An Integrative view of Cognitive Architecture: Process/Structure/Behaviours

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Motivation

- How do humans handle all different types of interaction with ease - in such a competent manner?
- How such a rich system can be built?
- What are the underlying mechanisms?
  - Understanding the Processes and controls
- Explore and exploit what has been learnt from other fields of discipline: philosophy, neuroscience, psychology, physiology etc.

Our View: Understanding Through Creating

- we share the view that human-like response can only be yielded through a richly integrated humanoid system
- an appropriate tool will automatically enhance the way we think [Dennett, Gregory] - thus, a humanoid will help us think deeper about humans and their behaviours
- gain a better understanding through reproducing Human-like behaviours on Humanoid Robots

Human Activities Motivation

- involve many sensory receptors:
  - seeing,
  - hearing,
  - touching etc.
- bombard us continuously on multiple basis [Berthoz, Damasio, Dennett, Kelso]
- producing varieties of similar responses

An Integrated Human-oid

- Why an integrated system?
  - Humans are complete systems, therefore it only makes sense to conduct our studies with an Integrated System
- What do we get from an integrated system like humans?
  - make available a rich sensory system for research – with concurrent and continuous processing
  - enable to respond to the large and numerous types of inputs with a wide range of responses - in a richer manner
  - ensure mutual human-like interaction is embraced (due to expectation)

An Integrated Human-oid

- What do we get from an integrated system like humans?
  - provide a vast number of alternatives in which problems can be solved, e.g. exploiting the rich sensory system available
  - a diverse system will yield a highly robust and redundant system - allowing it to adjust to failure
  - extend the boundary and limitation of current methodology – increasing the variation of possible solutions

Consideration for Humanoid Interaction

- Integrated point of view
  - seamlessness/continuity
    - which allows the system to interact with the environment in a continuous manner. The system should be able to interact continuously in a responsive and timely manner, thus without stopping or re-starting.
  - adaptivity/redundancy
    - the mechanism used should provide the system with redundancy by being adaptive. The system should be able to adapt to failure of sub-systems or components, for example if one component fails another is able to function without any dependency. Thus, a system will be able to support Self-Preservation.

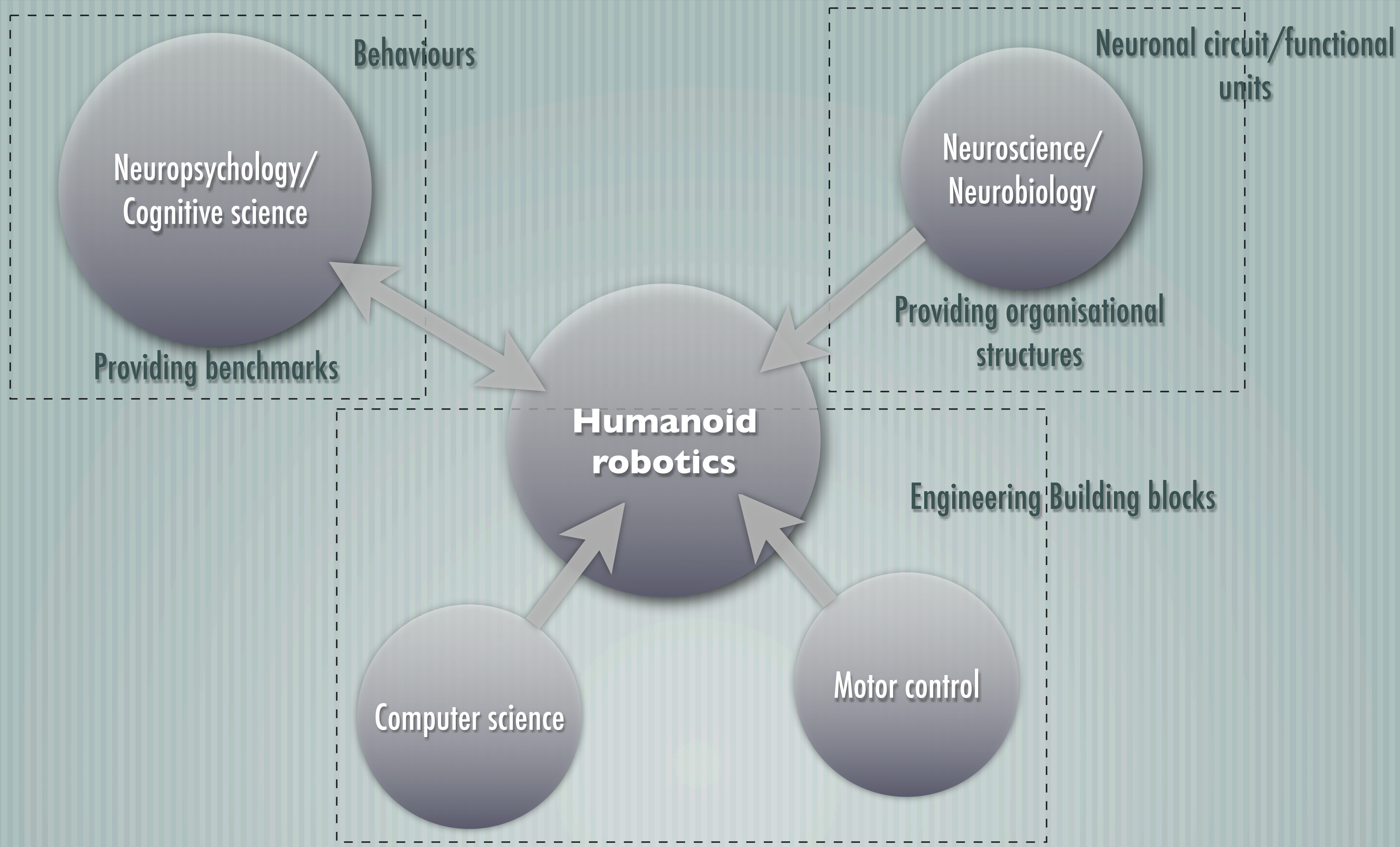
Consideration for Humanoid Interaction

- dominance/competition/cooperation
  - channelling all inputs into an integrated system, in a competitive manner. [Damasio, Dennett, Kelso]
- flexibility
  - additional components should be able to be introduced in a simple manner. Flexibility is an important attribute for the process of integration. E.g. Neural-based architecture

Emulating: ecologically driven

- natural environment
  - the environment in which the humanoid occupies should remain unmodified
    - unmodified in anyway to accommodate for any special perceptual need.
- multiple input/multiple output
  - consideration should be taken into account for a large number of sensors, and a wide range of concurrent responses should be exhibitable.

Multi-disciplinary integration



Biological-based framework for the studies of Human

- “Beyond simple Neural Network modelling”: Neuroscience/Neurobiology providing guideline for the low-level construction of “modulars/pathways” - allows spatial-temporal studies of organisational structures
- “Beyond simple behaviours” as Benchmarking: behavioural outcomes can be taken as benchmarks, evaluated within nature environment - ecological
- “Systematic studies of complex models”: even for impairments and defects - “lesion studies”

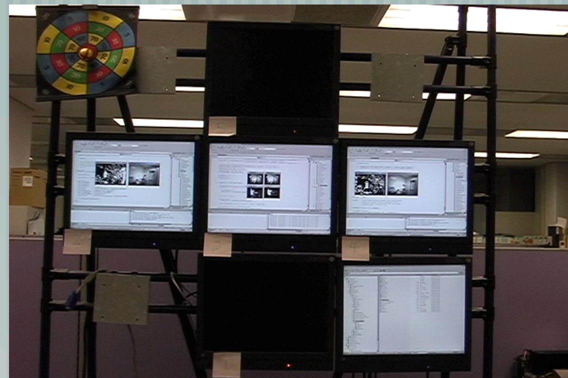
Integration is about process structure

- Naturally the process elements/modules plays a key role
- The underlying structure being important for:
  - Behavioural outcome of the system
  - Facilitate the understanding of the overall system/sub-modules
- More recent ideas tends to converge on the idea that behaviours being the end goal, without accounting for internal organisations

Key aspects

- Temporal adjustment: controlling of delays
- Allow connection between functional units: mechanisms for bottom-up inputs and top-down influence to bottom-up processing
- Providing: rich inputs (low-level inputs, visual/auditory/etc); and diverse outputs (control of motor);

Exploring Cognition and beyond

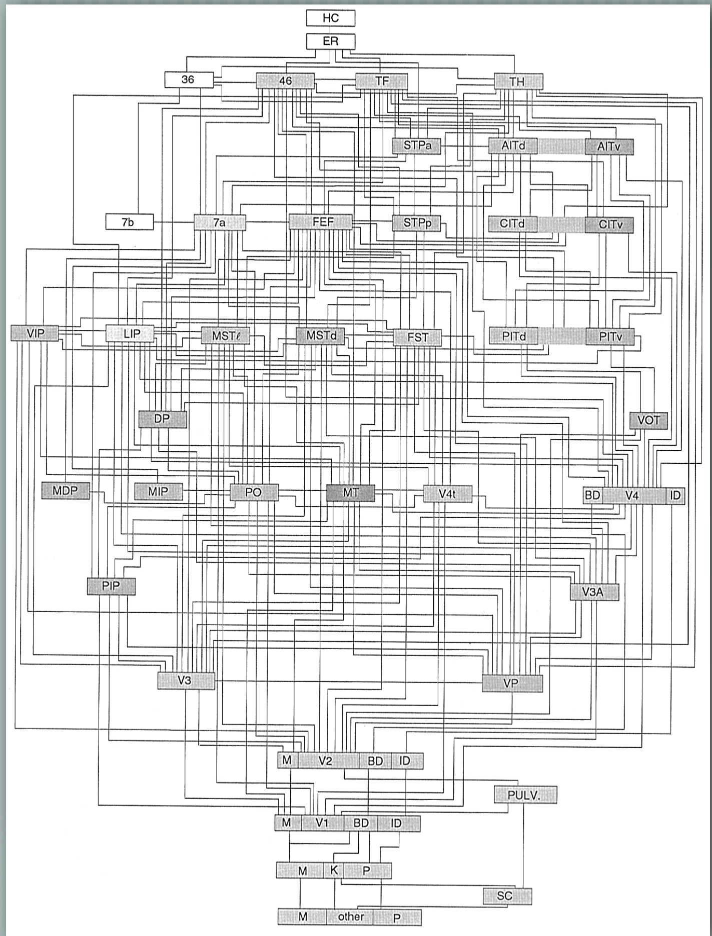


- A framework for combining Brain/Body for:
  - Perception
  - Action
  - Learning

Human-oid Response

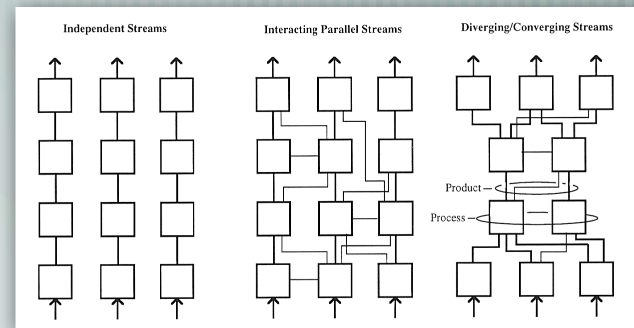
- Having the body of a human automatically gains:
  - Induce and deduce expectation of human-like response(s)

Scaleable and Distributed Computation Architecture



- The supporting architecture need to be flexible/scaleable to allow the construction of complexly systems

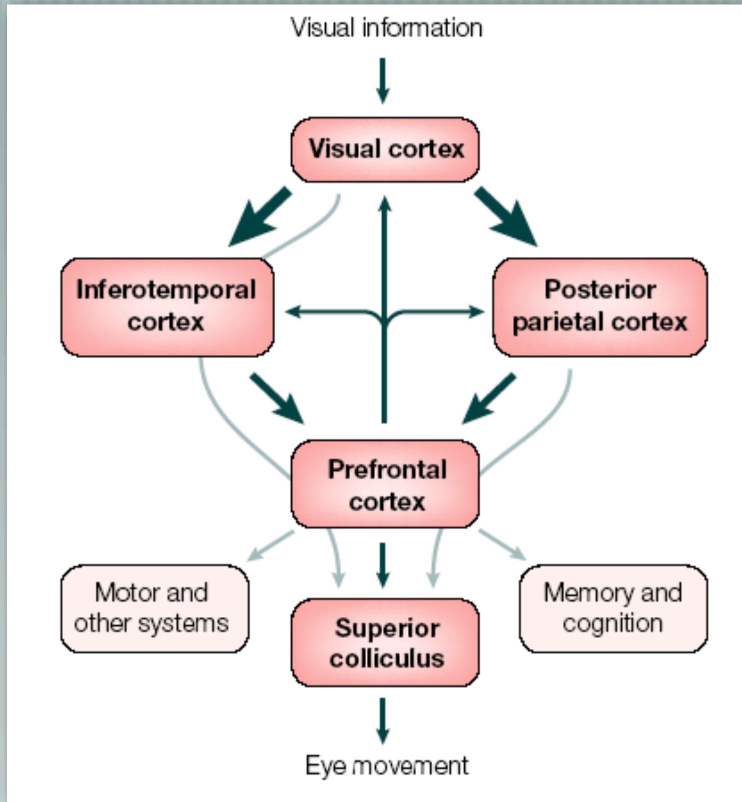
- Example: Hierarchy of the visual areas in the macaque - from "Concurrent Processing in the Primate Visual Cortex" by Van Essen and Deyoe, 1992



Looking at Synthesising Neuronal mechanisms

- Cortical areas along the ‘dorsal stream’ (including the posterior parietal cortex; PPC) are primarily concerned with spatial localisation and directing attention and gaze towards objects of interest in the scene

- Cortical areas along the ‘ventral stream’ (including the inferotemporal cortex; IT) are mainly concerned with the recognition and identification of visual stimuli



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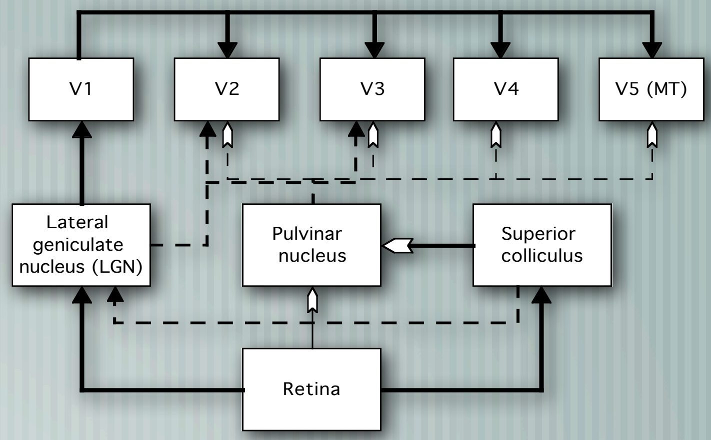
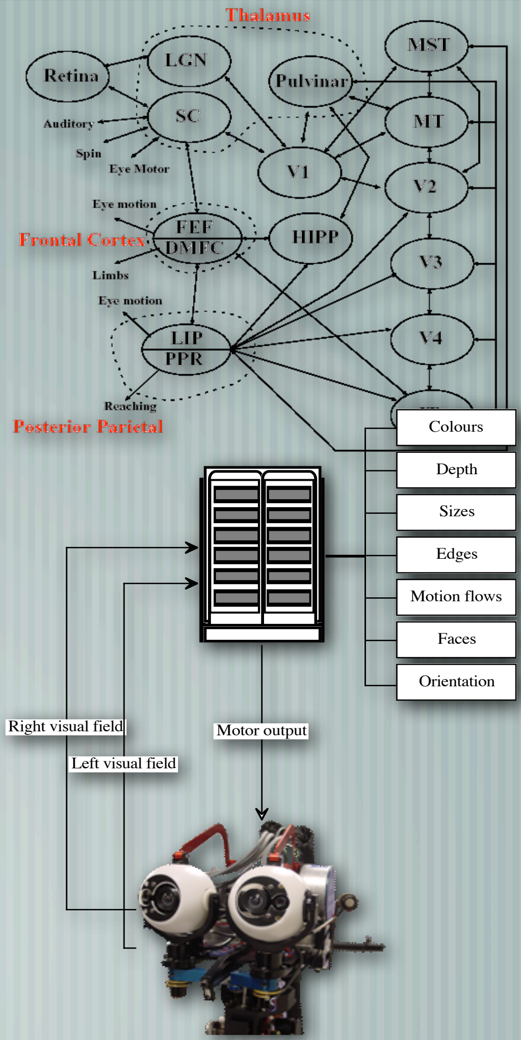
Network-based vision processing

- Attempt to emulate parts of the visual pathways
  - V1 (Primary visual cortex):
    - Retinal disparity (difference in the relative position of the stimuli in the visual field of the two eyes)
    - Colour
  - V5:
    - Motion and depth
- Initially simplified into two pathways:
  - What: e.g. V1 projection to the temporal lobes



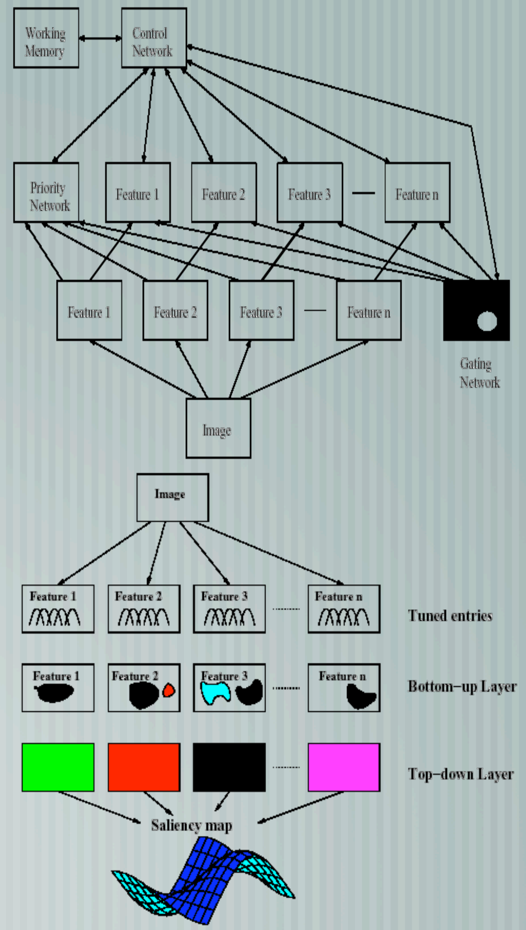
Distributed architecture

- Synthesising the human visual system
- To make better sense of human sensory processing
- More closely match the ways people process visual stimuli
- Network-based: nodes are connected together to form the overall structure
- Specialised vision processing at each node: colour, motion, depth, etc
- Basic system, a feature-based visual mechanism

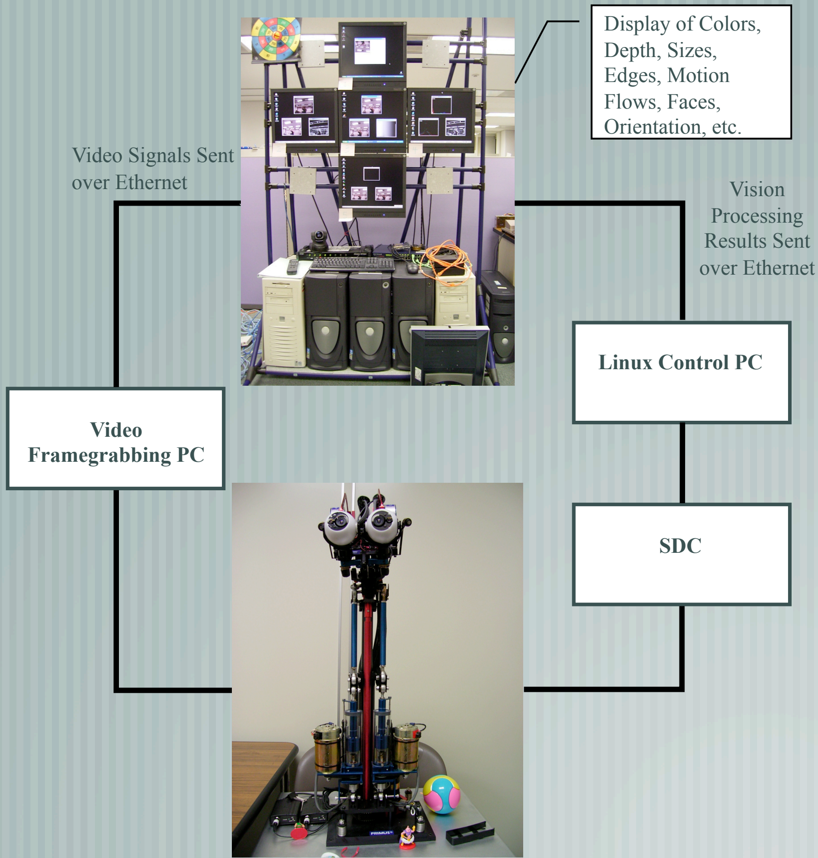


Feature-based network

- Channelling features together
    - For object encoding
- Bi-directional: encoding/ decoding
- Start with performing spatial orientation towards stimulus

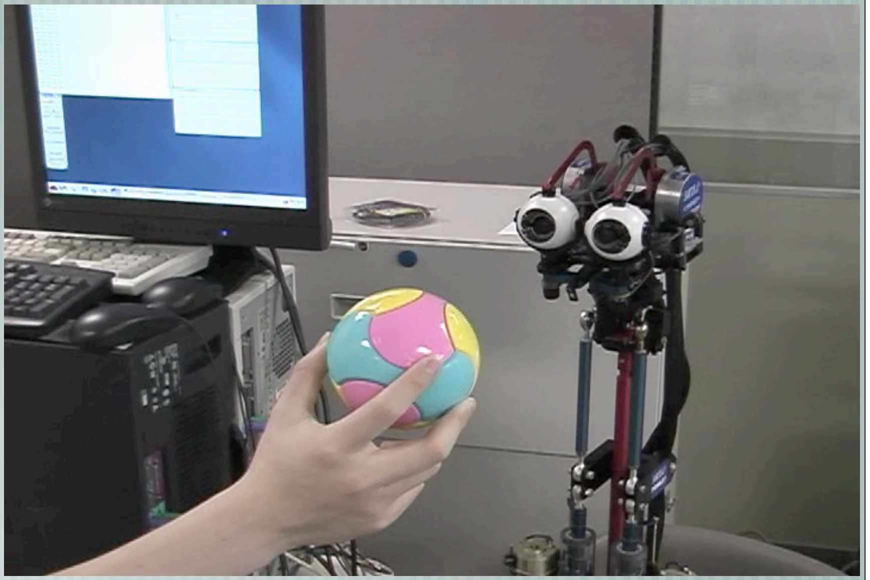


Overall structure



Distributed Architecture

- Distributed processing
  - Connection oriented i.e. network of connection
- Low latency
- Scalable across platform
- Distributed
  - Sensory processing
  - Control (work across robotics platforms)



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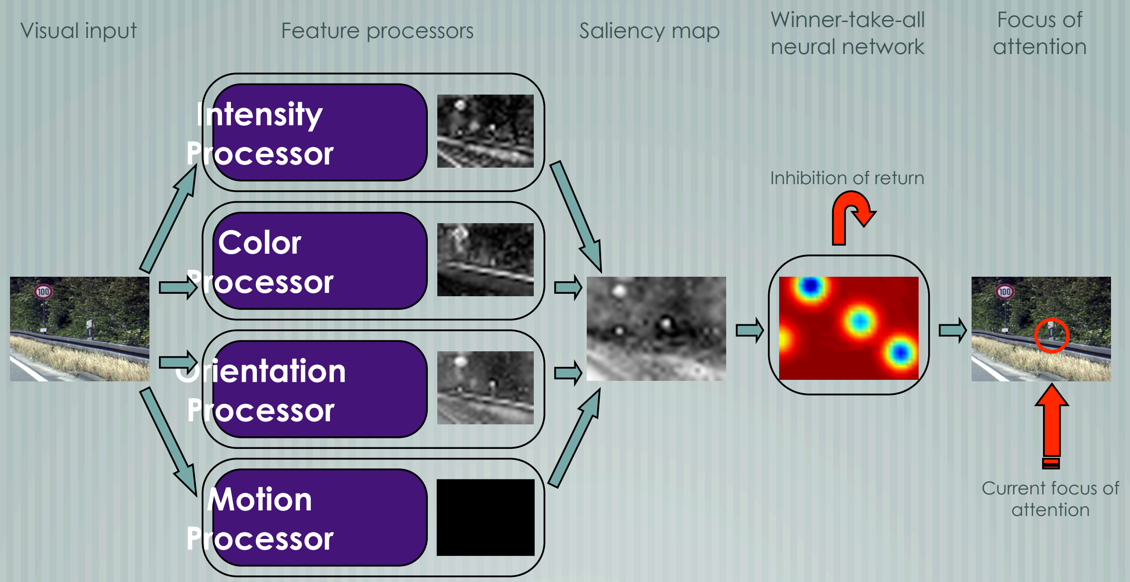
Saliency-based Visual Attention System

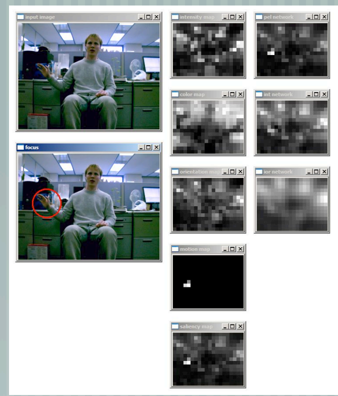
- We want a robot to be able to interpret a complex scene within a small amount of time, by focusing its processing power on a limited region, selected as interesting, at a time.
- We build a visual attention system inspired by the architecture and the behaviour of the primate primary visual cortex (V1).
  - General architecture originally proposed by L. Itti and C. Koch (1998).
  - By interesting, we mean considered as salient by the receptive cells of V1.

Visual Attention processing Model



Biologically motivated perception and action

- Gabor Filters have similar shape as the receptive fields of simple cells in the visual cortex
- Utilised for visual attention (dorsal stream/where pathway)
- Utilised for early vision to support recognition (ventral stream/what pathway)



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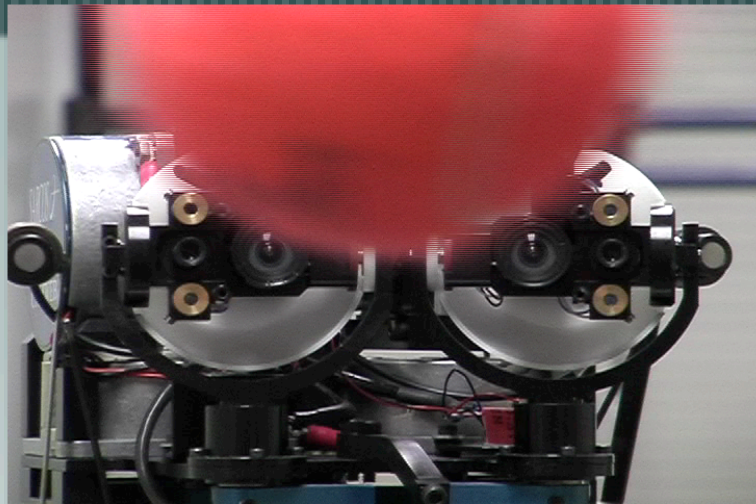
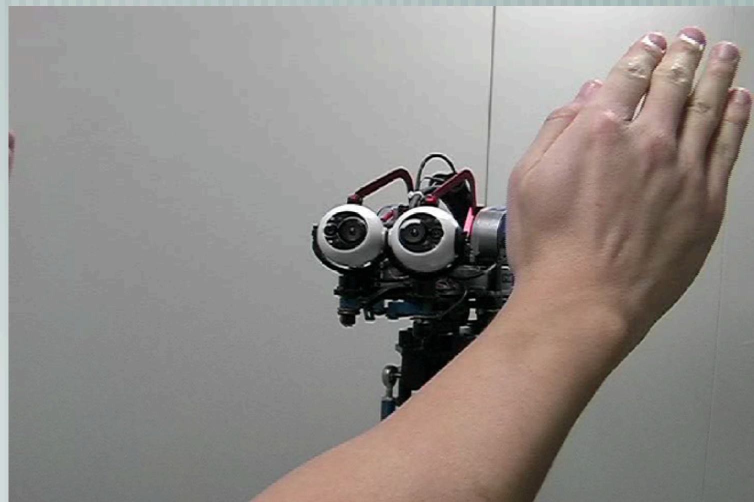
Active Vision Outline

- Version (keeping the target centered in the visual field of each eye)
- Vergence (minimizing target disparity by symmetric eye movement)
- Saccadic eye motion (quick knee-jerk type eye movements to detected motion)
- VOR (gaze stabilisation by compensating for externally induced head movements)
- Coupling of eye movements with head movement
- Saccade followed by smooth pursuit of target in an integrated control environment

Eyes movements

- Eye movements
  - Smooth pursuit (visual tracking)
  - Version
  - Vergence
  - Saccadic eye movement
- Visual processing:
  - Stereo vision
  - Motion detection
  - Colour processing





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Seeing & Reaching Development

- Human-like reaching
  - A head with two eyes
    - Look at the target for accuracy
    - See the hand when it nears the target
  - Reach using the whole body
  - Cope with change and disturbances
- Our implementation
  - Combine endpoint closed-loop and endpoint open-loop visual servoing
  - Learned motor-motor mapping

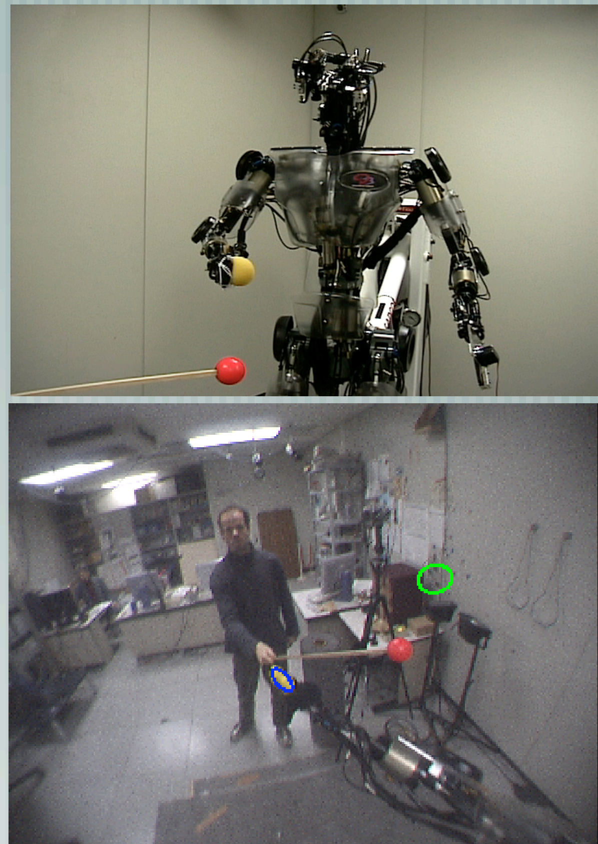
Development of Human Reaching

- Babies spend a lot of time reaching out and looking at their hands
- Perhaps a sensor-motor map between view of the hand and the position of the hand is learnt first... – retinal coordinate system
- Then, based on the sensor-motor map, a motor-motor map could be learnt that allows more awareness of the body e.g. proprioception, and reaching when the hand is not visible

  – joint coordinate system

Exploring Human-like Behaviour

- Reproducing Human-like Behaviour:
  - Seeing & Reaching
  - Real-time vision/Active Stereo Tracking
  - Full-body movements
    - To maximise coverage
- Developmental/Interactive approach
  - Learning through interaction
  - Motor-motor mapping
    - From Close-loop to Open-loop representations are learnt



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Higher-level vision

- Visual search for detection / visual attention, saccadic movements (peripheral vision)
- Tracking and smooth pursuit (peripheral / foveal vision)
- Recognition (foveal vision) and action

Visual goal selection

- Combining
  - Peripheral and Foveal vision
  - Colour Tracking
  - Object Recognition
- Better Recognition is Gained by using Foveal view of the object - through visual acuity

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Robotic Hand as a Trestbed

- Allows testing of various computational models on a physical platform
  - e.g. Imitation, skill acquisition via reinforcement learning, and affordance learning
- Our first project using the Gifu Hand infrastructure as a model testing tool:
  - LEARNING TO IMITATE

Ways to Learn to Imitate

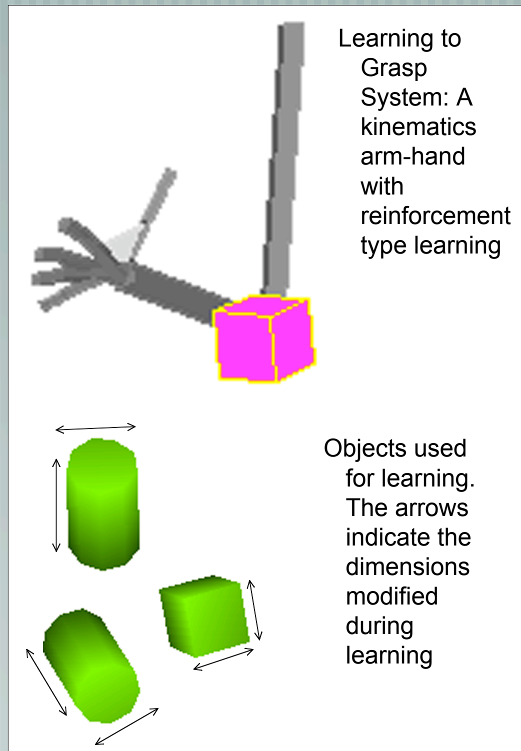
- Self observation
  - Agent produces action (A)
  - Agent sees consequence of the action (V)
  - Agent associates A and V
- Social learning
  - Through interacting with other agents in the environment.

SOCIAL LEARNING FOR IMITATION

- Social (reinforcement) learning
  - Agent observes action (V)
  - Agent generates an action (A)
  - If social reward is collected,
    - agent associates A and V
- Social (supervised) learning
  - Agent shows action (A)
  - Agent sees teacher’s imitation (V)
  - Agent associates A and V

Simulation of a Learning to Grasp system

- The monkey parietal area AIP has been shown to contain neurones that extract object features relevant for grasping such as the width and the height.
- AIP is strongly interconnected with the ventral pre-motor area F5, that is involved in grasp planning and execution.
- We present evidence supporting our simulation results from infant developmental studies.
- The focus of this study is to investigate the formation (emergence) of AIP neurons during grasp development



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Exploring brain mechanisms for dexterity

- Motion capture studies of human dexterity
- Emergent Grasp Affordance Encoding via Grasp Learning
  - "Affordances" are properties of the object relevant for action (for example grasping)
  - AIP cells encode "affordances" for grasping from the visual stream and sends these

    on to area F5
  - These ideas from biology will be tested on a real robotic system (Gifu Hand III)

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Associative memory hypothesis of imitation bootstrapping

- study a range of topics ranging from manual skill learning, imitation and affordance learning
- we have explored the "associative memory" hypothesis of imitation bootstrapping

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Conclusions

- A framework to support the investigation/development of Embodied Cognition has been proposed
  - Merging Brain and Body together
- An architecture for the construction of components and more importantly the connective organisation of these components
- Some initial results (at various levels) have been proposed/developed