese/Chinese dictionary alone. A **candidate solution** is sketched: Symbolic representations must be grounded bottom-up in **nonsymbolic** representations of two kinds: (1) **iconic representations**, which are analogs of the proximal sensory projections of distal objects and events, and (2) **categorical representations**, which are learned and innate feature detectors that pick out the invariant features of object and event categories from their sensory projections. Elementary symbols are the names of these object and event categories, assigned on the basis of their (nonsymbolic) categorical representations. Higher-order (3) symbolic representations, grounded in these elementary symbols, consist of symbol strings describing category membership relations (e.g. "An X is a Y that is Z").

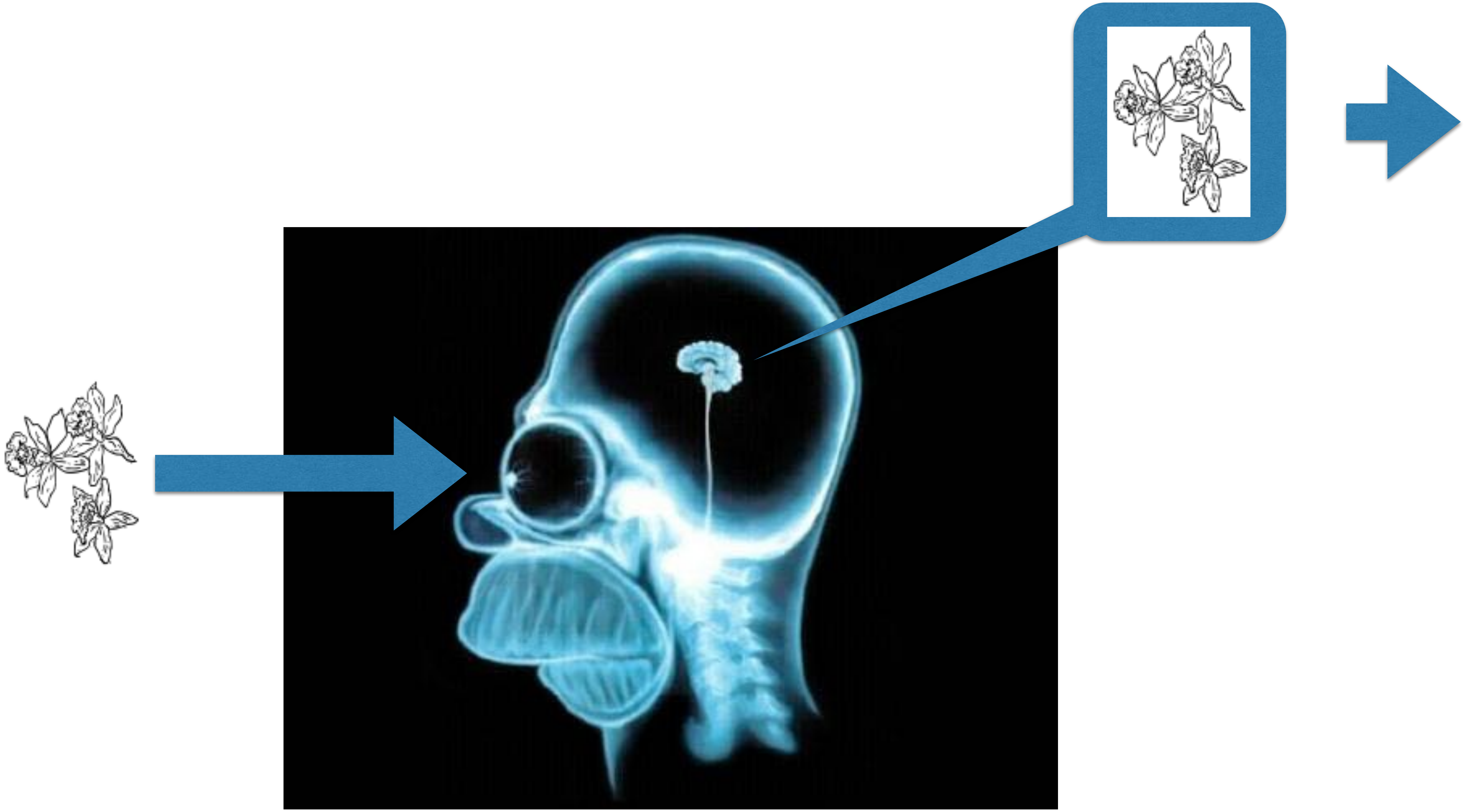
Stevan Harnad: The Symbol Gounding Problem, Physica D: Nonlinear Phenomena, Volume 42, Issues 1–3, June 1990, Pages 335-346

The Symbol Grounding Problem

- **Connectionism** is one natural candidate for the mechanism that learns the invariant features underlying categorical representations, thereby connecting names to the proximal projections of the distal objects they stand for. In this way connectionism can be seen as a complementary component in a hybrid nonsymbolic/symbolic model of the mind, rather than a rival to purely symbolic modeling. Such a hybrid model would not have an autonomous symbolic "module," however; the symbolic functions would emerge as an intrinsically "dedicated" symbol system as a consequence of the bottom-up grounding of categories' names in their sensory representations. **Symbol manipulation would be governed not just by the arbitrary shapes of the symbol tokens, but by the nonarbitrary shapes of the icons and category invariants in which they are grounded.**

Stevan Harnad: The Symbol Gounding Problem, Physica D: Nonlinear Phenomena, Volume 42, Issues 1–3, June 1990, Pages 335-346

Levels of Representation



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Flower(ka)
Flower(kb)
Flower(kc)
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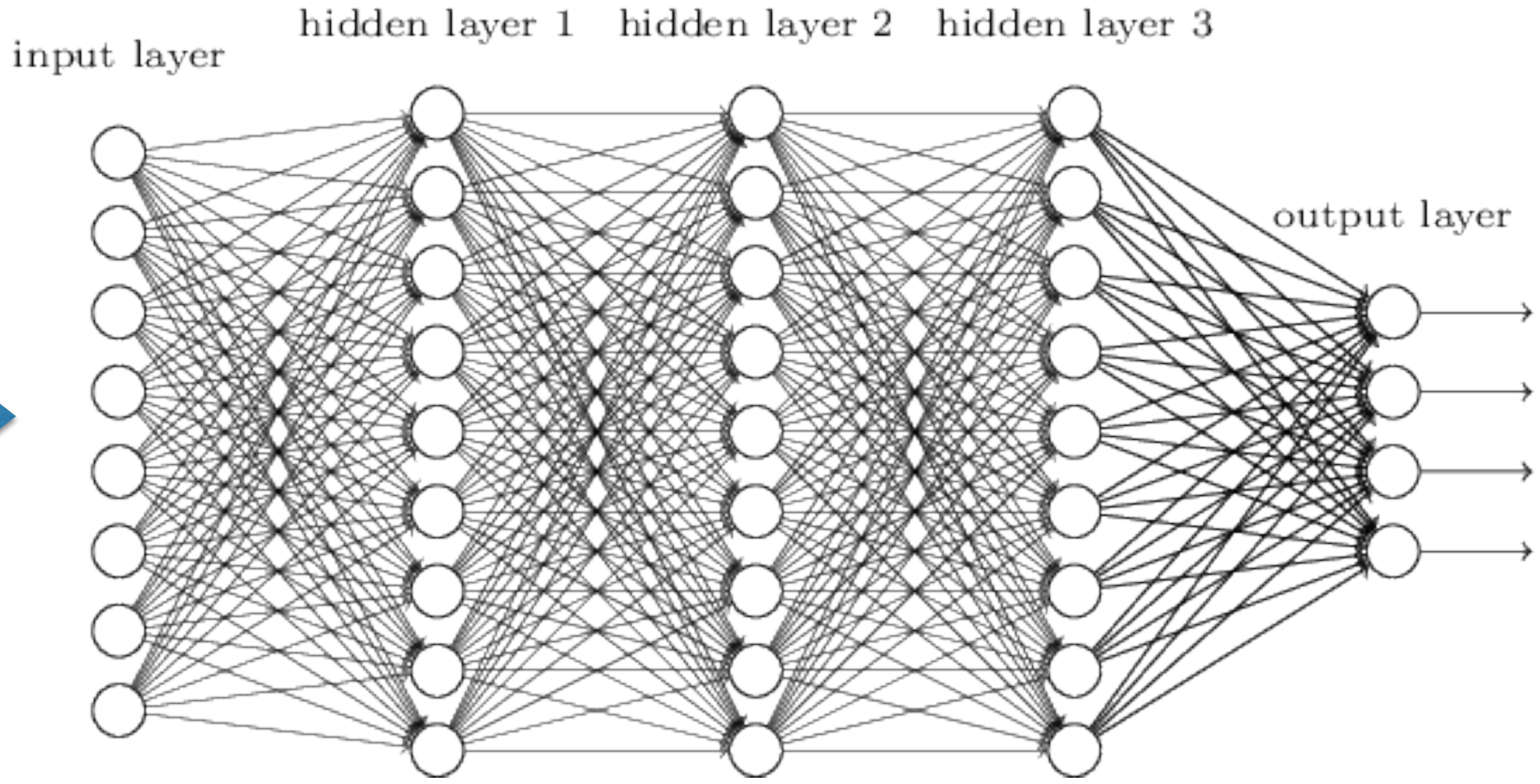
Levels of Representation

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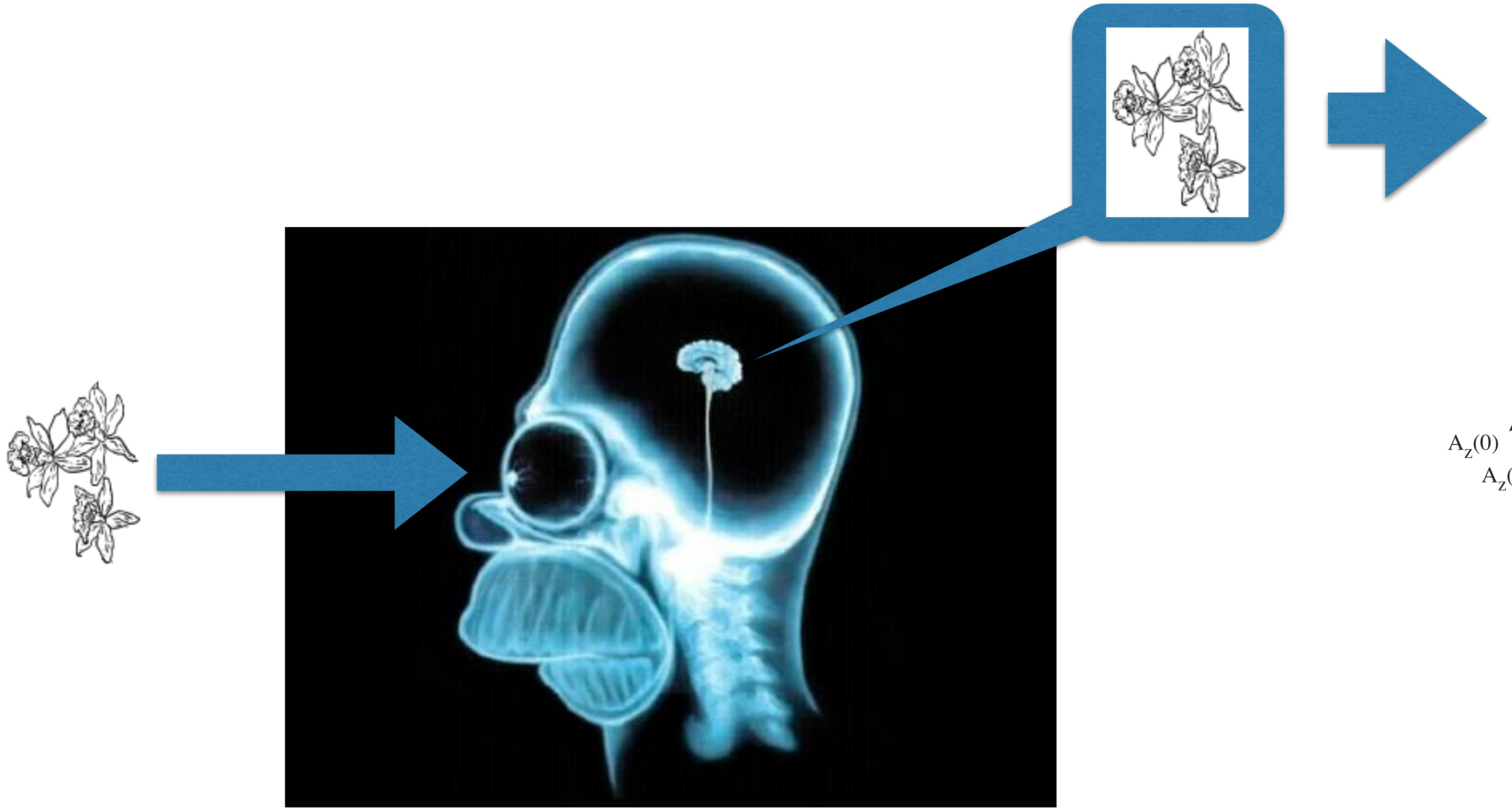
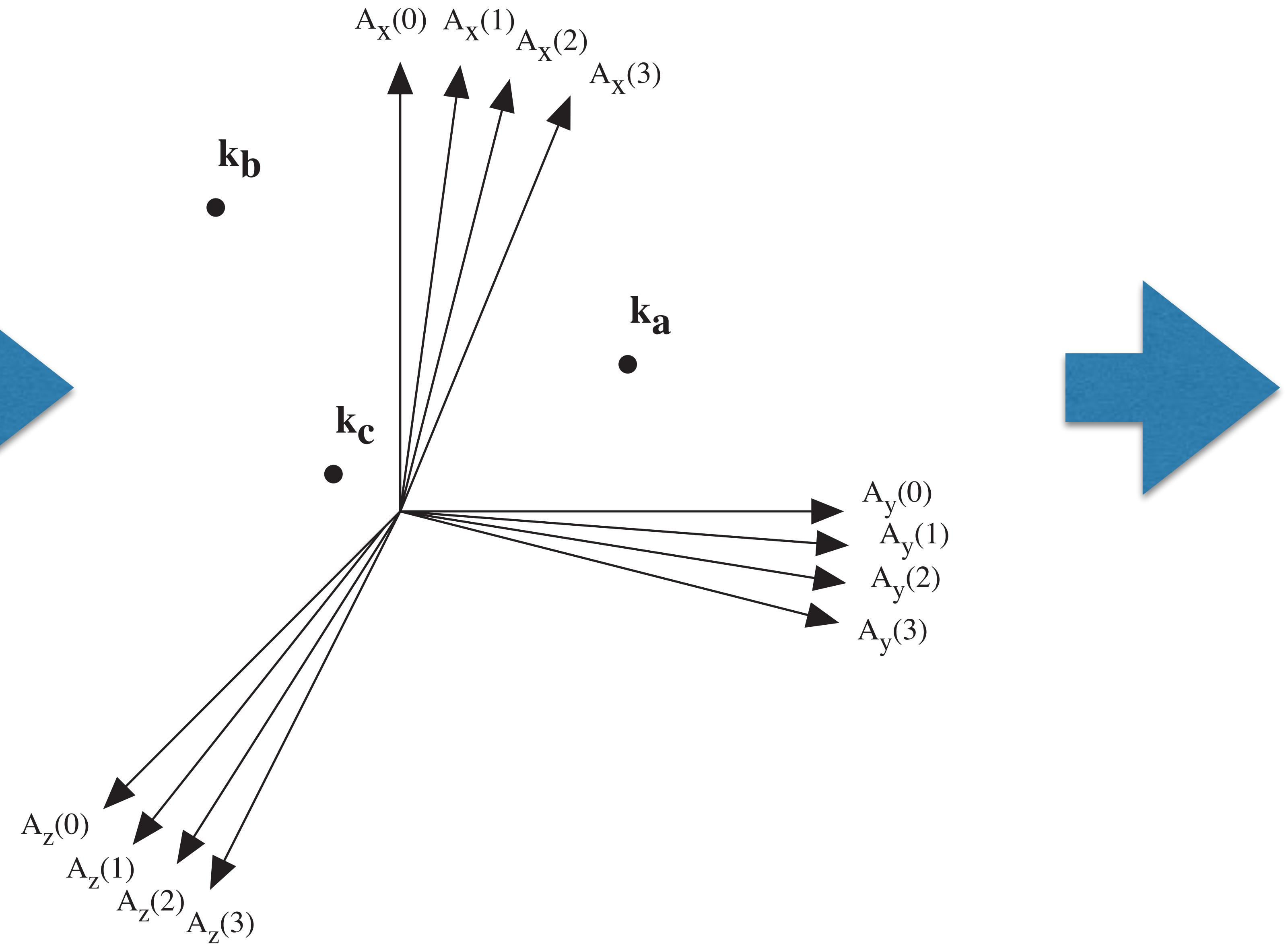
Problems with Neural Networks

- Opacity (black box)
- Huge training set
- Difficult incremental learning
- Difficulties in compositionality
- Difficulties in analogic reasoning
- ....

An Intermediate Geometric Level of Representation



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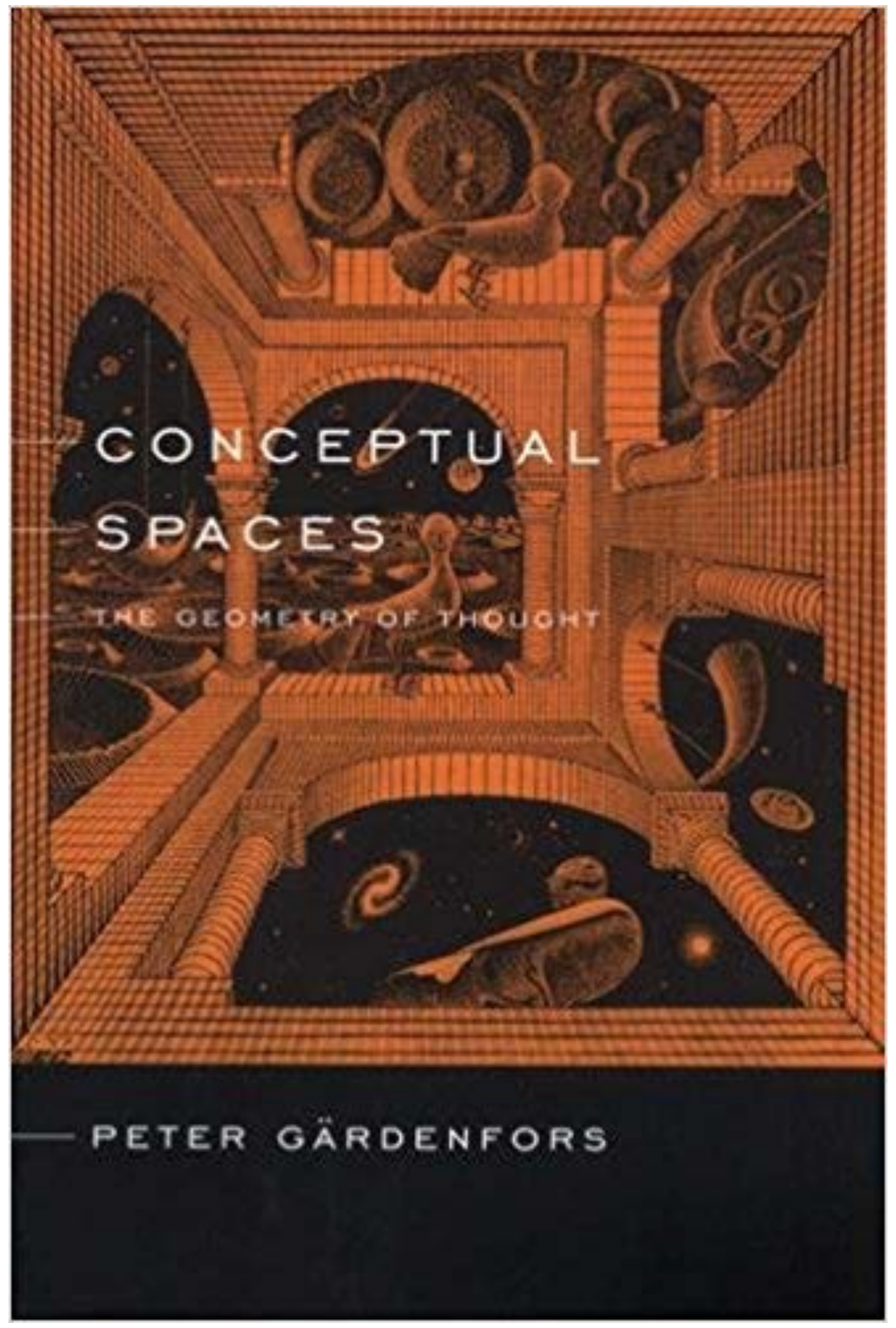
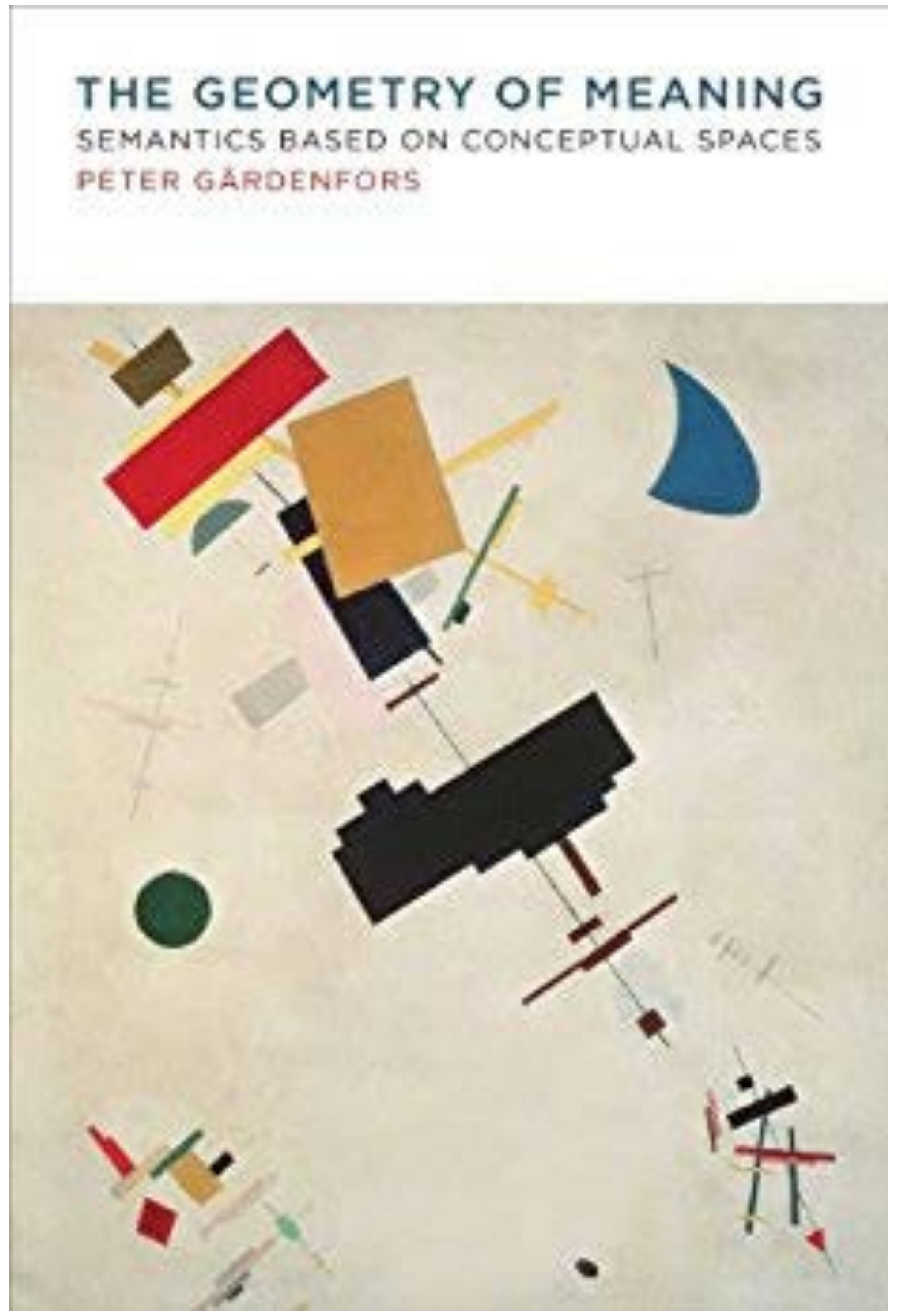
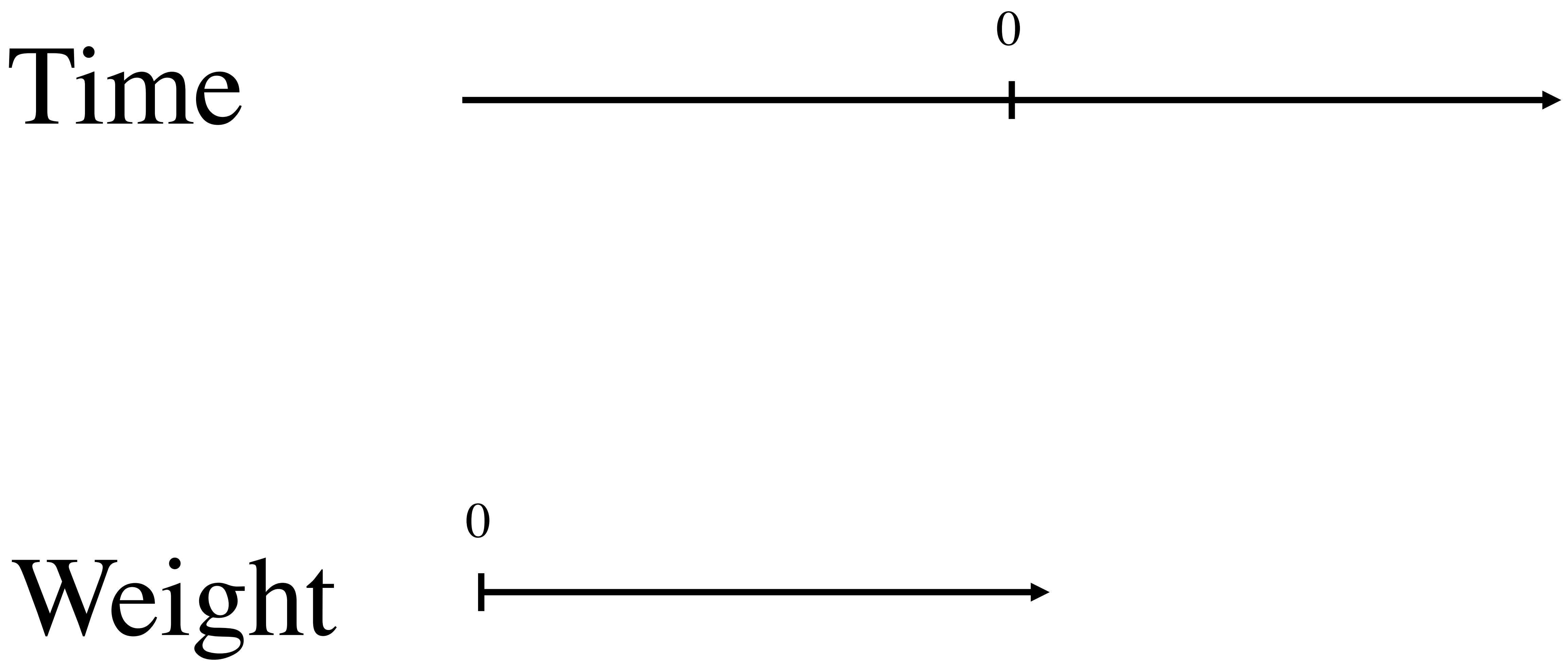
Conceptual Spaces

- A Conceptual Space CS (Gärdenfors, 2000) is a **metric space** whose dimensions are related to sensory based quantities (Color, pitch, spatial coordinates, etc.).
- Dimensions do not depend on any specific linguistic description.
- A percept is a point in CS.
- Convex shapes as basic concepts





Linear Quality Dimensions



The Color Spindle

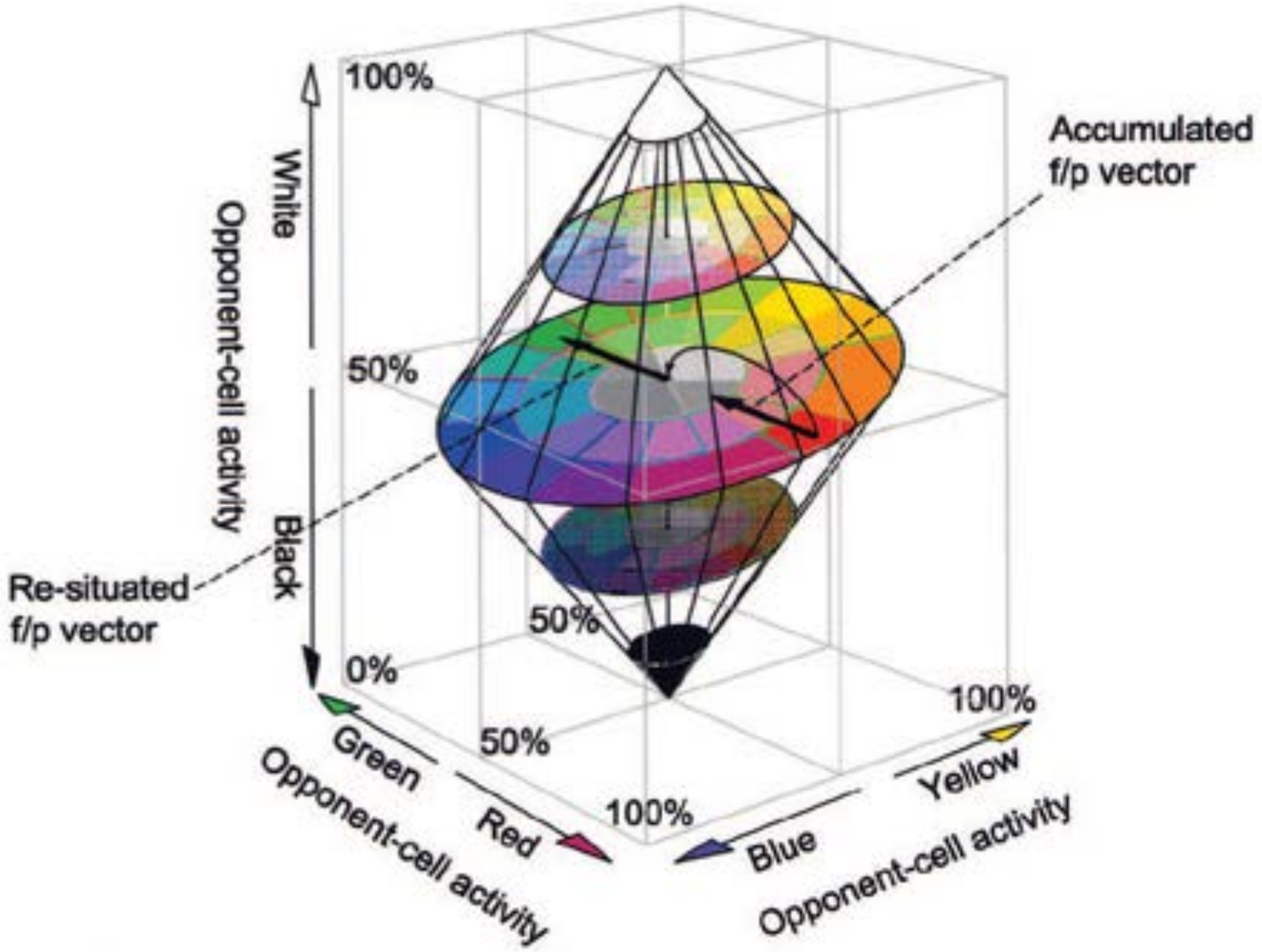


Figure 7 Predicting the Character of After Images.

Vowel Space

A Psychophysical Investigation of Vowel Formants

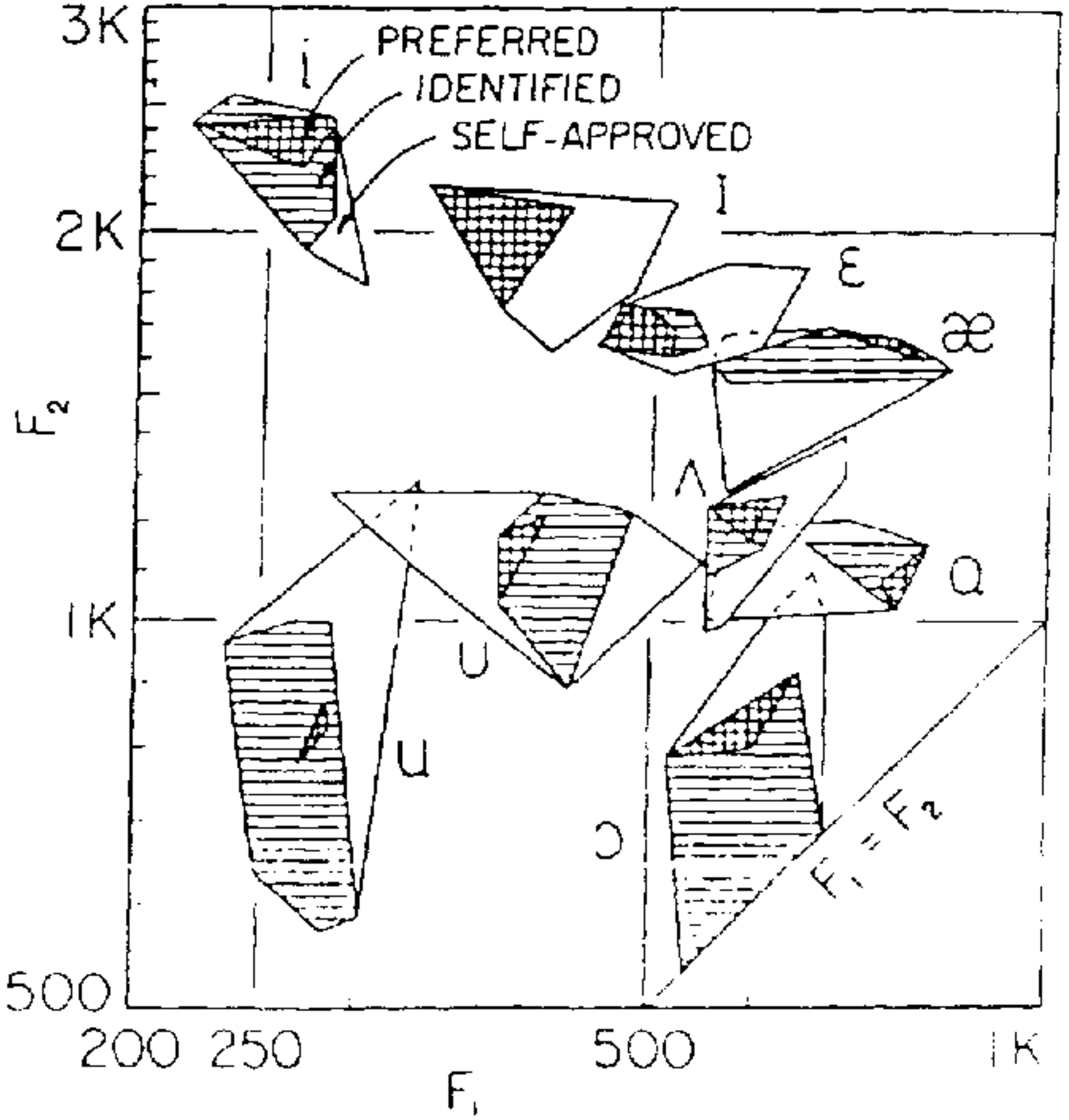
GRANT FAIRBANKS

PATTI GRUBB

Although acoustic vowels are specified by combinations of formant frequencies, it is commonly understood that these frequencies vary considerably from utterance to utterance. The investigations of such variations have provided useful information about individual differences in speech and about the range of vowel approximations in the speech attempts that a listener or a voice-operated device must be prepared to accept. The experiment reported here, however, has proceeded in a different direction. It has taken for its main purpose the study of the formant structure of vowel samples that meet high standards of identifiability and judged representativeness under controlled laboratory conditions. may be produced without ambiguity in the steady state. The speakers who furnished samples were seven men, professors from the Department of Speech at the University of Illinois, ranging in age from 34 to 57 years with a median age of 43 years. All had been teachers for many years, were experienced speakers and habitual users of the General American dialect. About one week before formal procedure in the laboratory a copy of the following statement was given to each speaker and discussed with him. It is quoted in full because it explains the general rationale of the problem.

Explanation of the Problem for Speakers

This experiment is concerned with nine vowels of the General American dialect



Musical Pitch

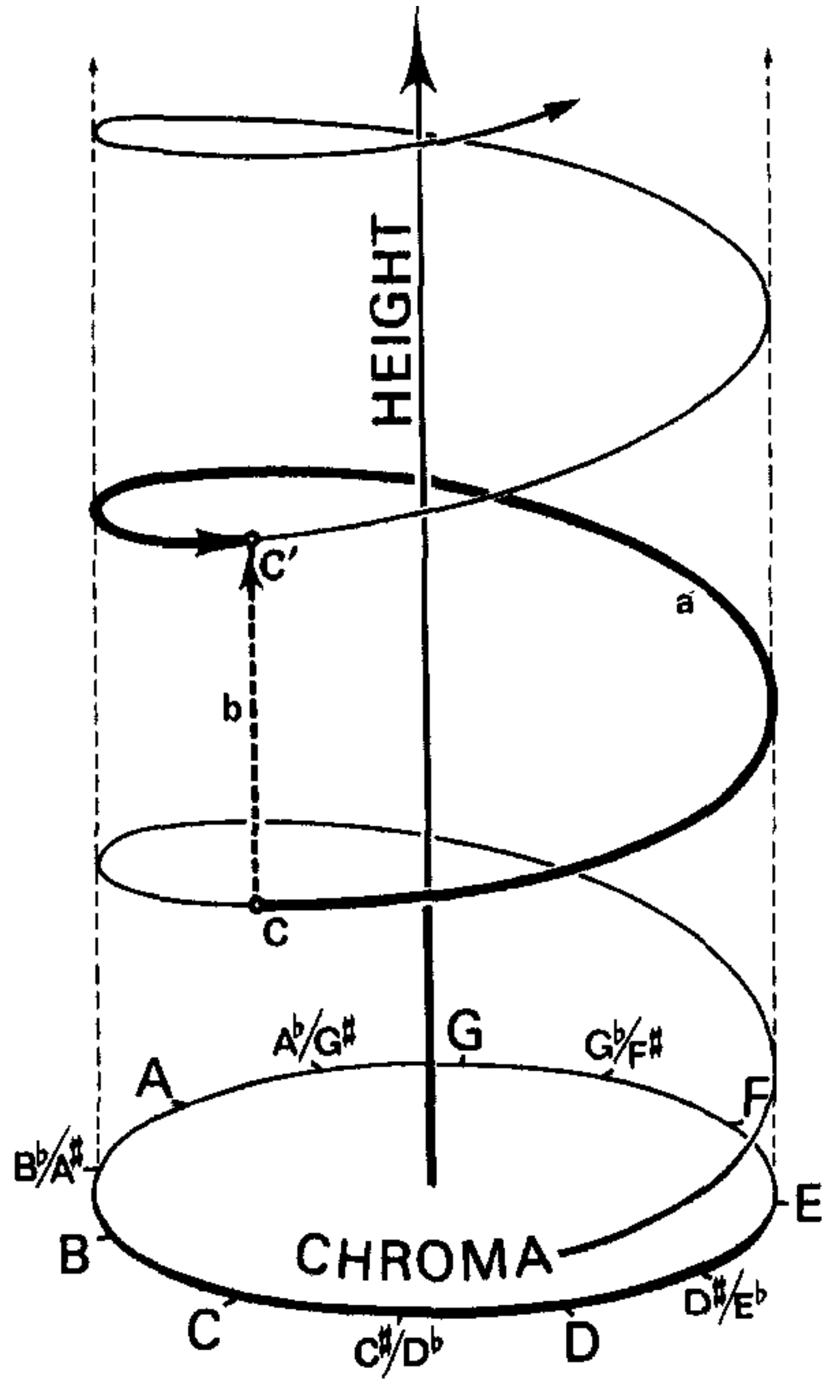
Psychological Review

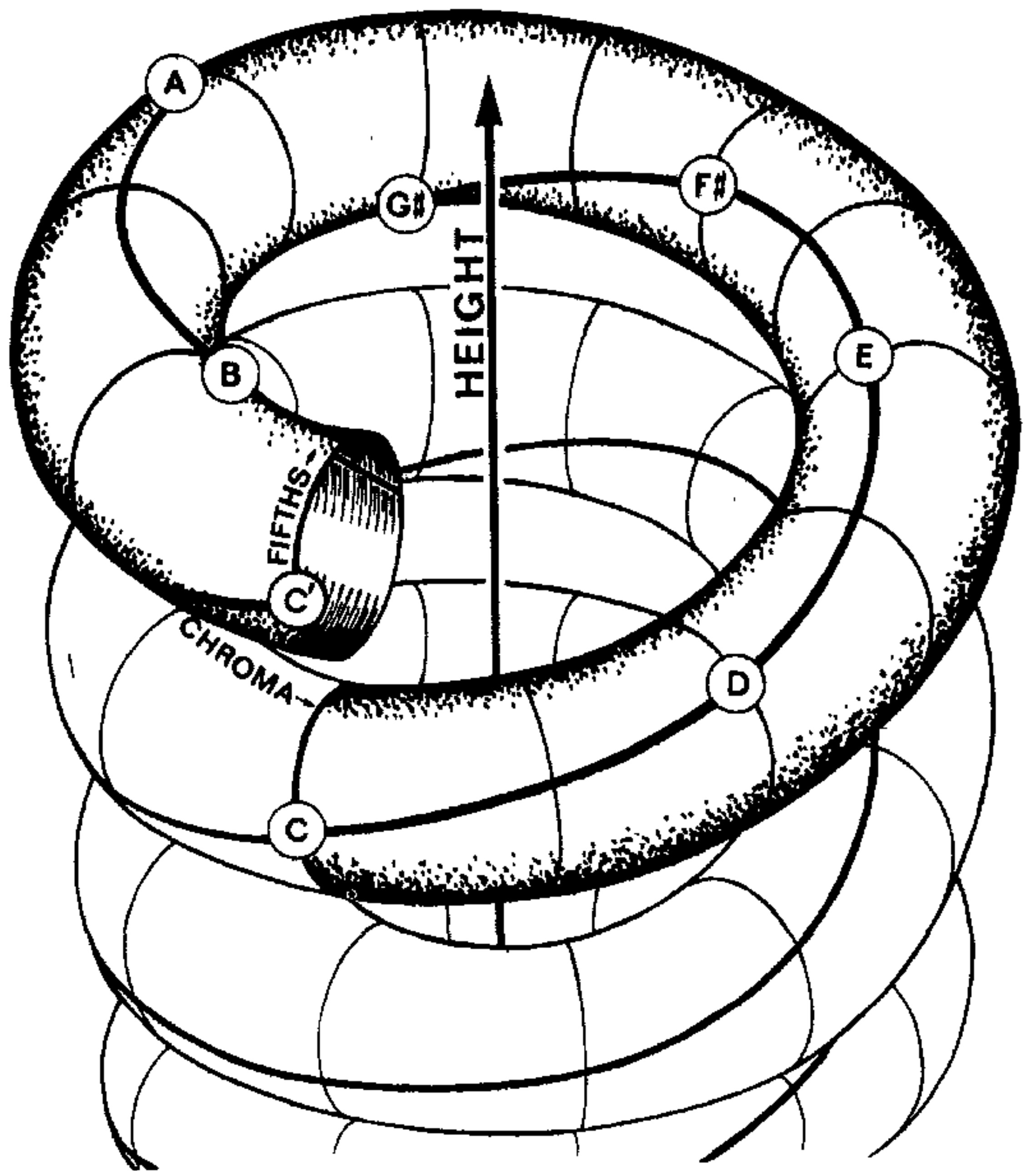
VOLUME 89 NUMBER 4 JULY 1982

Geometrical Approximations to the Structure of Musical Pitch

Roger N. Shepard
Stanford University

Rectilinear scales of pitch can account for the similarity of tones close together in frequency but not for the heightened relations at special intervals, such as the octave or perfect fifth, that arise when the tones are interpreted musically. Increasingly adequate accounts of musical pitch are provided by increasingly generalized, geometrically regular helical structures: a simple helix, a double helix, and a double helix wound around a torus in four dimensions or around a higher order helical cylinder in five dimensions. A two-dimensional "melodic map" of these double-helical structures provides for optimally compact representations of musical scales and melodies. A two-dimensional "harmonic map," obtained by an affine transformation of the melodic map, provides for optimally compact representations of chords and harmonic relations; moreover, it is isomorphic to the toroidal structure that Krumhansl and Kessler (1982) show to represent the psychological relations among musical keys.





Circumplex Model of Emotions

Journal of Personality and Social Psychology
1980, Vol. 39, No. 6, 1161–1178

A Circumplex Model of Affect

James A. Russell
University of British Columbia, Vancouver, Canada

Factor-analytic evidence has led most psychologists to describe affect as a set of dimensions, such as displeasure, distress, depression, excitement, and so on, with each dimension varying independently of the others. However, there is other evidence that rather than being independent, these affective dimensions are interrelated in a highly systematic fashion. The evidence suggests that these interrelationships can be represented by a spatial model in which affective concepts fall in a circle in the following order: pleasure (0°), excitement (45°), arousal (90°), distress (135°), displeasure (180°), depression (225°), sleepiness (270°), and relaxation (315°). This model was offered both as a way psychologists can

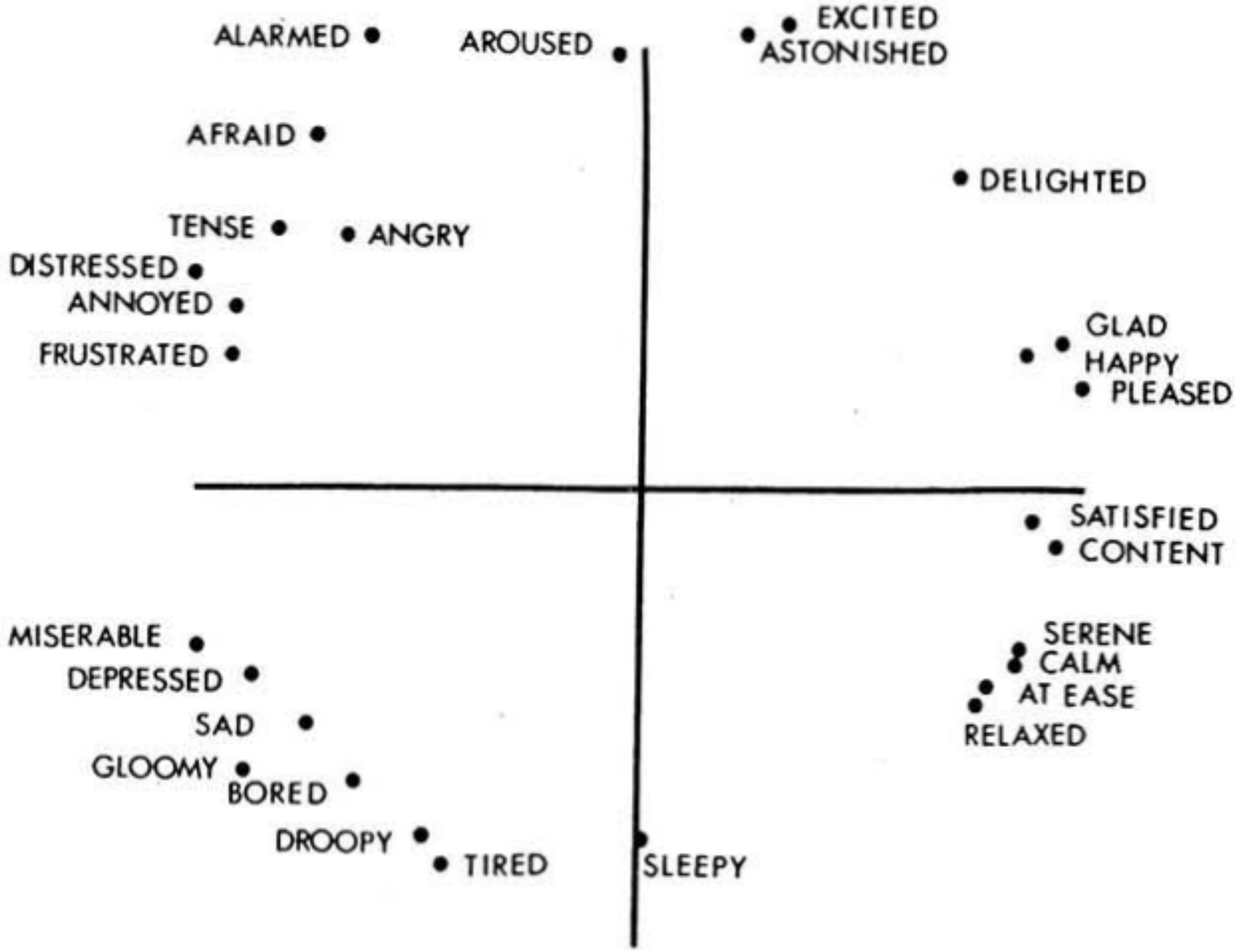


Figure 3. Multidimensional scaling solution for 28 affect words.

Conceptual Spaces

- Information is organized by quality dimensions
- … that are sorted into domains (space, time, temperature, weight, color, shape …)
- Dimensions within domains are integral
- Domains are endowed with a topology or metric
- •Similarity is represented by distance in a conceptual space

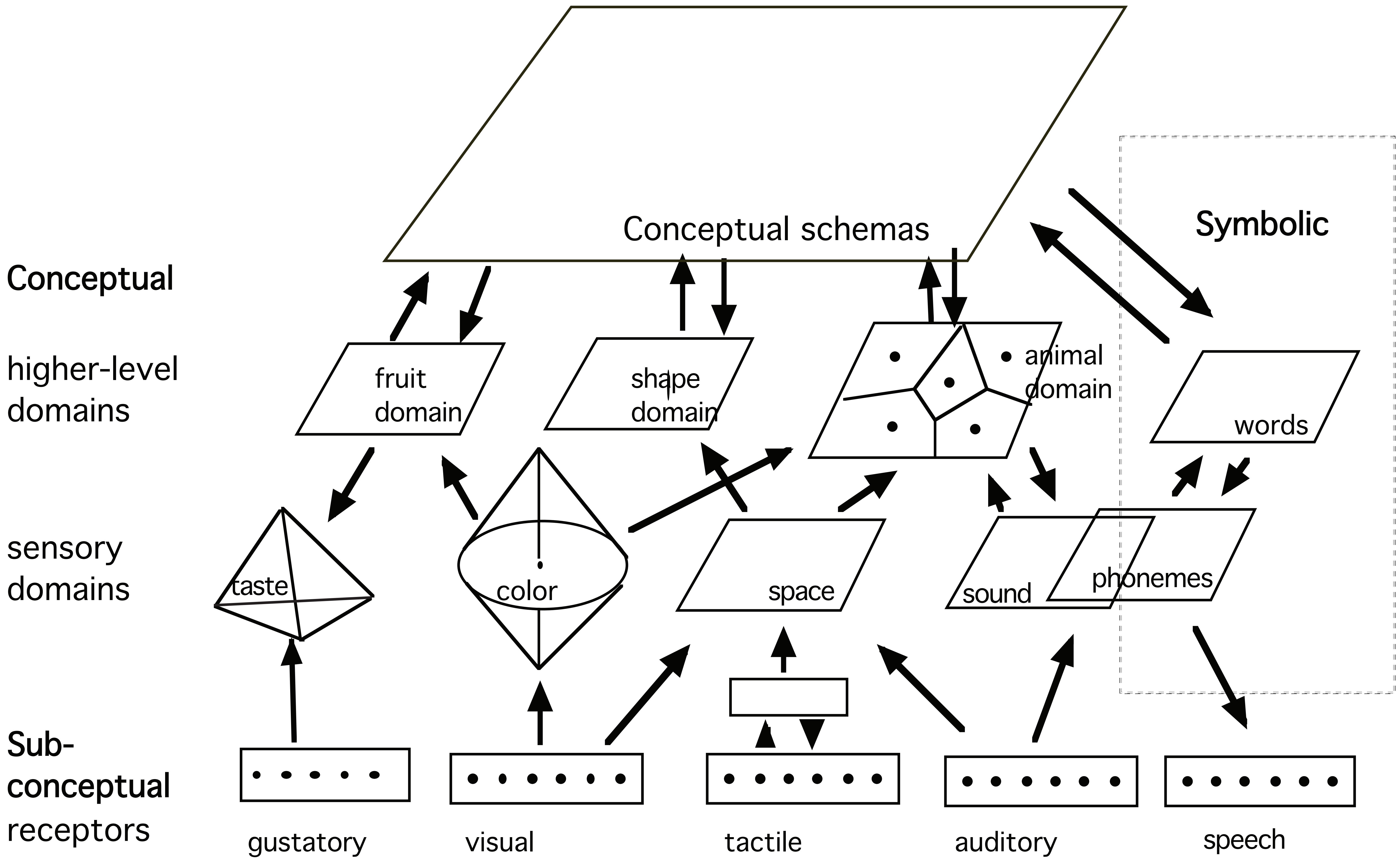
Properties and Concepts

- Property: A **convex** region in a single domain
- Concept: A set of **convex** regions in a number of domains; together with
  - (1) prominence values of the domains and
  - (2) information about how the regions in different domains are correlated

Example of Concept "Apple"

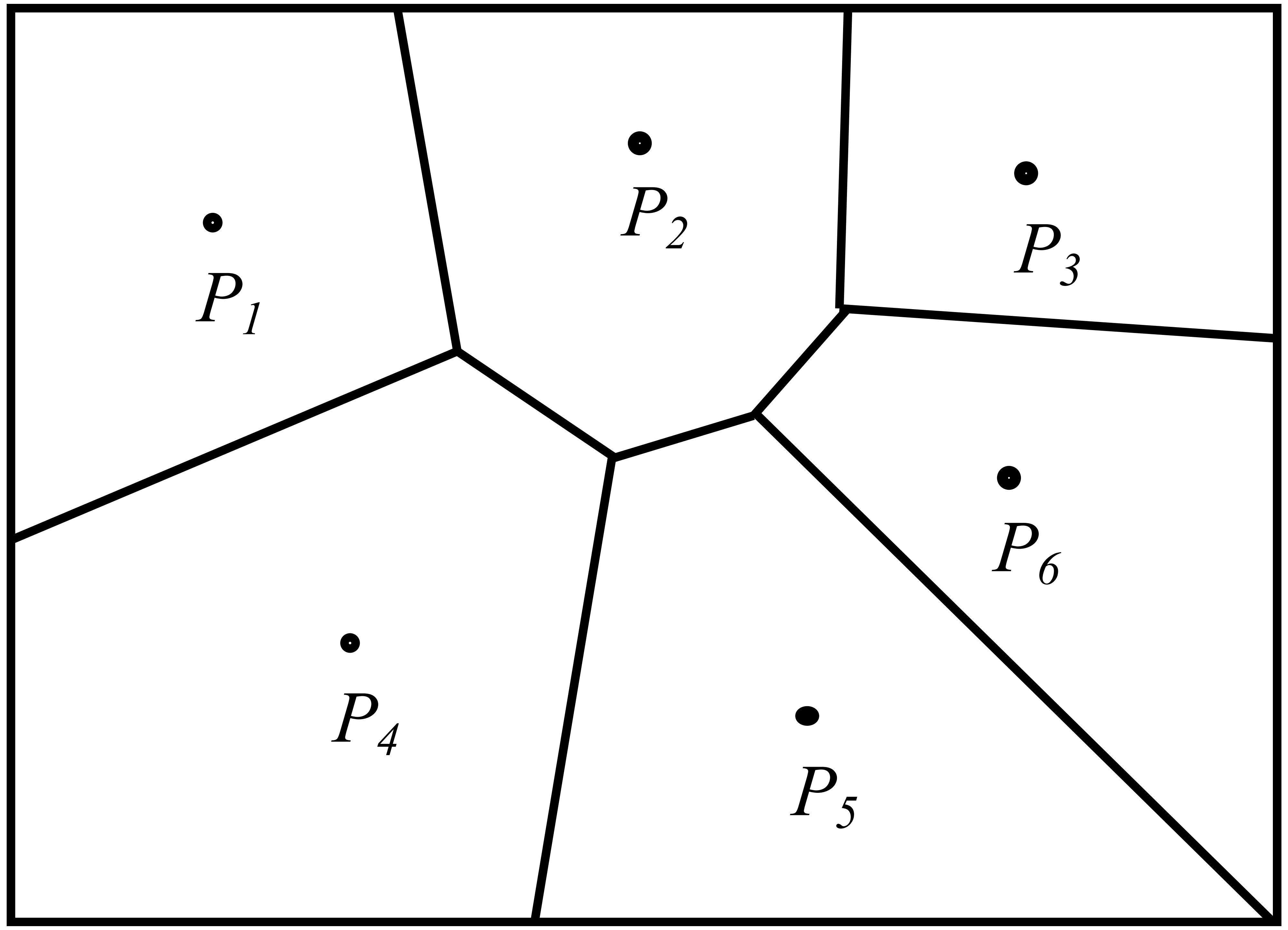
Domain	Region
Fruit	Values for skin, flesh and seed type
Color	Red-green-yellow
Taste	Values for sweetness, sourness etc
Shape	"Round" region of shape space
Nutrition	Values for sugar, vitamin C, fibres etc

The "Full Monty" of CS



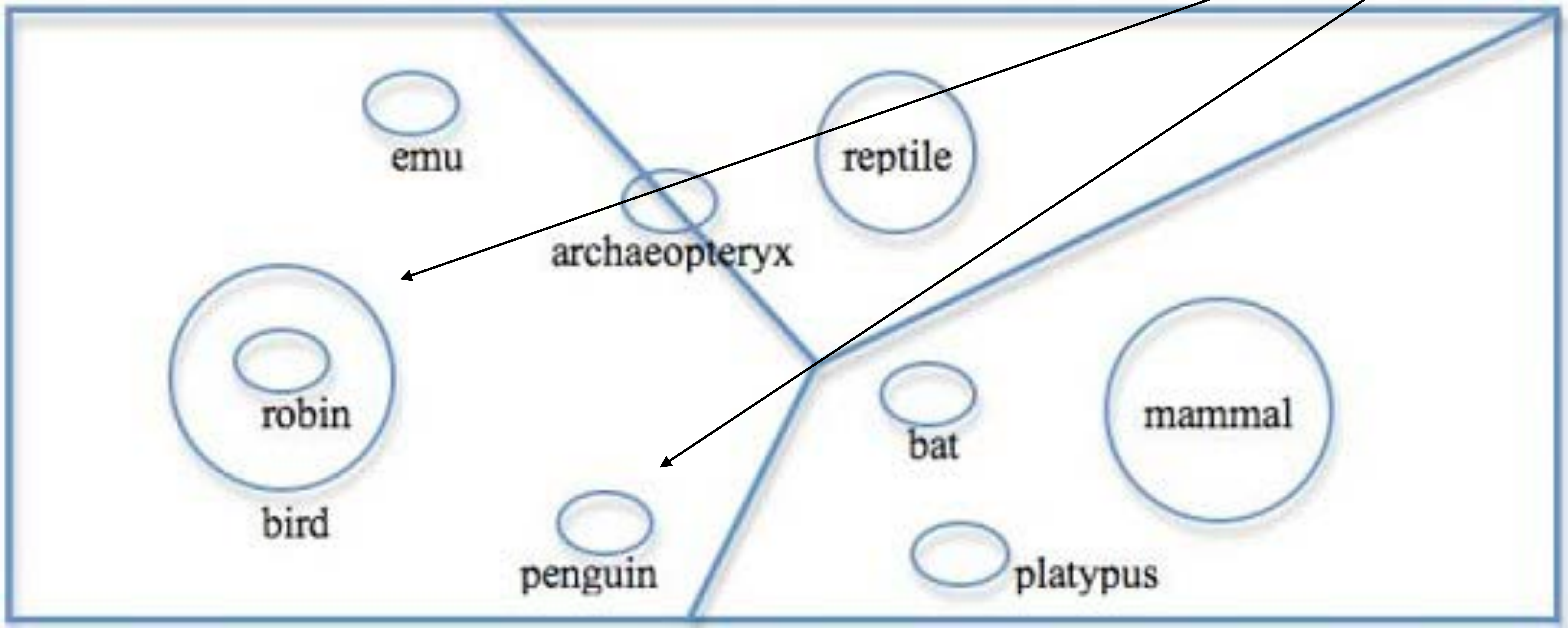
Categorization in CS

- Voronoi tessellations around prototype objects divides conceptual spaces into categories based on the nearest neighbour rule, i.e. each object is associated with the prototype closest to it.

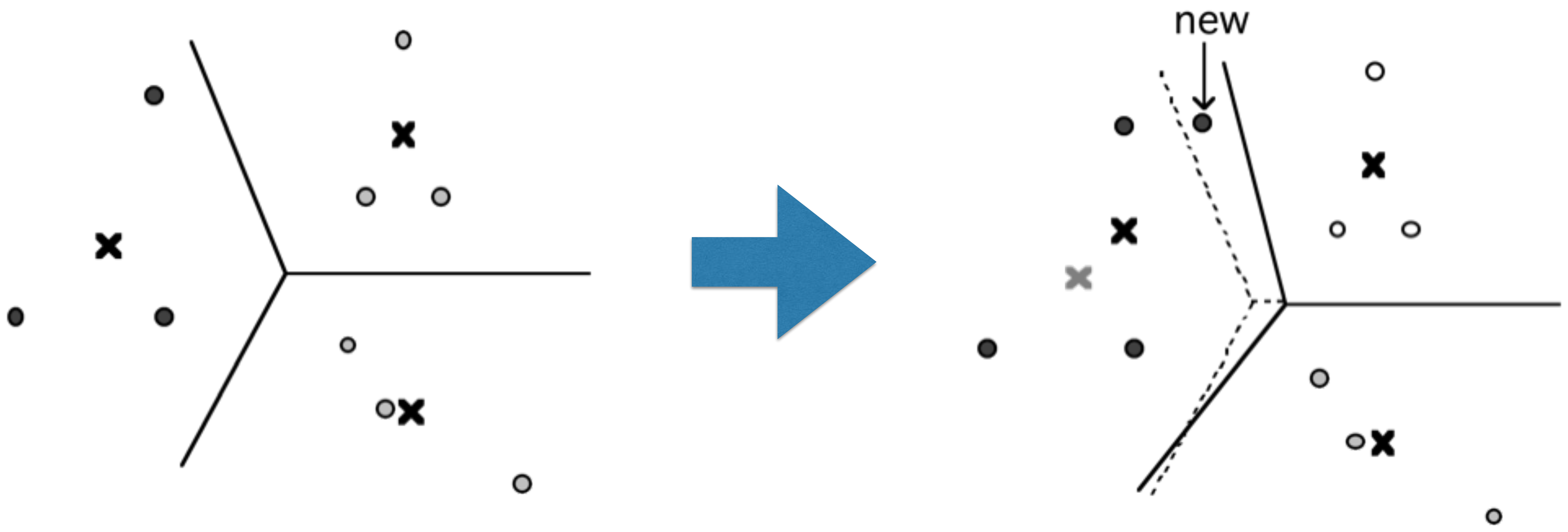


Categorization in CS

Different prominences
of prototypes



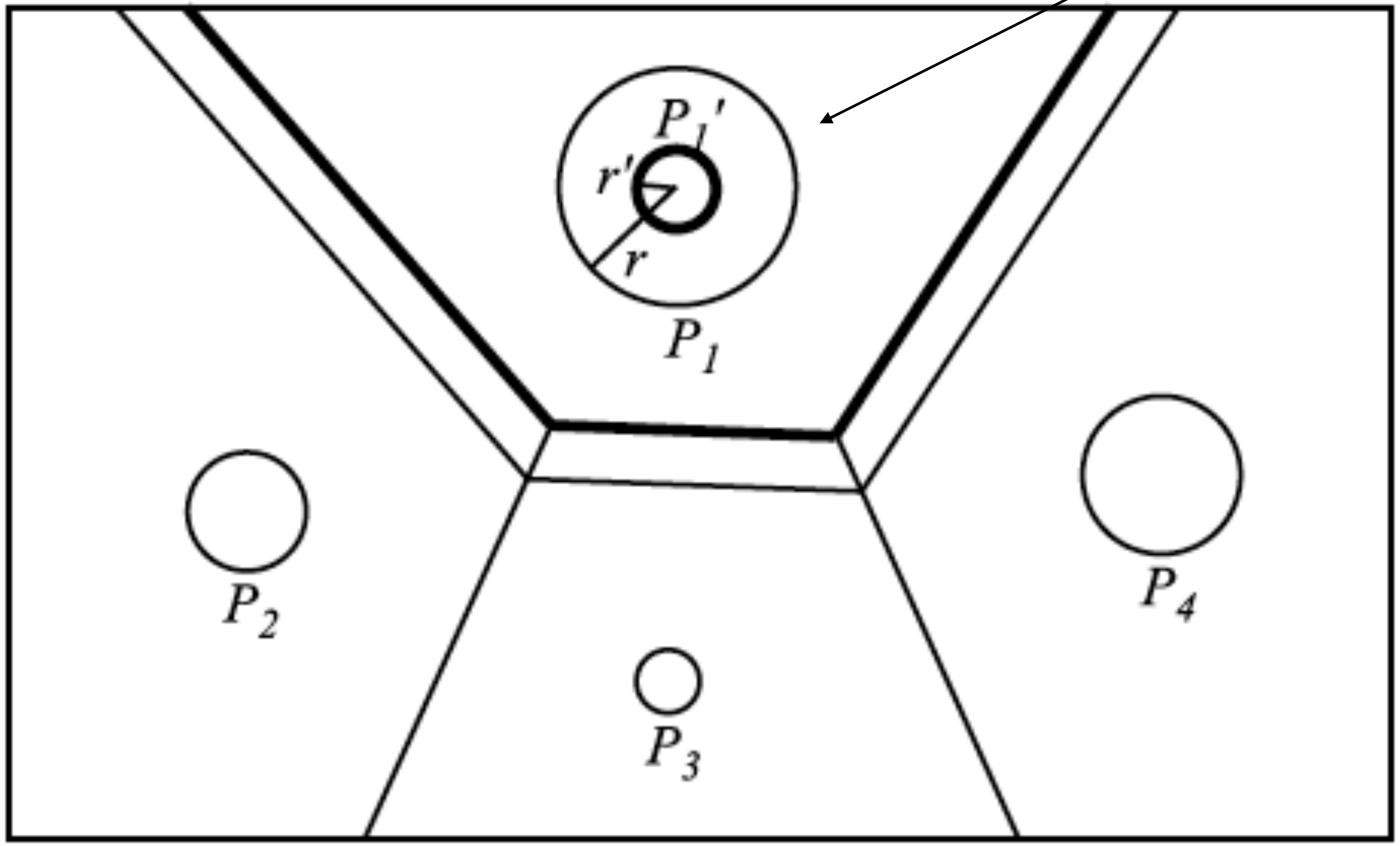
Learning in CS



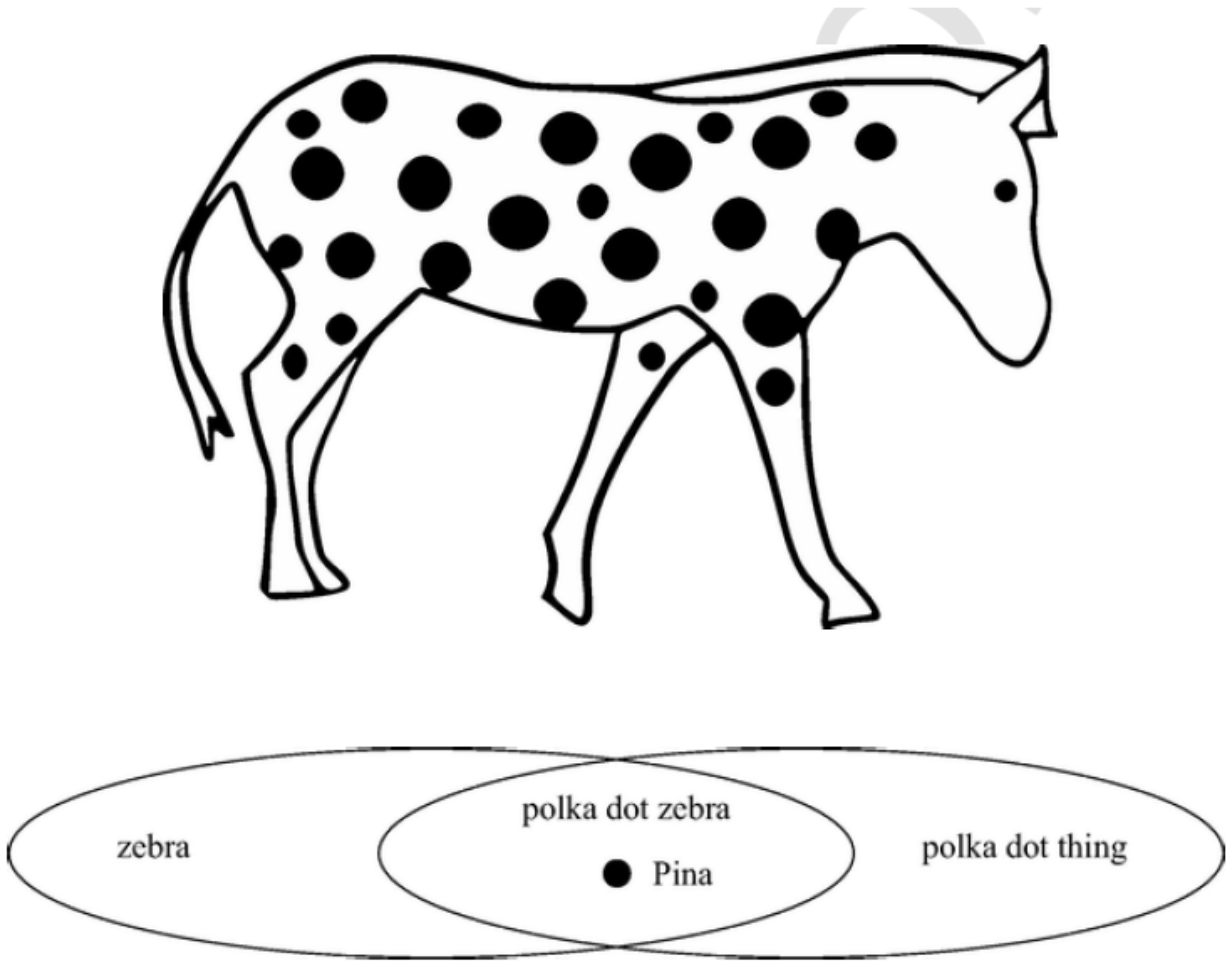
P. Gärdenfors, M.A. Williams: Reasoning about Categories in Conceptual Spaces, Proc. of the Fourteenth International Joint Conference of Artificial Intelligence, Morgan Kaufmann, 385 - 392, 2001.

Learning in CS

Crisping a prototype

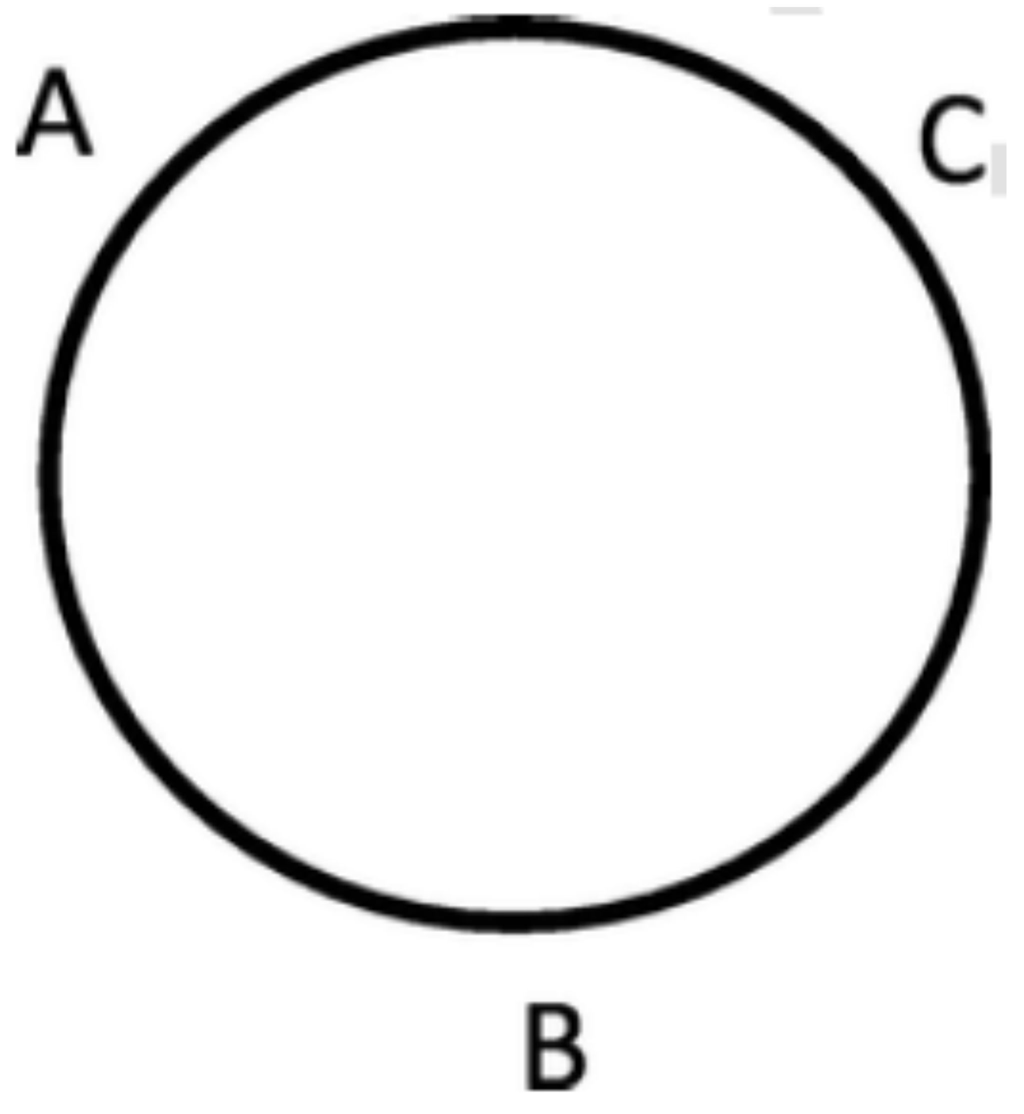


Compositionality in CS



Polka Dot Zebra

Analogic Reasoning



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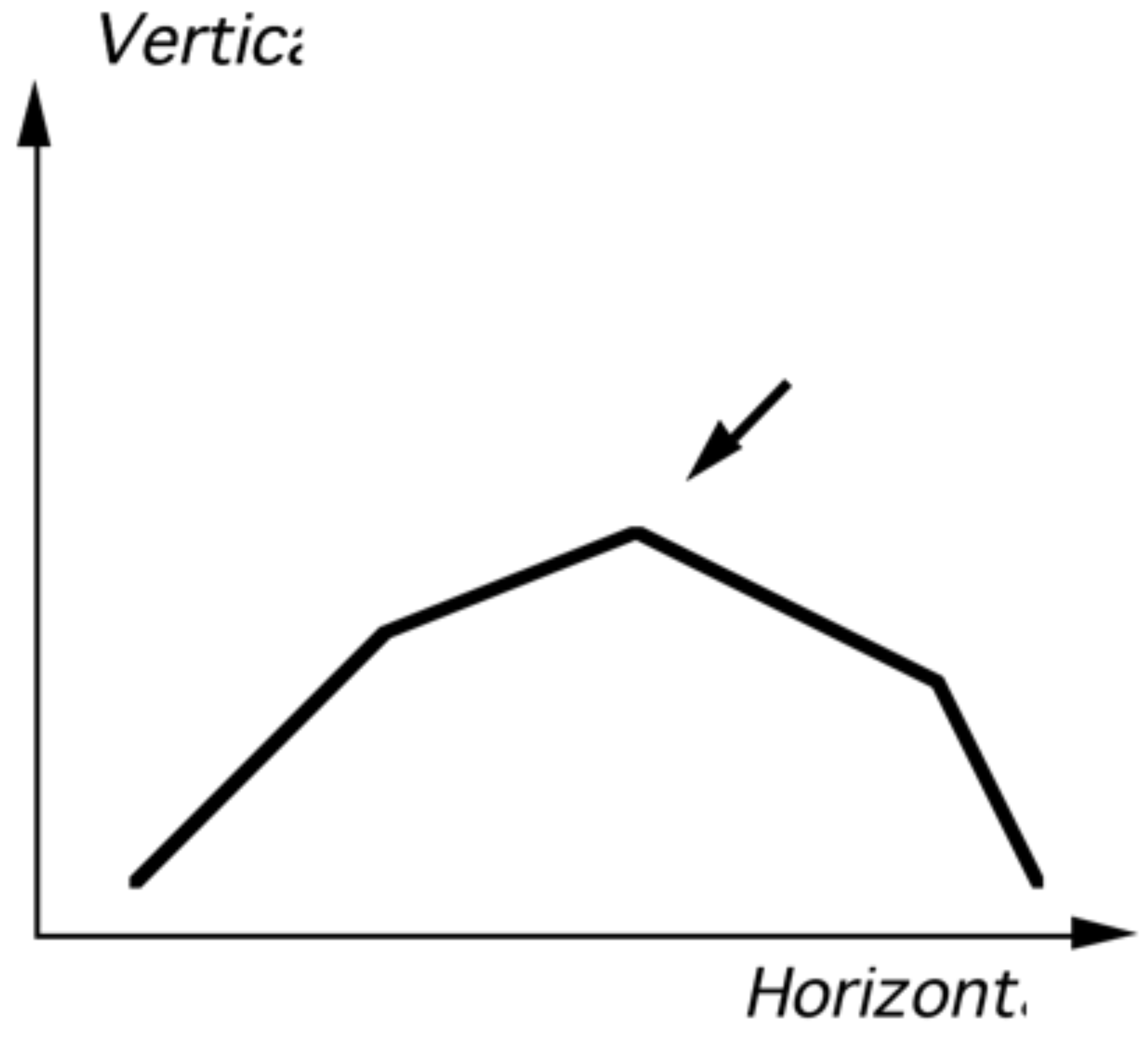
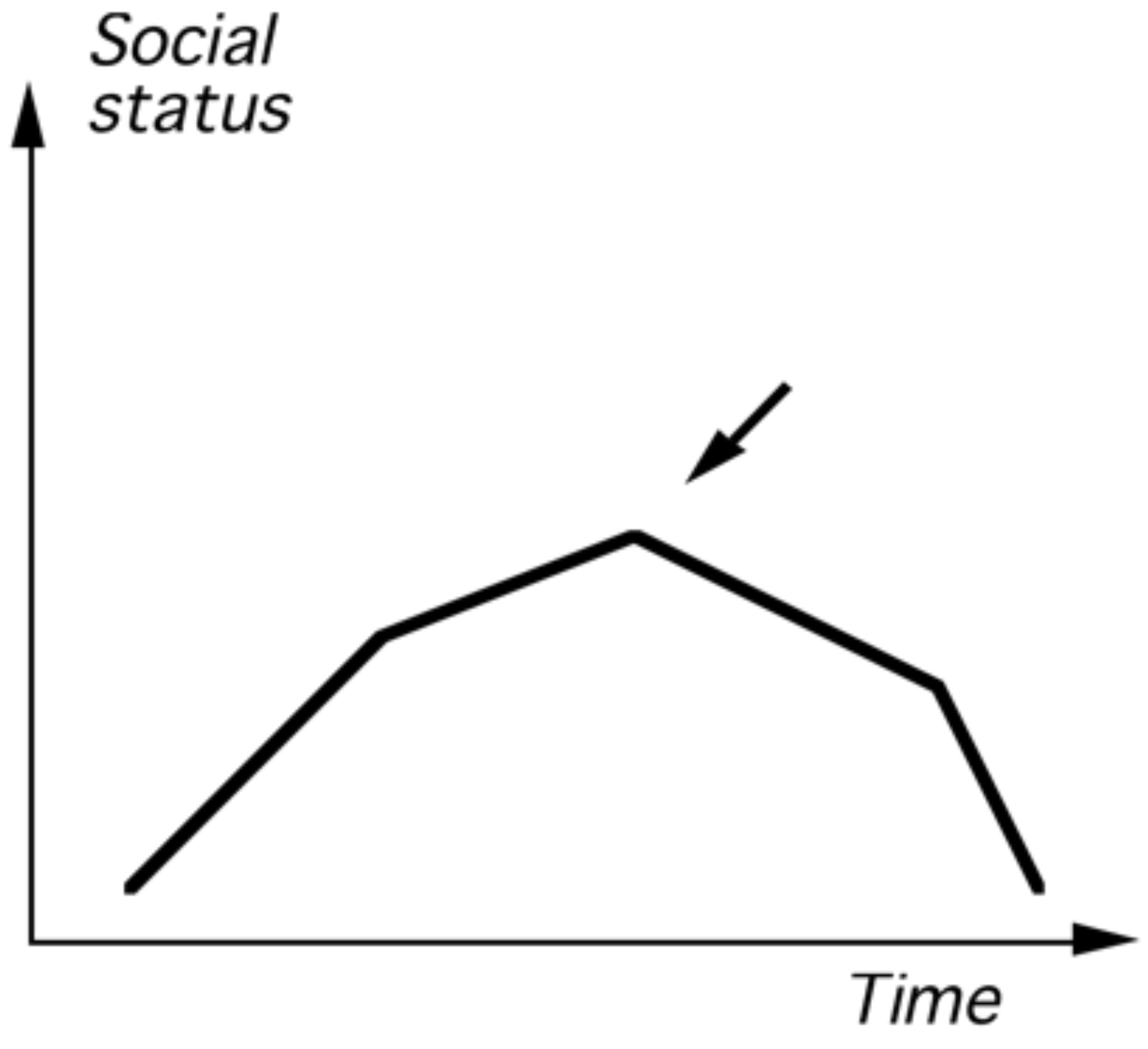


The peak of a mountain



The peak of a career

Neural Networks vs Conceptual Spaces

- Opacity (black box)
- Huge training set
- Difficult incremental learning
- Difficulties in compositionality
- Difficulties in analogic reasoning
- ....

- More transparent representation (no black box)
- Even small training set
- Incremental learning
- Compositionality
- Some forms of analogic reasoning
- ....

frontiers
in Psychology

REVIEW
published: 22 November 2016
doi: 10.3389/fpsyg.2016.01820

Spaces in the Brain: From Neurons to Meanings

Christian Balkenius and Peter Gärdenfors*

Cognitive Science, Lund University, Lund, Sweden

Spaces in the brain can refer either to psychological spaces, which are derived from similarity judgments, or to neurocognitive spaces, which are based on the activities of neural structures. We want to show how psychological spaces naturally emerge from

Biologically Inspired Cognitive Architectures 19 (2017) 1–9

Contents lists available at ScienceDirect

Biologically Inspired Cognitive Architectures

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Research article

Conceptual Spaces for Cognitive Architectures: A *lingua franca* for different levels of representation

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[b] *University of Turin, Dip. di Informatica, Torino, Italy*
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frontiers
in Computational Neuroscience

ORIGINAL RESEARCH
published: 12 June 2017
doi: 10.3389/fncom.2017.00048

Cliques of Neurons Bound into Cavities Provide a Missing Link between Structure and Function

Michael W. Reimann [1†], Max Nolte [1†], Martina Scolamiero [2], Katharine Turner [2], Rodrigo Perin [3], Giuseppe Chindemi [1], Paweł Dłotko [4‡], Ran Levi [5‡], Kathryn Hess [2‡] and Henry Markram [1,3*‡]*

[1] Blue Brain Project, École Polytechnique Fédérale de Lausanne, Geneva, Switzerland, [2] Laboratory for Topology and Neuroscience, Brain Mind Institute, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, [3] Laboratory of Neural Microcircuitry, Brain Mind Institute, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, [4] DataShape, INRIA Saclay, Palaiseau, France, [5] Institute of Mathematics, University of Aberdeen, Aberdeen, United Kingdom

The lack of a formal link between neural network structure and its emergent function has hampered our understanding of how the brain processes information. We have now come closer to describing such a link by taking the direction of synaptic transmission into account, constructing graphs of a network that reflect the direction of information flow,

COGNITIVE SCIENCE
A Multidisciplinary Journal

Cognitive Science (2015) 1–35

ISSN: 0364-0213 print / 1551-6709 online
DOI: 10.1111/cogs.12265

Concepts as Semantic Pointers: A Framework and Computational Model

Peter Blouw, Eugene Solodkin, Paul Thagard, Chris Eliasmith

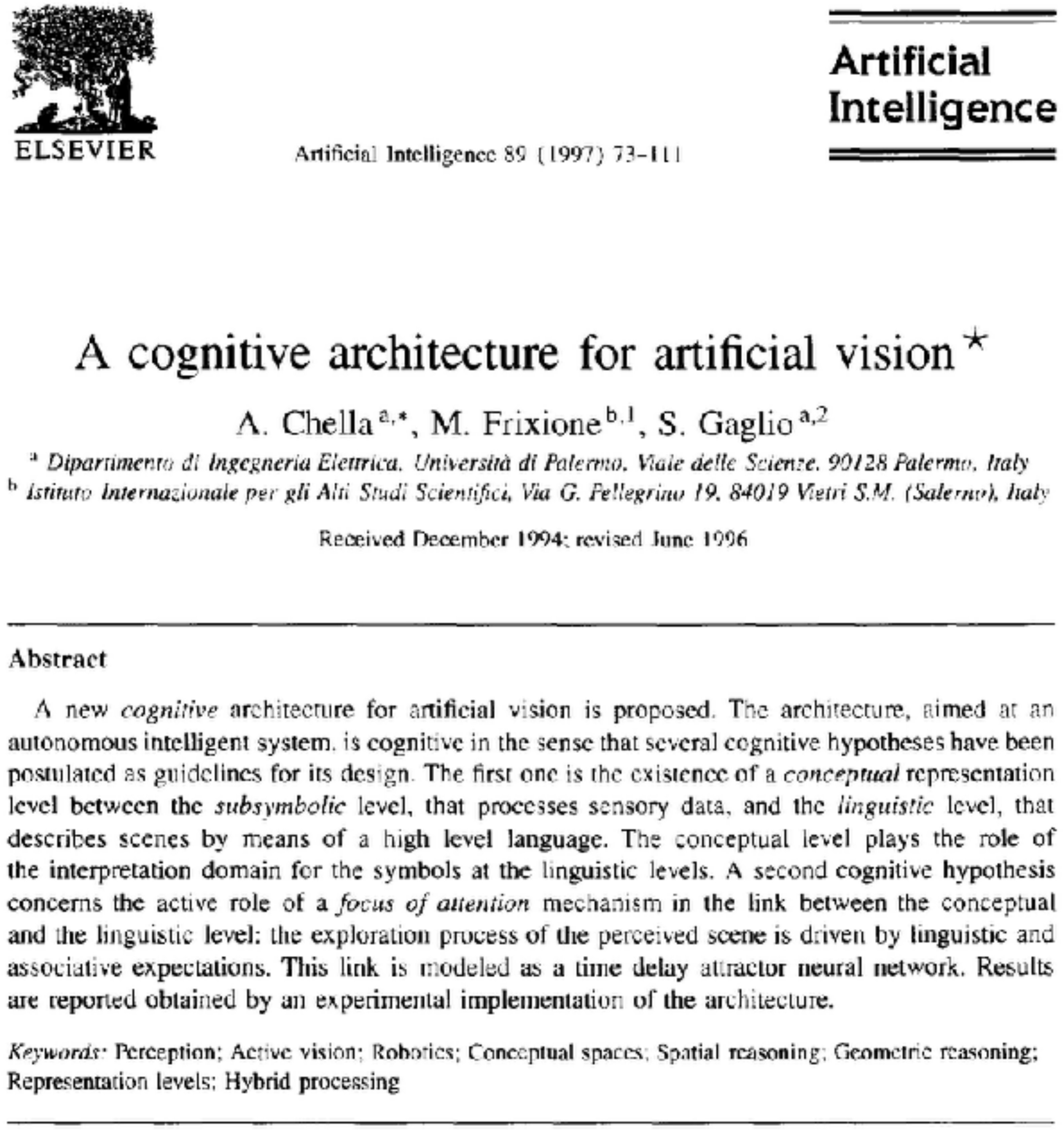
Center for Theoretical Neuroscience, University of Waterloo

Received 9 July 2013; received in revised form 24 February 2015; accepted 20 March 2015

Abstract

The reconciliation of theories of concepts based on prototypes, exemplars, and theory-like structures is a longstanding problem in cognitive science. In response to this problem, researchers have recently tended to adopt either hybrid theories that combine various kinds of representational

Grounding Objects



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Artificial Intelligence 89 (1997) 73–111

Artificial Intelligence

A cognitive architecture for artificial vision ★

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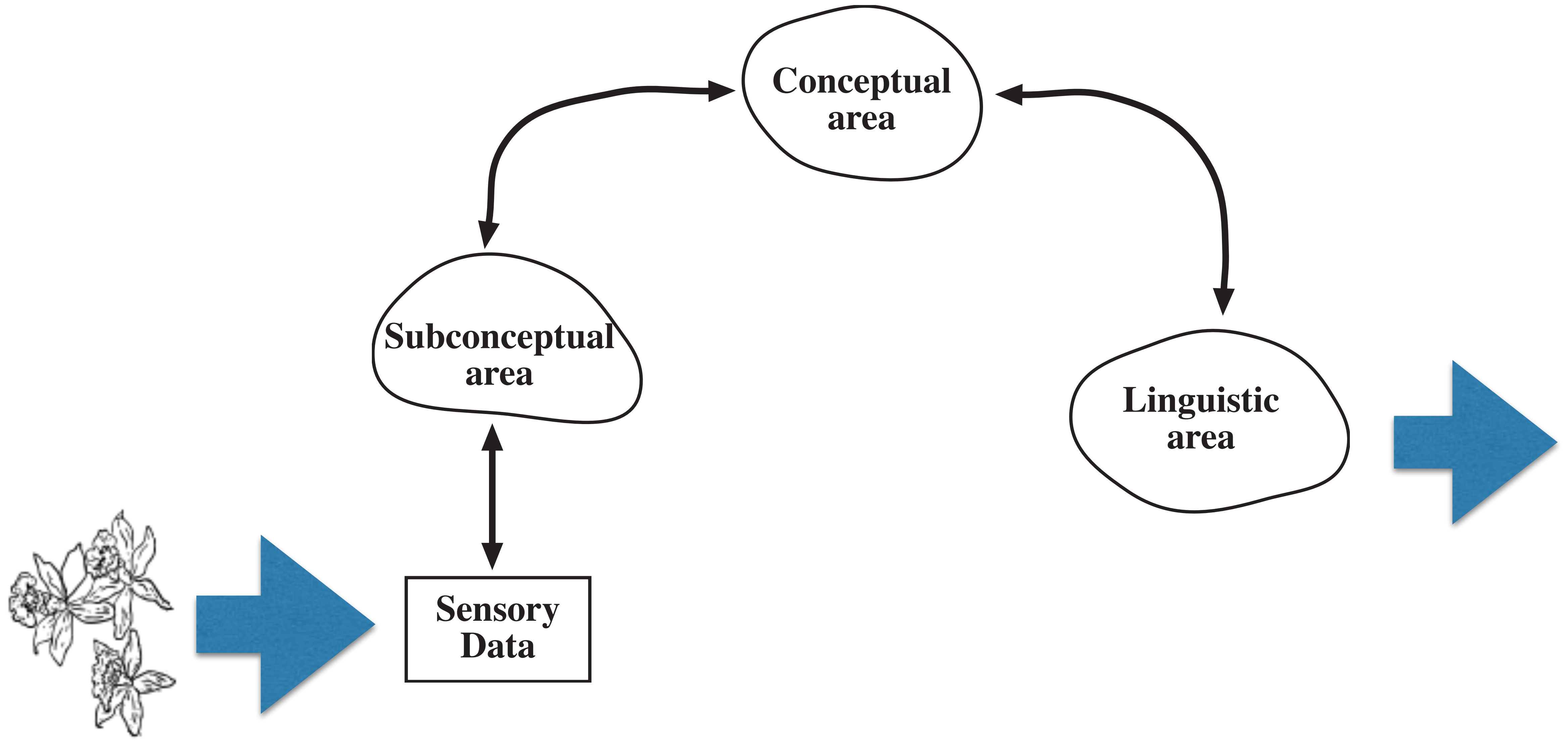
Received December 1994; revised June 1996

Abstract

A new *cognitive* architecture for artificial vision is proposed. The architecture, aimed at an autonomous intelligent system, is cognitive in the sense that several cognitive hypotheses have been postulated as guidelines for its design. The first one is the existence of a *conceptual* representation level between the *subsymbolic* level, that processes sensory data, and the *linguistic* level, that describes scenes by means of a high level language. The conceptual level plays the role of the interpretation domain for the symbols at the linguistic levels. A second cognitive hypothesis concerns the active role of a *focus of attention* mechanism in the link between the conceptual and the linguistic level: the exploration process of the perceived scene is driven by linguistic and associative expectations. This link is modeled as a time delay attractor neural network. Results are reported obtained by an experimental implementation of the architecture.

Keywords: Perception; Active vision; Robotics; Conceptual spaces; Spatial reasoning; Geometric reasoning; Representation levels; Hybrid processing



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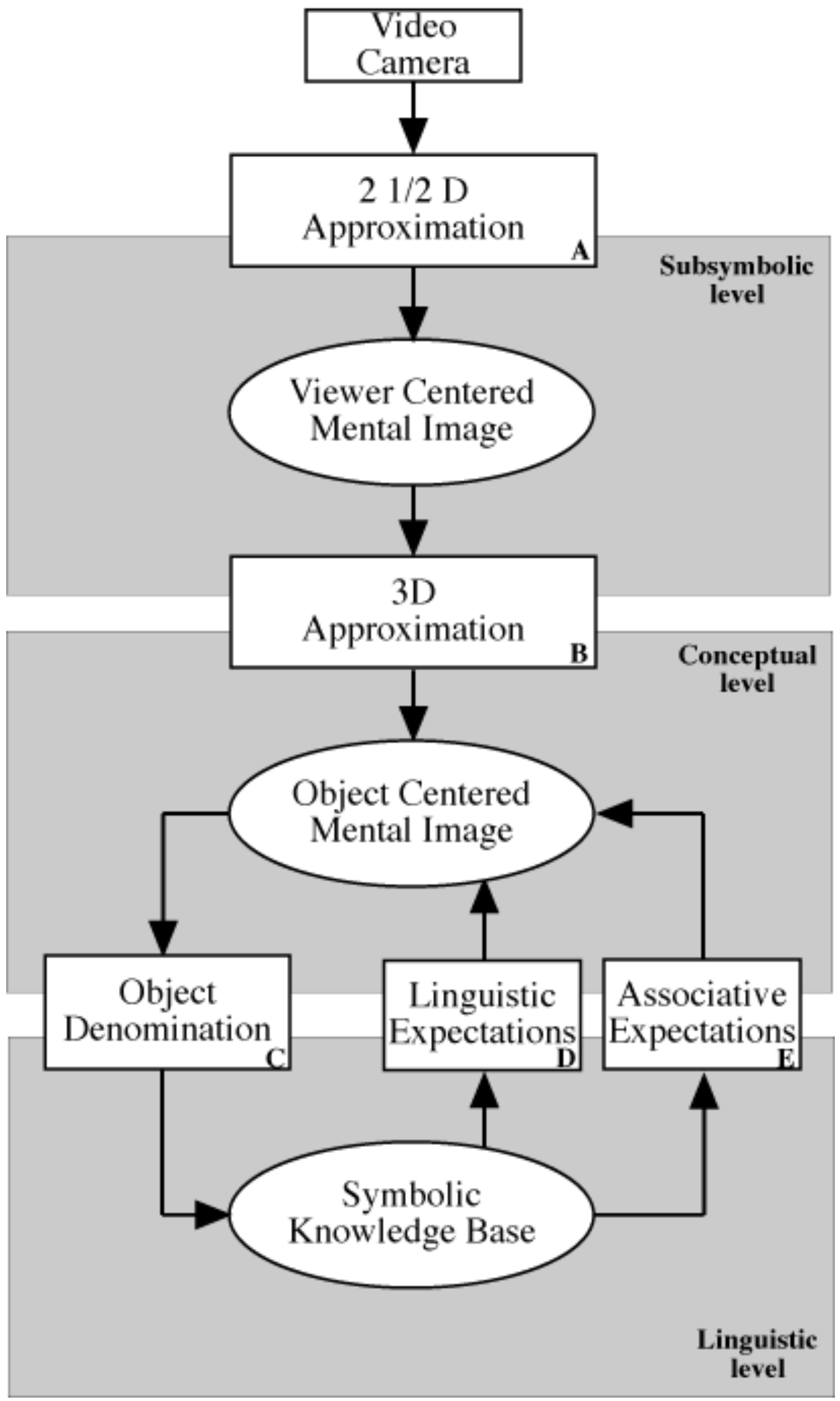
A Cognitive Architecture

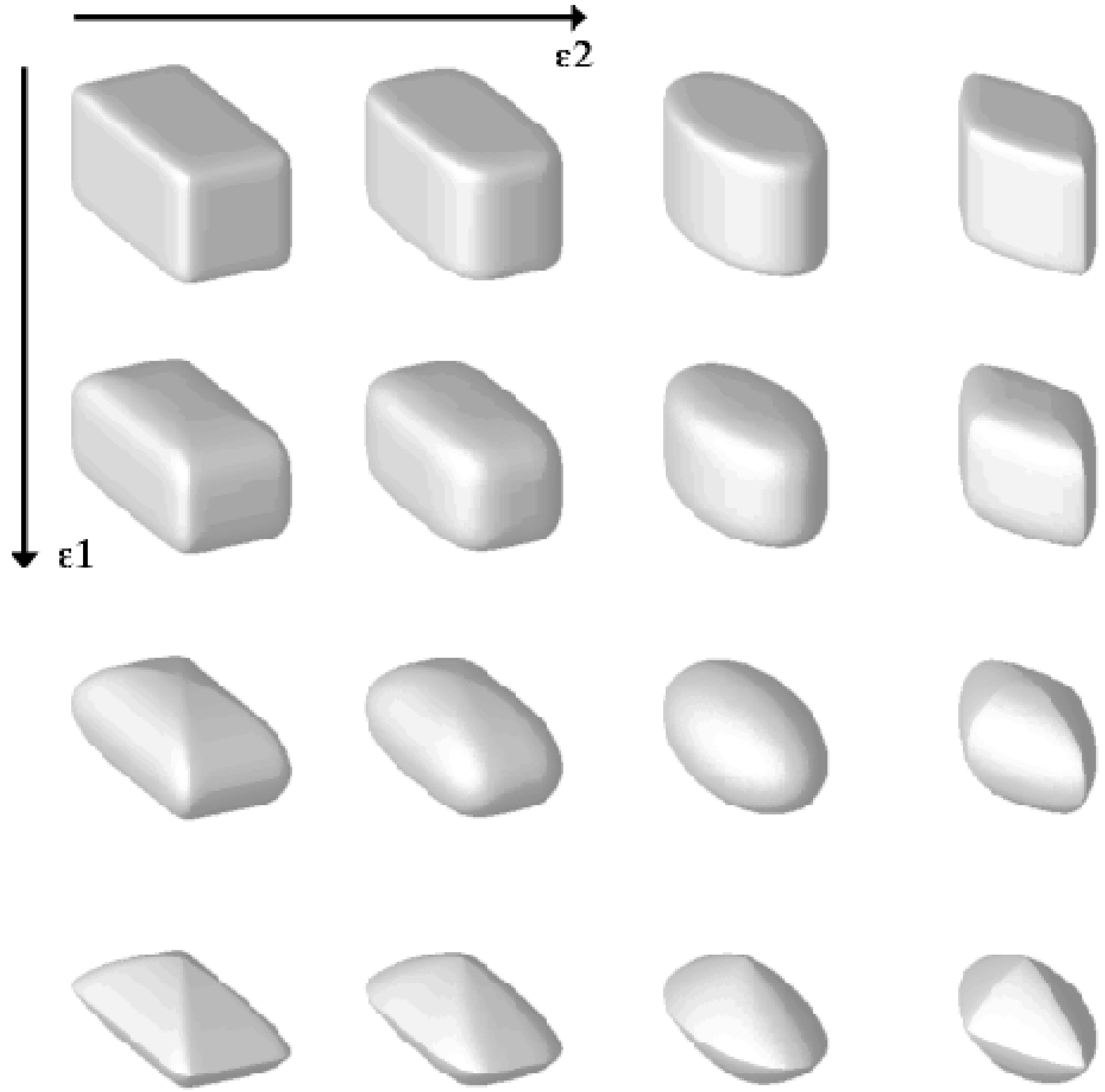


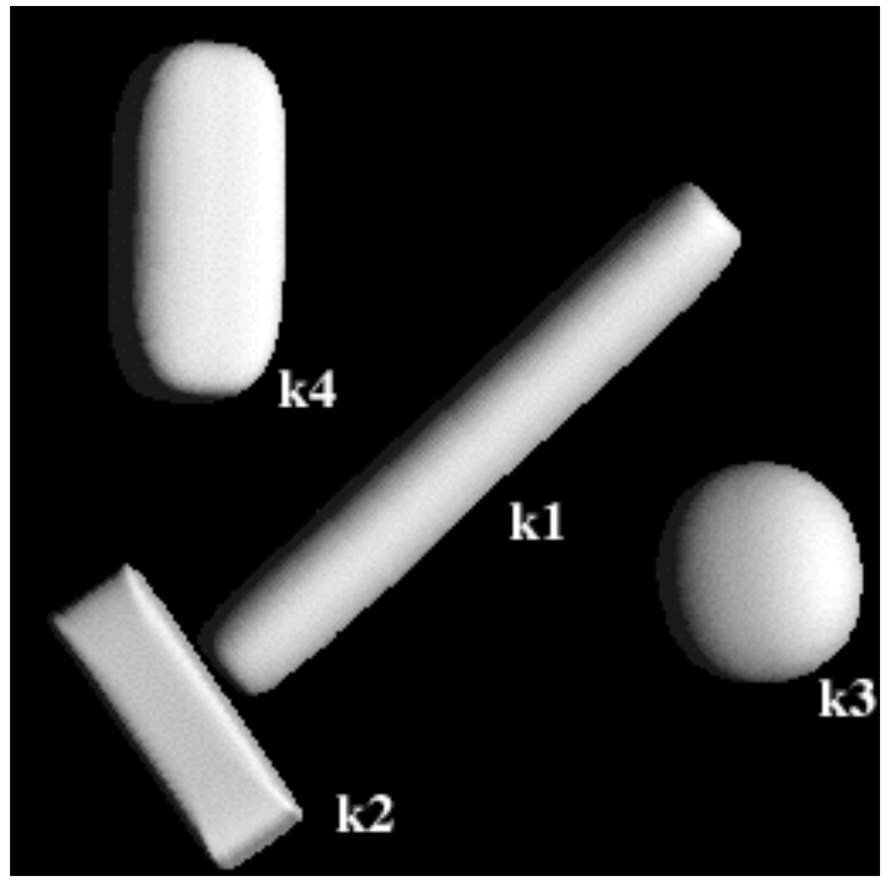
The Subsymbolic Level

- Low level processing of data coming from sensors.
- Information is not yet organized in terms of conceptual structures and categories.
- Extraction of the 3-D model

The Static CS

- A point is a superquadric
- An object is a composition of superquadrics

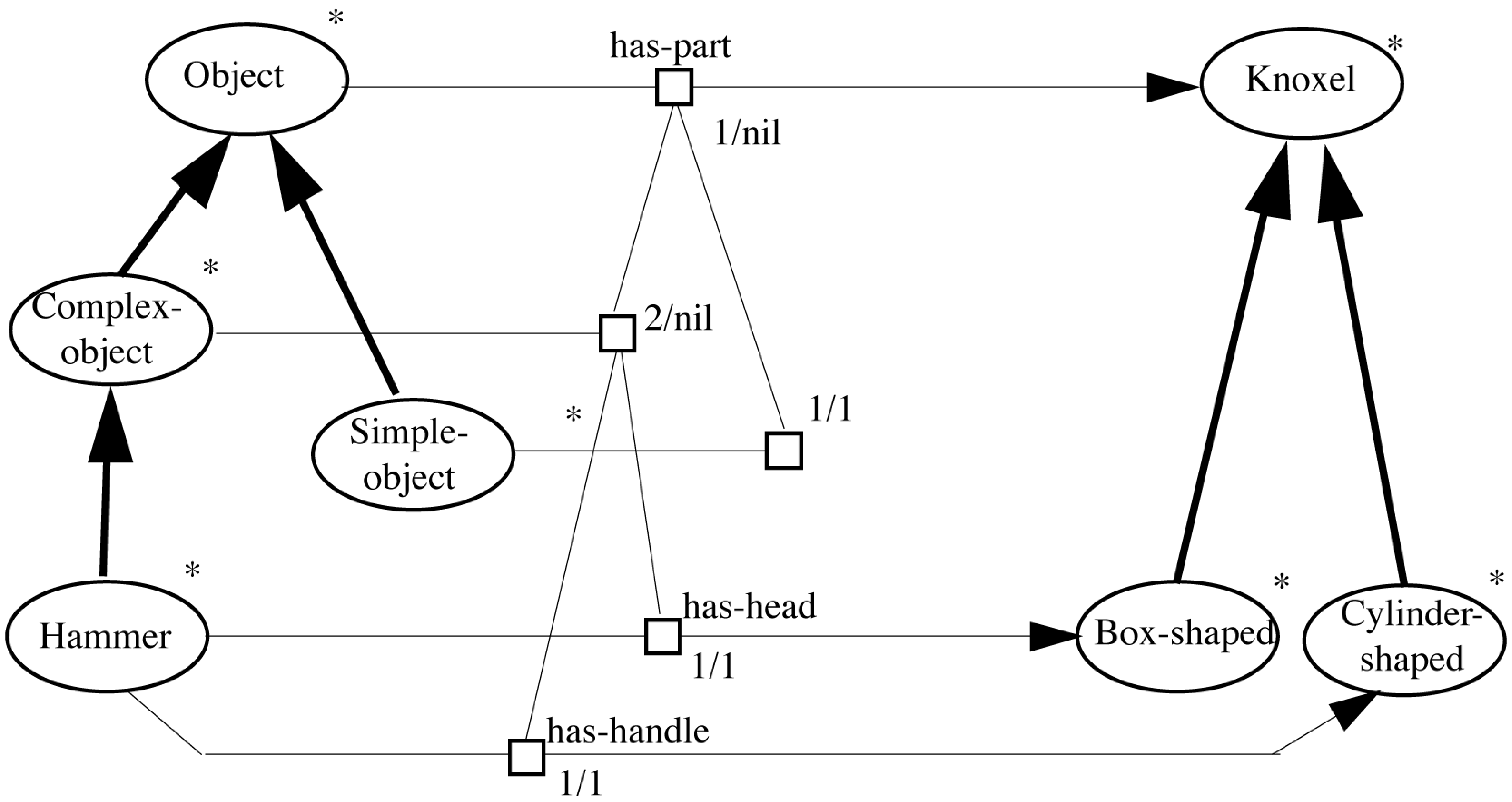




The Linguistic Level

- Hybrid formalism in the KL-ONE tradition
- **Terminological component**
  - terminological language: semantic networks (SINets)
  - concept descriptions (general knowledge)
- **Assertional component**
  - assertional language: ground atoms
  - information about specific scene

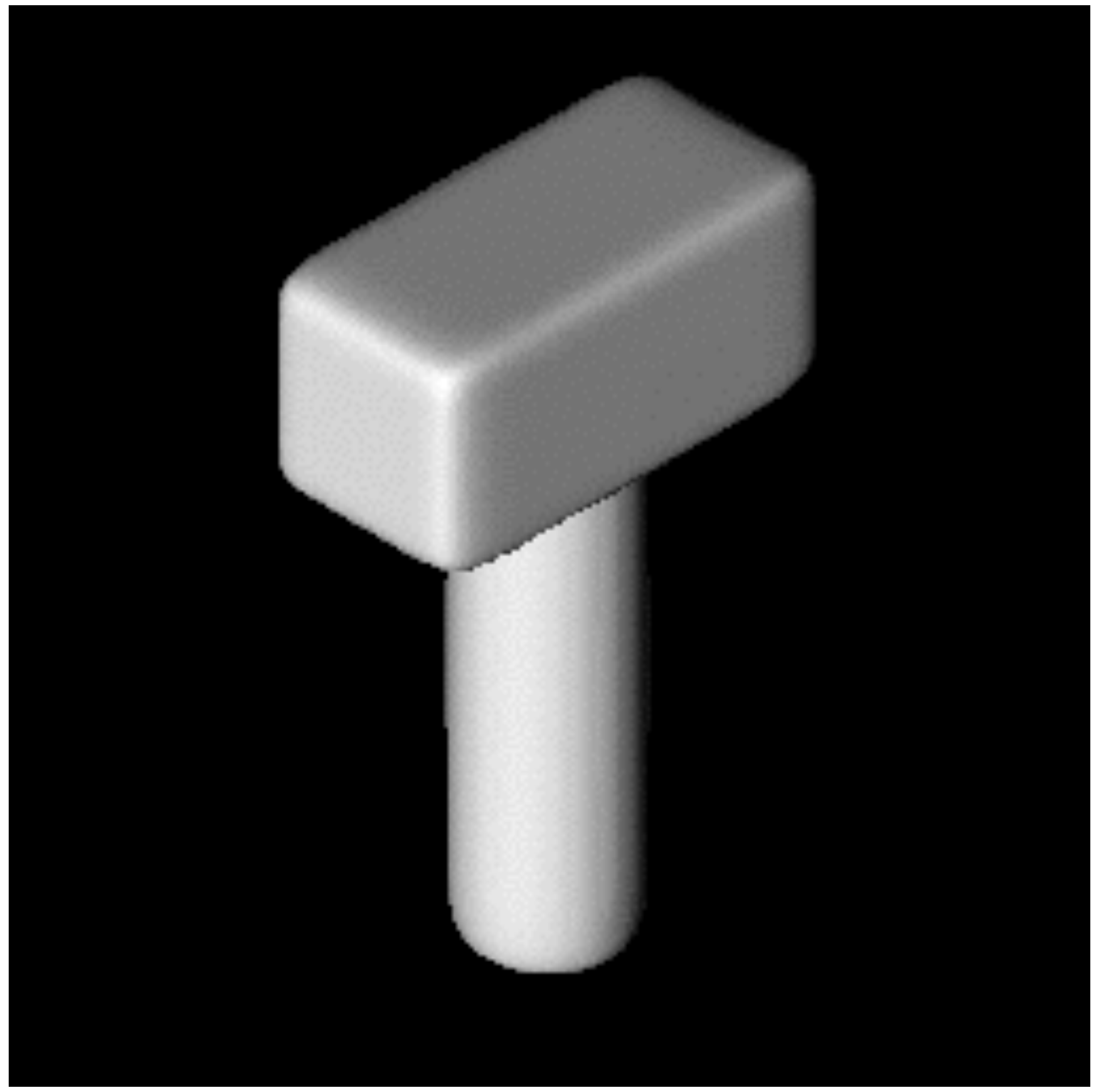
Terminological Component

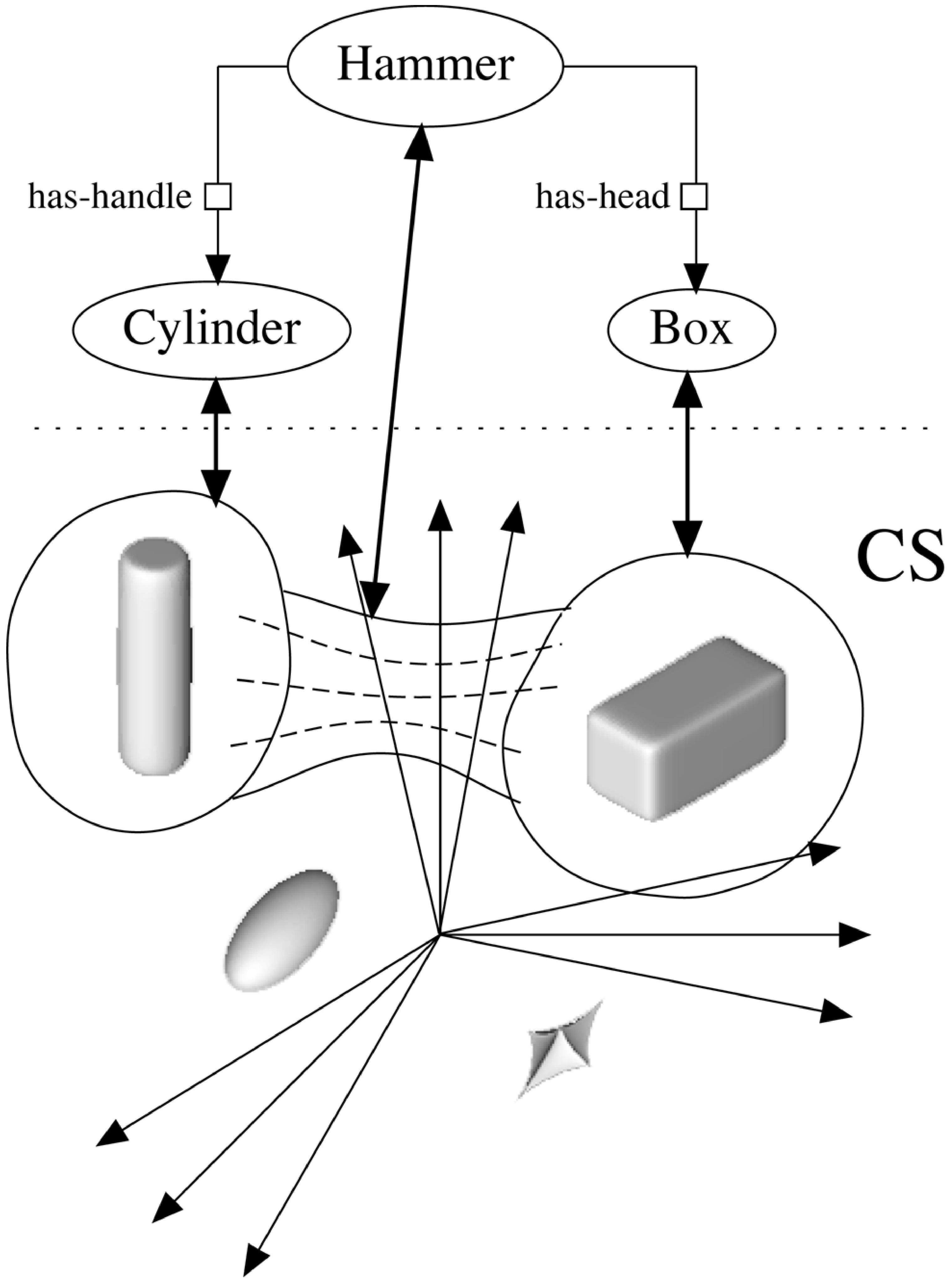


Assertional Component

- First order logic
- Concepts → One place predicates
- Roles → Two place predicates

Grounding Objects

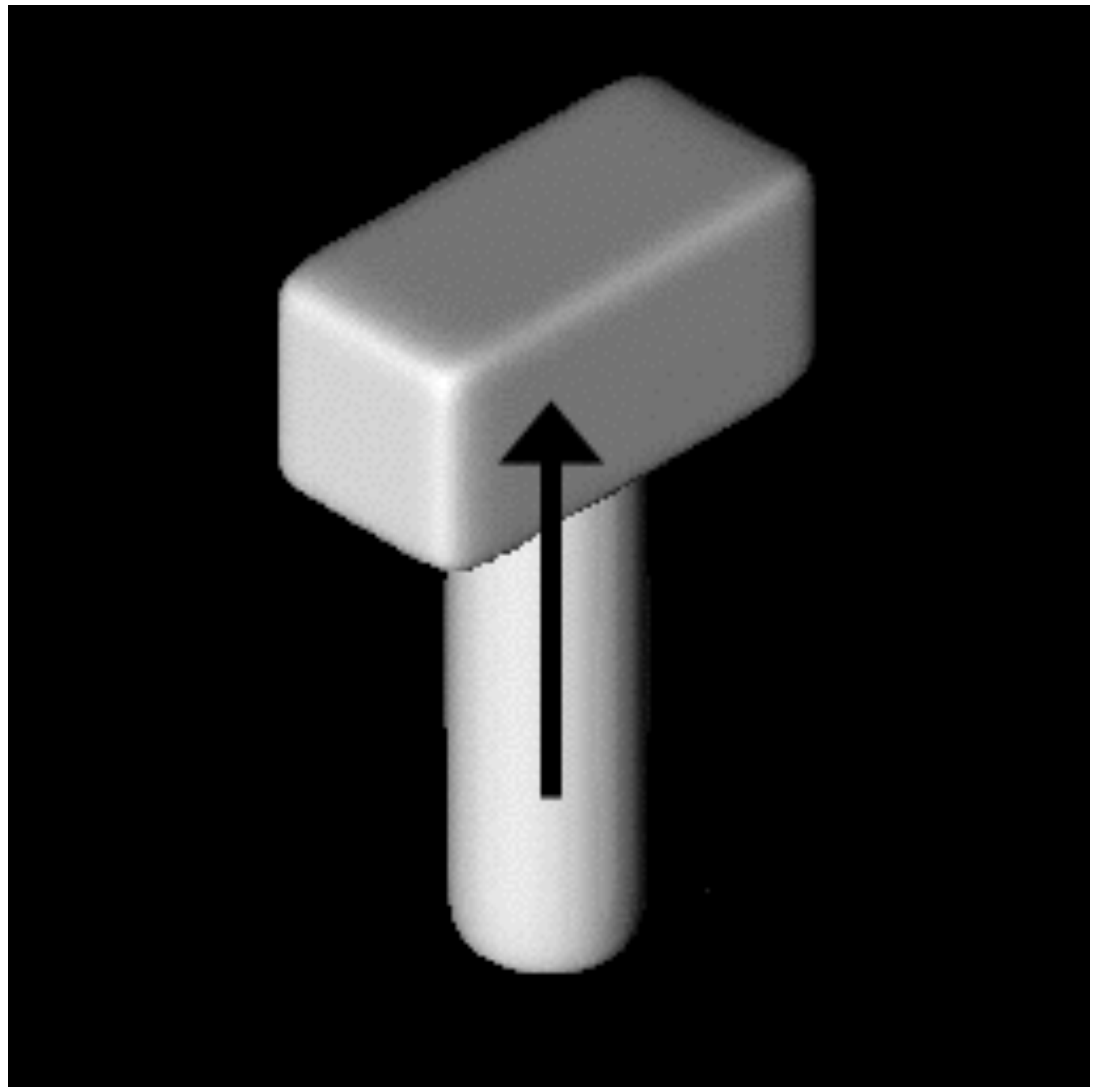


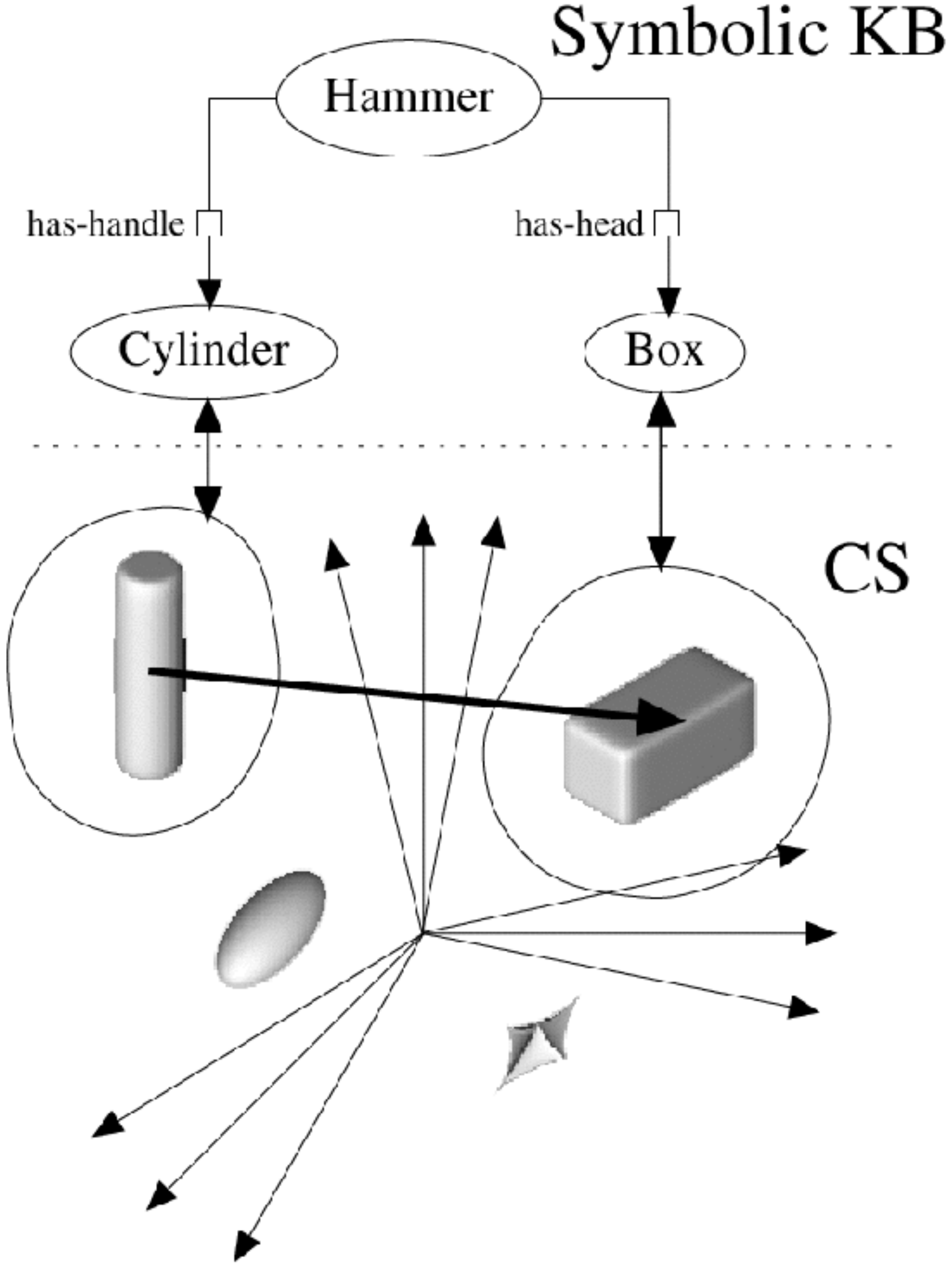


Generation of Assertions

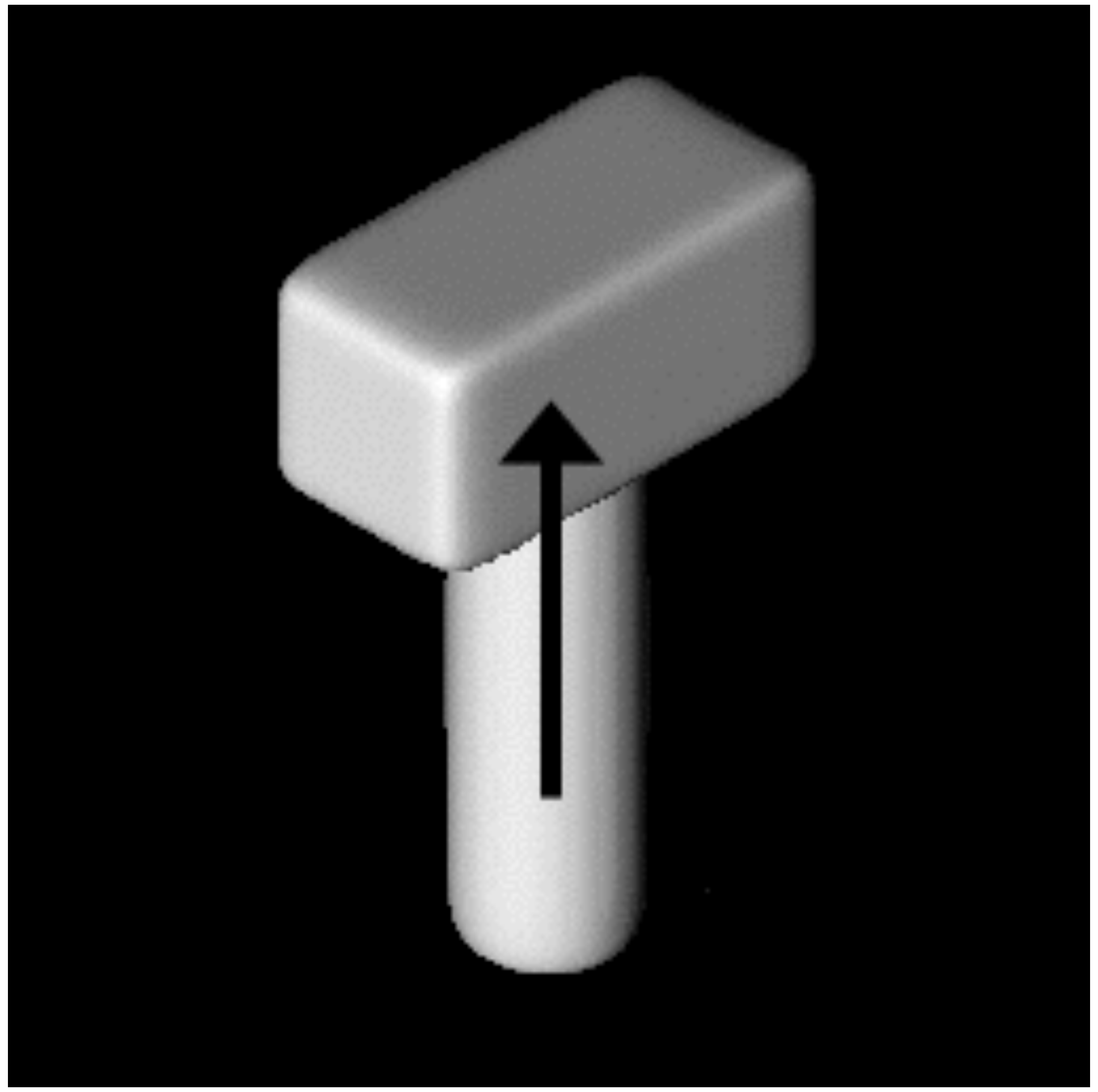
- Driven by the focus of attention
  - **associative** expectations: learned by NNs
  - **linguistic** expectations: driven by linguistic KB

Focus of attention





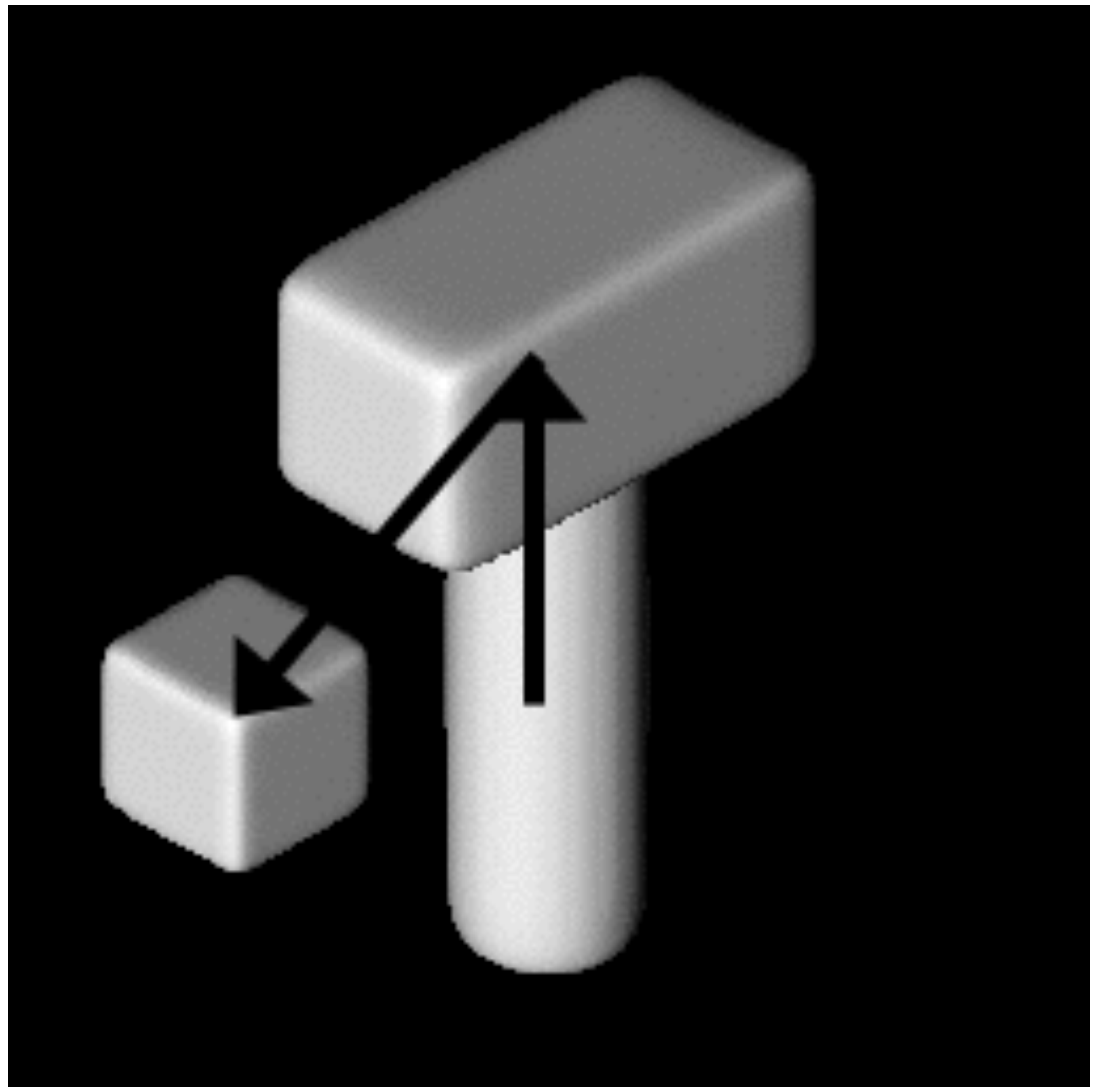
Linguistic expectations



```
Cylinder-shaped(#k1)
Box-shaped(#k2)
Hammer (Hammer#1)
has-part(Hammer#1,#k1)
has-part(Hammer#1,#k2)
```

A priori knowledge of the object shape

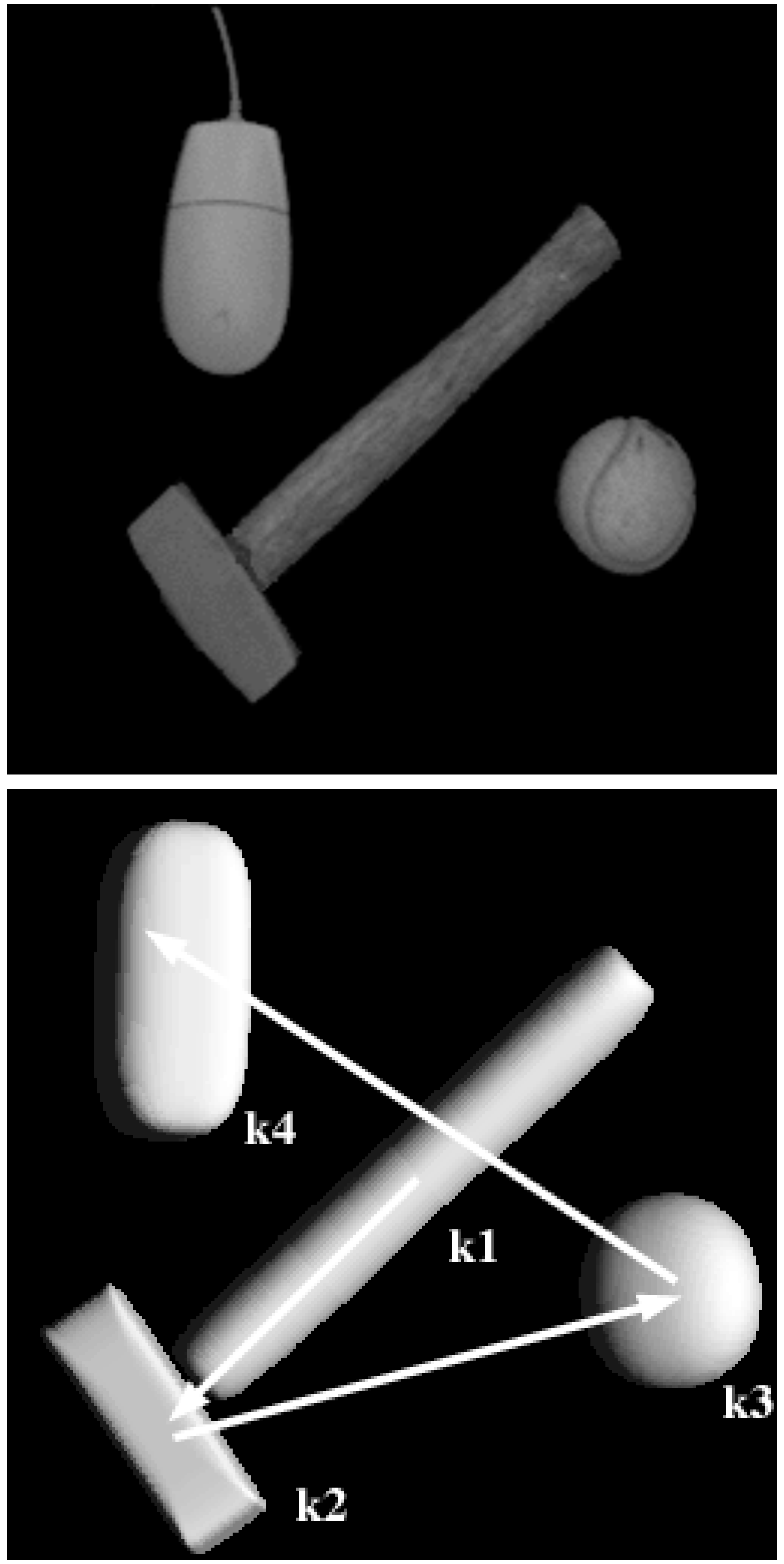
Associative expectations



```
Hammer (Hammer#1)
Box (Box#1)
Next-to(l#1)
Has-part(l#1,Hammer#1)
Has-part(l#1,Box#1)
```

Free associations among previously seen objects

System At Work




```
Cylinder-shaped(#k1)
Box-shaped(#k2)
Hammer (Hammer#1)
has-handle(Hammer#1,#k1)
has-head(Hammer#1,#k2)
Ball-shaped(#k3)
Ball(Ball#1)
has-part(Ball#1,#k3)
Ellipsoid-shaped(#k4)
Mouse(Mouse#1)
has-part(Mouse#1,#k4)
```

Grounding Actions

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Artificial Intelligence 123 (2000) 89–132

Artificial Intelligence

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Understanding dynamic scenes

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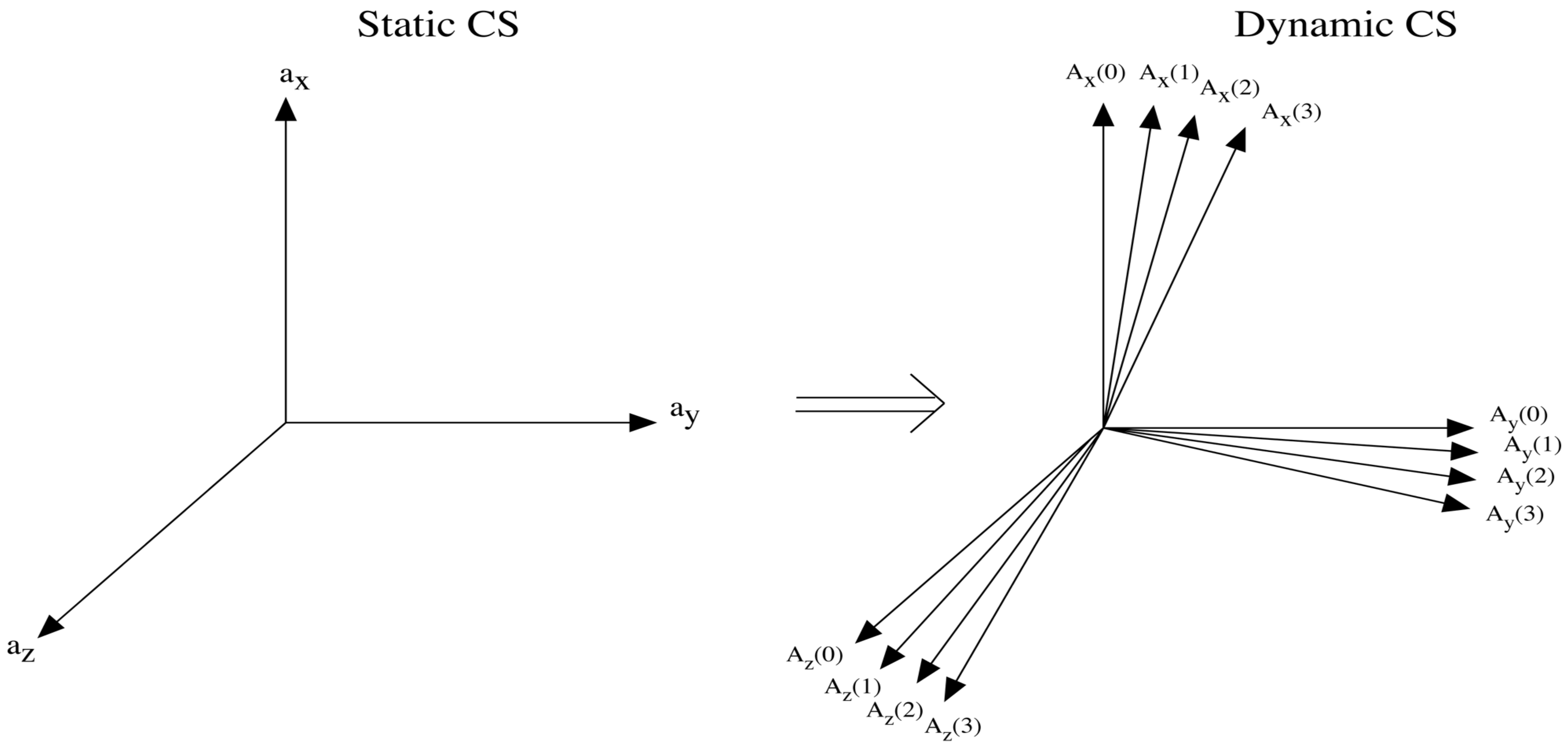
Abstract

We propose a framework for the representation of visual knowledge in a robotic agent, with special attention to the *understanding* of dynamic scenes. According to our approach, understanding involves the generation of a high level, declarative description of the perceived world. Developing such a description requires both *bottom-up*, data driven processes that associate symbolic knowledge representation structures with the data coming out of a vision system, and *top-down* processes in which high level, symbolic information is in its turn employed to drive and further refine the interpretation of a scene.

On the one hand, the computer vision community approached this problem in terms of 2D/3D shape reconstruction and of estimation of motion parameters. On the other, the AI community

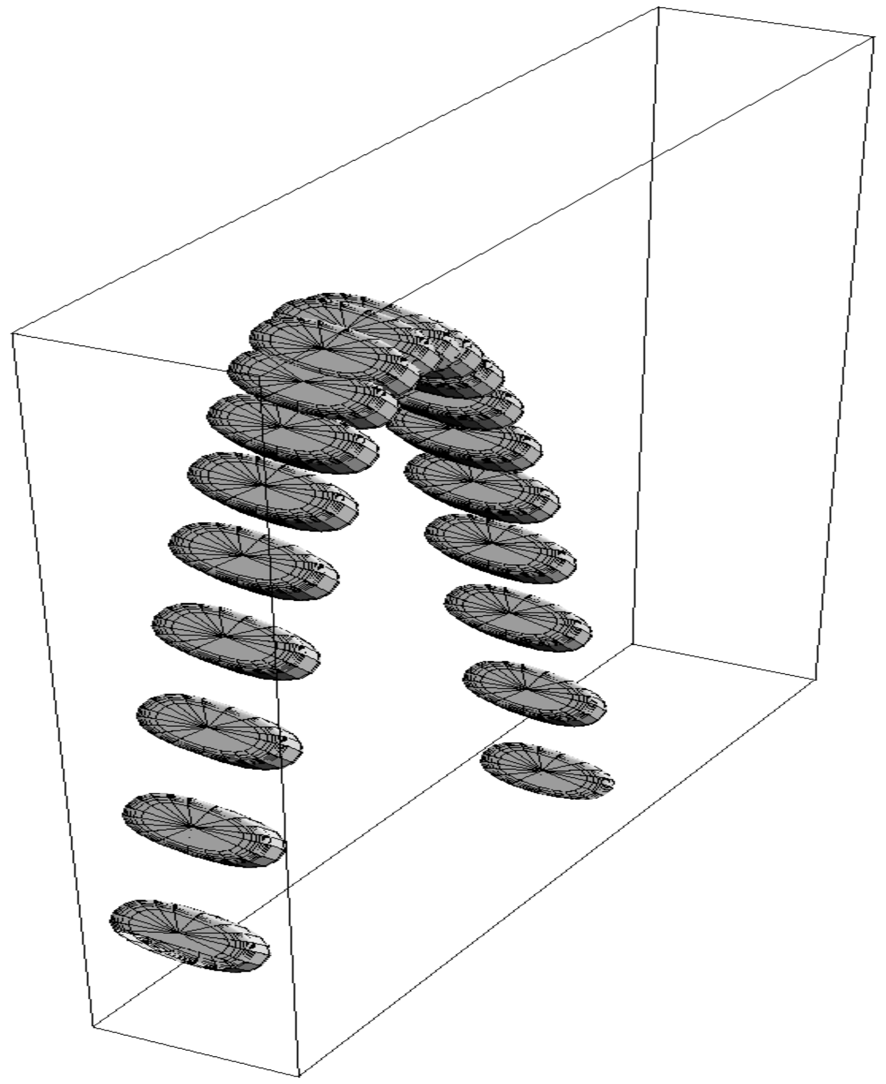


Dynamic scenes

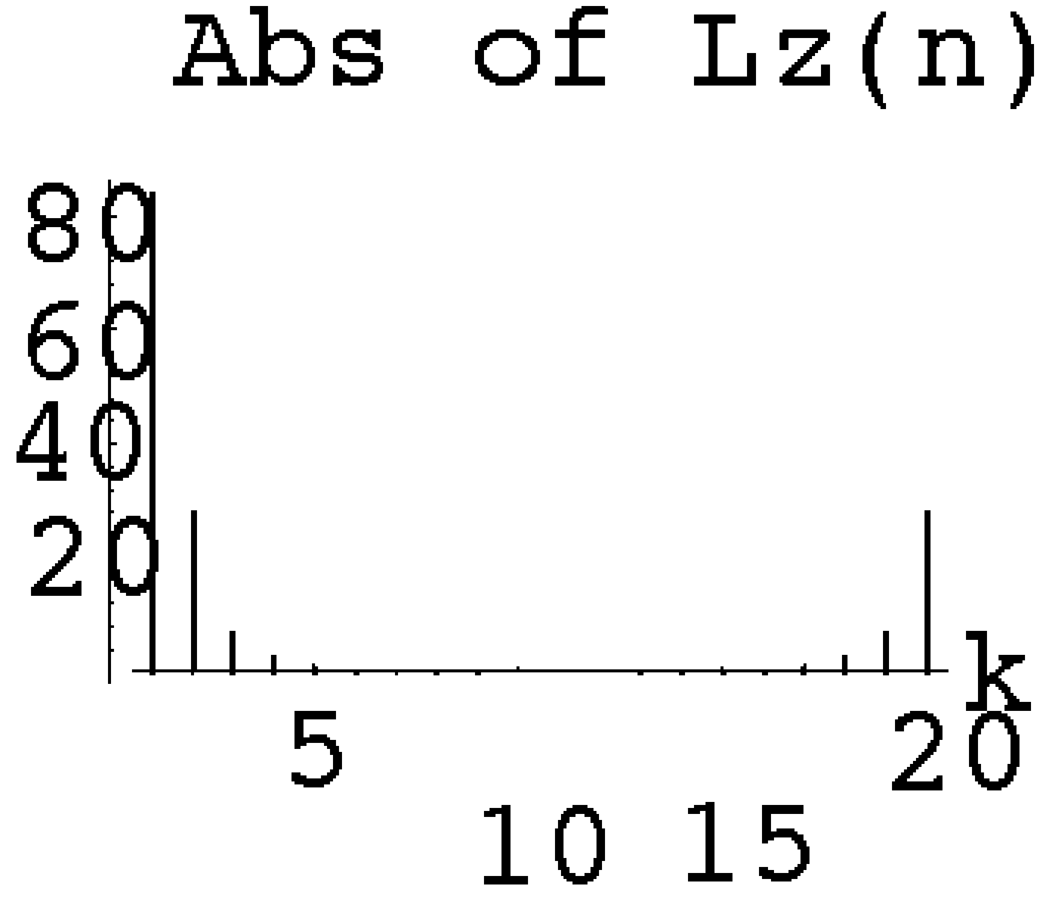
- Generic movements are made of smooth functions of time separated by instantaneous discontinuities (Marr).

- A simple motion - delimited by two discontinuities - can be approximated by the superimposition of frequency harmonics (FFT analysis)

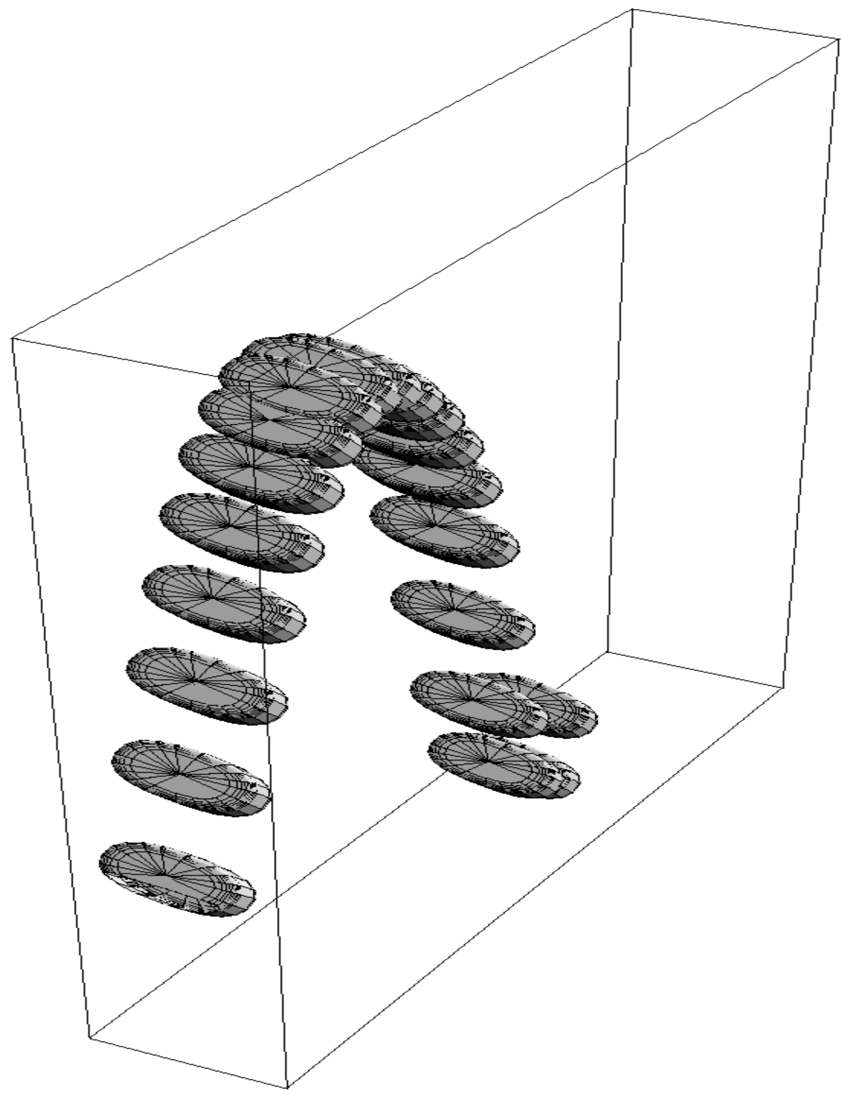
FFT Analysis Of A Simple Motion



Parabolic motion



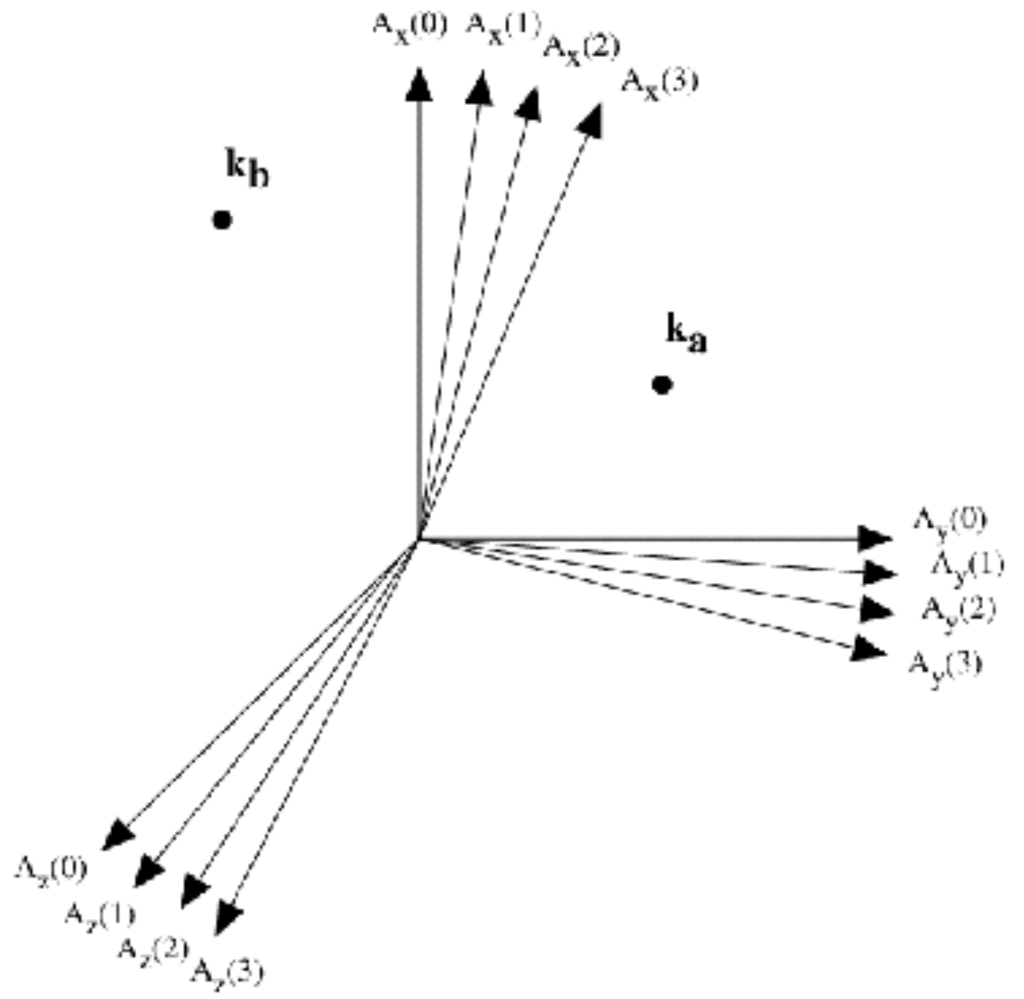
FFT of the motion



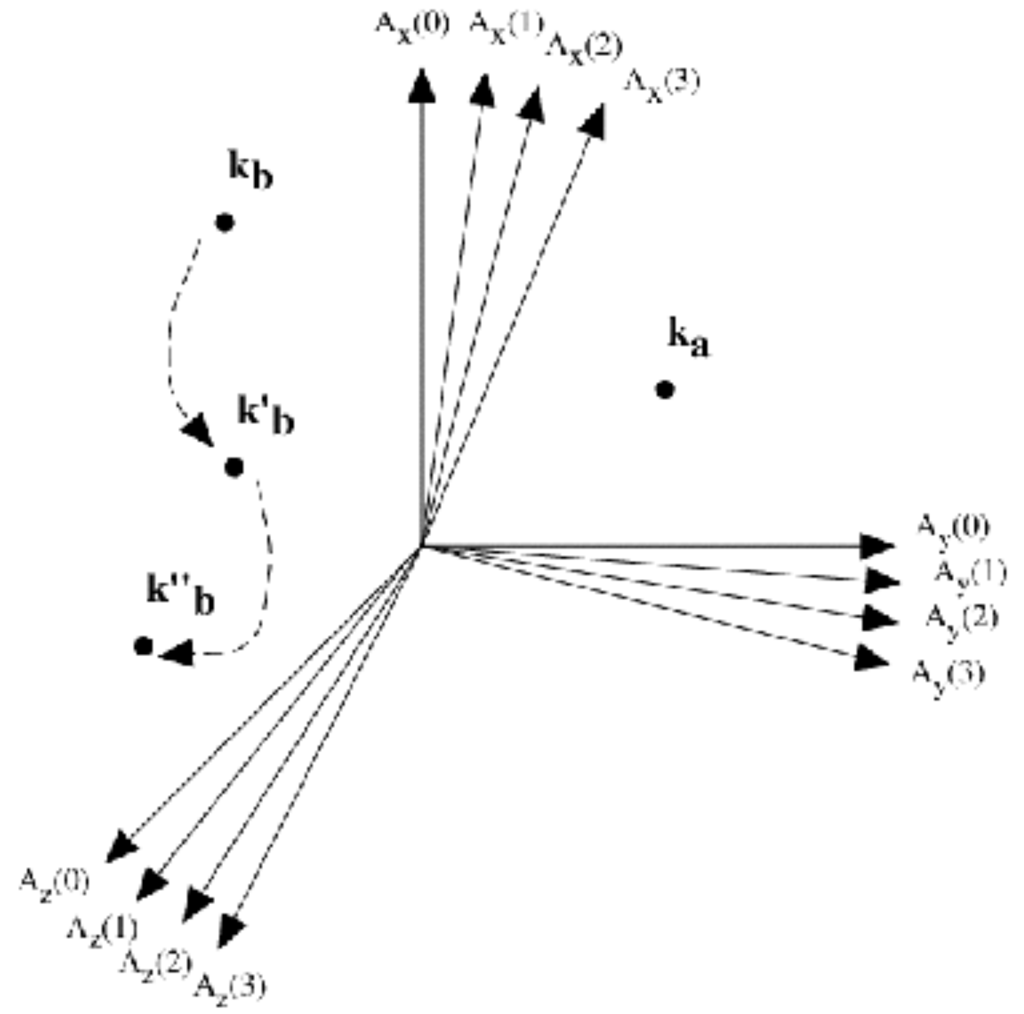
Recovered motion
by the first frequencies of FFT

Actions and Situations

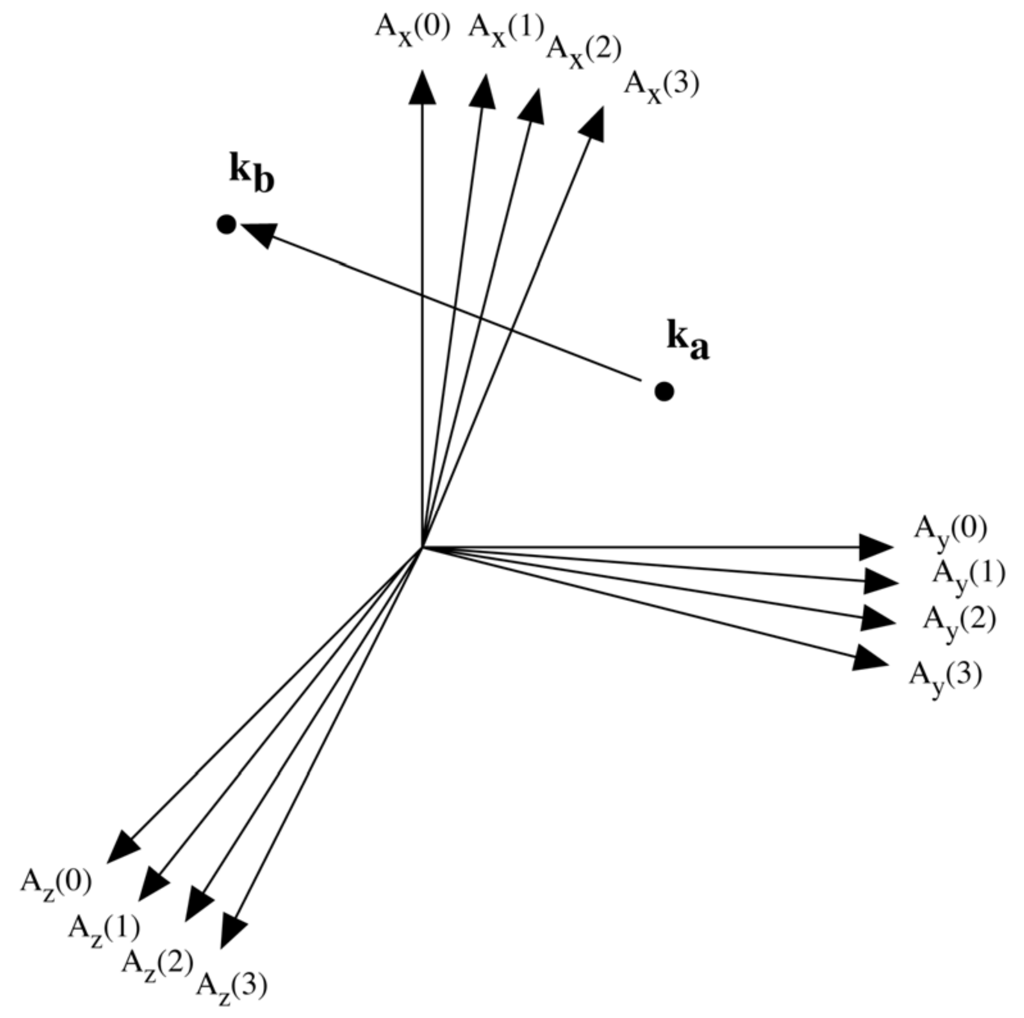
- A Situation is a configuration of points in CS: objects maintain their motions states



- An (instantaneous) Action is a scattering of points in CS: an event occurs, and some objects may change their motion state

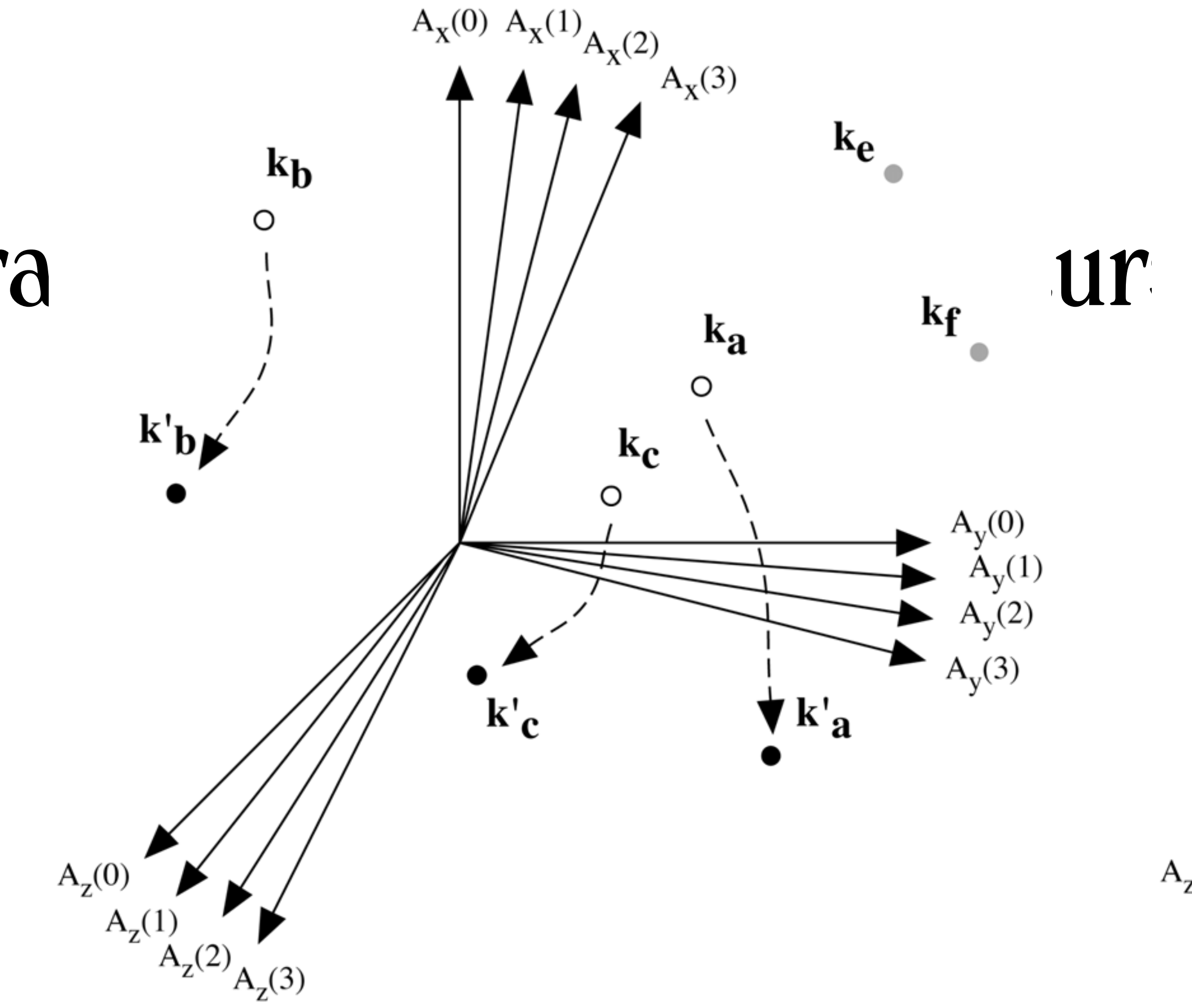


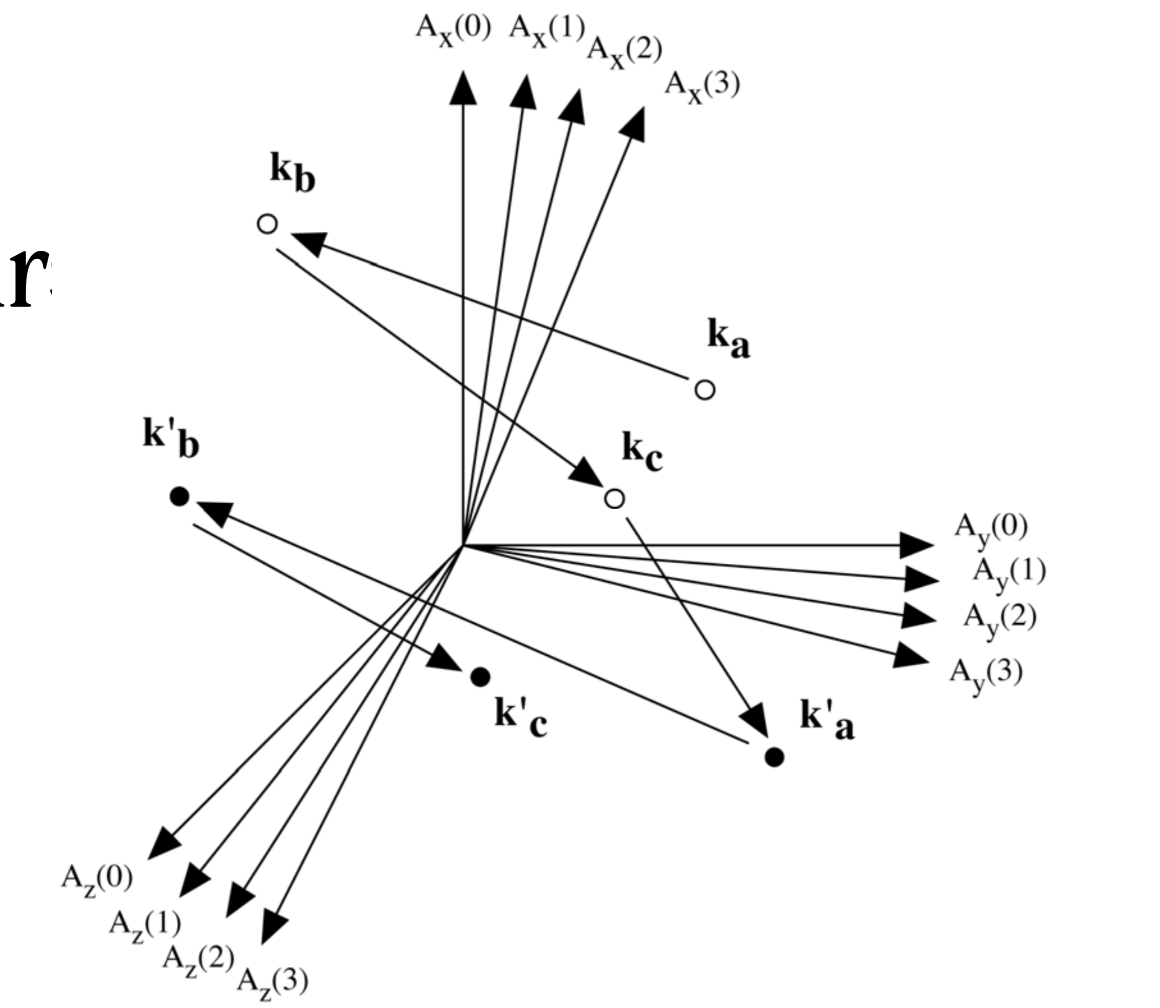
Dynamic focus of attention



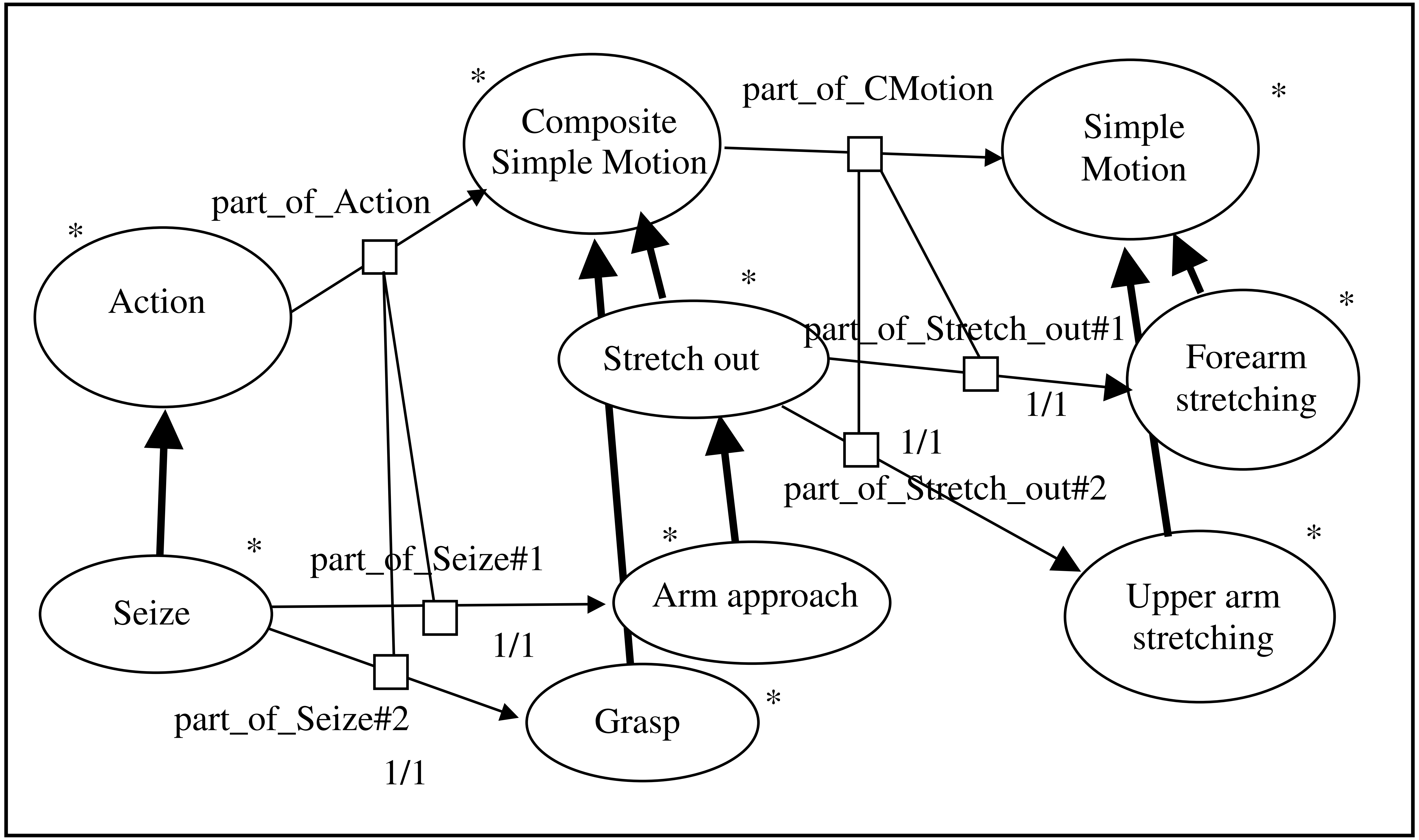
- Synchronic attention:
  scan operation in the same CS frame.

- Diachronic attention:
  Scan operation in subsequent CS fra ur.

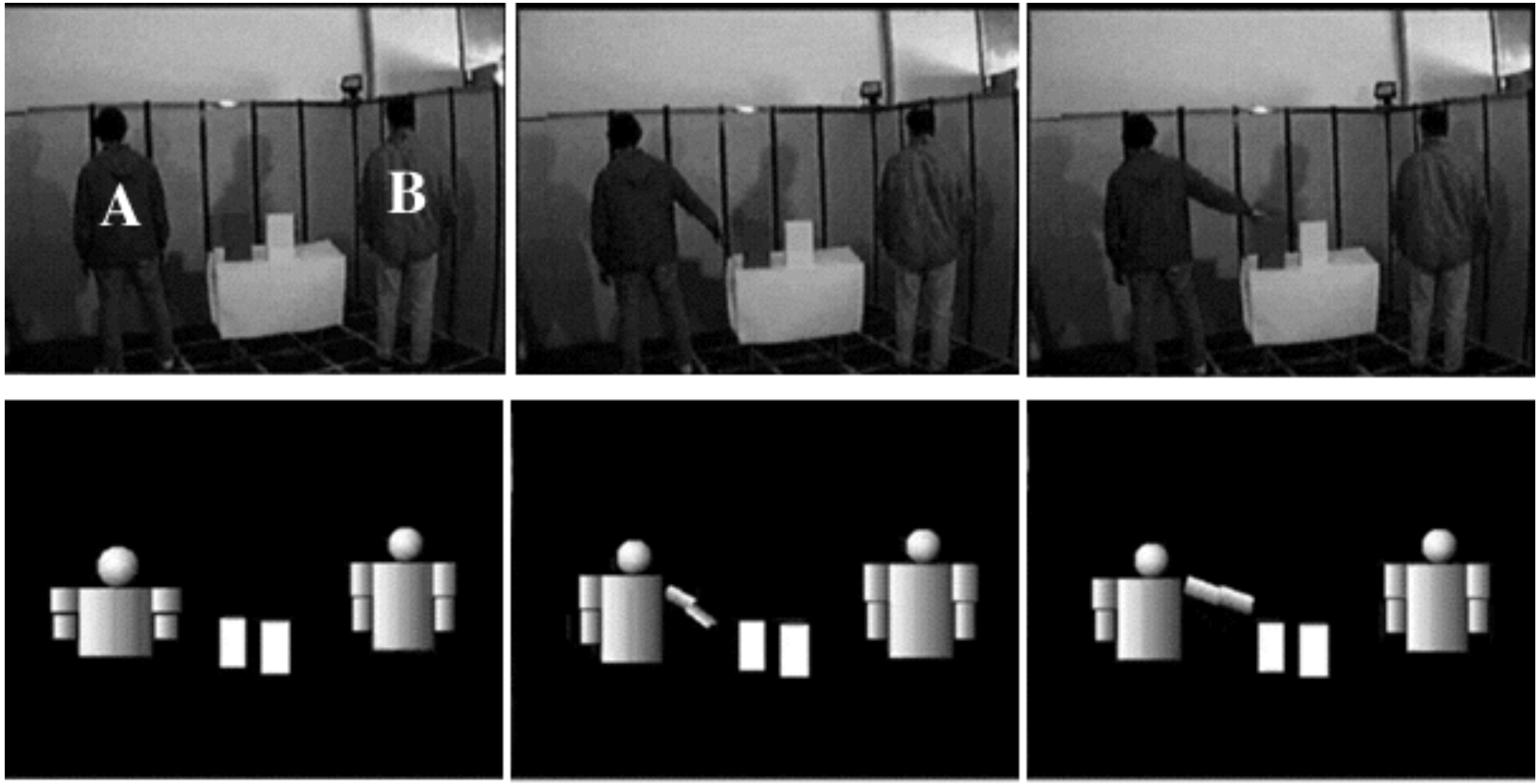




Terminological component

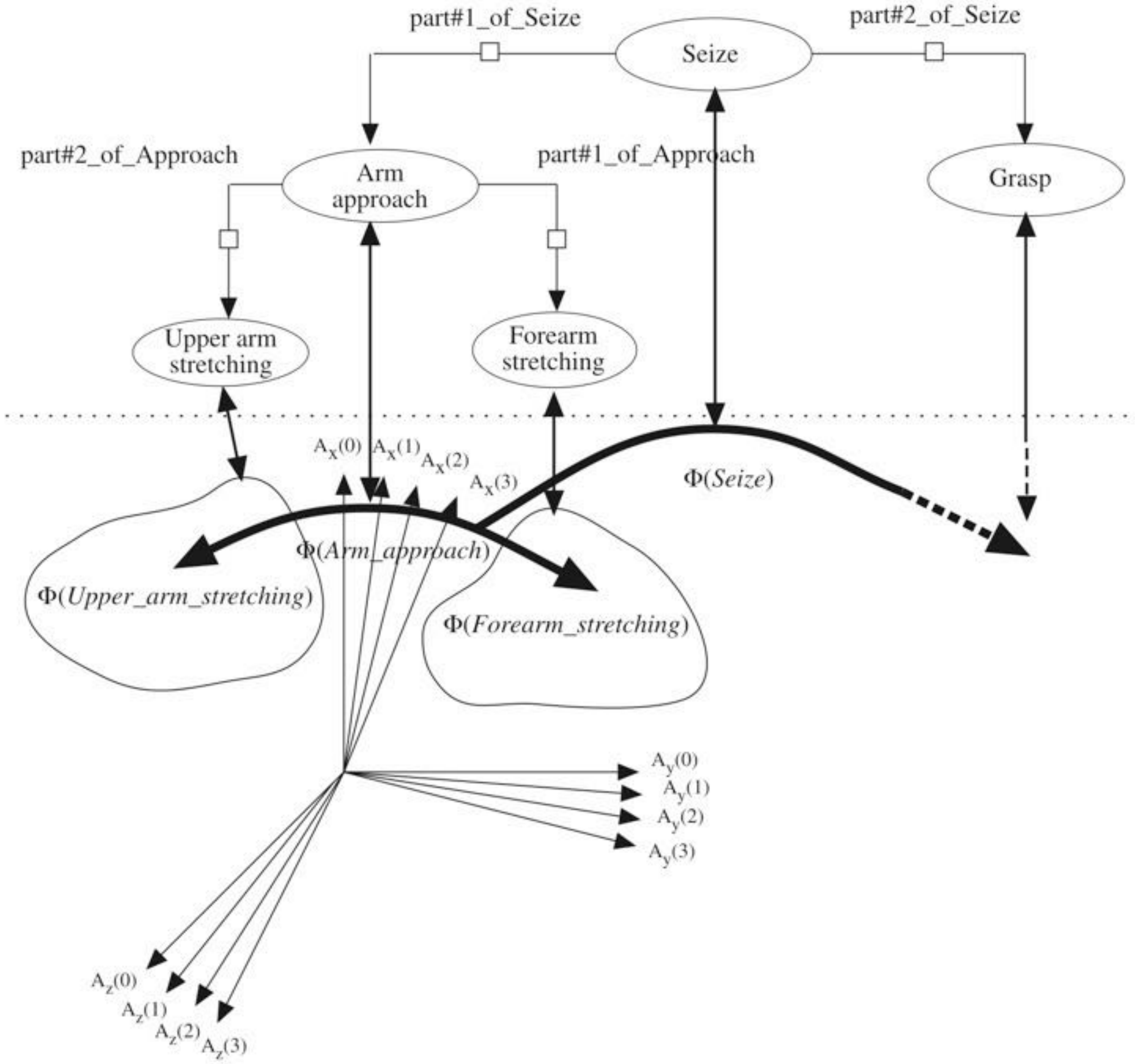


System at work

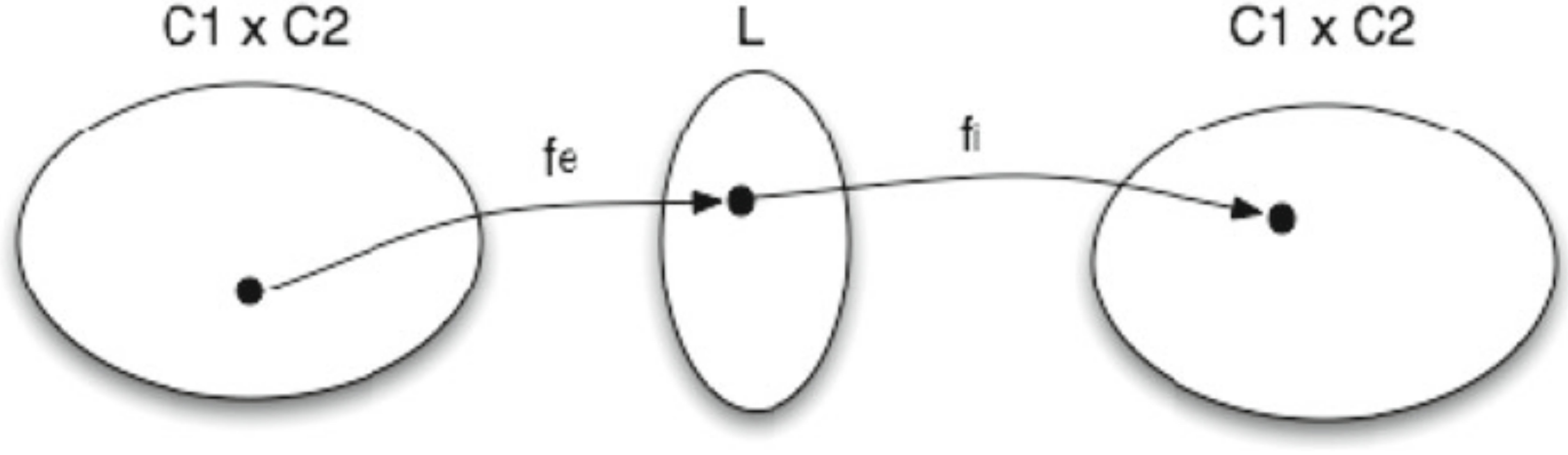


A seizes an object

Grounding Actions



Meeting of Minds

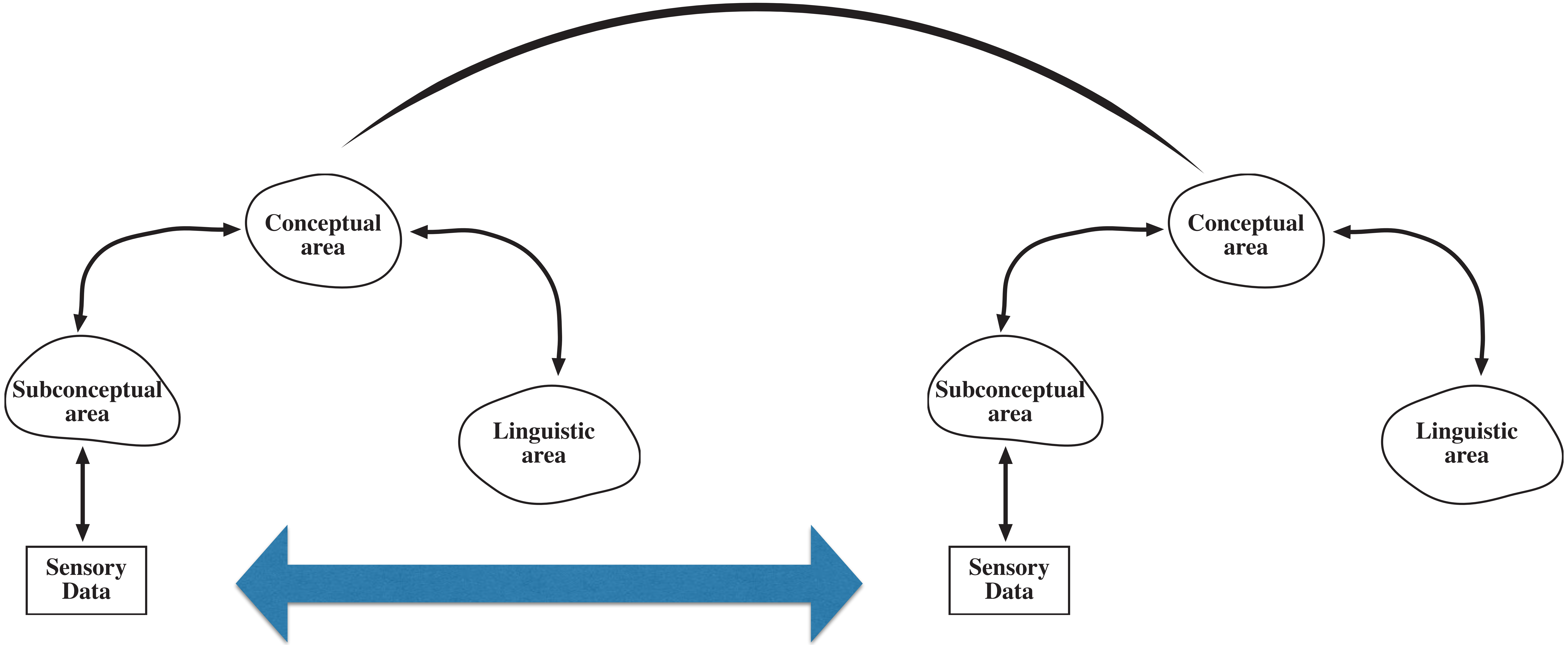


M. Warglien & P. Gärdenfors: Semantics, conceptual spaces, and the meeting of minds, Synthese (2013) 190:2165–2193

Grounding of Word Classes

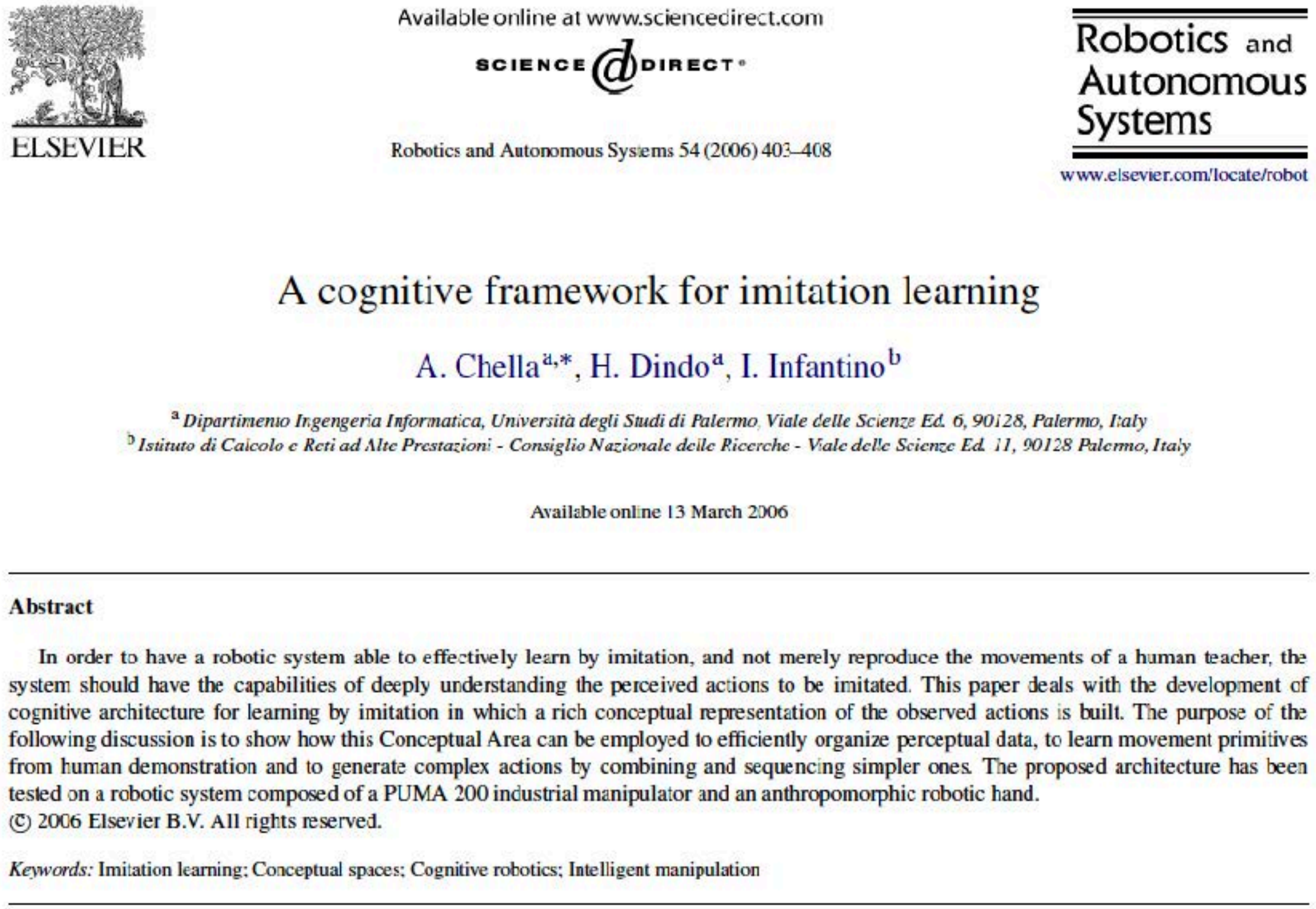
Concepts	Nouns
Properties	Adjectives
Dynamic properties	Verbs
Spatial Relations	Prepositions

Sharing CSs



Conceptual area
Subconceptual area
Linguistic area
Sensory Data
Conceptual area
Subconceptual area
Linguistic area
Sensory Data

Grounding Intentions



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Robotics and Autonomous Systems 54 (2006) 403–408

Robotics and Autonomous Systems

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A cognitive framework for imitation learning

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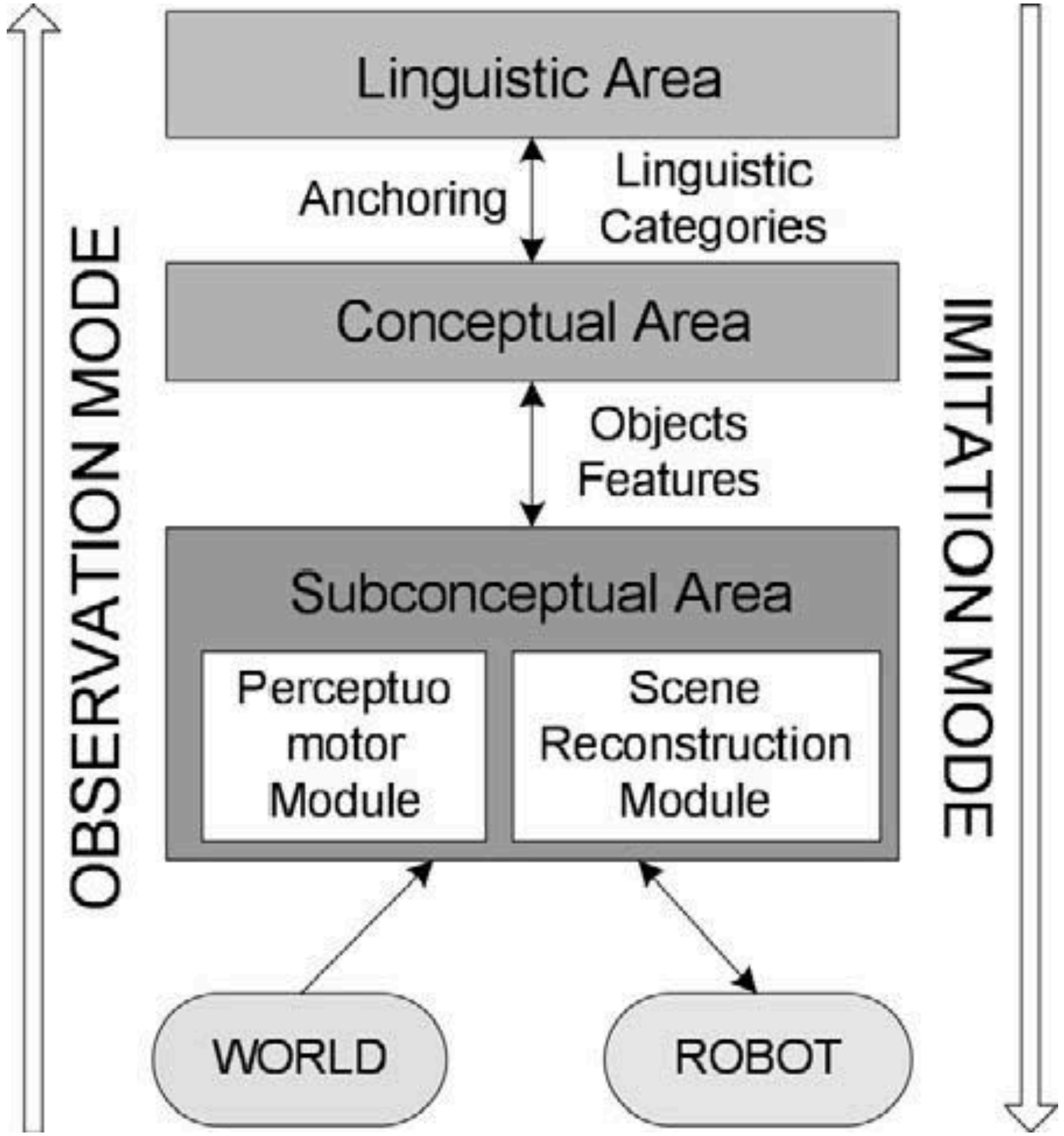
Available online 13 March 2006

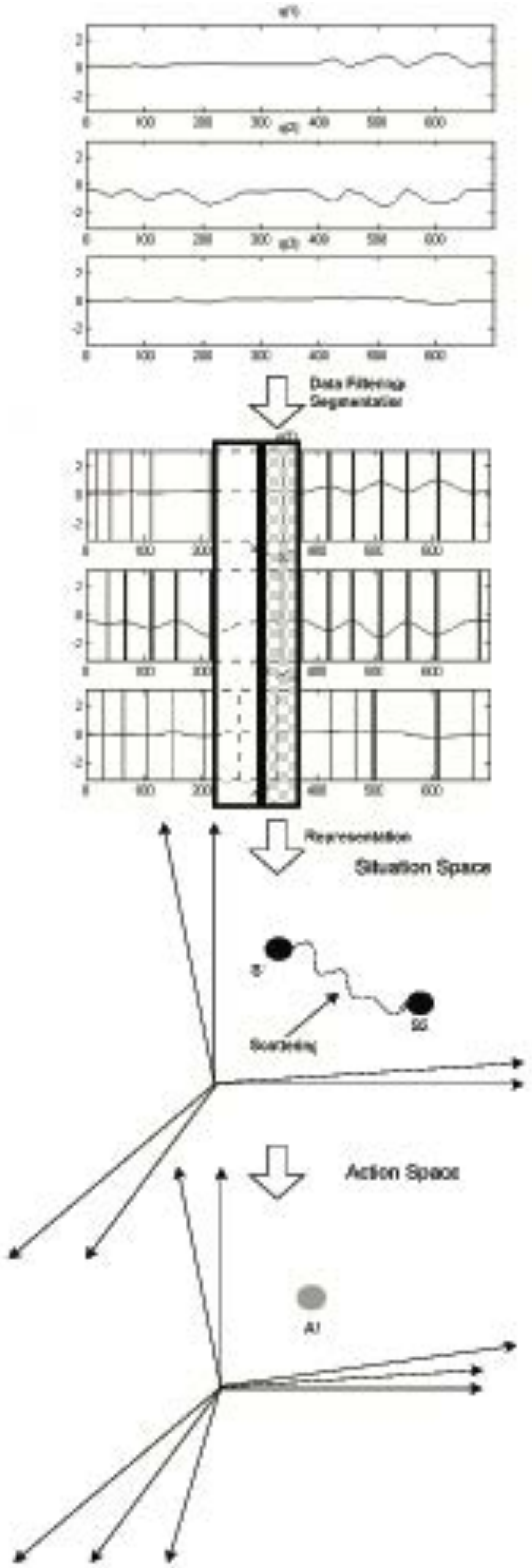
Abstract

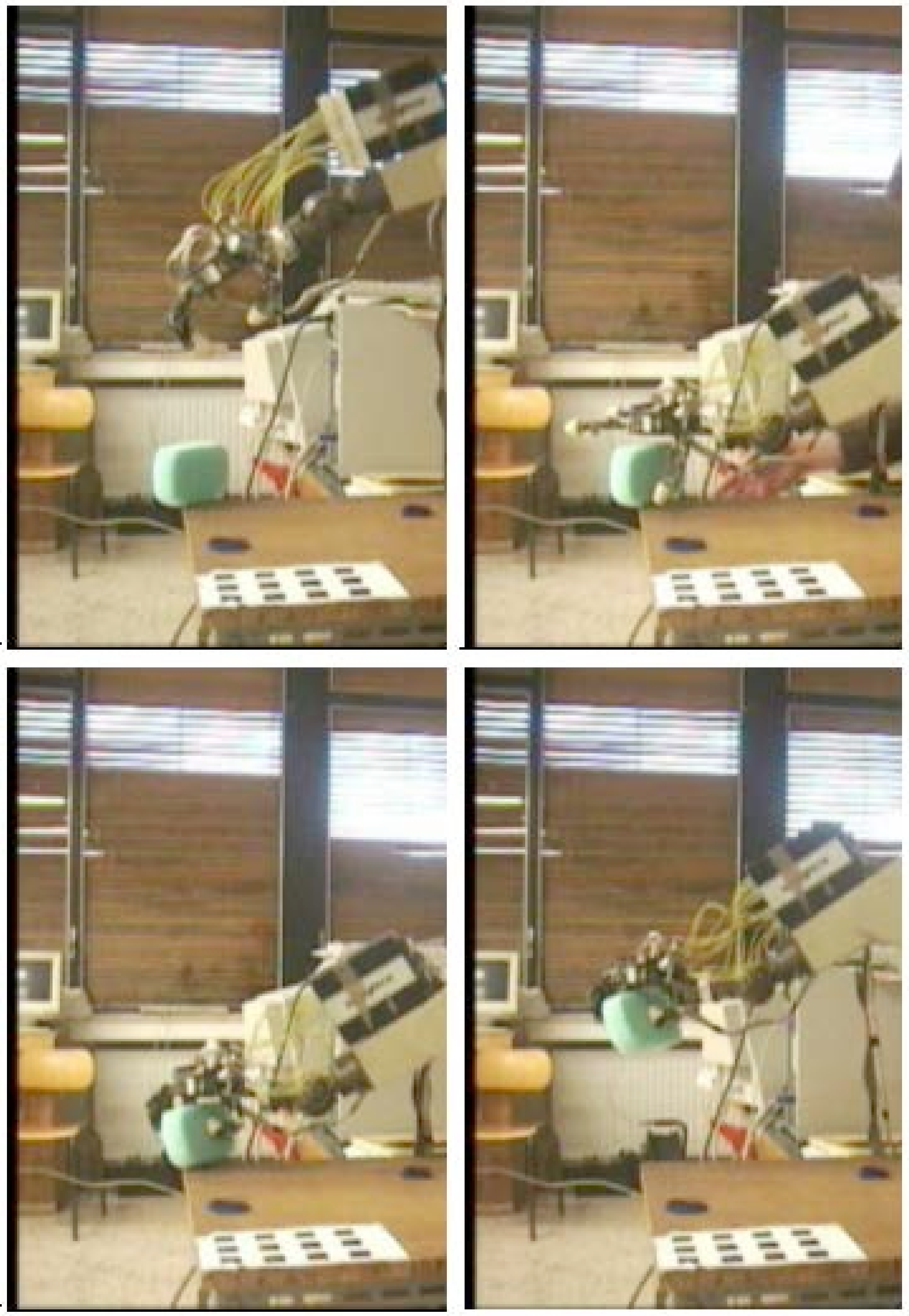
In order to have a robotic system able to effectively learn by imitation, and not merely reproduce the movements of a human teacher, the system should have the capabilities of deeply understanding the perceived actions to be imitated. This paper deals with the development of cognitive architecture for learning by imitation in which a rich conceptual representation of the observed actions is built. The purpose of the following discussion is to show how this Conceptual Area can be employed to efficiently organize perceptual data, to learn movement primitives from human demonstration and to generate complex actions by combining and sequencing simpler ones. The proposed architecture has been tested on a robotic system composed of a PUMA 200 industrial manipulator and an anthropomorphic robotic hand.

Keywords: Imitation learning; Conceptual spaces; Cognitive robotics; Intelligent manipulation

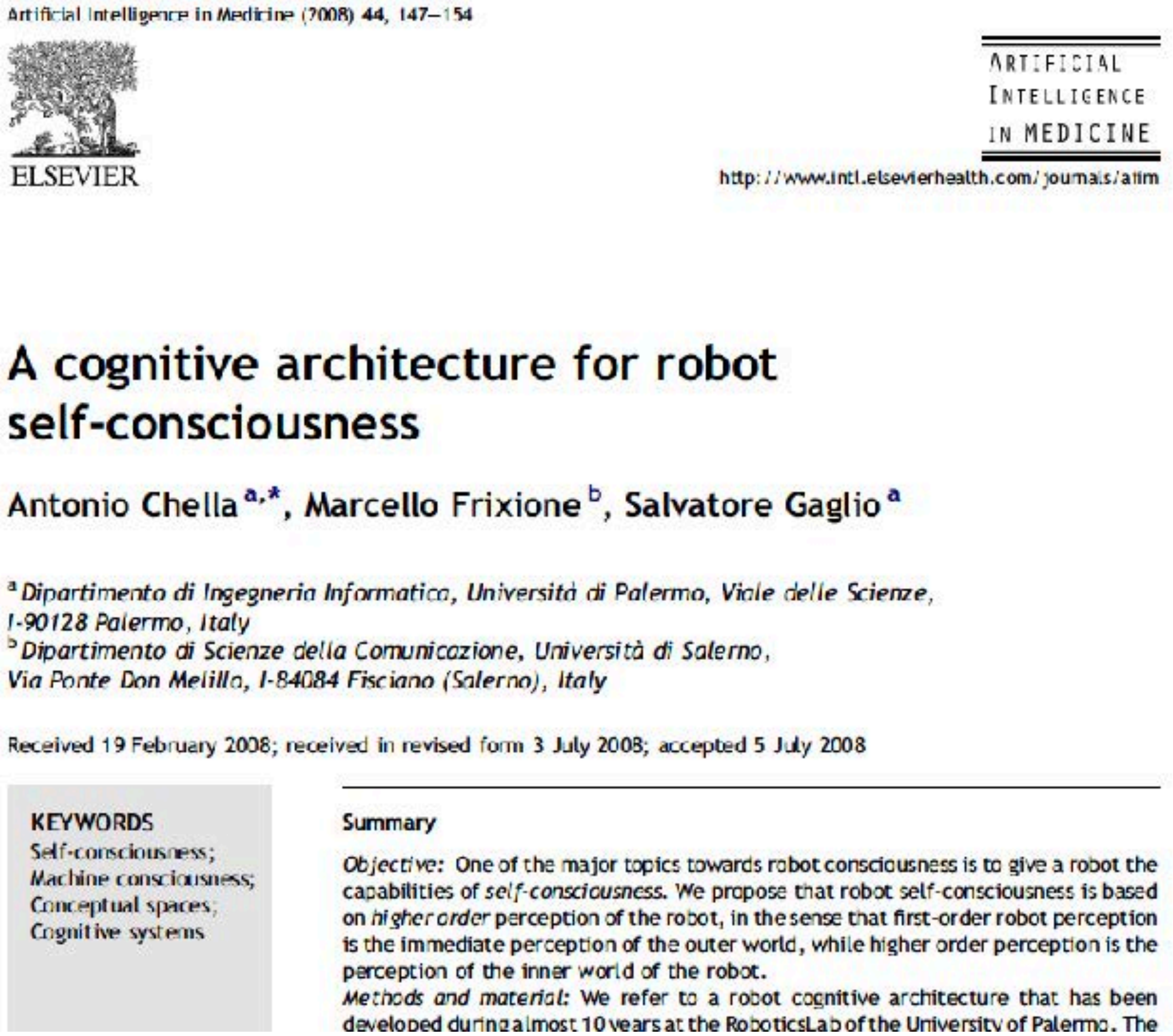



Frame #819-Joint Angles: 49.2999 -55.2373 -0.306789


Data Filtering
Segmentation
Representation
Situation Space
Action Space



Self Reflection: Meeting with Its Own Mind


Artificial Intelligence in Medicine (2008) 44, 147—154

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ARTIFICIAL INTELLIGENCE IN MEDICINE

http://www.intl.elsevierhealth.com/journals/aiim

A cognitive architecture for robot self-consciousness

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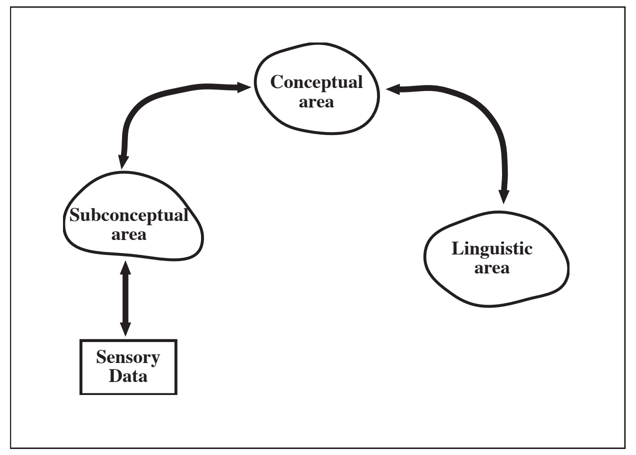
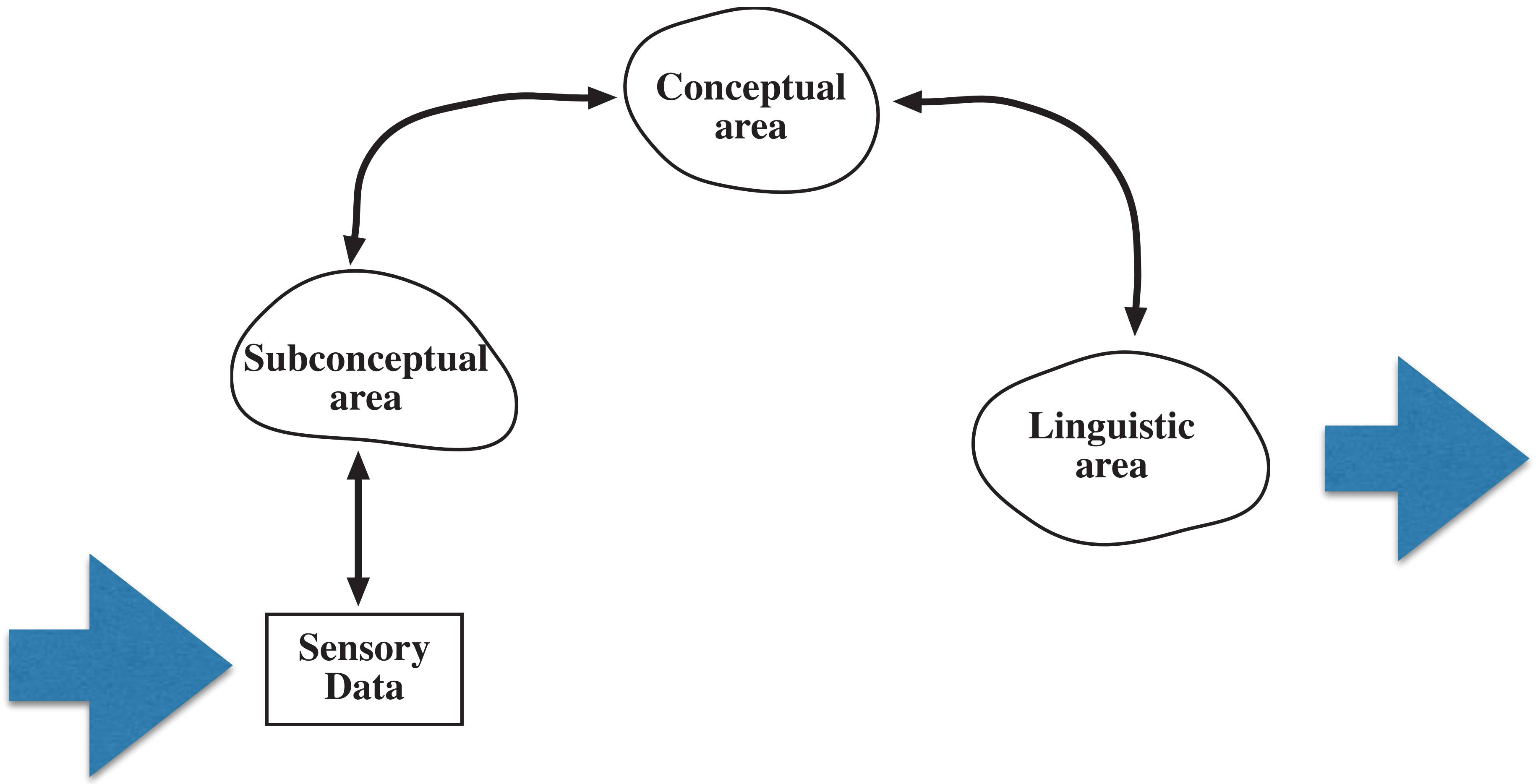
KEYWORDS
Self-consciousness;
Machine consciousness;
Conceptual spaces;
Cognitive systems

Summary

Objective: One of the major topics towards robot consciousness is to give a robot the capabilities of *self-consciousness*. We propose that robot self-consciousness is based on *higher order* perception of the robot, in the sense that first-order robot perception is the immediate perception of the outer world, while higher order perception is the perception of the inner world of the robot.
Methods and material: We refer to a robot cognitive architecture that has been developed during almost 10 years at the RoboticsLab of the University of Palermo. The

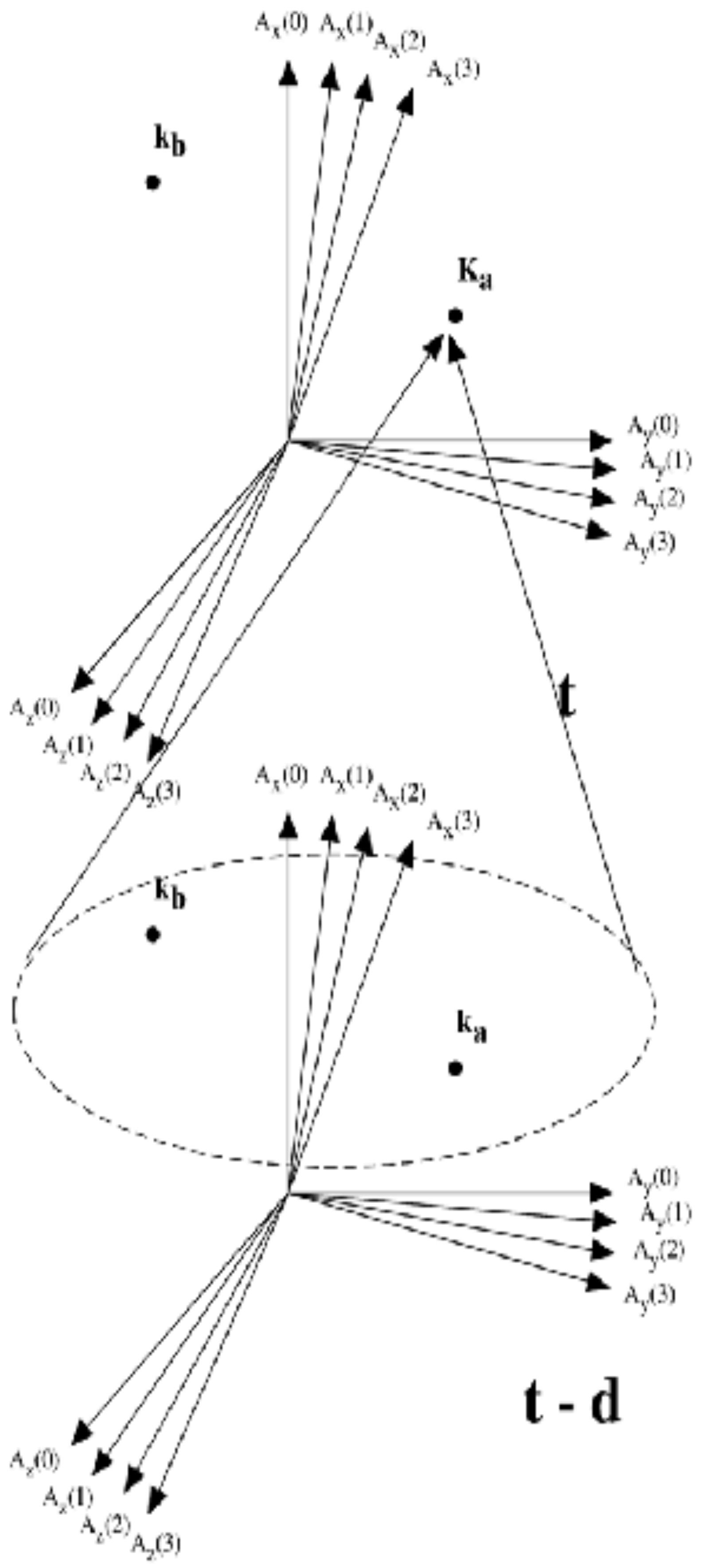


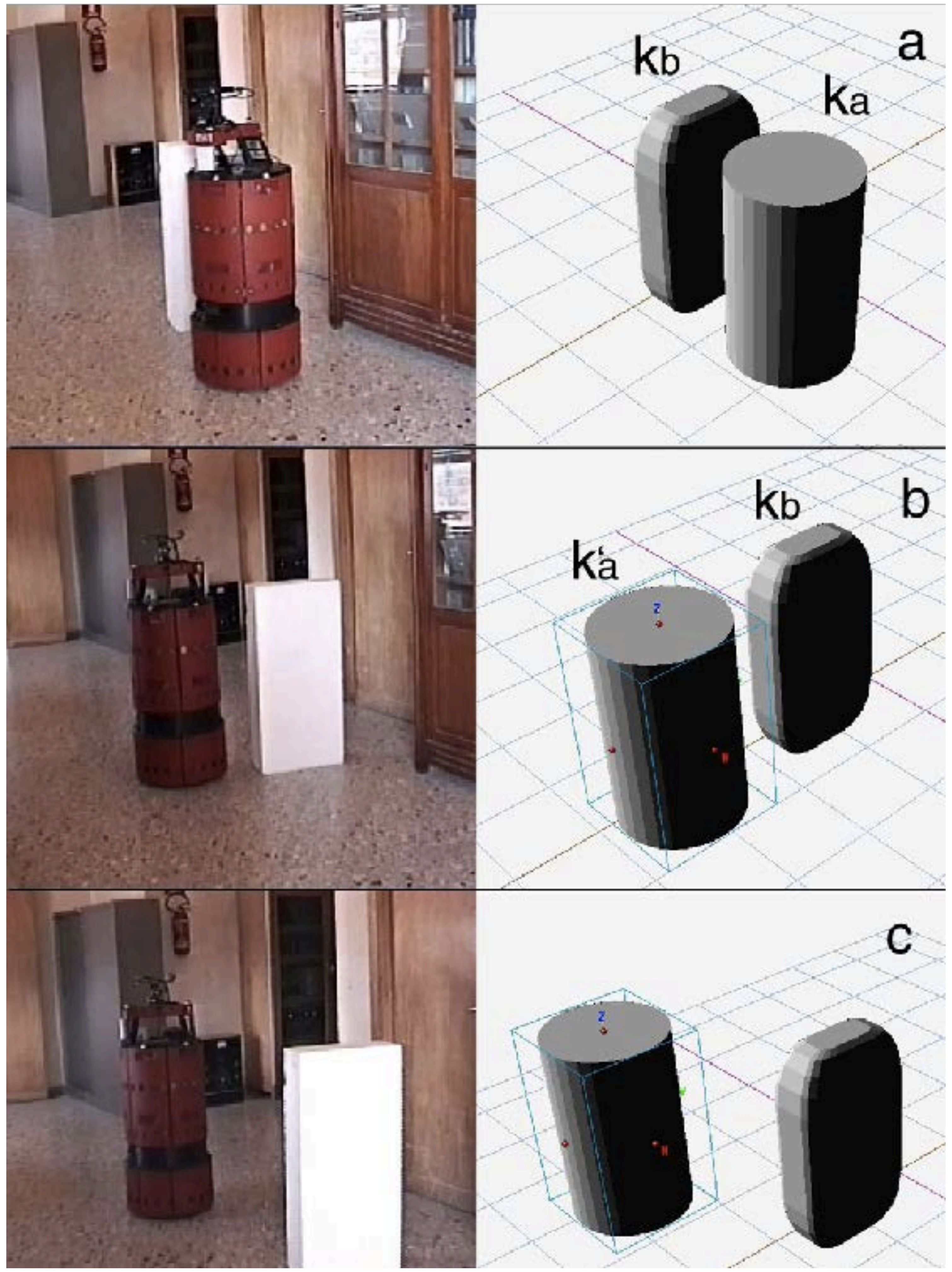


SELF(Robot)

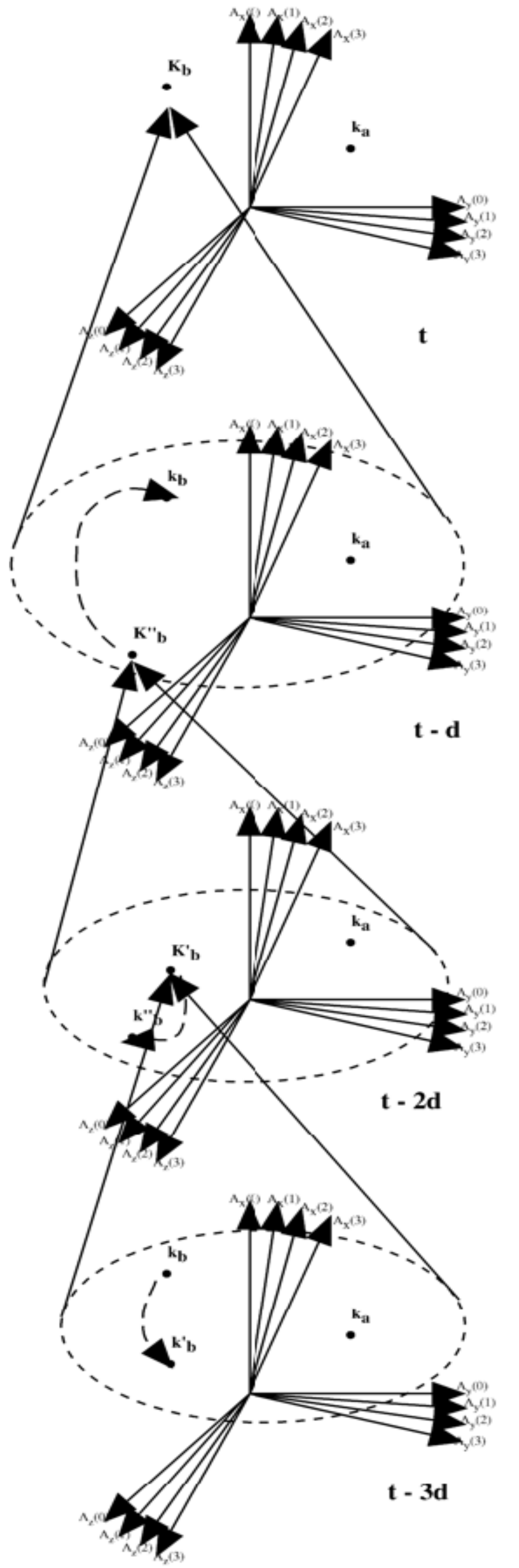
Grounding Second Order Concepts

- A second order perception at time **t** describes the perception of the conceptual space of the agent at time **t-d**.
- The agent perceives itself and its environment
- "I know I am / I am not able to do this"
- "I know that I don't know this"

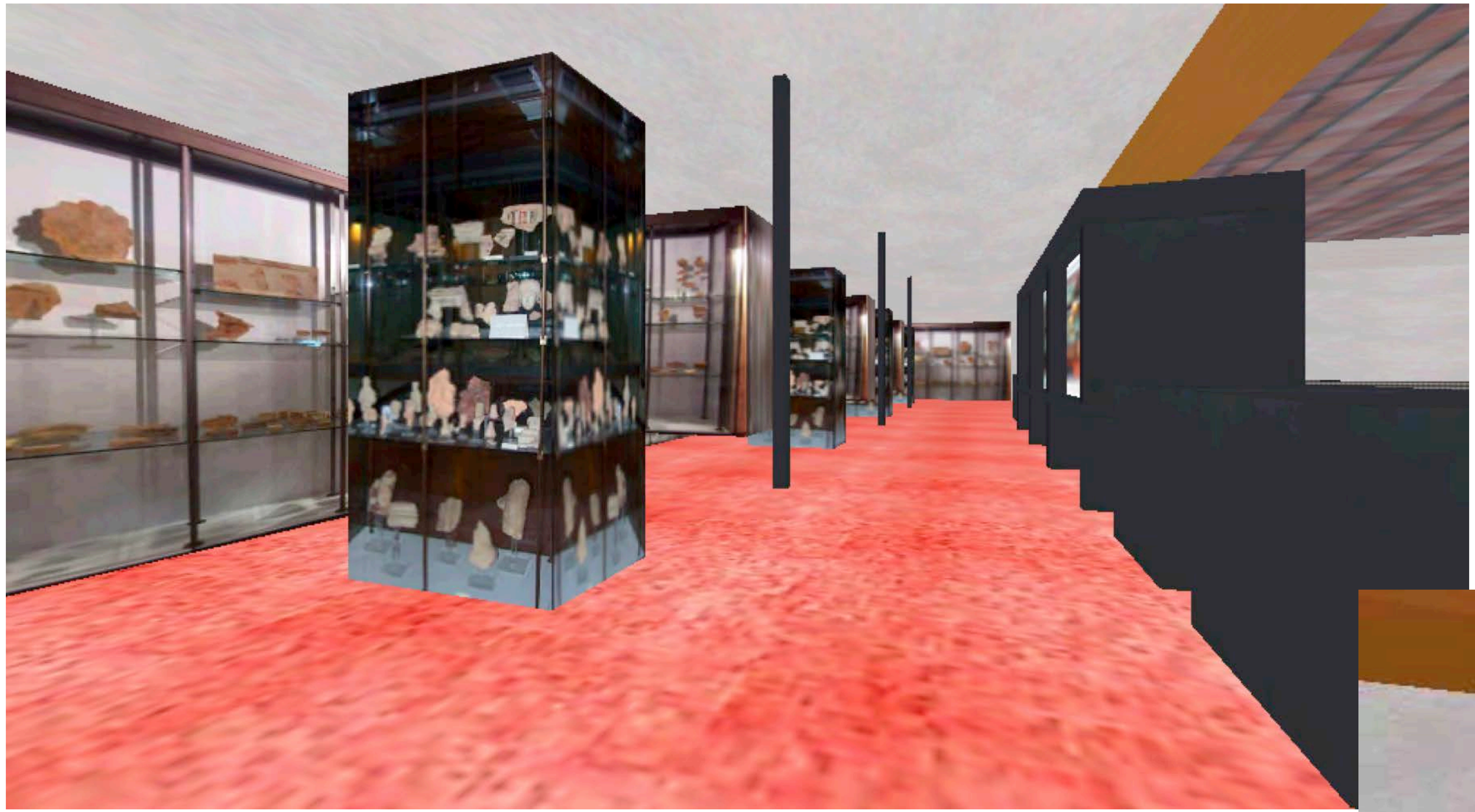




Higher Order Perceptions



- The robot self is generated and supported by the CS dynamics, in the sense that the system generates dynamically first-order, second-order and higher-order perceptions during its operations, and this mechanism of generation of higher-order perceptions is responsible for the robot of self-consciousness.



Cicerobot

Neurocomputing 72 (2009) 760–766

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The perception loop in *CiceRobot*, a museum guide robot

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A R T I C L E I N F O

Available online 5 November 2008

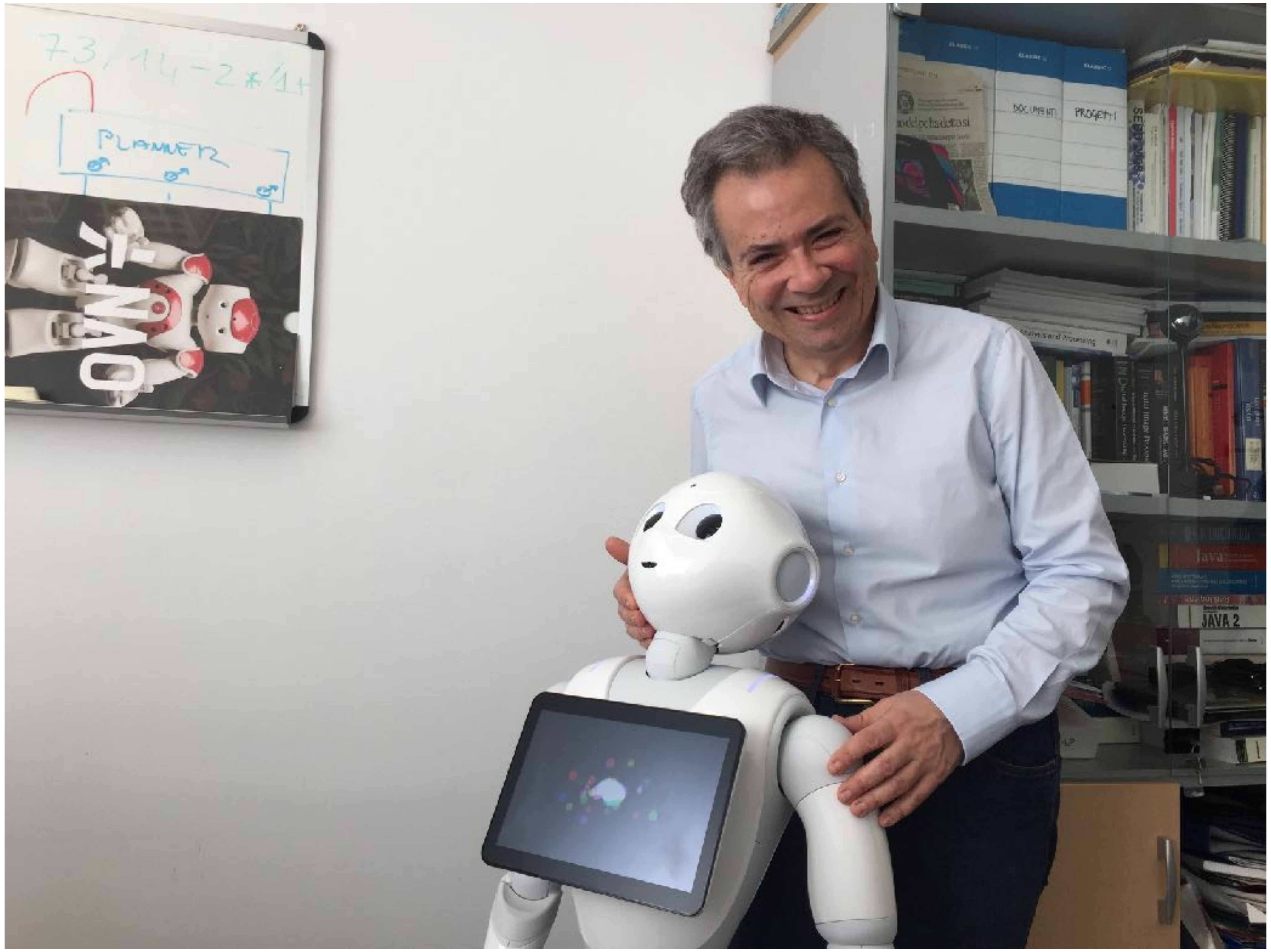
Keywords:
Perception loop
Machine perception
3D robot vision

A B S T R A C T

The paper discusses a model of robot perception based on a comparison loop process between the actual and the expected robot input sensory data generated by a 3D robot/environment simulator. The perception loop process is operating in *CiceRobot*, a functional robot architecture implemented on an autonomous robot RWI B21 offering guided tours at the Archaeological Museum of Agrigento, Italy.

A Robot Prototype

- To design and implement a prototype of the integrated computational model of the meeting of mind on a **Pepper** humanoid robot platform.



Take Home Message

- Conceptual Spaces: Intermediate between symbolic and sub symbolic representations
- Grounding:
  - Concepts
  - Actions
  - Intentions
  - Second Order Concepts

Thank you for your grounded attention!

- Marcello Frixione
- Salvatore Gaglio
- Antonio Lieto
- Haris Dindo
- Ignazio Infantino

Doodle by Jorge Cham
creator of PhD Comics

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