Cognitive Vision
Past, Present, and Future

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Cognitive Vision: Past, Present, and Future

European Research Network for Cognitive Computer Vision Systems

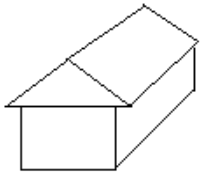
www.ecvision.info

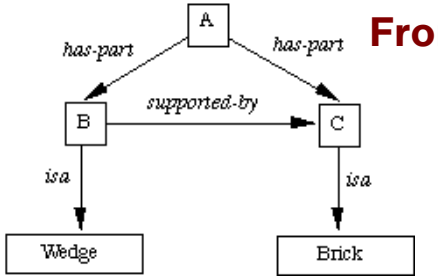
Cognitive Vision: Past, Present, and Future

Computer Vision in 1965

The Blocks World

Roberts 65





From Winston '75

Hongeng 03

Computer Vision in 2003

Automatic Event Detection

?

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Hongeng 03

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4 Decades of Computer Vision

60s

Blocks World / Micro Worlds

70s

Model-based vision

80s

Hierarchical modular information processing
Mathematically-sound robust early vision

90s

Computational projective geometry
Appearance-based vision

00s

Probabilistic techniques, machine learning, & video interpretation

Significant Achievements

- Machine vision of industrial inspection
- Analysis of video data for remote monitoring of events
- Image analysis to facilitate special effects in the film industry

The Ultimate Goal

- General-purpose vision system with the robustness and resilience of the human visual system

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H. Bülthoff, Max Planck Institute, Tübingen

The Ultimate Goal

- General-purpose vision system with the robustness and resilience of the human visual system

- As elusive as ever!
- The latest answer:

Cognitive Computer Vision

Cognitive Vision – What's That?

Cognitive Vision – What's That?

'Cognitive computer vision is concerned with integration and control of vision systems using explicit but not necessarily symbolic models of context, situation and goal-directed behaviour. Cognitive vision implies functionalities for knowledge representation, learning, reasoning about events & structures, recognition and categorization, and goal specification, all of which are concerned with the semantics of the relationship between the visual agent and its environment.'

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Cognitive Vision – What's That?

'Cognitive computer vision is concerned with integration and control of vision systems using **explicit** but not necessarily symbolic **models** of **context**, **situation** and **goal-directed behaviour**. Cognitive vision implies functionalities for **knowledge representation**, **learning**, **reasoning** about **events** & **structures**, **recognition** and **categorization**, and **goal specification**, all of which are concerned with the semantics of the relationship between the visual agent and its environment.'

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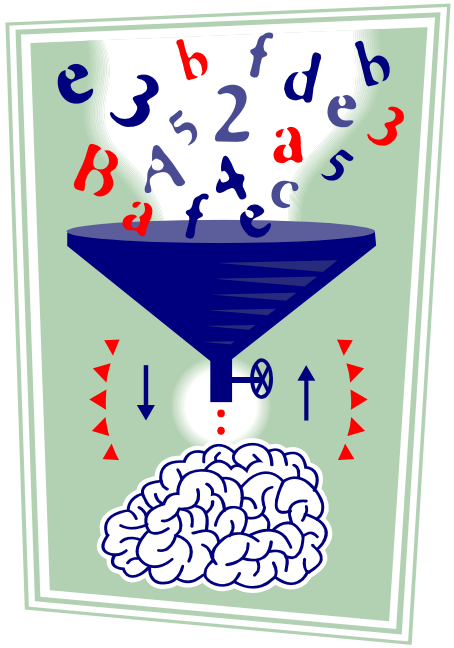
But ..... Not Everyone Agrees!



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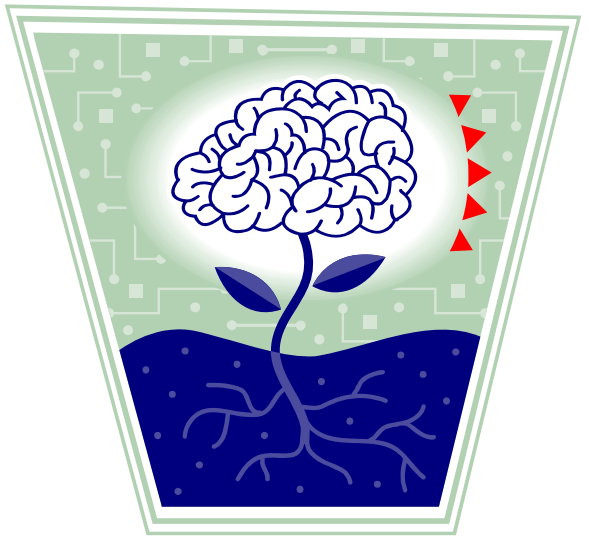

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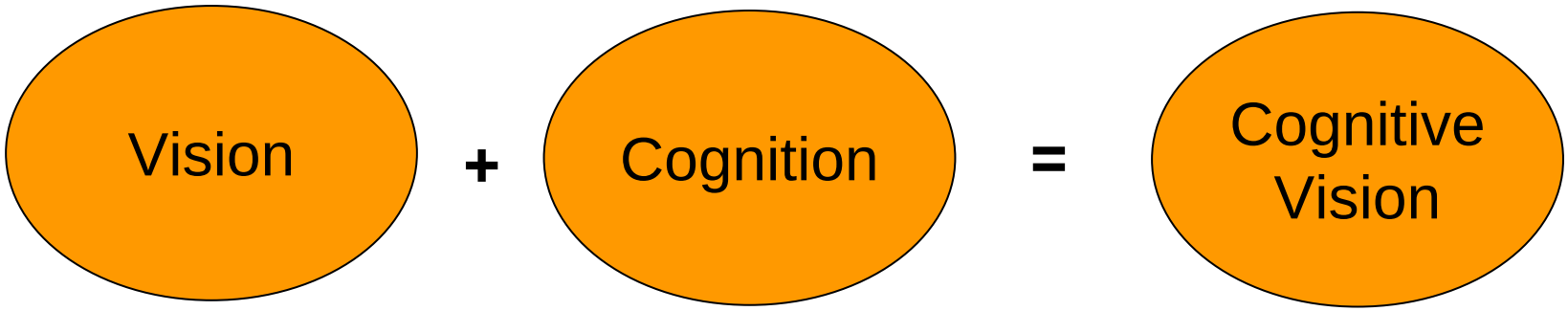
Can we split cognitive vision?



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Who Do We Ask?

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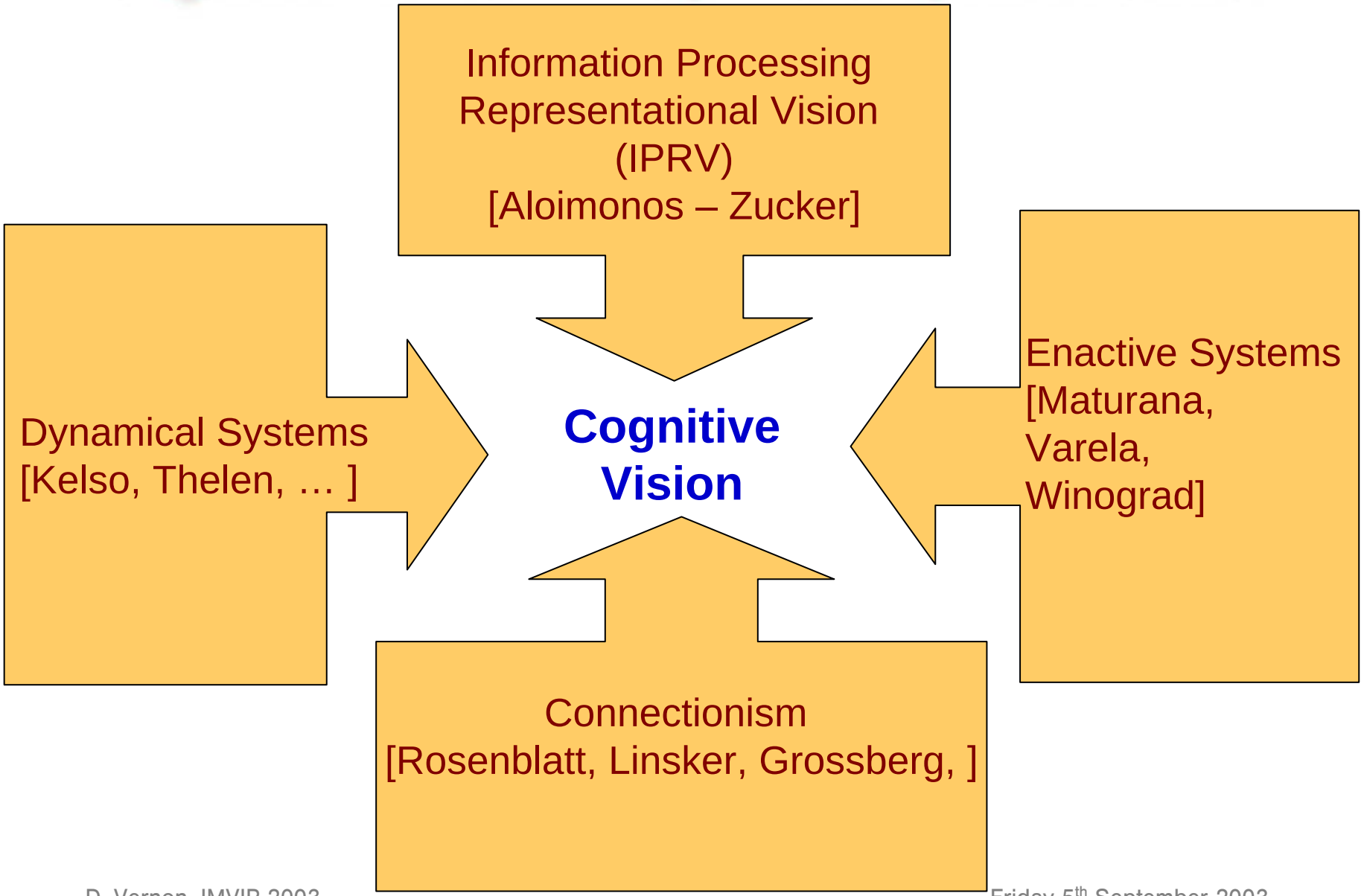

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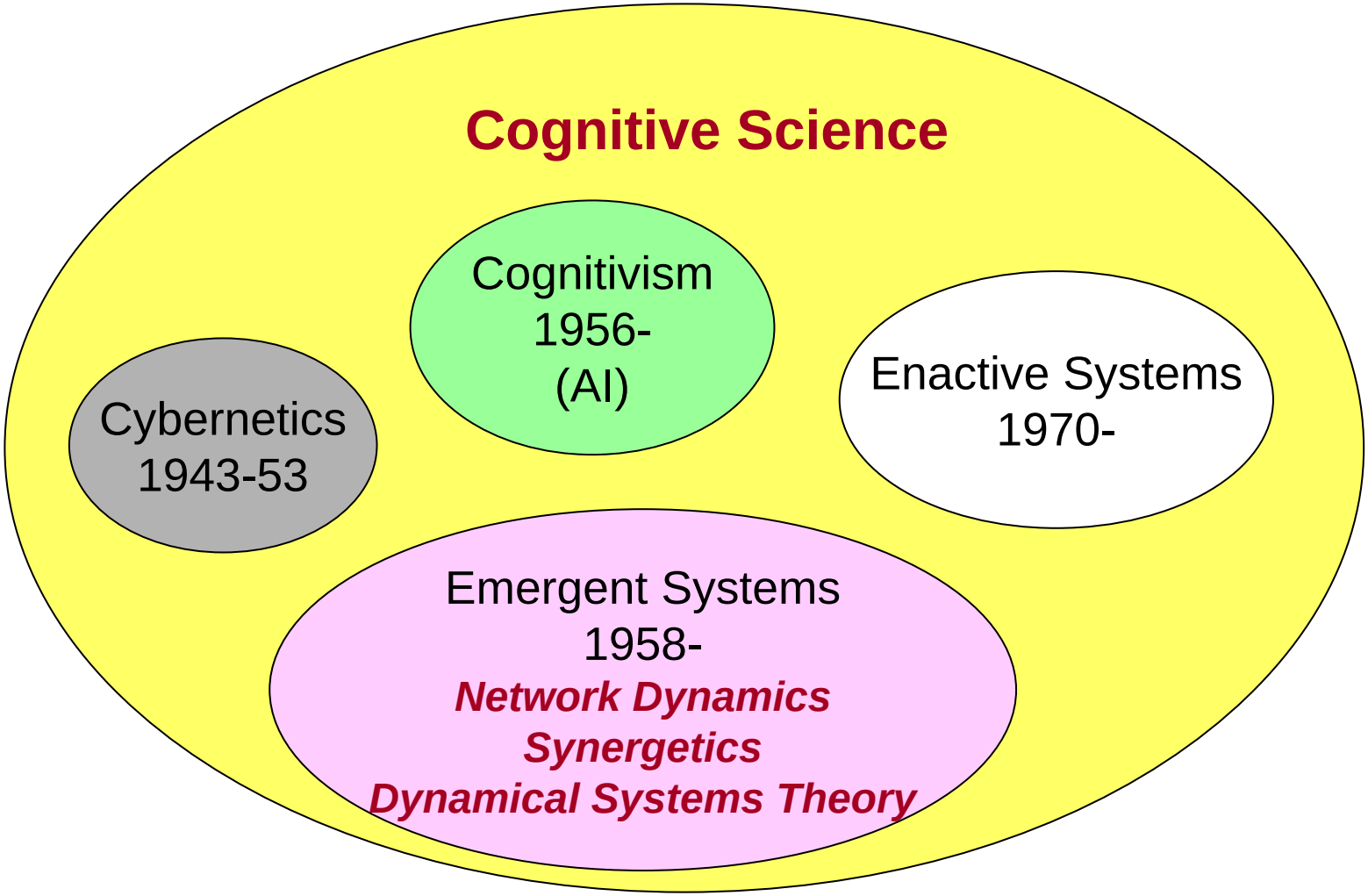

[Varela 88]

Cognitivism, Cognitive Science, and Information Processing

- Artificial intelligence is the study of complex information processing problems that often have their roots in some aspect of biological information processing [Marr '77]
- Cognitive science is a term used to describe approaches to the study of cognition which are 'information processing' in foundation and utilize symbol manipulation approach [Haugland '82]
- 'There is something close to a working consensus among cognitive scientists that intelligence can be characterized as computations over data structures or representations' [Pinker '84]
- Information processing paradigm of human cognition in cognitive science: structures for storing information & processes for transferring information from one structure to another [Kihlstrom '87]
- Contemporary cognitive science, for the most part, asserts that mental processes involve computations defined over internal representations [Kelso '95]

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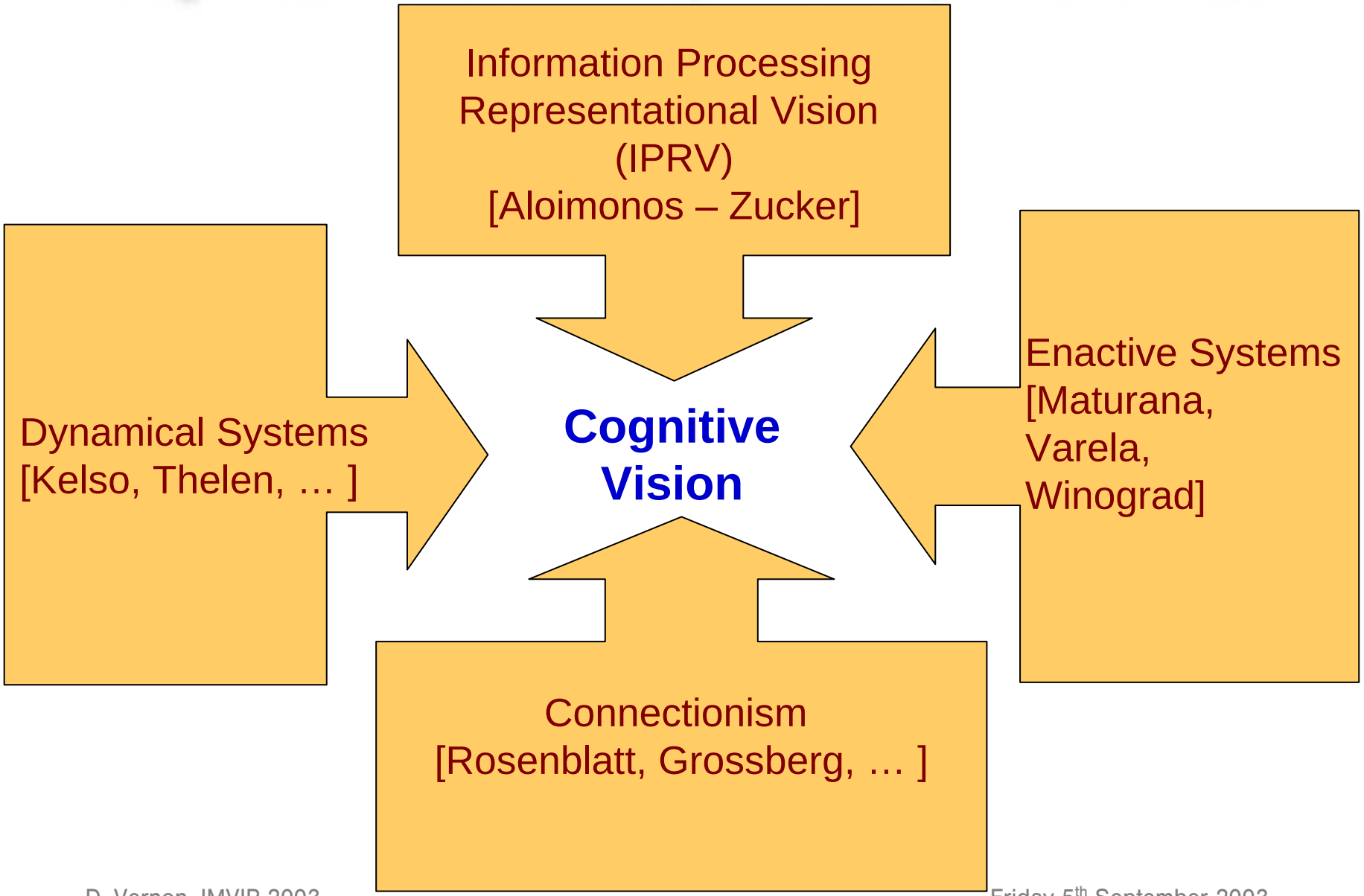

Different Facets of Cognitive Vision

Information Processing Representational Vision

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1962	Hough	Hough Transform
1965	Roberts	The first vision system: blocks world image analysis
1968	Guzman	Analysis of polyhedral objects
1970	Prewitt	Edge Detection
1971	Huffman	Blocks world: interpretation of line drawing of polyhedra
1971	Binford	Generalized cylinders
1971	Land	Computation of lightness
1971	Rosenfeld & Thurston	Multiscale edge detection

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1972	Waltz	Blocks World
1973	Shirai	Knowledge-based vision: context-sensitive line finder for recognition of polyhedra
1973	Fu	Syntactic pattern recognition
1975	Bajscy	Knowledge-based vision: context-dependent image filtering
1975	Badler	Scene analysis - Linguistic interpretation of natural scenes

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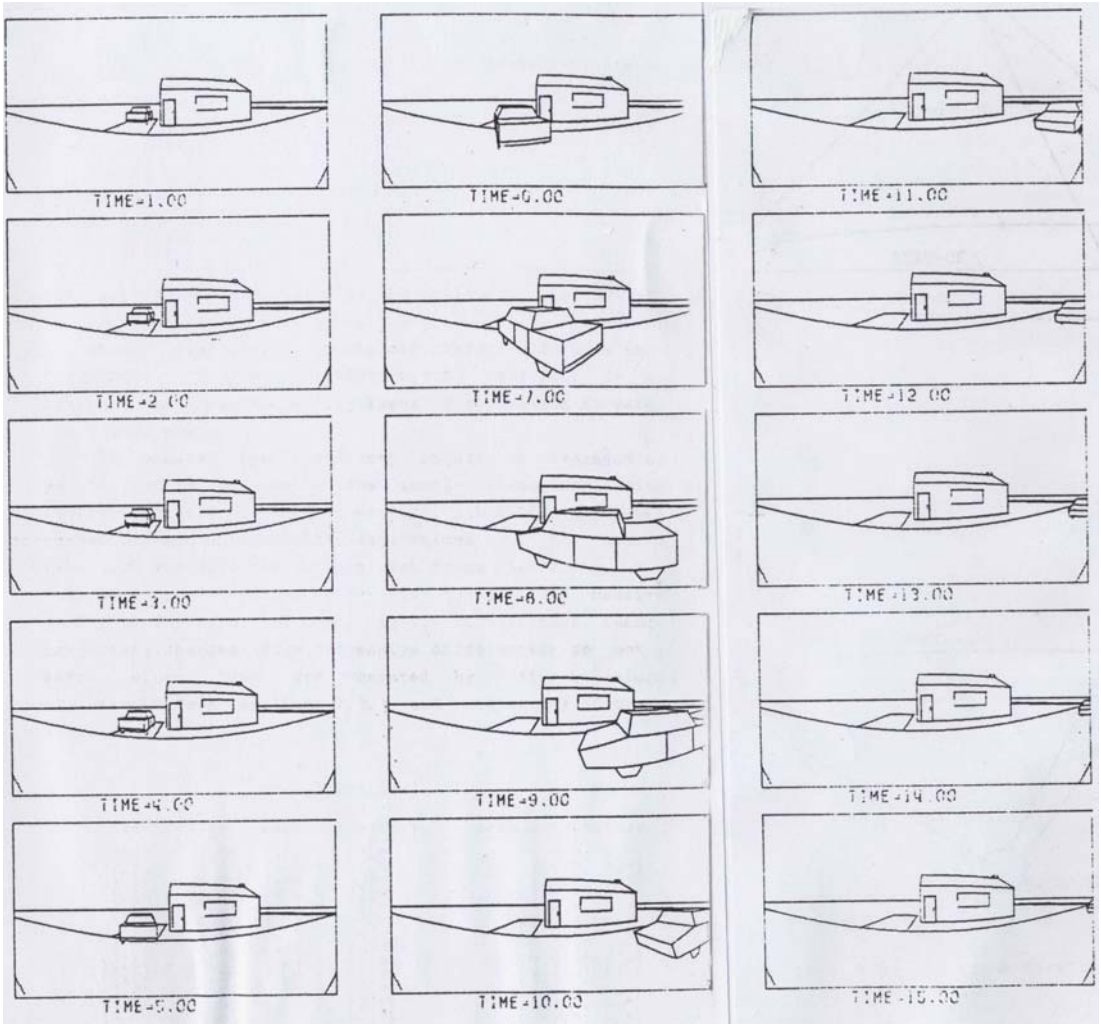

Scene analysis: linguistic interpretation of natural scenes. Badler 1975

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1975 **Keating et al.**
First explicit use of epipolar constraints in stereo matching

1975 **Horn** Shape from shading

1976 **Marr** Early visual processing – the primal sketch

1976 **Marr and Poggio**
Stereopsis

1976 **Zucker** Texture

1977 **Tenenbaum & Barrow**
Knowledge-based vision:
Interpretation-guided segmentation

1978 **Hanson and Riseman**
Knowledge-based vision: Scene interpretation

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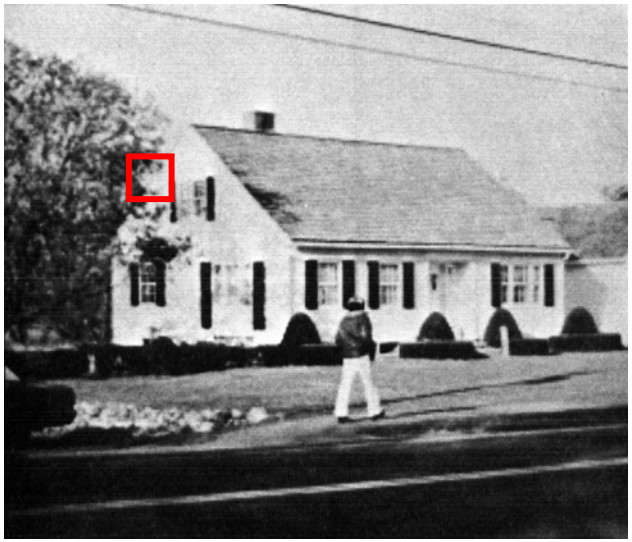

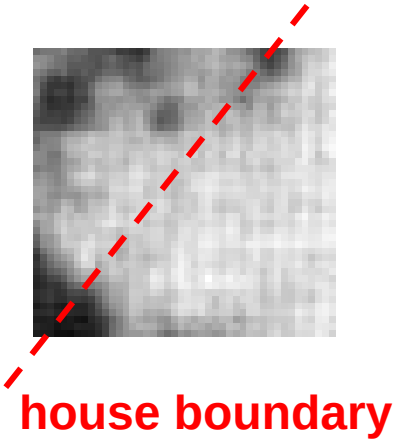

Hanson and Riseman 78

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1978 Marr Representing visual information (2 ½ D Sketch)

1978 Marr & Nishihara
Spatial organization of 3-D structure

1978 Barrow & Tenenbaum
Intrinsic Images

1979 Gibson Ecological Vision

1979 Tsotos Motion classification (ventricular motion)

1979 Brooks ACRONYM – Model based vision

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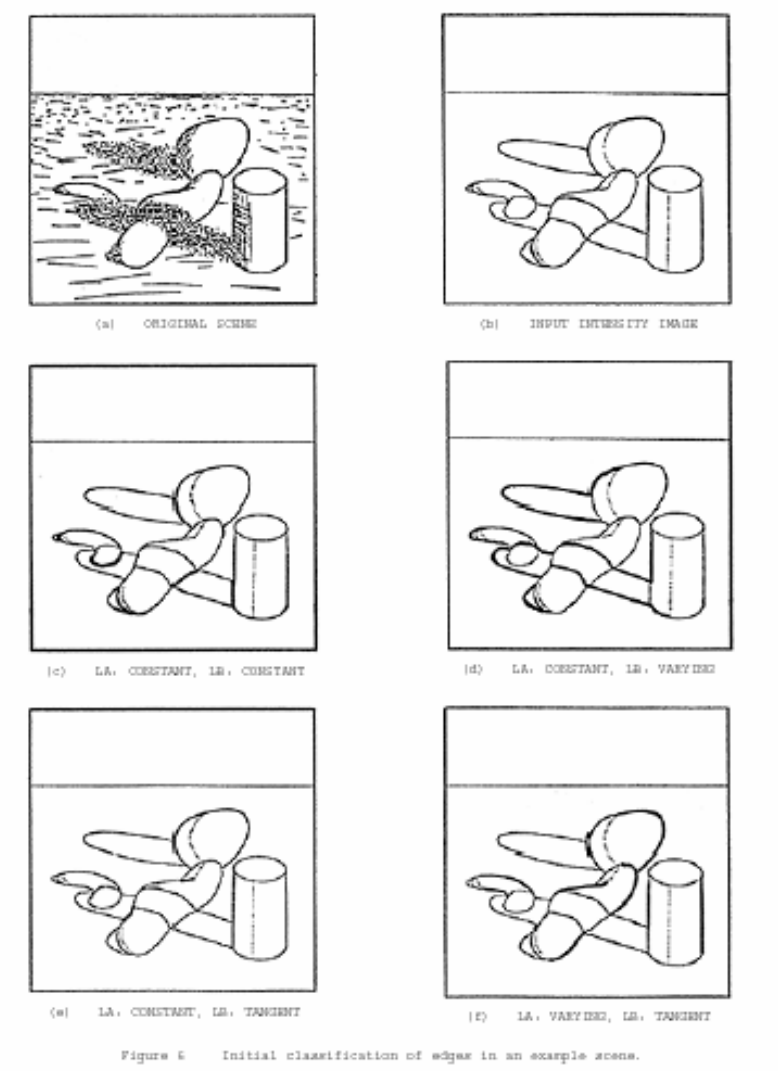

Figure 6 Initial classification of edges in an example scene.

Intrinsic Images, Barrow & Tenenbaum ,78

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1980 Marr & Hildreth Edge Detection

1980 Woodham Photometric Stereo

1980 Fischler & Bolles RANSAC

1980 Bolles Local feature focus method for occluded part recognition

1981 Horn & Schunck Optical Flow

1981 Marr & Ullman Optical Flow

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1981	Ballard	Generalized Hough Transform
1981	Ikeuchi	Photometric stereo
1982	Marr	Vision as an information processing task
1983	Canny	Edge detection
1984	Witkin	Scale-space
1984	Hogg	Model-based tracking of jointed moving objects

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Model based tracking of jointed moving objects, Hogg 1984

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1984 Horn Extended Gaussian Image

1985 Brady Curve-based surface representations

1985 Lowe Perceptual Organization

1986 Neumann & Novak
Natural Language Description of Traffic Scene

1986 Pentland
Superquadrics in computer vision (cf Barr 81 in graphics)

1986 Tsai Camera calibration

1987 Grimson & Lozano-Perez
Recognition of partially-occluded objects

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1988 Aloimonos
Active Vision

1988 Kass, Witkin, & Terzopoulos
Snakes / Active Contours

1990 Fleet & Jepson
Image velocity measurement from phase information

1990 Szeliski Bayesian modeling of uncertainty in vision

1990 Huttenlocher and Ullman
Appearance-based recognition of 3-D objects

1991 Ballard Animate vision

1991 Swain & Ballard
View-based recognition using colour histograms

1991 Koller, Heinze, and Nagel
Linguistic description of traffic behaviour in image sequences

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1993 **Faugeras**
Geometric 3-D computer vision

1996 **Schiele & Crowley**
Object recognition using receptive field histograms

1996 **Blake** **Active contours; CONDENSATION**

1998 **Cootes, Edwards, Taylor**
Active Appearance Models

1999 **Granlund**
Action-dependent perception

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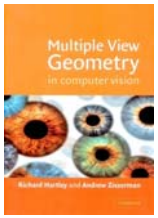
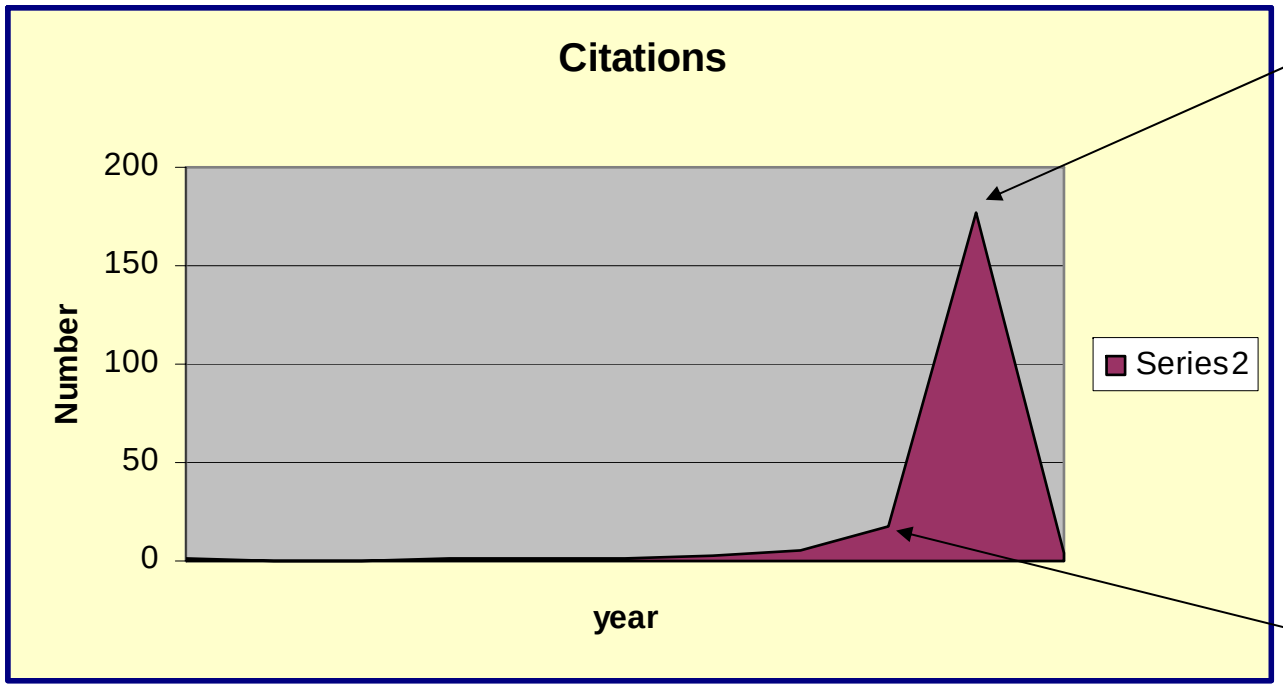
1990's – The Decade of Geometry

Multiple View Geometry
Hartley and Zisserman 2000





Citation of 177 papers published in the 1990s

Citations of 18 papers published in the 1980s

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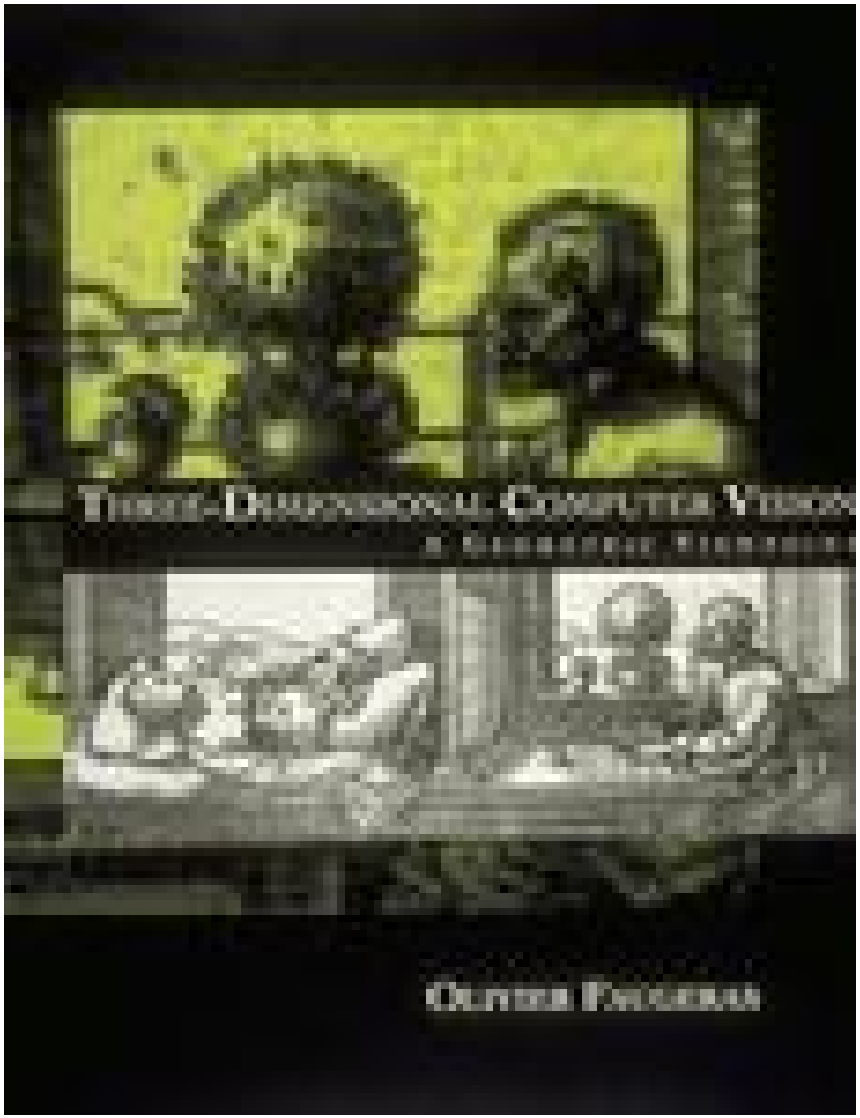

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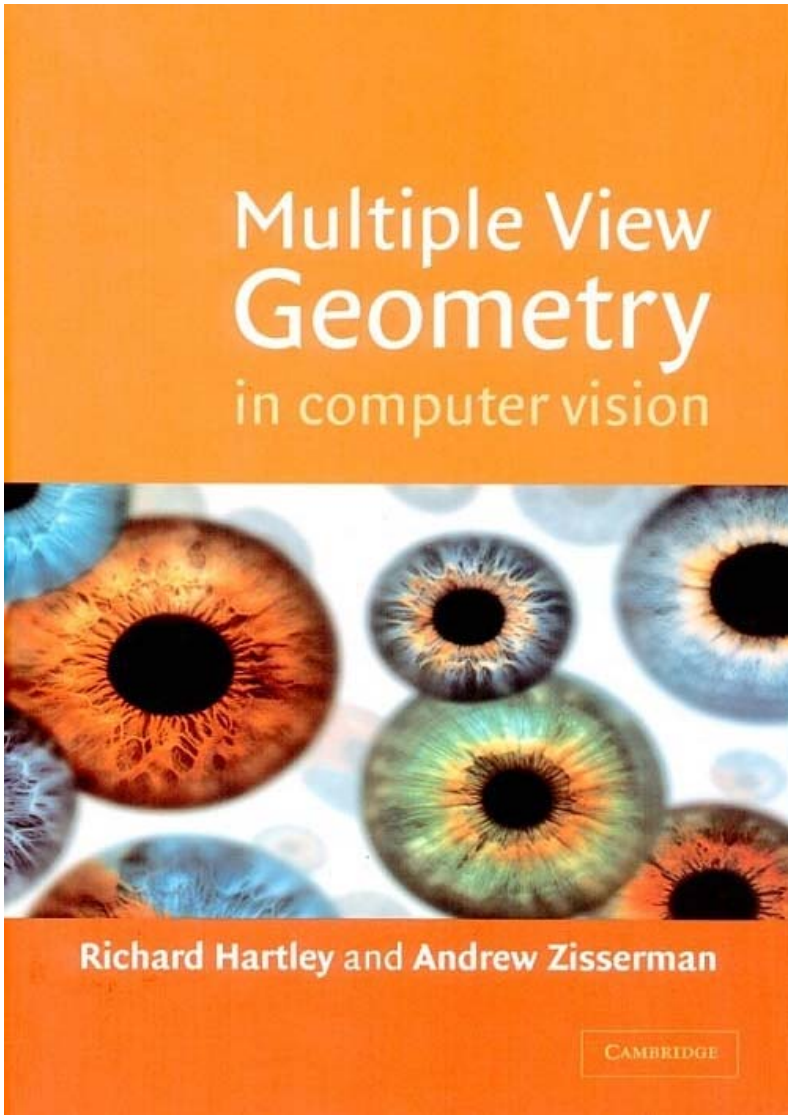

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2000	Hartley & Zisserman	Multiple view geometry
2000	Pope & Lowe	Probabilistic models of appearance
2002	Javed & Shah	Tracking and object classification for automated surveillance
2003	Lowe	Scale Invariant Feature Transform (SIFT)

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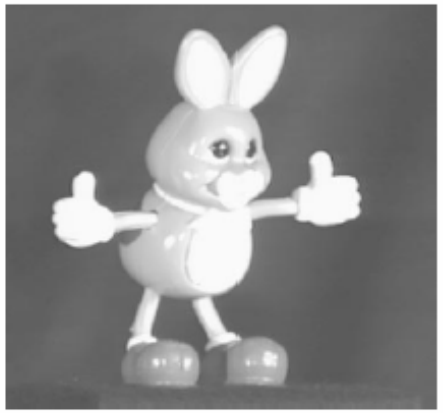
25° elevation, 90° azimuth

0° elevation, 90° azimuth



0° elevation, 10° azimuth

Figure 8: *Left:* Bunny test image 2 with clutter and occlusion. *Right:* Match of bunny model graph D with test image 2.

From: Pope and Lowe 2000

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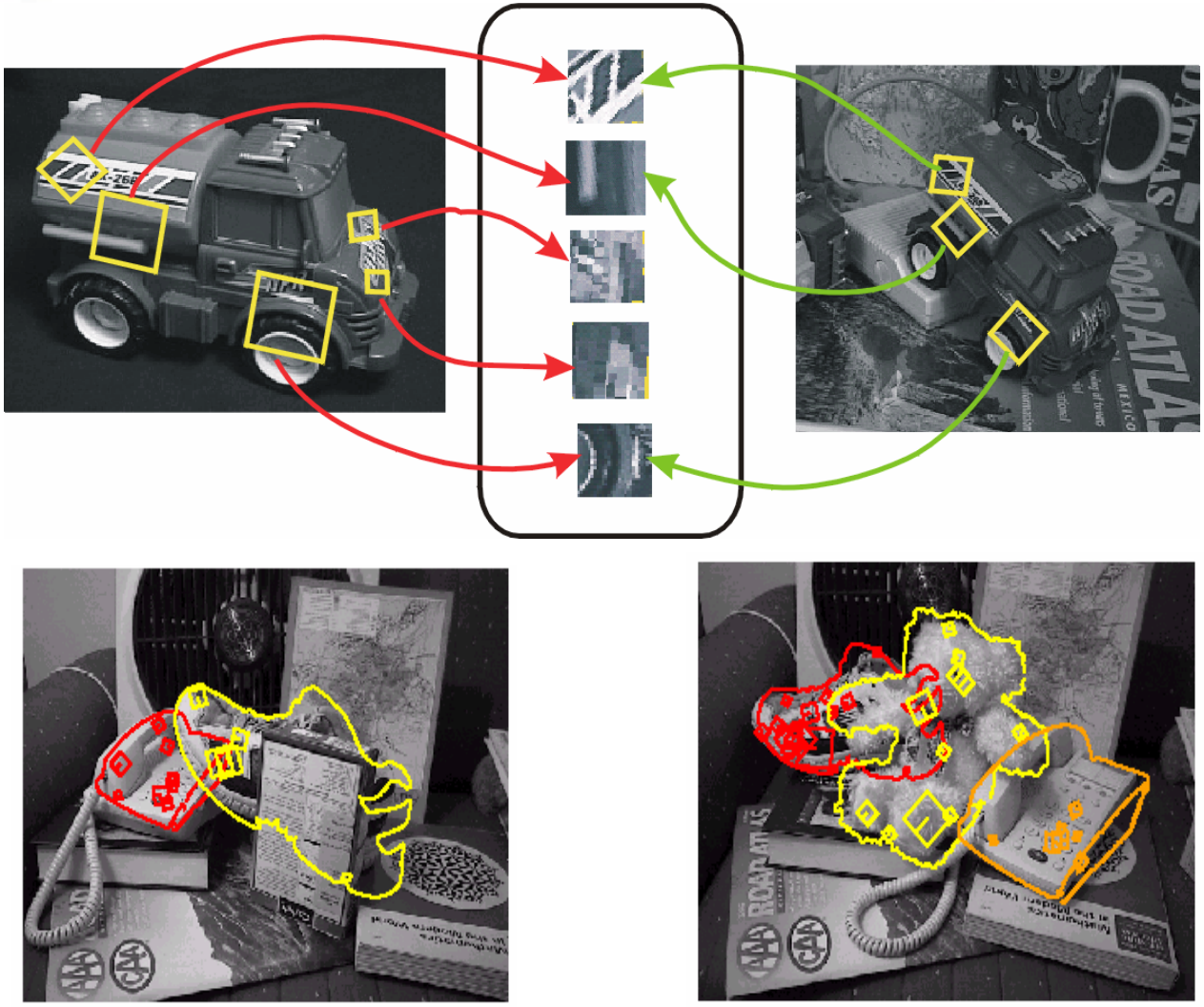

SIFT: Scale Invariant Feature Transform. Lowe 2003

Cognitive Vision: Past, Present, and Future

'The world we perceive is isomorphic with our perceptions of it as a geometric environment'

[Shepard & Hurwitz '84]

Cognitive Vision: Past, Present, and Future

'Cognition is *a type of computation'*

'People "instantiate" ... representations physically as cognitive codes and that their behaviour is a causal consequence of operations carried out on these codes'

[Pylyshyn '84]

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'One trend which started around or right after the Marr era was to the push of complex and new mathematical techniques in computer vision'

[Shah '02]

Cognitive Vision: Past, Present, and Future

'The idea is to find some mathematical technique which has not been used widely in computer vision, study it well, and find problems where it can be used.

Sometimes, this has resulted in only finding uses for mathematical techniques instead of actually solving the vision problems'

[Shah '02]

Cognitive Vision: Past, Present, and Future

'Computer vision started as an Artificial Intelligence (AI) problem'

[and since the seventies]

'we almost forgot about the original AI problem'

[Shah '02]

Cognitive Vision: Past, Present, and Future

'We need to solve the original high level vision problem, which requires more qualitative than quantitative information, and employs knowledge and context'

[Shah '02]

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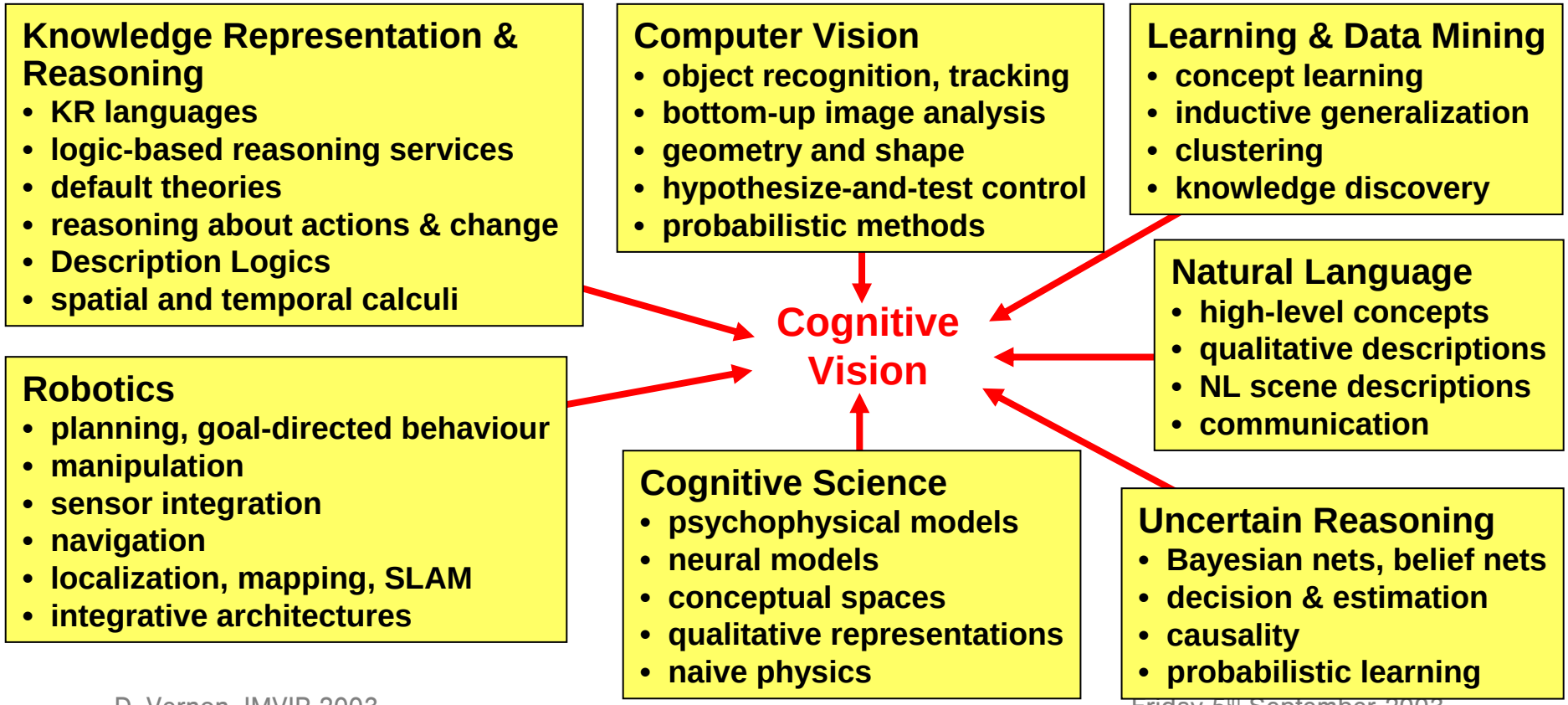
Bernd Neumann, 2003 (ECVision Summer School on Cognitive Vision)

CSL Cognitive Systems Laboratory

Cognitive Vision research requires multidisciplinary efforts and escape from traditional research community boundaries.



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Davis et al. '93: What is a Knowledge Representation?

- Representations
  - A 'surrogate' of substitute for a think itself
  - Set of ontological commitments
  - Fragmentary theory of intelligent reasoning
  - Medium for efficient computation
  - Medium for human expression

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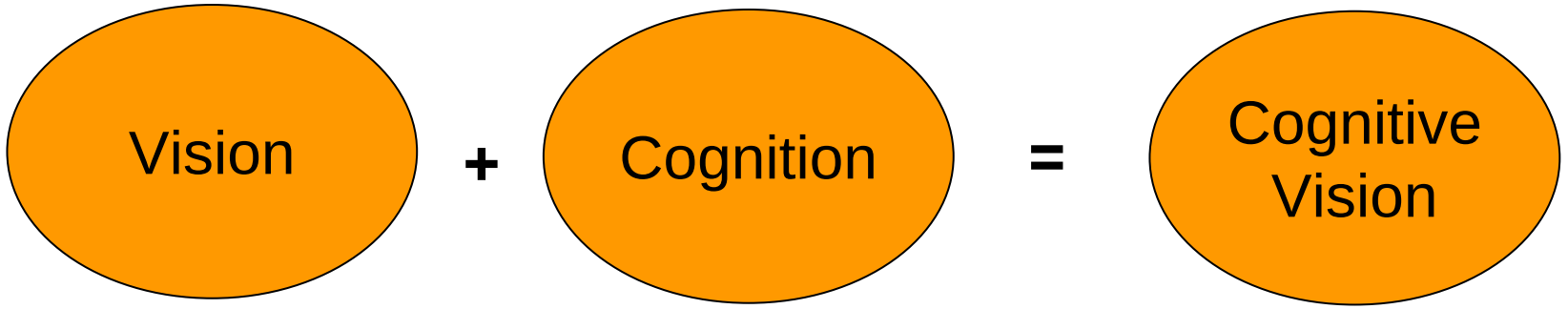

Representations Reasoning Intelligent Perception

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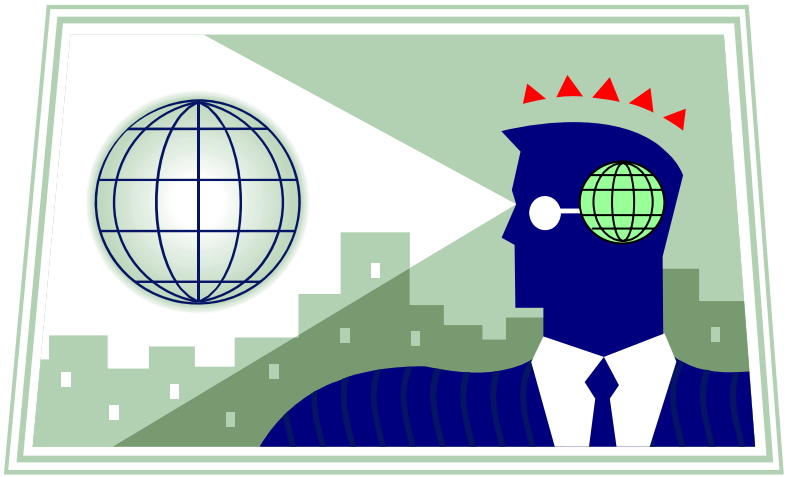
Sense ⇨ Reason ⇨ Plan ⇨ Act



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Information Processing Representational Vision

Stirrings in the Camp

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Dreyfus '82:
From Micro-Worlds to Knowledge Representation: AI at an Impasse

- 'The organization of world knowledge provides the largest stumbling block to AI precisely because the programmer is forced to treat the world as an object, and our know-how as knowledge '
- Intelligence must be situated and therefore predicated on what we *are*
- learn by experience
  (knowing how to swim doesn't require a data structure'

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Ballard '91: Animate Vision

- 'Rather than thinking of visual processing as separate from cognitive or motor processing, they are interlinked in terms of integral behaviours'
- Animate Vision
  - Physical search (gaze) with known movement
  - Exocentric coordinate frames (vergence / fixation)
  - Qualitative algorithms
  - Pre-categorical segmentation
  - Environmental context (renaissance after post-Marr dip)
  - 'Tailor made ... for learning'

Granlund '99a: The Complexity of Vision

- 'Our conscious perception of the external world is in terms of the actions we can perform upon the objects around us'
- Action-Dependent Vision
  - Objects should be represented as 'invariant combinations of percepts and response'
  - These invariances (not restricted to geometric properties) need to be learned through interaction rather than specified or programmed *a priori*
  - *Action precedes perception*

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Granlund '99b: Does Vision Inevitably have to be Active?

- 'A systems ability to interpret objects and the external world is dependent on its ability to flexibly interact with it'
- Action-Dependent Vision
  - One cannot have any meaningful access to the internal semantic representations
  - Cognitive systems must be embodied (at least during the learning phase)

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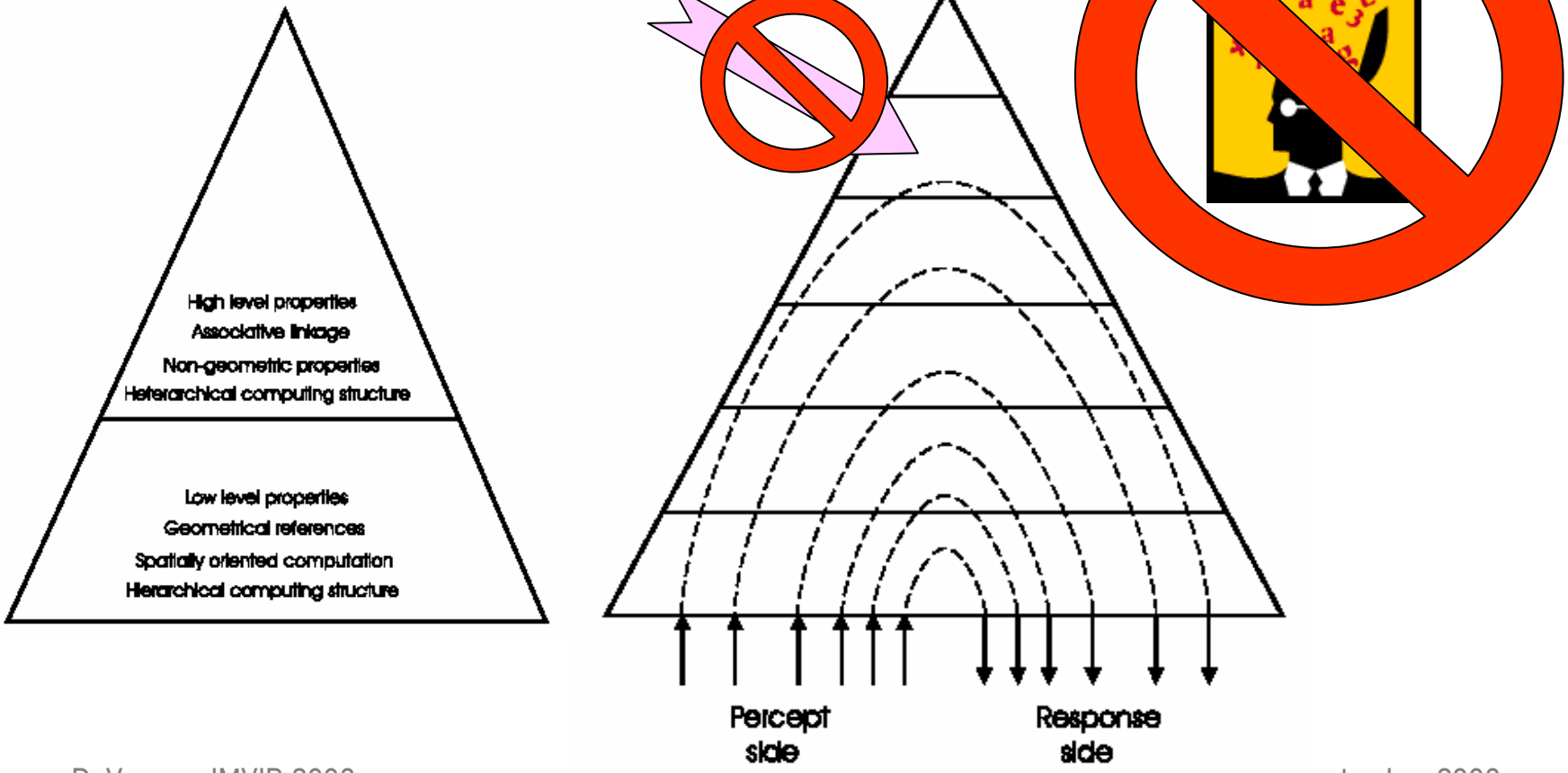

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Sense ⇨ Reason ⇨ Plan ⇨ Act

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Cognitive Vision: Past, Present, and Future

'Cognitive systems need to acquire information about the external world through learning or association'

'Ultimately, a key issue is to achieve behavioural plasticity, i.e., the ability of an embodied system to learn to do a task it was not explicitly designed for'

[Granlund'02]

Different Facets of Cognitive Vision

Dynamical Systems Theory

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Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

- 'Perceiving is not strictly speaking *in* the animal or an achievement of the animal's nervous system, but rather is a process in an animal-environment *system*'
- Dynamical Systems
  - Motoric and perceptual systems are both dynamical systems, each of which self-oranizes into meta-stable patterns of behaviour
  - Perception / action coordination is also a dynamical system (open dissipative non-linear non-equilibrium dynamical system)

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Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

- Dynamical Systems
  - System: large number of interacting components & large number of degrees of freedom
  - Dissipative: diffuse energy – phase space decreased in volume with time (⇨ preferential sub-spaces)
  - Non-equilibrium: unable to maintain structure or function without external sources of energy, material, information (hence, open)
  - Non-linearity: dissipation is not uniform – small number of system's degrees of freedom contribute to behaviour
    - Order parameters / collective variables

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Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

Reduce high dimensional systems to low dimensional systems:
Control parameters (non-specific)
Order parameters

Dynamical Systems

- Multi-stability
- Adaptability
- Pattern formation
- Self-organization
- Bifurcation
- Hysteresis
- Intermittency (relative coordination)

Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

Haken-Kelso-Bunz (HKB) Model

$$\dot{\phi} = -\frac{dV}{d\phi} = -a\sin\phi - 2b\sin 2\phi$$

Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

Haken-Kelso-Bunz (HKB) Model

Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

Haken-Kelso-Bunz (HKB) Model

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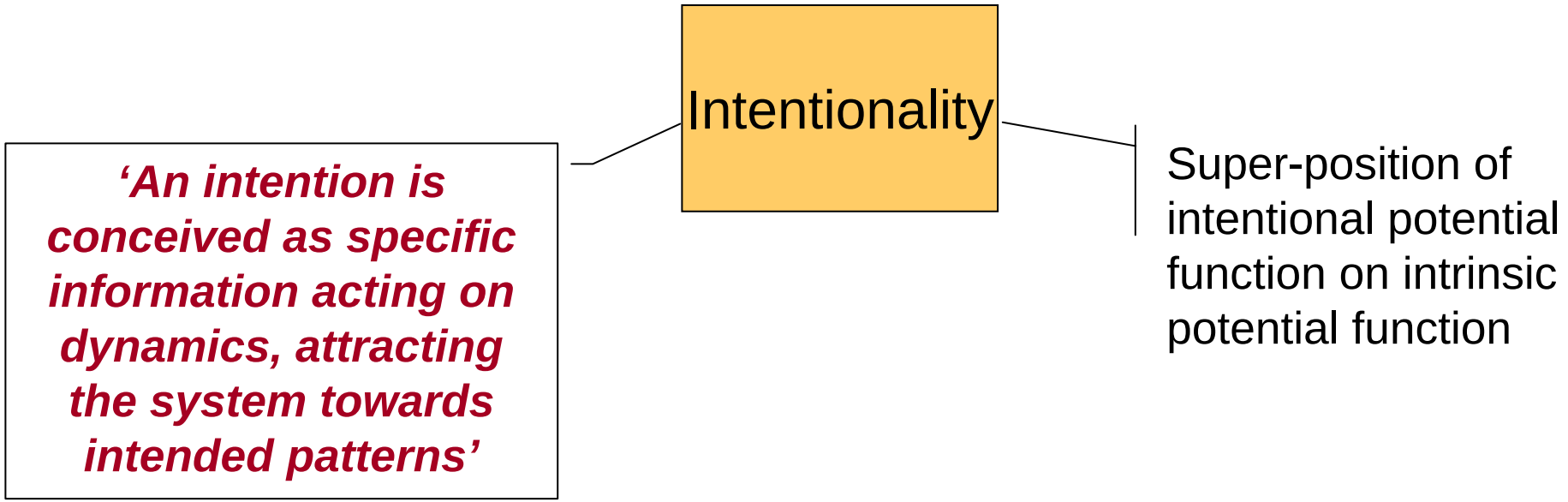
Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour



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Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

Modification of an already-existing behavioural patterns in the direction to be learned

Learning

$$\dot{\phi} = f_{\text{intr}}(\phi) + f_{\text{inf}}(\phi)$$

Occurs in a historical context

Entire attractor layout is modified

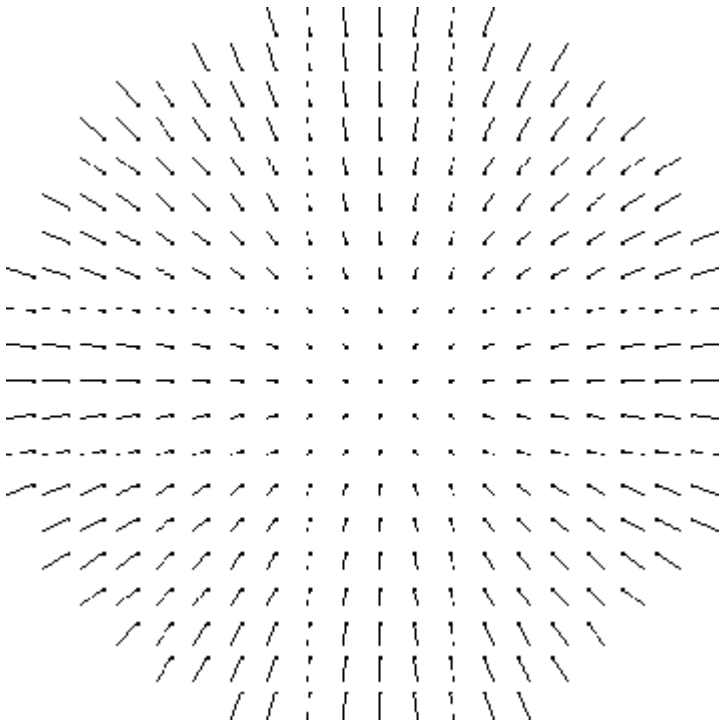
Learning changes the whole system

New attractor developed

Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

Gibson's Theory of Vision – Optic Array [Gibson 50, 79]

Time to contact τ, control parameter: Wing position for Glide & Dive



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Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

Gibson's Theory of Vision – Affordances [Gibson 50, 79]

Leg-to-riser ratio Π, control parameter: Step or clamber

$\Pi = 0.88$
Directly perceived
Spontaneous switch;
Identical to biomechanical model [Warren 90]

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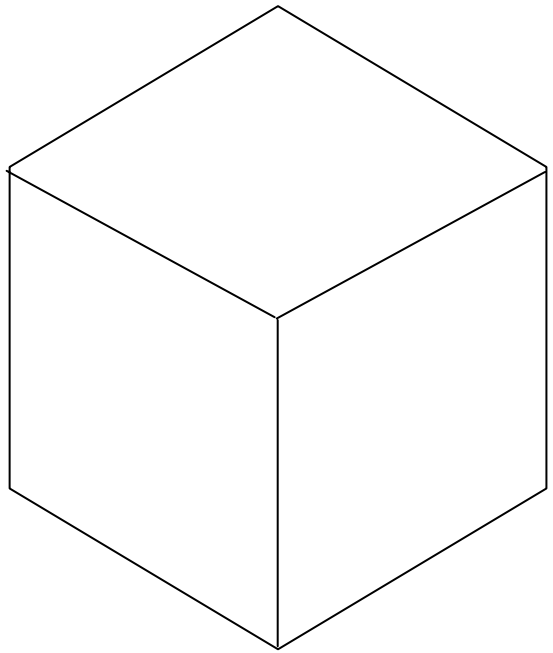
Gestalt Theory of Vision – bi-stable perception



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Kelso '95: Dynamic Pattern – The Self-Organization of Brain and Behaviour

Motivated by Herman Haken's synergetics
(term introduced in 1960's)

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Thelen & Smith '94: A Dynamic Systems Approach to the Development of Cognition and Action

'Perception and action are the primary basis for cognition'

'Cognition is non-symbolic, nonrepresentational ... and all mental activity is emergent, situated, historical, and embodied'

'Cognition is embodied and socially constructed'

'We believe that our theory of activity-driven, reentrant, high-dimensional cognition offers the best hope for understanding symbolic thought'.

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Van Gelder & Port '86: It's about Time: an overview of the dynamical approach to cognition

'The cognitive system is not a discrete sequential manipulator of static representational structures; rather it is a structure of mutually and simultaneously influencing *change*'

'The cognitive system is not a computer, it is a dynamical system'

'Timing always matters'

The system components 'must be interactive and self-contained'

Key issue: cognitive processes are temporal processes that 'unfold' in real-time and synchronously with events in their environment ('context')

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Different Facets of Cognitive Vision

Enactive Systems

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Maturana & Varela '87: The Tree of Knowledge – The Biological Roots of Human Understanding
also [Maturana '70, Maturana '75, Maturana & Varela '80, Varela '79, Varela '92, Winograd & Flores '86]

- 'Cognition is effective action'
- 'The nervous system does not "pick up information" from the environment ... the popular metaphor of calling the brain an "information processing device" is not only ambiguous but patently wrong'
- 'All knowing is doing as sensory-effector correlations in the realm of structural coupling in which the nervous system exists'

Cognitive Vision: Past, Present, and Future

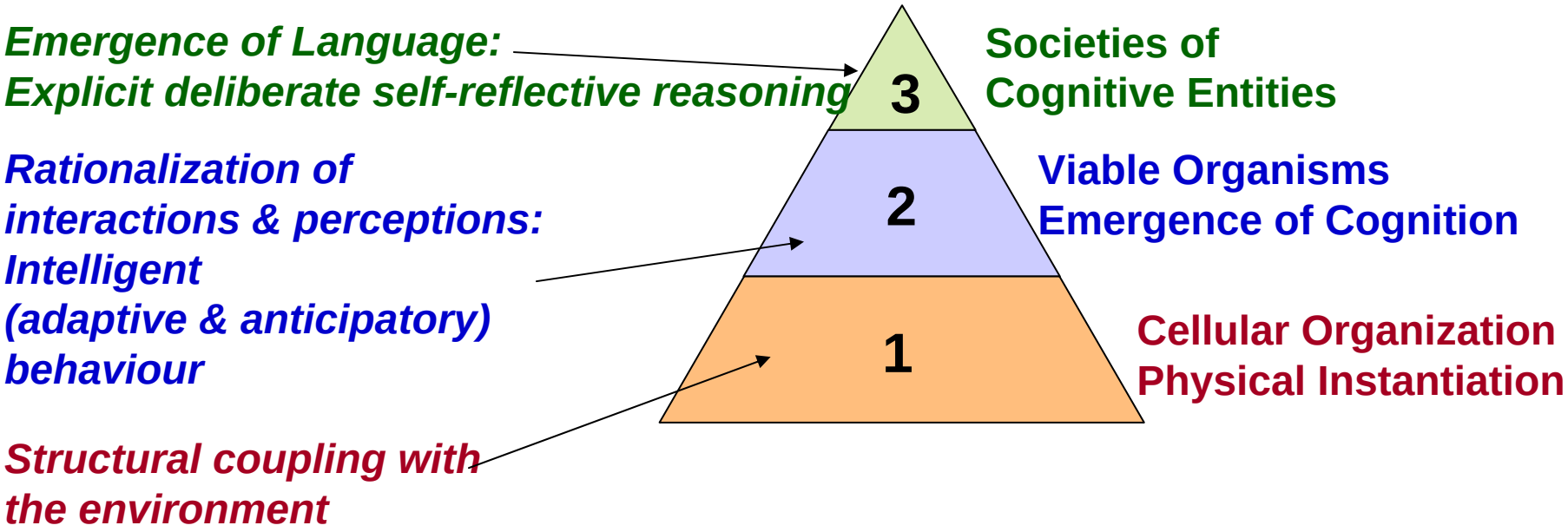
Maturana & Varela '87: The Tree of Knowledge – The Biological Roots of Human Understanding

Enactive systems

- Nature and emergence of autonomous, cognitive, social systems
- Autopoiesis (self-production): a system emerges as a coherent systemic entity, distinct from its environment, as a consequence of self-organization
- Three orders of system ...

Cognitive Vision: Past, Present, and Future

Enactive Systems [Maturana & Varela 87]



Multilevel Autopoeitic / Cognitive Systems

Cognitive Vision: Past, Present, and Future

Maturana & Varela '87: The Tree of Knowledge – The Biological Roots of Human Understanding

- Enactive systems
  - First-order system
    - environmental perturbations trigger structural changes 'that permit it to continue operating'

Cognitive Vision: Past, Present, and Future

Maturana & Varela '87: The Tree of Knowledge – The Biological Roots of Human Understanding

- Enactive systems
  - Second-order systems
    - Cognitive systems (cognition is effective action)
    - Structural coupling via the nervous system, enabling 'the association of many internal states with different interactions in which the organism is involved'

Cognitive Vision: Past, Present, and Future

Maturana & Varela '87: The Tree of Knowledge – The Biological Roots of Human Understanding

- Enactive systems
  - Third-order systems: coupling between second-order (cognitive) systems
    - Recurrent (common) ontogenic drift from reciprocal coupling
    - Instinctive behaviour based on second-order organization (phylogenic evolution)
    - Ontogenic behaviour, development *qua* learning over its lifetime
    - Communicative behaviour: third order structural coupling (social coupling)
    - Linguistic behaviours: establishment of a shared epistemology

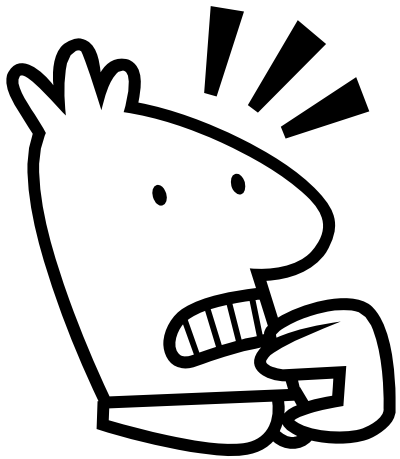
Cognitive Vision: Past, Present, and Future

Varela '84: Whence Perceptual Meaning? A Cartography of Current Ideas

'The kingpin of cognition is its capacity for "bringing forth" meaning: information is not pre-established as a given order, but regularities emerge from a co-determination of the cognitive activities themselves'

'Cognition [is a] creative bringing forth of a world where the only required condition is that of effective action: it permits the continued integrity of the system involved'

Cognitive Vision: Past, Present, and Future



Cognitive Vision: Past, Present, and Future

Phillipona et al. '03: Perception of the structure of the physical world using unknown multimodal sensors and effectors

Phillipona et al. '03: Is there something out there? Inferring space from sensorimotor dependencies

- Biological organisms perceptions of their bodies and the dimensionality & geometry of the space in which they are embedded
  - Deduced (learned, discovered) from analysis of dependencies between motoric commands and consequent sensory data
  - Without any reference to an external model of the world or the physical structure of the organism

Cognitive Vision: Past, Present, and Future

Winograd & Flores '86:
Understanding Computers and Cognition

- Any computational cognitive entity would have to exibit structural coupling with its environment
  - Any representations would be predicated upon its action in and interaction with its medium
  - Dependent on the nature of the perturbation of the system by the medium
  - Particular to that system
  - The only possible way to achieve this is by learning and evolutionary adaptation (cf. programmer's prejudice systems)

Cognitive Vision: Past, Present, and Future

Winograd & Flores '86:
Understanding Computers and Cognition

- Learning
  - Parameter adjustment in fixed representation systems
  - Concept learning (combinatorial exercise on programmer representations)
  - Evolutionary computation
    - Theoretically-possible
    - The problem of synchronous evolution of system and environment

Cognitive Vision: Past, Present, and Future

What is Cognition?	
Cognitivism (IPRV)	Information processing: rule-based manipulation of symbols

Adapted from [Thelen & Smith 94] and [Varela 88]

Cognitive Vision: Past, Present, and Future

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Cognitive Vision: Past, Present, and Future

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Cognitive Vision: Past, Present, and Future

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Dynamical Systems	A history of activity that brings forth change and activity
Enactive Systems	Effective action: history of structural coupling which enacts (brings forth) a world

Adapted from [Thelen & Smith 94] and [Varela 88]

Cognitive Vision: Past, Present, and Future

How Does it Work?	
Cognitivism (IPRV)	Through any device that can manipulate symbols

Cognitive Vision: Past, Present, and Future

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Dynamical Systems	Through self-organizing processes of interconnected sensorimotor subnetworks
Enactive Systems	Through a network of interconnected elements capable of structural changes undergoing an uninterrupted history

Cognitive Vision: Past, Present, and Future

What does a good cognitive system do?	
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Cognitive Vision: Past, Present, and Future

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Cognitive Vision: Past, Present, and Future

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Connectionism	Develops emergent properties that yield stable solutions to tasks
Dynamical Systems	Becomes an active and adaptive part of an ongoing and continually changing world
Enactive Systems	Becomes part of an existing on-going world of meaning (in ontogeny) or shapes a new one (in phylogeny)

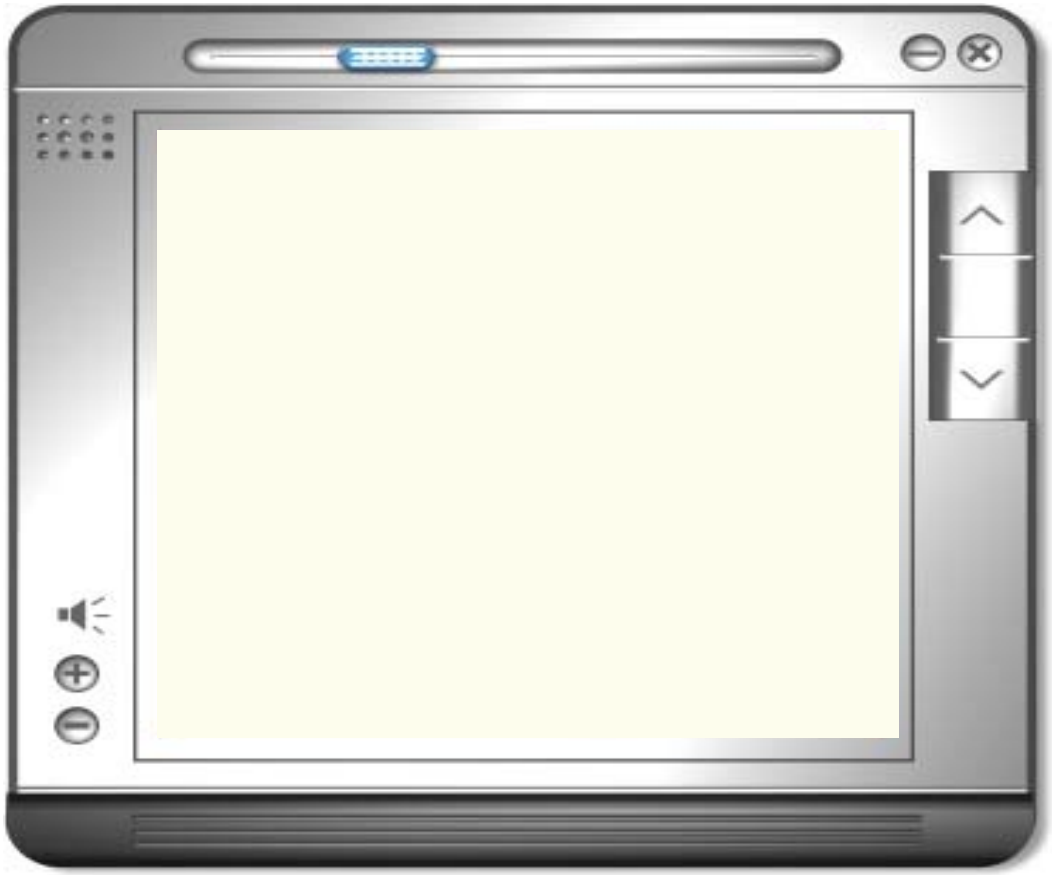
Cognitive Vision: Past, Present, and Future

State of the Art

Some Results for EU Projects

Cognitive Vision: Past, Present, and Future

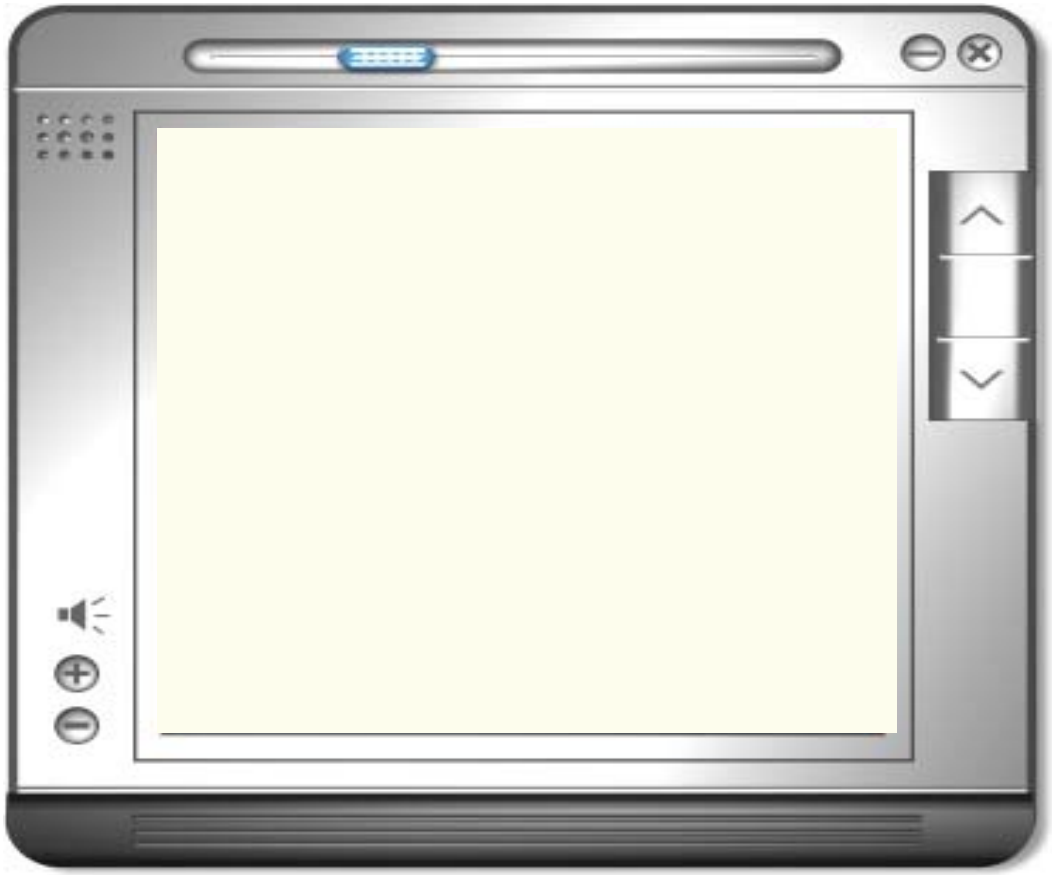
Interpreting and Understanding Activities of Expert Operators for Teaching and Education



Cognitive Vision: Past, Present, and Future

Interpreting and Understanding Activities of Expert Operators for Teaching and Education

`http://actipret.infa.tuwien.ac.at`



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Real Time Detection of Motion Picture Content in Live Broadcasts (brand detection, agent tracking, agent recognition)

`http://www.detect-tv.com`

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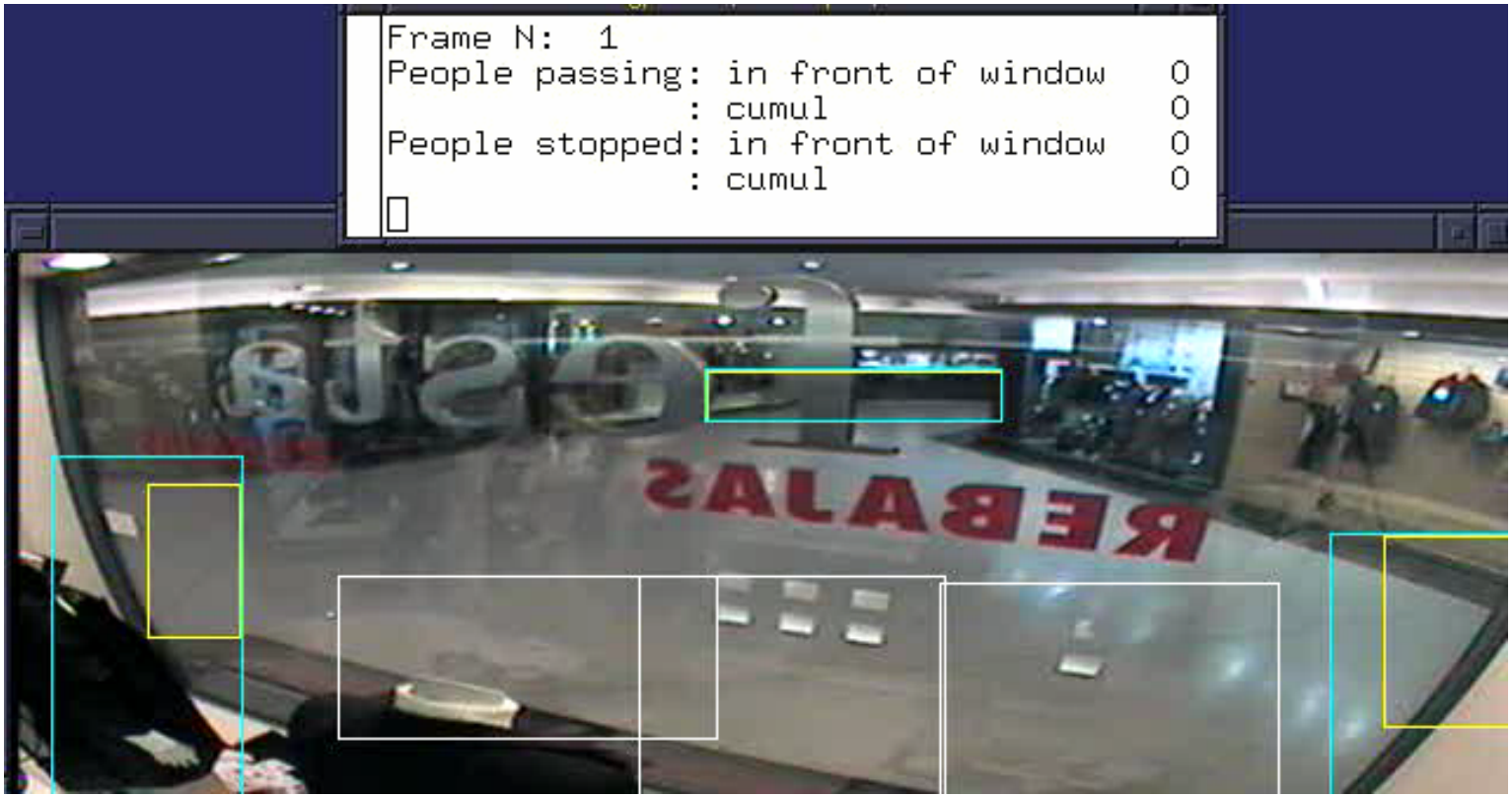
Cognitive Vision: Past, Present, and Future

Blue Eye Video

http://perso.wanadoo.fr/pierre.delasalle/Eng/index.htm



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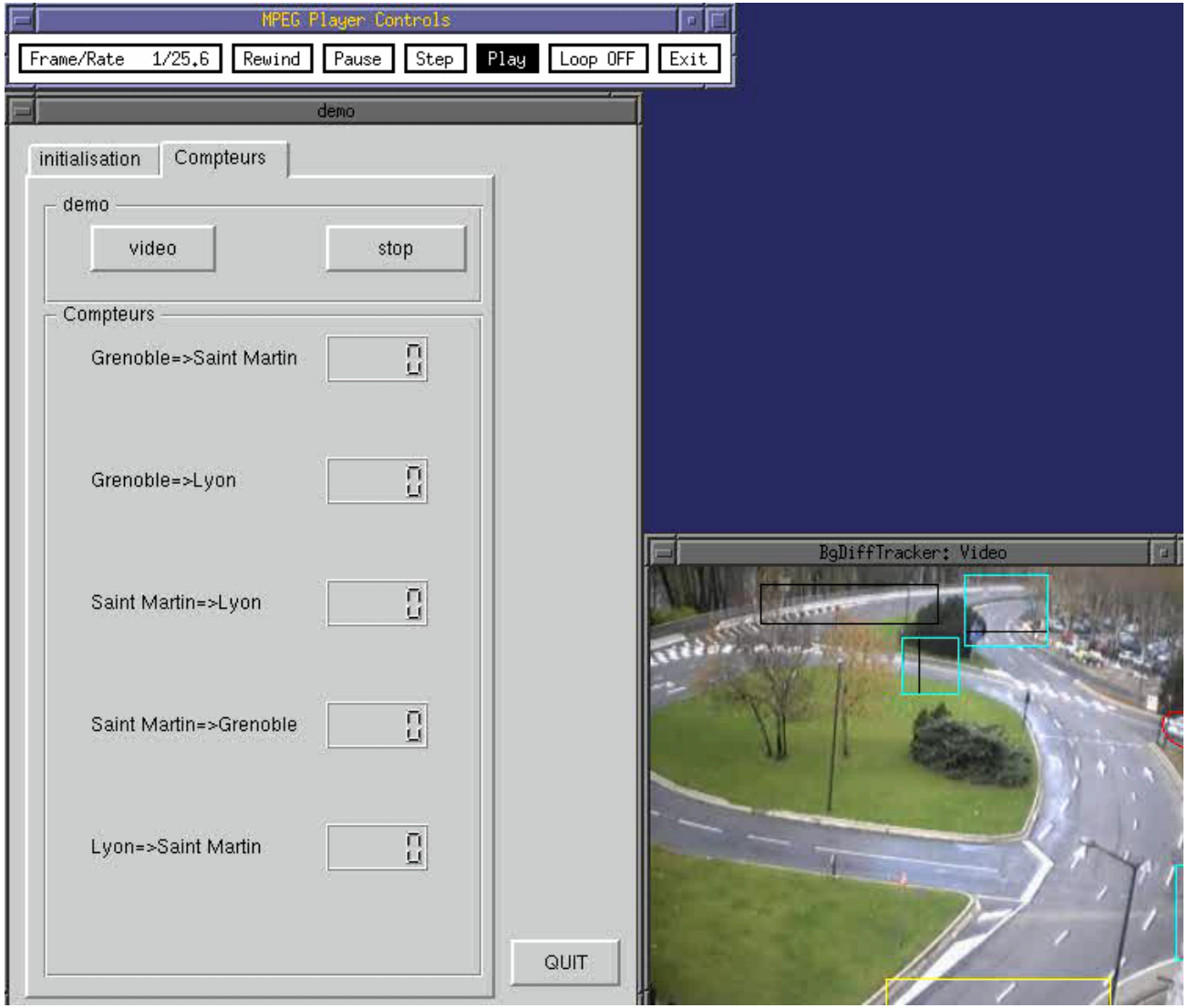


Cognitive Vision: Past, Present, and Future

Cognitive Vision: Past, Present, and Future

CAVIAR: Context Aware Vision using Image-based Active Recognition

http://www.dai.ed.ac.uk/homes/rbf/CAVIAR/

COGVIS - Computational Vision and Active Perception

http://cogvis.nada.kth.se

COGVISYS - Cognitive Vision Systems

http://cogvisys.iaks.uni-karlsruhe.de

LAVA - Learning for Adaptable Visual Assistants

http://www.l-a-v-a.org

VISATEC - Vision-based Integrated Systems Adaptive to Task and Environment with Cognitive Abilities

http://www.visatec.info

VAMPIRE - Visual Active Memory Processes and Interactive Retrieval

http://www.TechFak.Uni-Bielefeld.DE/ags/ai/projects/VAMPIRE/

Perspectives on Cognitive Vision

Cognitive Vision: Past, Present, and Future

- **IPRV**
  - Knowledge and scene representations
    - Situations & structure
    - Behaviours (spatial and temporal)
    - Categories (function over form)
    - Qualitative descriptions / conceptual knowledge
  - Reasoning over representations
    - Inference over partial information
    - Experience / expectation driven interpretation
  - Interaction (with humans)
  - Motoric control (optional)
  - Agent intentions (and intentional models)
  - Robust perception and learning to build the models
  - Robust reasoning capabilities to produce sensible communication with humans and/or its motoric interface
  - *Constraints (knowledge) render representational vision practicable in (almost) general-purpose computer vision*

Cognitive Vision: Past, Present, and Future

IPRV

‘The semantic gap is the lack of coincidence between the information that one can extract from the visual data and the interpretation that the same data have for a user in a given situation’
[Smeulders ’00]

The solution: integrate information from other sources

Cognitive Vision: Past, Present, and Future

- **Action-Dependent Vision**
  - The purpose of cognitive systems is to produce a response to input stimulus
  - Context is as important as the percepts
  - *Autonomous* adaptivity to the environment and its demands
  - Systems must be able to learn from the environment (not just geometry, but also consequences and values)
  - ***The central mechanism is the perception-action feedback cycle where, in the learning phase, action precedes perception***
  - Symbolic output should be viewed as primarily for communication
  - ***Symbolic representations should be derived from the action output (not the perceptual interpretation)***
  - Language is low in information content but works effectively *iff* it is received by a system with the right (similar) perception/action structure. In some sense, language indexes understanding in a second party ('it pushes the right buttons').

Cognitive Vision: Past, Present, and Future

Action-Dependent Vision

The only way to acquire semantic information is through association or learning

This implies that, for the training phase at least, the system must be an ***embodied*** entity

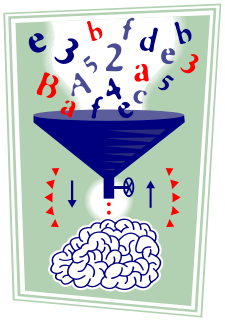
Cognitive Vision: Past, Present, and Future

Infants & Adolescents

Can you do this???

Cognitive Vision: Past, Present, and Future

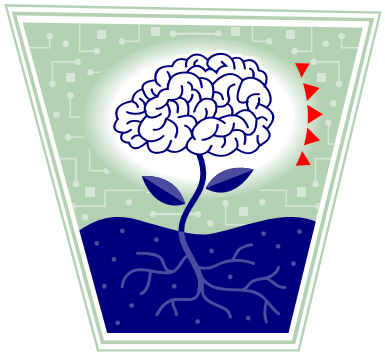
- ***Reasoning, Planning, & Linguistic Communication: Deliberative Behaviour***
  - ***IPRV:by definition, no problem***



Machine representations reflect the designer's epistemology

Cognitive Vision: Past, Present, and Future

- ***Reasoning, Planning, & Linguistic Communication: Deliberative Behaviour***
  - ***Emergent Approaches ... not so easy***
  - ***Is only reflexive behaviour is on offer?***
  - ***No: recall Varela's and Granlund's triangles***



Machine representations reflect the machine's epistemology

Problems for the Future

The Research Agenda

The Research Agenda

- **The nature of cognition:**
  - What makes a system cognitive?
  - What are the requirements for a cognitive system?
  - What properties characterise cognitive systems? What categories of cognitive tasks can be defined?
  - To what extent is embodiment necessary for cognitive systems?
  - To what extent are perception, reasoning, language, and embodied action necessary for cognition?
  - Is action required to define perception?

Questions are taken from the European Commission document expanding on the call for proposals in cognitive systems;
See www.ecvision.info/news/CS-Support_Document-v2.pdf

The Research Agenda

- **Architectures for cognition:**
  - What architectural models can be used to design cognitive systems?
  - How can perception, action, learning, communication and self-description and self-awareness be integrated?
  - What is the nature and function of memory?
  - Can we build systems that are auto-descriptive, auto-critical, auto-regulating and auto-healing?

The Research Agenda

- **The nature of knowledge:**
  - What kinds of informational states, memory and knowledge are useful to identify?
  - How can knowledge enable generation of new knowledge.
  - What are the roles and nature of spatial, temporal and causal concepts?
  - What is the role of language in cognition and of cognition in language?
  - How can meaning be characterised?

The Research Agenda

- **Perception:**
  - Is action necessary for perception?
  - How can affordances be learned and perceived?
  - Is the distinction between top-down and bottom-up processes useful in perception?

The Research Agenda

- **Learning:**
  - How can a system learn of competences, affordances, categories and concepts?
  - What are the different modes of learning needed in a cognitive system?
  - How can new knowledge or skills be integrated coherently with old knowledge or skills without compromising the stability of the system?

The Research Agenda

- **Autonomous systems:**
  - What are the varieties and mechanisms of autonomy?
  - What is required for a system to be autonomous?
  - What is the relation between cognitive systems and autonomous systems?
  - To what extent are emotions and other affective states and processes necessary for autonomy?

The Research Agenda

- **The Notion of Self:**
  - What does it mean for an artificial system be aware?
  - What is the functional role of consciousness in an artificial system?
- **Social Interaction:**
  - How do considerations of communication, cooperation, and competition impact on cognition?

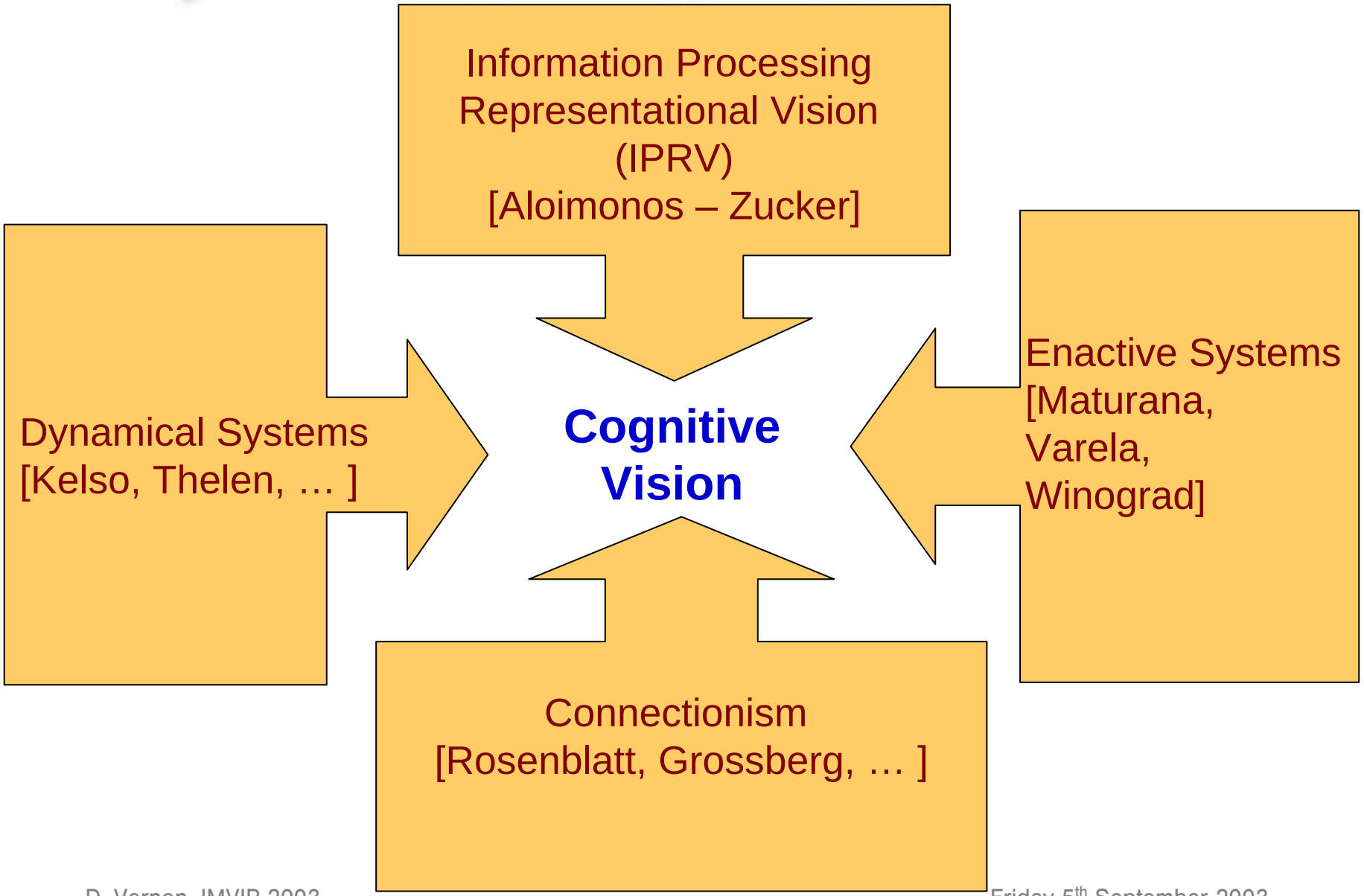
The Research Agenda

Goals:

- How can goals be identified to a cognitive system?
- How does language impact on goal specification?
- Can cognitive systems be instructed to achieve goals and at what level and in what manner?
- Can goals be specified at all or must they be learned?

Predicting the Future

Cognitive Vision: Past, Present, and Future



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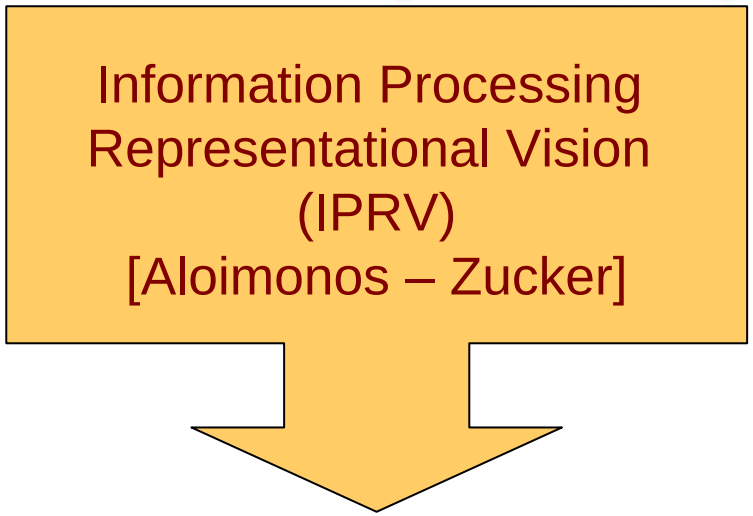
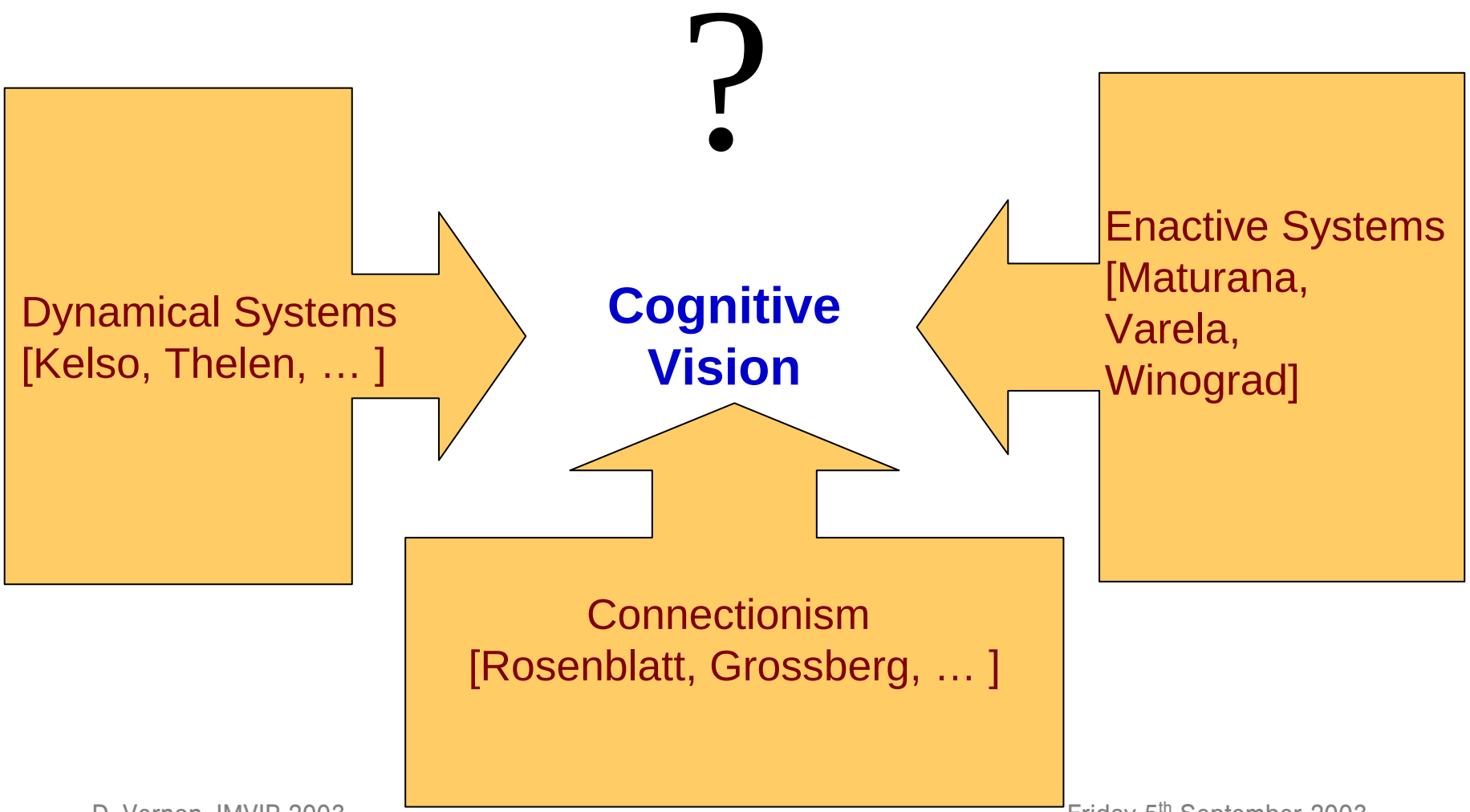


Cognitive Vision

Will go from strength to strength

- **Bounded/constrained domains**
- **Incorporation of**
  - **learning**
  - **probabilistic models**
  - **invariant representations**
  - **qualitative reasoning**
  - **video-stream data**

Cognitive Vision: Past, Present, and Future



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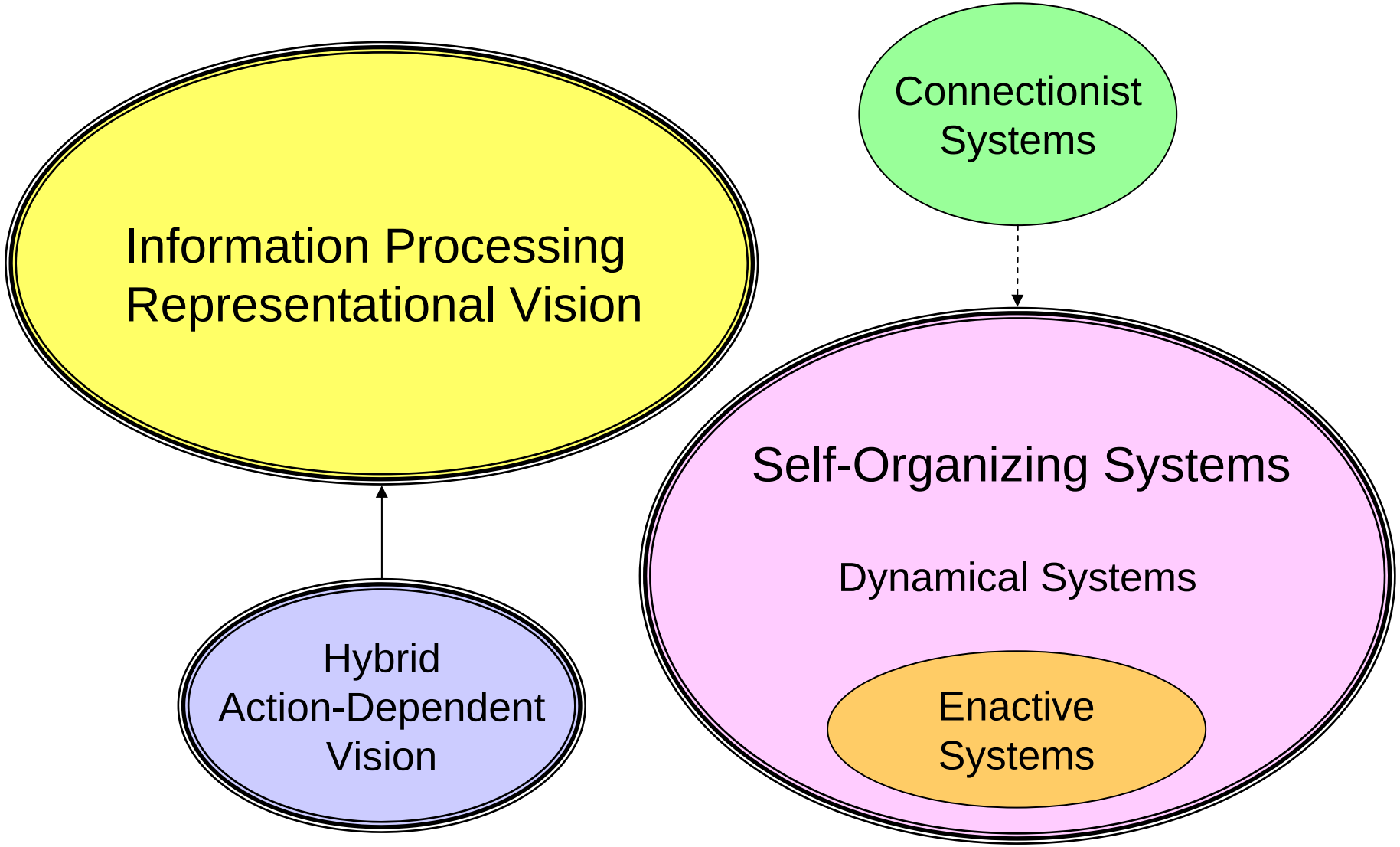

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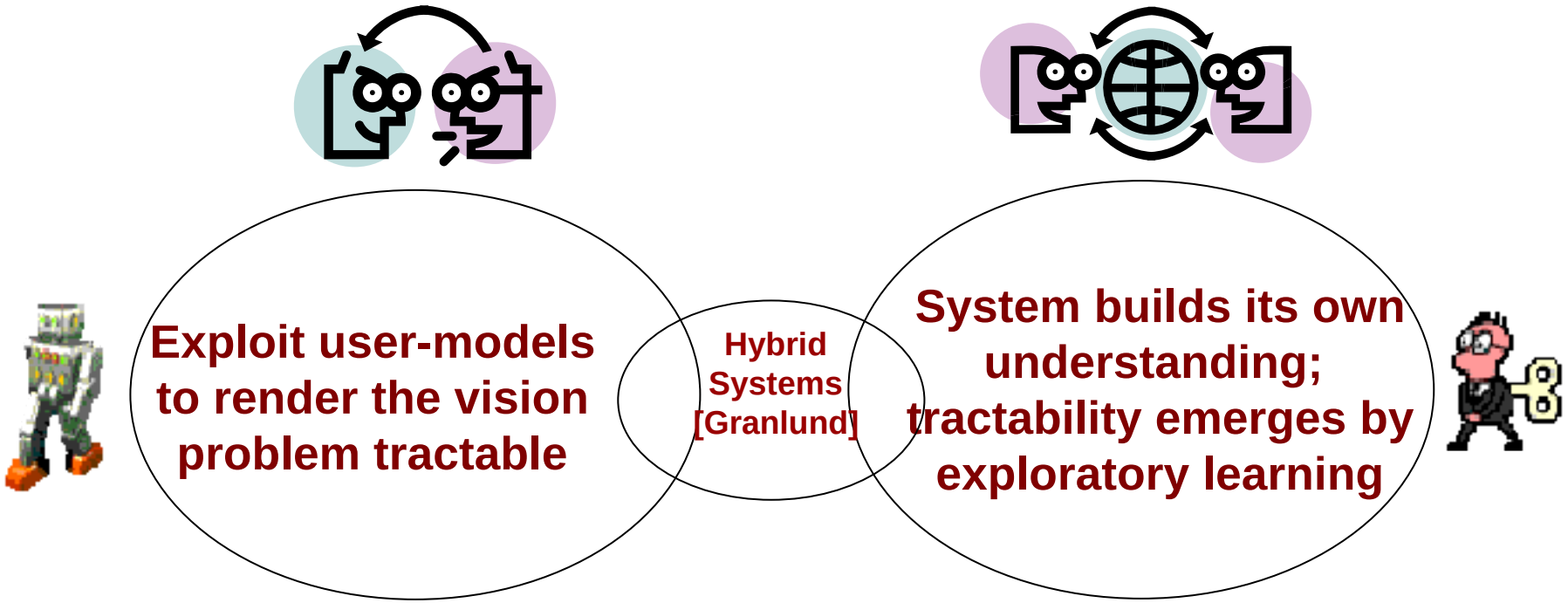
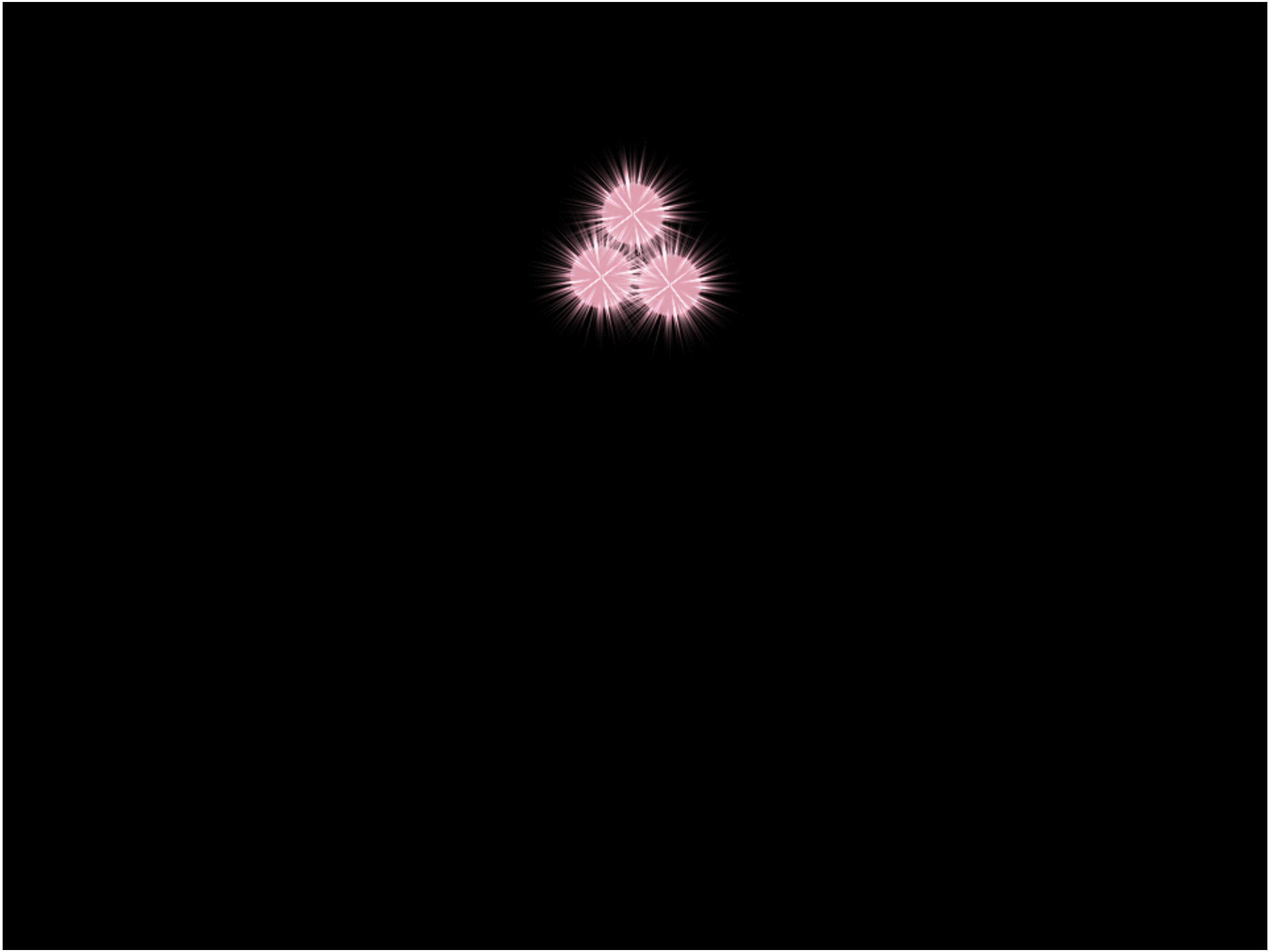


General Vision: The Tractability Problem

Cognitive Vision: Past, Present, and Future

- IPRV and Hybrid approaches work with descriptions of the world
  - IPRV: Observer/programmer based
  - Action-Dependent: System based
- Both are based on
  - models which draw on learning
    - data-generated
    - adaptively-refined
  - real-time interaction (video)
  - robust low level vision
  - context-based attention
- Significantly different situation to the 1970s



Cognitive Vision: Past, Present, and Future

European Research Network for Cognitive Computer Vision Systems

www.ecvision.info

Cognitive Vision
Past, Present, and Future

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