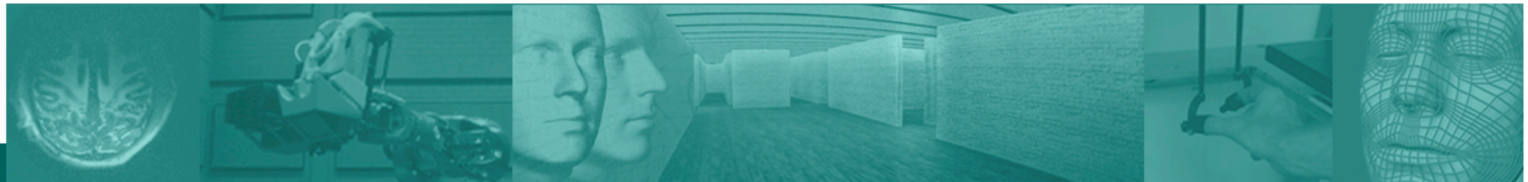
Multimodal categorization

Heinrich Bülthoff, Christian Wallraven



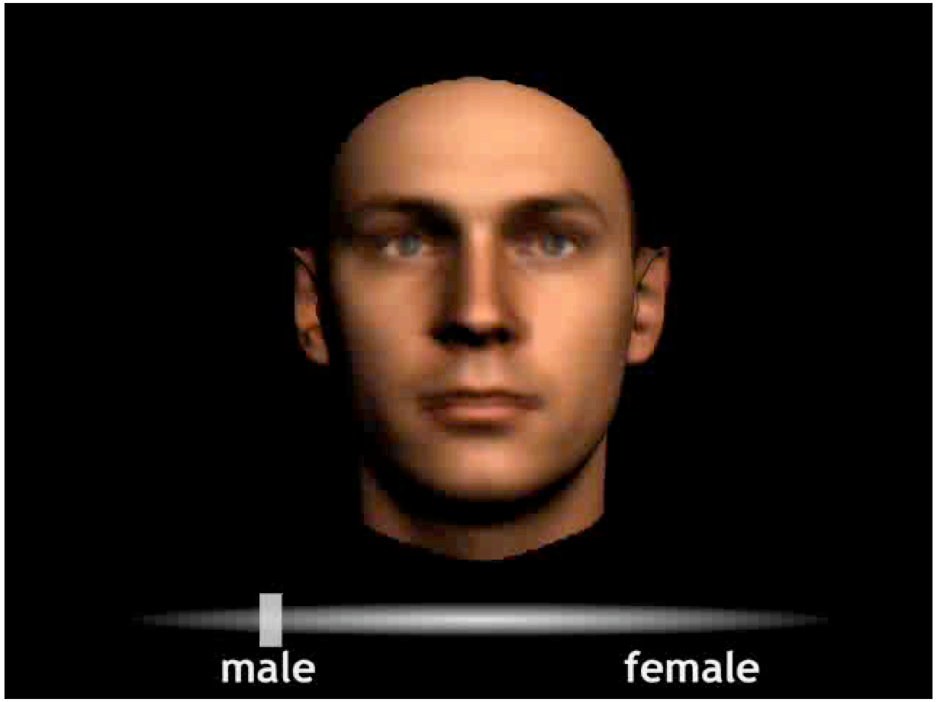
Cognitive & Computational Psychophysics
Max Planck Institute for Biological Cybernetics

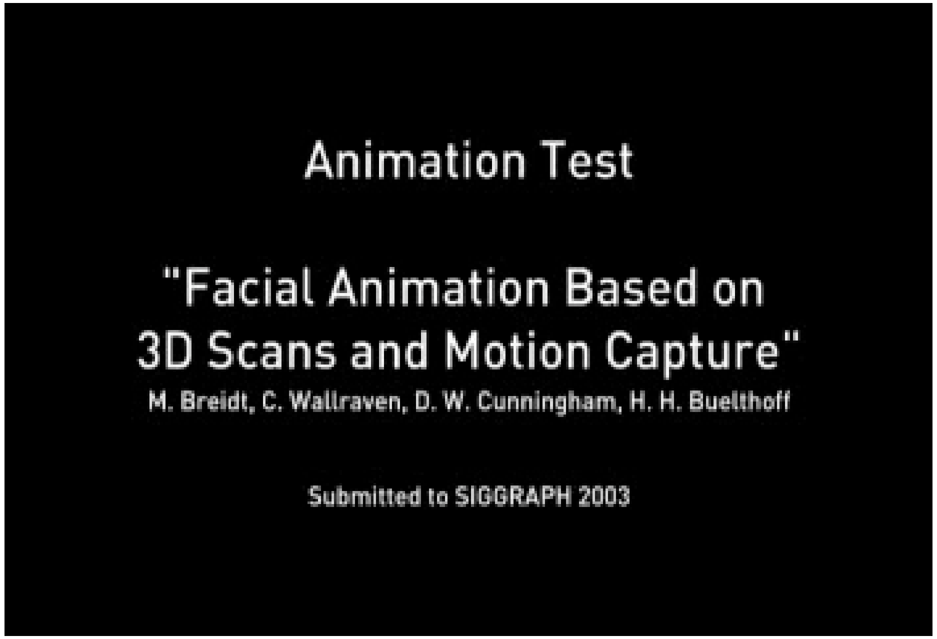
Overview

- The question of how the human brain "makes sense" of the sensory input it receives has been at the heart of cognitive and neuroscience research for the last decades.
- One of the most fundamental perceptual processes is **categorization** – the ability to compartmentalize knowledge for efficient retrieval.
- Recent advances in computer graphics and computer vision have made it possible to both produce highly realistic stimulus material for controlled experiments in life-like environments as well as to enable highly detailed analyses of the physical properties of real-world stimuli.

Research Philosophy

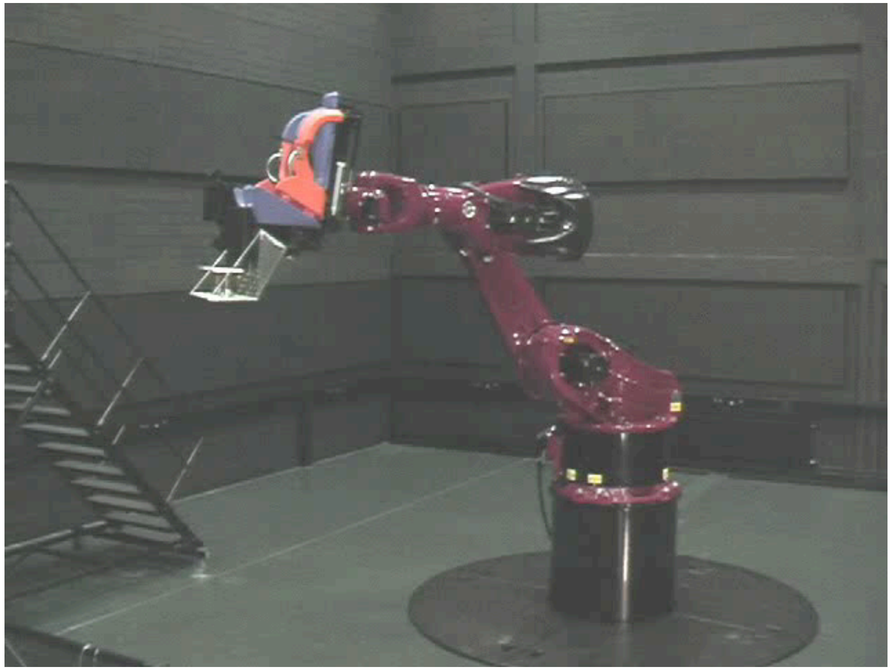
- Study perception and action with stimuli as close as possible to the real world, using
  - Computer Graphics
    to generate natural but well controlled stimuli of objects and scenes
  - MPI Face Database (open access)
    - faces.kyb.tuebingen.mpg.de
    - vdb.kyb.tuebingen.mpg.de
  - Database of High-Dynamic-Range Images (soon to come)
  - Virtual Reality
    to study perception and action in a closed loop





Research Philosophy

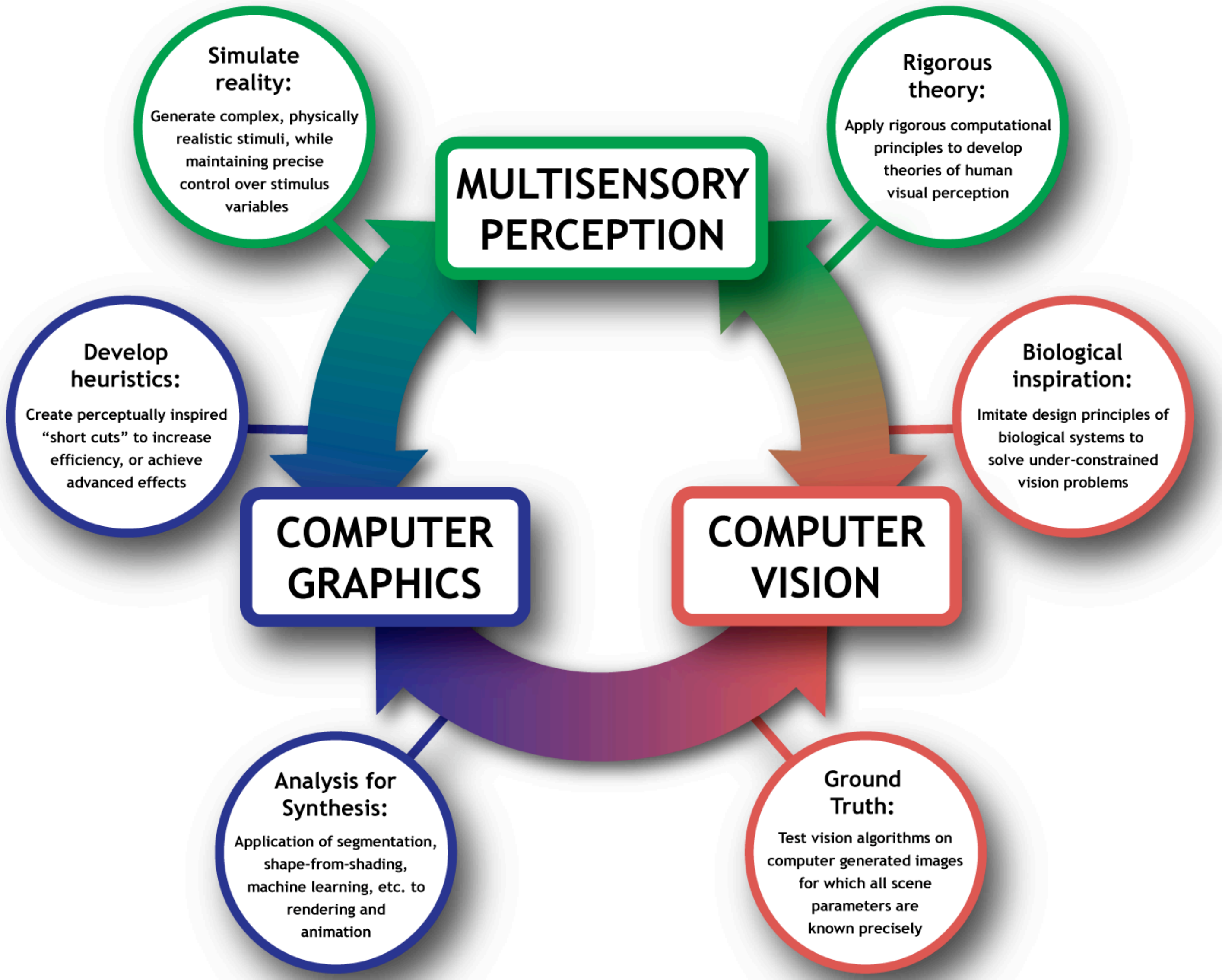
- Study perception and action with stimuli as close as possible to the real world, using
  - Computer Graphics
    to generate natural but well controlled stimuli of objects and scenes
  - Virtual Reality
    - www.cyberneum.de
    - motion simulators
    - haptic simulators
    - walking simulators
    - immersive environments
    - panoramic projections
    - EU-projects: JAST, BACS, CyberWalk, Immersense, Wayfinding



Overview

- In this talk, we will review some of the **key challenges** in understanding categorization from a combined cognitive and computational perspective:
  - the need for spatio-temporal representations
  - perception of material properties
  - multi-modal/multi-sensory aspects of object categorization
  - coupling of perception and action

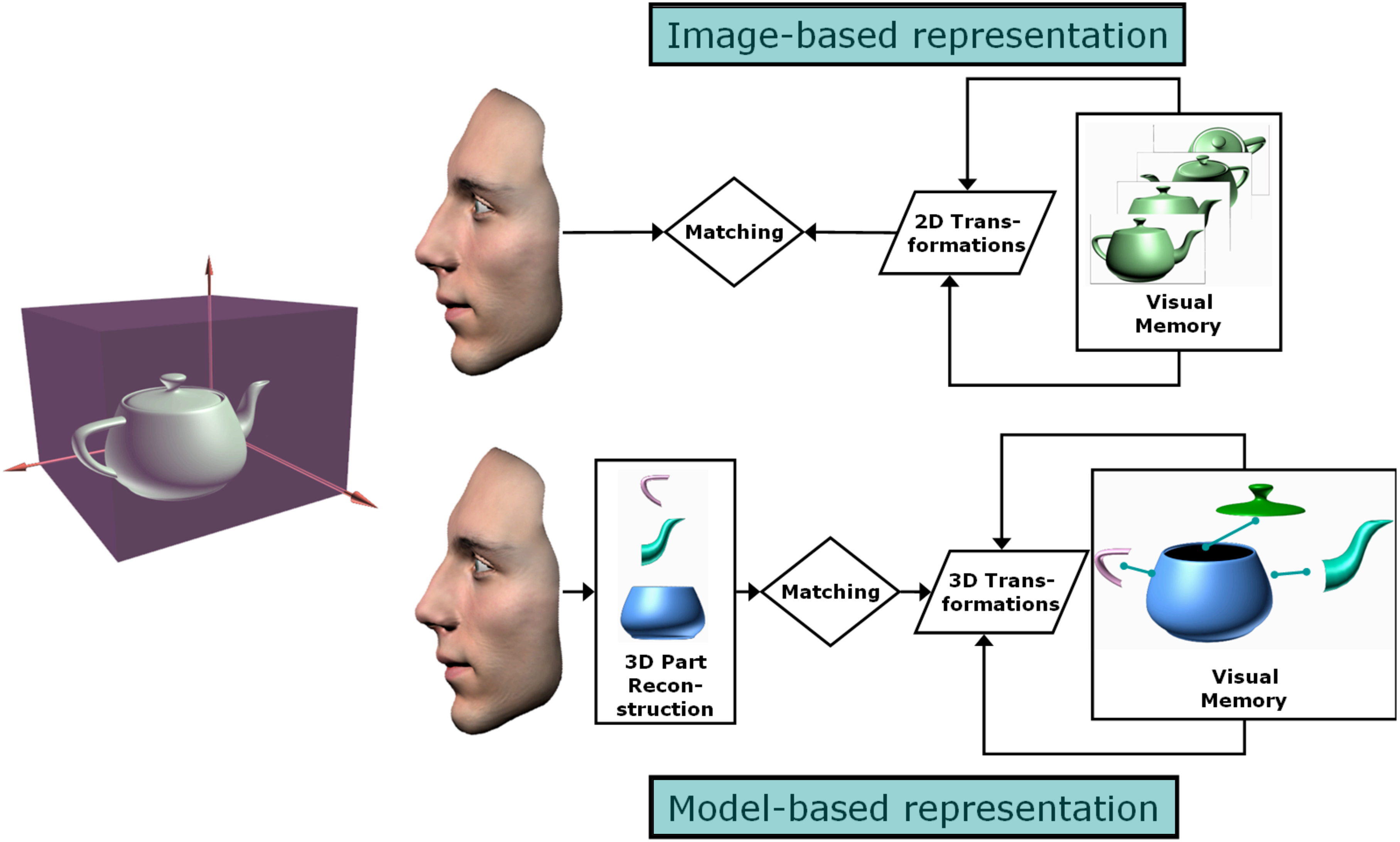
Research Paradigm



Overview

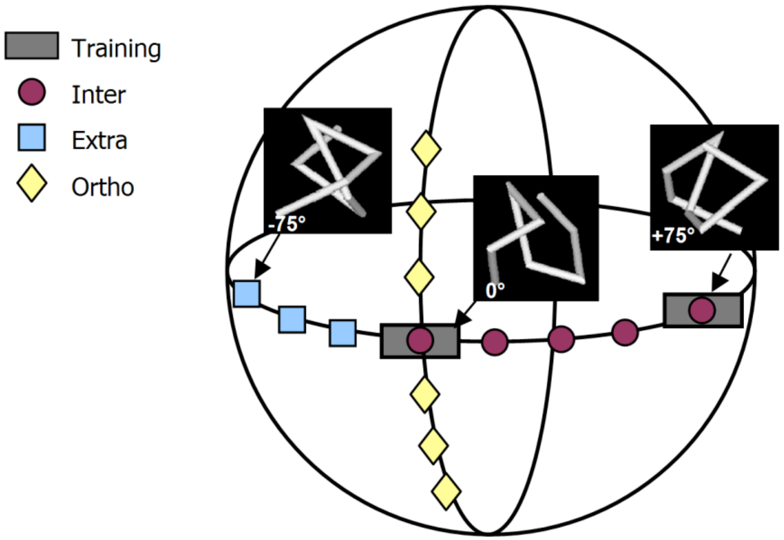
- The talk will focus on issues that so far have only started to be addressed but that are crucial for a deeper understanding of perceptual processes:
  - **the need for spatio-temporal representations**
  - perception of material properties
  - multi-modal/multi-sensory aspects of object categorization
  - coupling of perception and action

Representing objects: two models

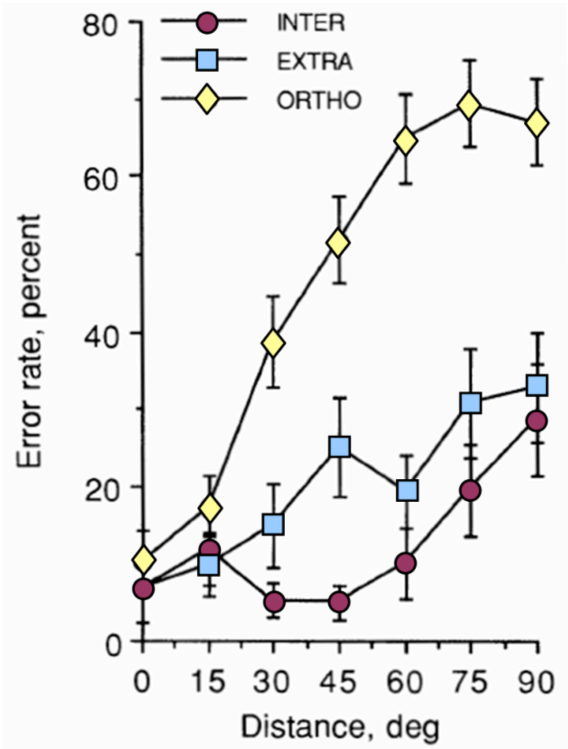


Representing objects: image-based recognition
Bülthoff and Edelman [*PNAS*, 1992]

- Recognition of novel objects depends on the viewing conditions (→ image-based recognition)



Design

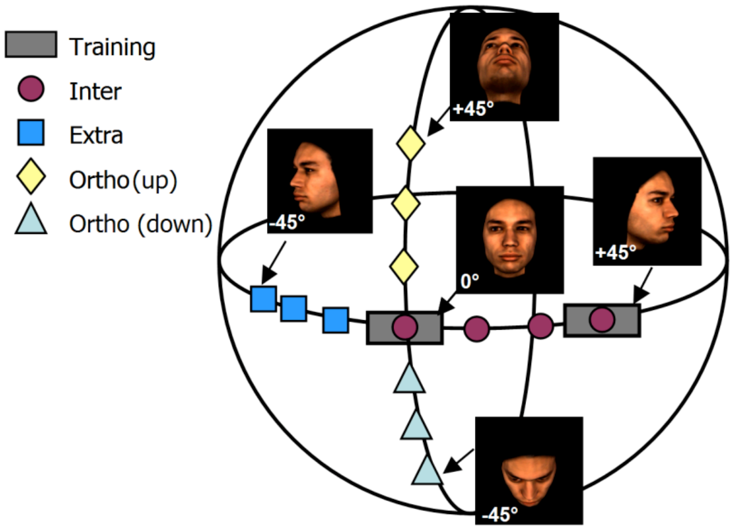


Inter > Extra > Ortho

Representing faces: image-based recognition

Wallraven, Schwaninger, Schumacher, Bülthoff [*BMCV*, 2002]

- Recognition of novel **and familiar** objects depends on the viewing conditions (→ image-based recognition)



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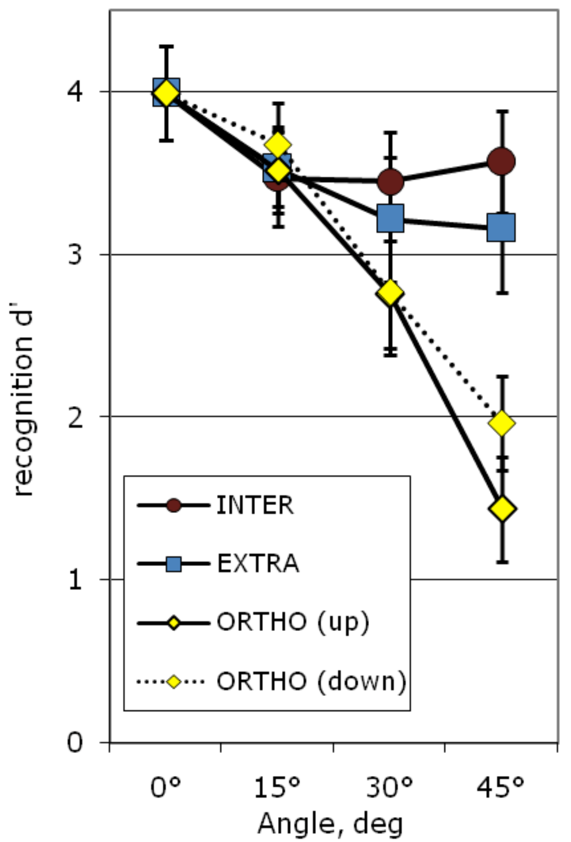


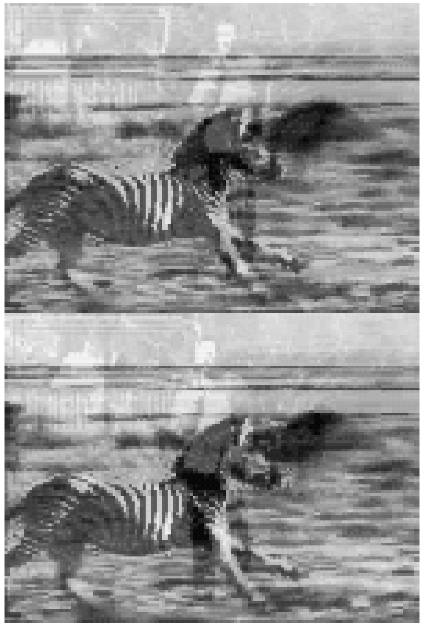
Inter > Extra > Ortho

The role of motion in recognition

1. Familiar motion facilitates person identification

2. Motion facilitates human target detection

3. Non-rigid motion is encoded as identity cue



Pilz, Vuong, Bülthoff, Thornton [*JEP: HPP*, subm]

Vuong, Hof, Bülthoff, Thornton [*Journal of Vision,* 2006]

Chuang, Vuong, Thornton, Bülthoff [*Visual Cognition,* 2006]

Quick summary (Spatio-temporal representations)

- Objects and faces are represented in an image-based fashion
- The temporal properties of objects play an important role during learning and recognition
- Object representations are spatio-temporal

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  - **perception of material properties**
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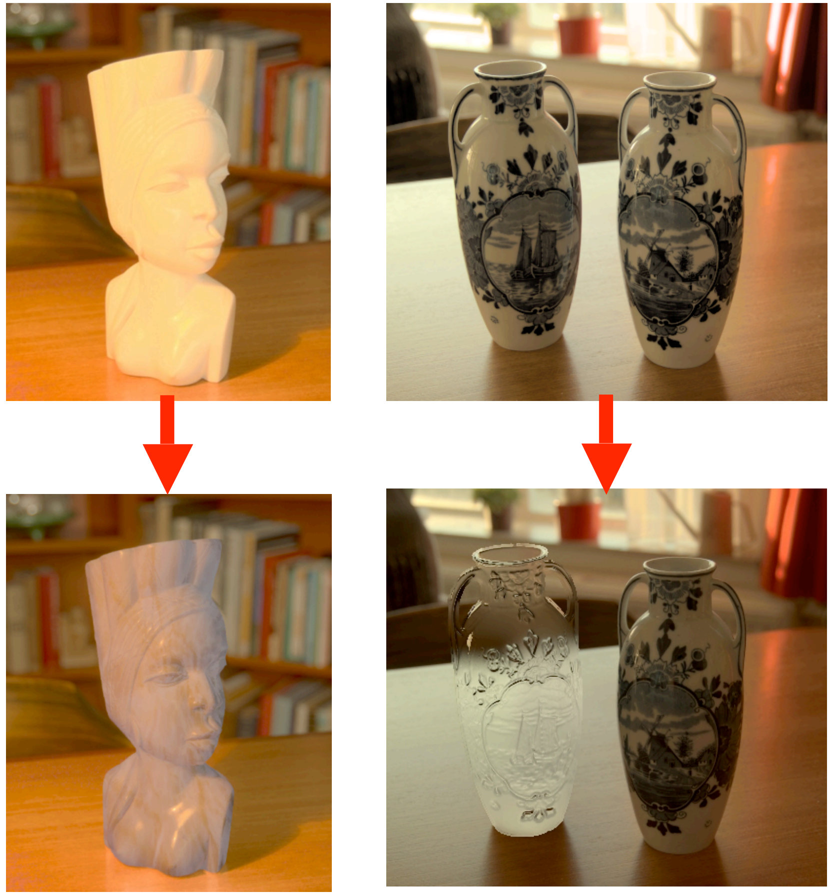
  - coupling of perception and action

Image-based material editing

Kahn, Reinhard, Fleming, Bülthoff [*SIGGRAPH*, 2006]

- Goals:
  - How do humans perceive materials?
    - Ill-posed problem
  - Can we exploit perceptual tricks to change materials in a photograph (without a 3D-model)?
- Methods:
  - Crude 3D shape reconstruction using bilateral filter (dark means deep – SFS)
    - Exploits **generic viewpoint assumption** as an image is consistent with many 3D models
  - Simple background-inpainting for transparency
    - Exploits **masking**
    - **weak model of refraction**
- Results:
  - Re-texturing
  - Medium gloss to matte or glossy
  - Opaque to transparent or translucent



re-textured **transparency**

Image-based material editing

Kahn, Reinhard, Fleming, Bülthoff [*SIGGRAPH,* 2006]

Quick summary (Material Perception)

- The brain does **not** use an inverse physics approach to perception
- Rather, the brain uses (complex) heuristics to estimate
  - Material properties
  - Shape
- By exploiting these heuristics one can create simple, but effective work-arounds to control these properties

Overview

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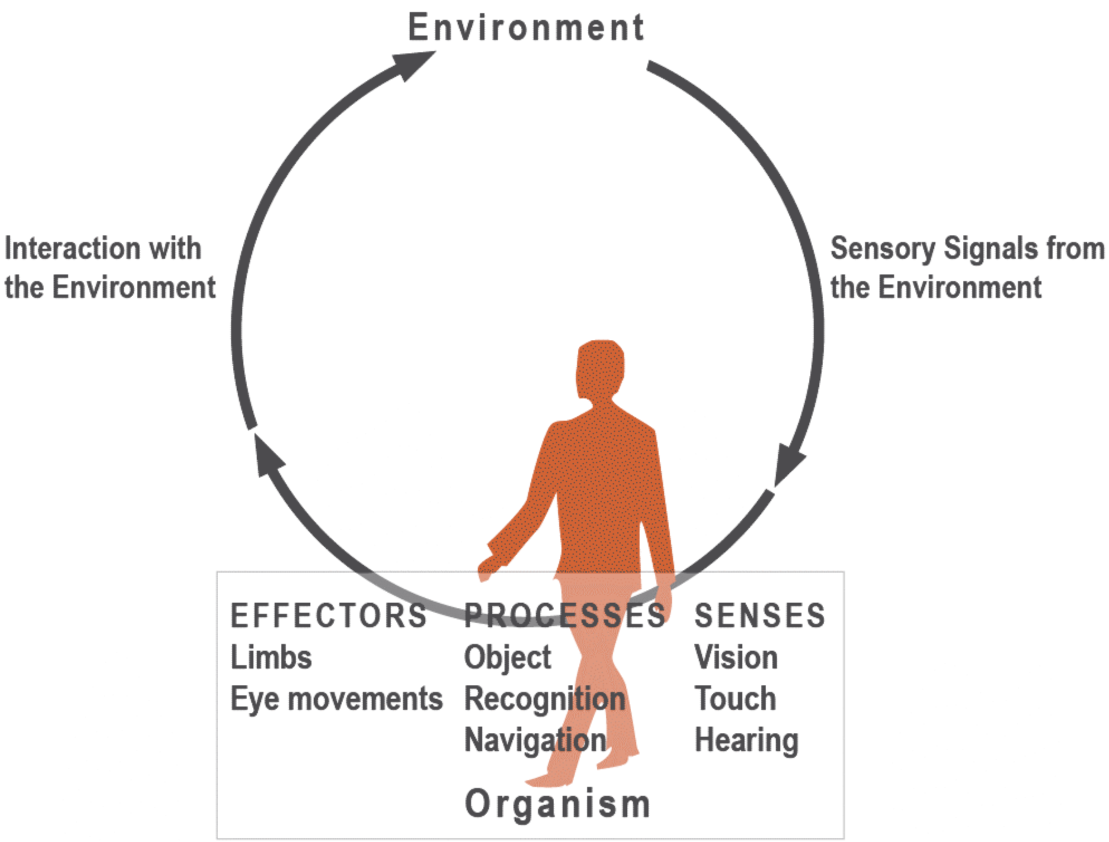
  - coupling of perception and action

Sensory integration

- Humans act upon objects in order to interact with the world.
- Two studies addressed the following questions:
  - Are object representations multi-modal?
  - How can we teach artificial agents how to interact with the world?



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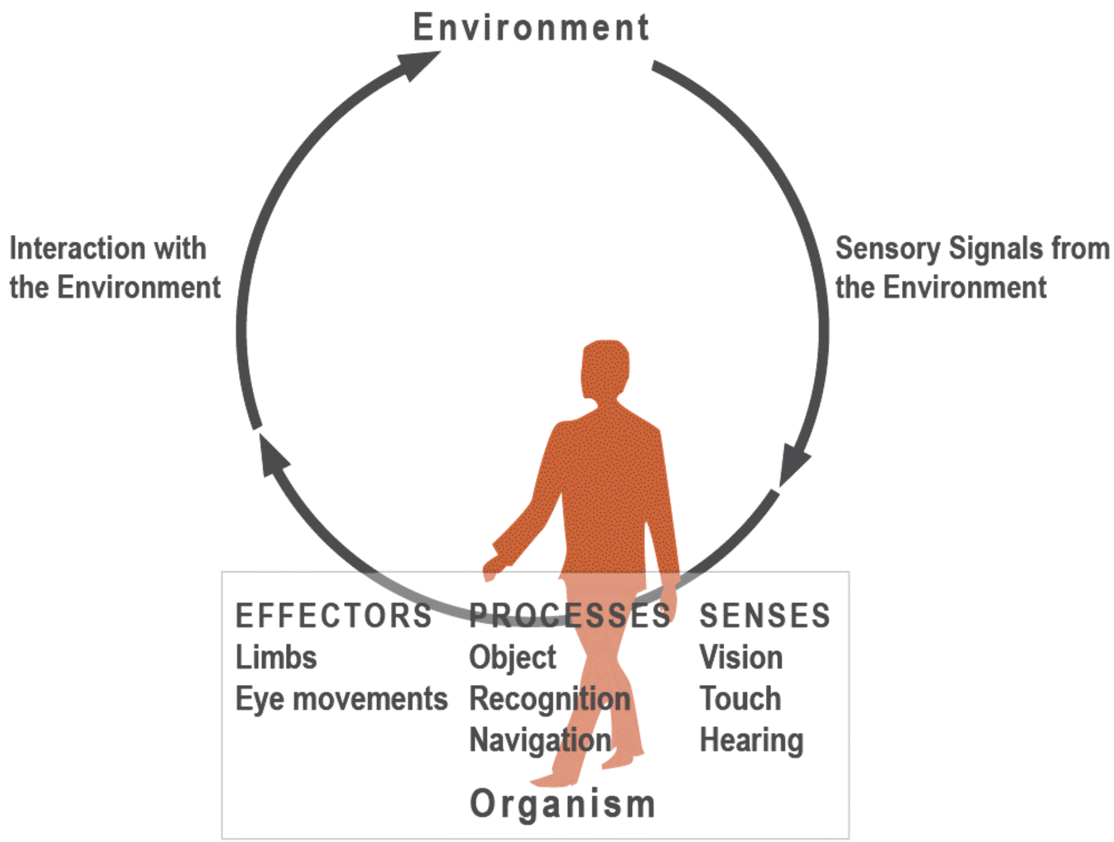
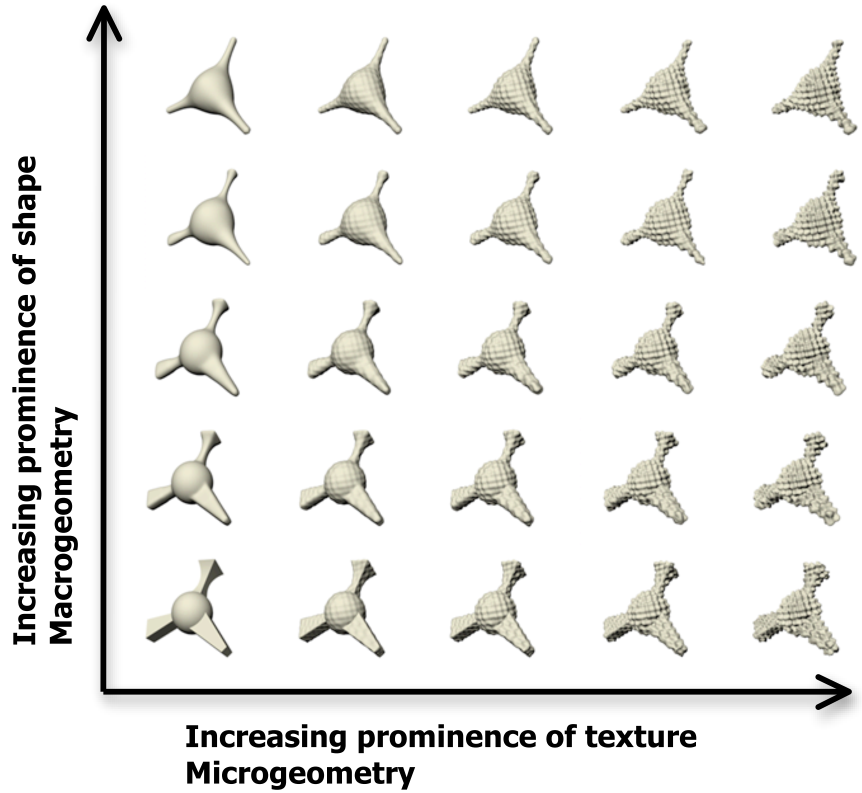
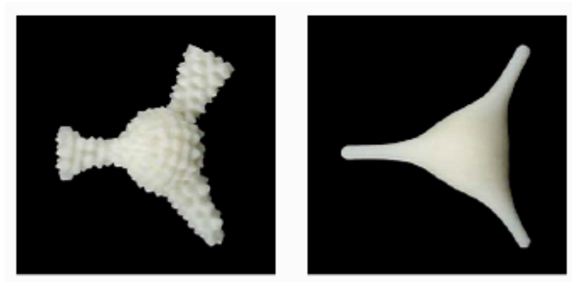


Multi-modal similarity and categorization of novel, 3D objects

Cooke, Jäkel, Wallraven, Bülthoff [*Neuropsychologia*, 2007]

- Goal:
  - Develop framework for understanding multi-sensory (visuo-haptic) object perception
- Methods:
  - Controlled space of visuo-haptic stimuli printed in 3D
  - Multi-Dimensional-Scaling for finding perceptual space for haptic, visual and bimodal exploration

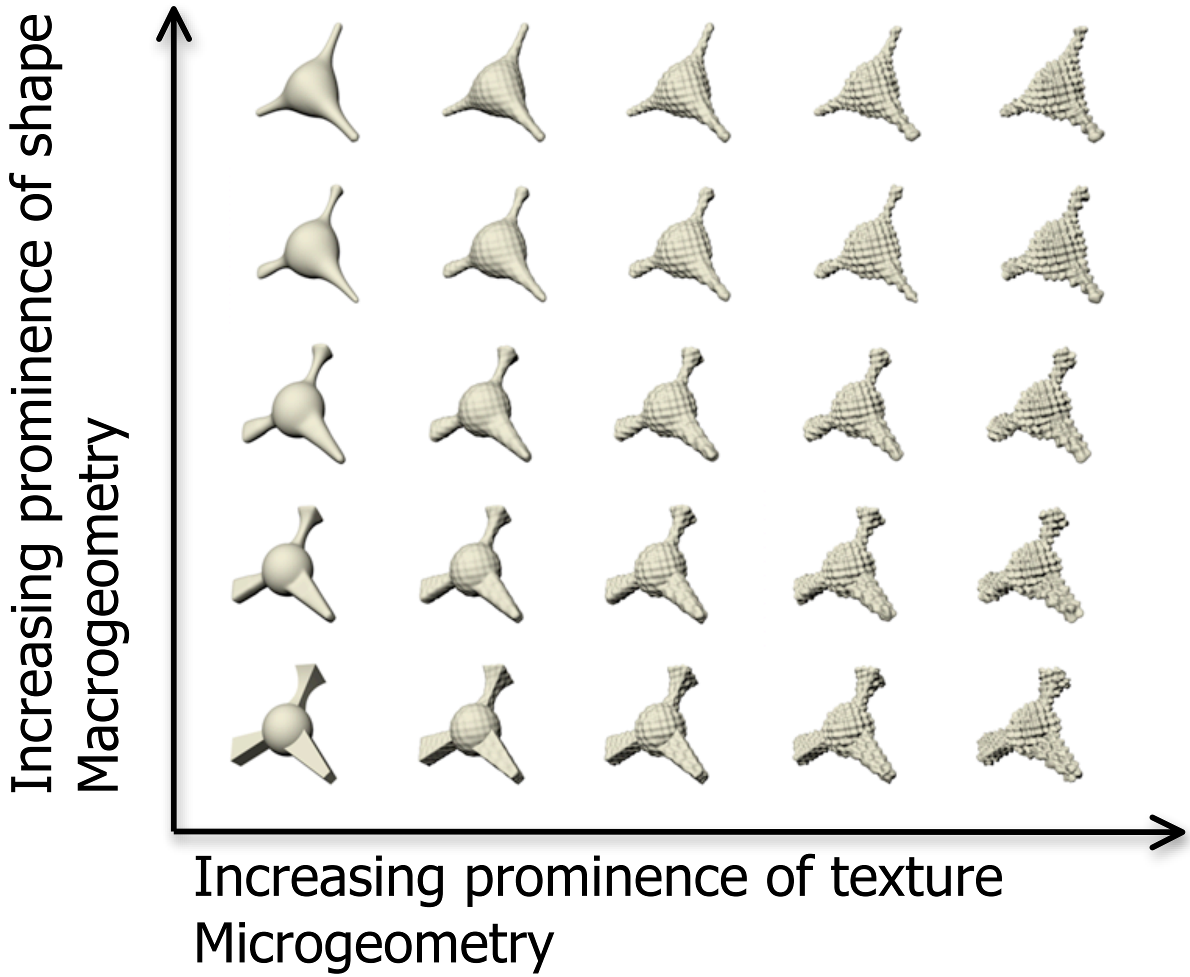




Photographs of printed 3D objects

The tools: Parametrically-defined stimuli & 3D printer

Cooke, Jäkel, Wallraven, Bülthoff [*Neuropsychologia*, 2007]

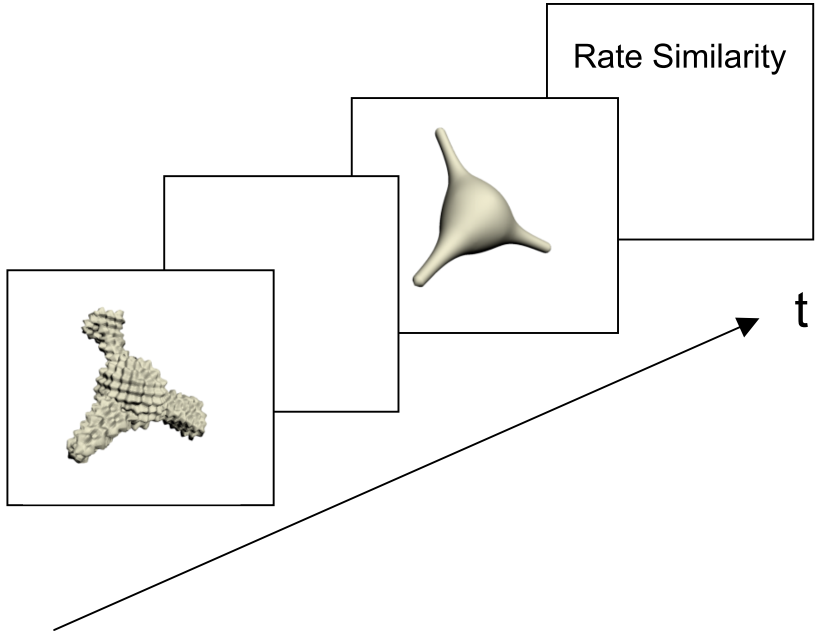


3D printer

Printed object

The experiment: Multi-sensory similarity
Cooke, Jäkel, Wallraven, Bülthoff [*Neuropsychologia*, 2007]

Experimental Setup

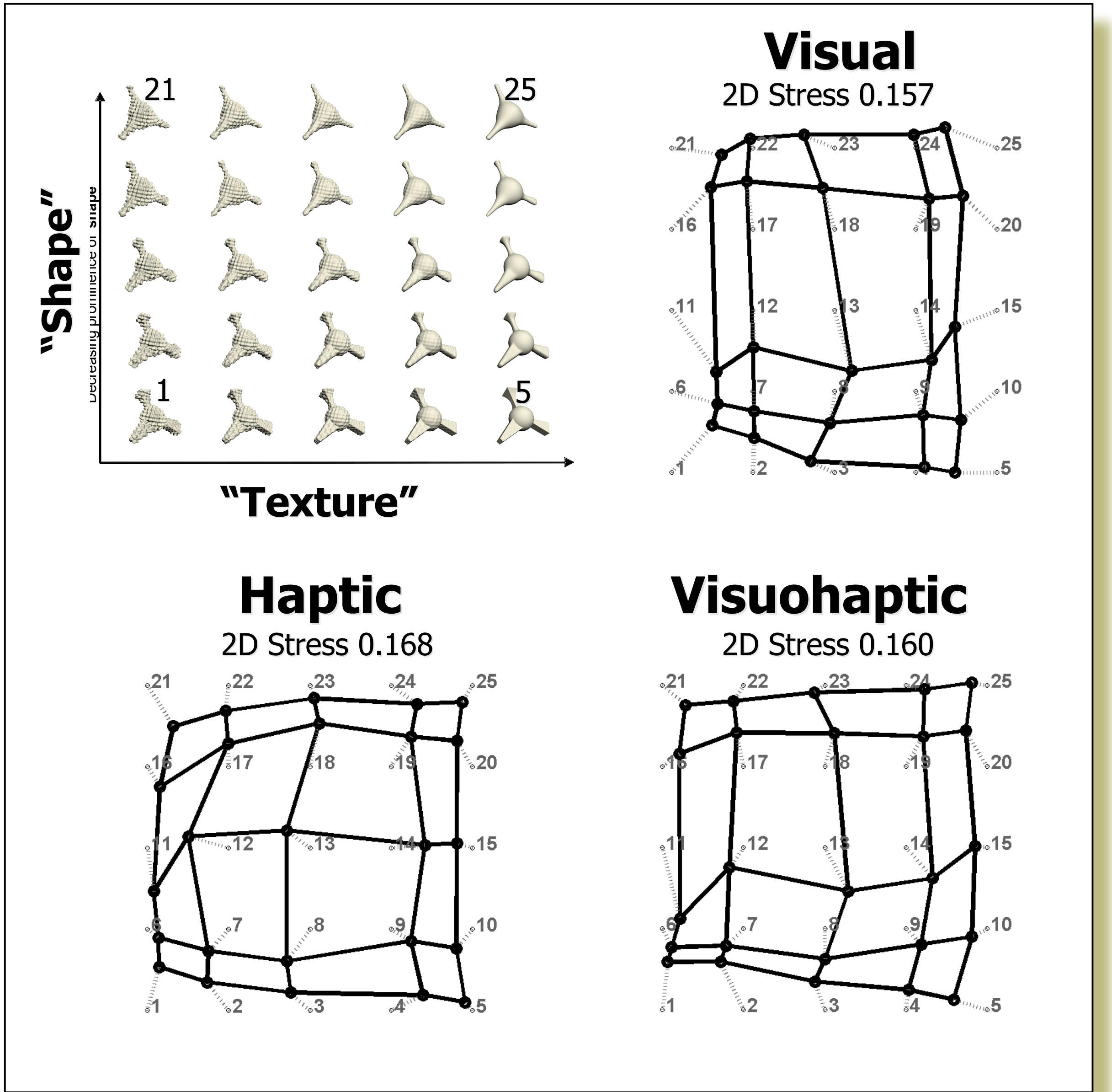


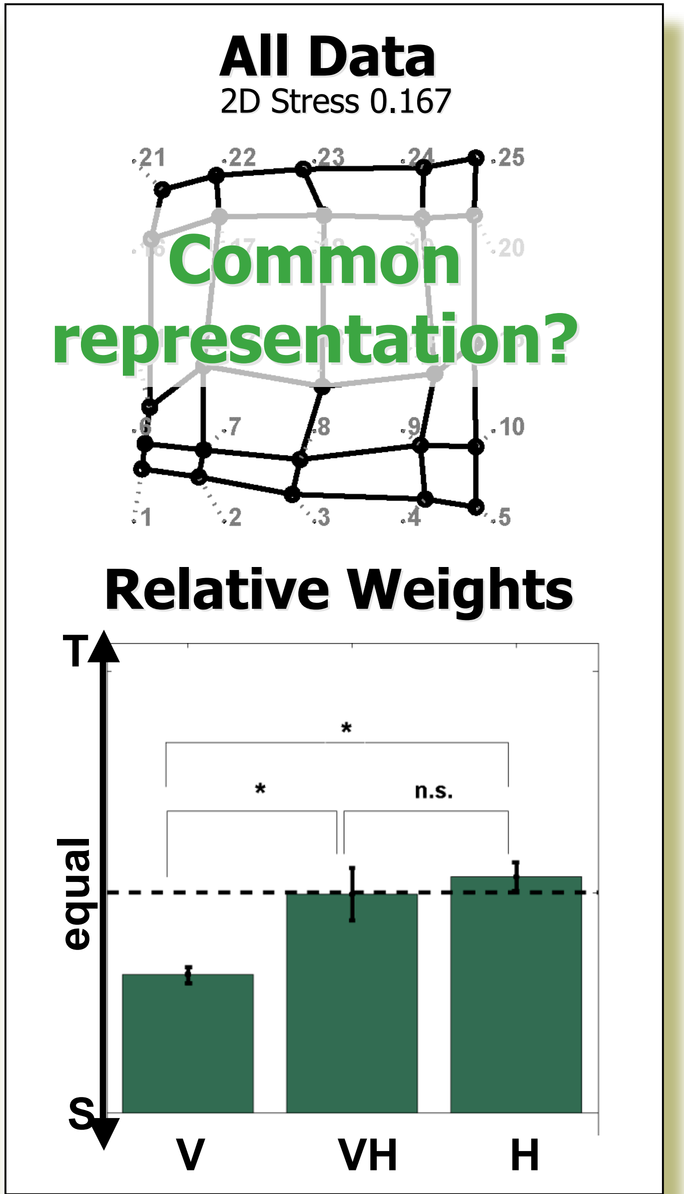
Trial Sequence

- 10 subjects x 3 conditions: Visual (V), Haptic (H), Visuohaptic (VH)
- Task : Similarity ratings

Results: Modality Effects

Cooke, Jäkel, Wallraven, Bülthoff [*Neuropsychologia*, 2007]

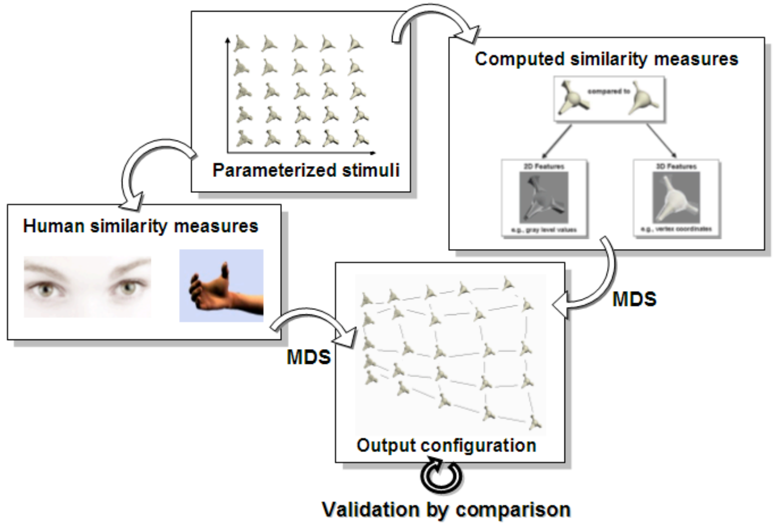


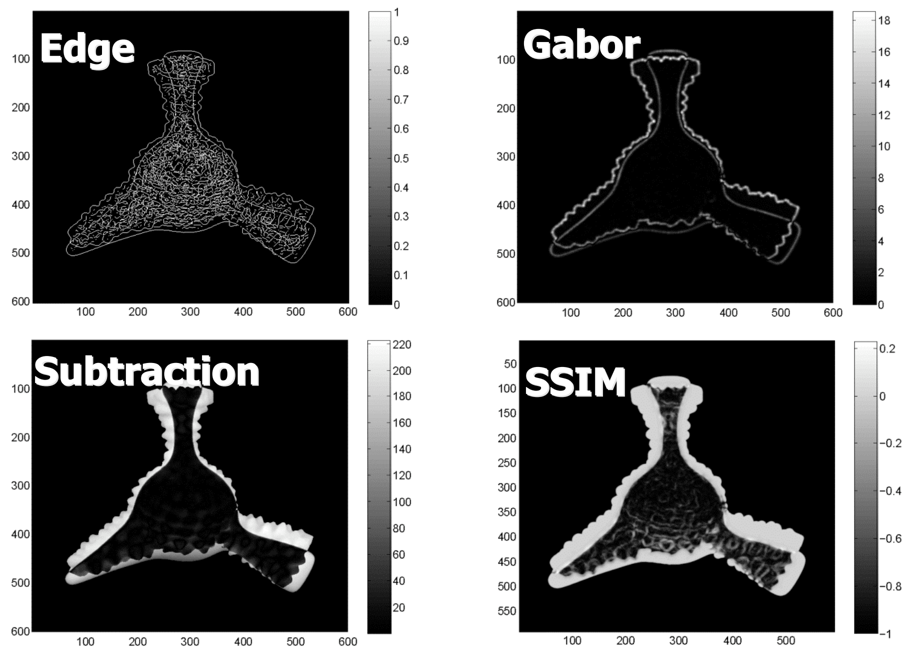


Perceptual Feature Toolbox

Wallraven, Cooke, Kannengießer [*http://pft.homeunix.org/*, 2007]

- Goal:
  - Develop toolbox for perceptual feature validation
- Methods:
  - 2D features from computer vision
    - Pixel values, Edge Images, Gabor filter response, Visual Difference Predictor, Structural Similarity, Shape Context
  - 3D features from computer graphics
    - Vertex Coordinates, Vertex Count, Perimeter, Mean Local Curvature, Shape Histograms
- Results:
  - Applied to Visuo-haptic similarity ratings:
    - Most 2D features model visual similarity judgments well but were not able to model human haptic perception





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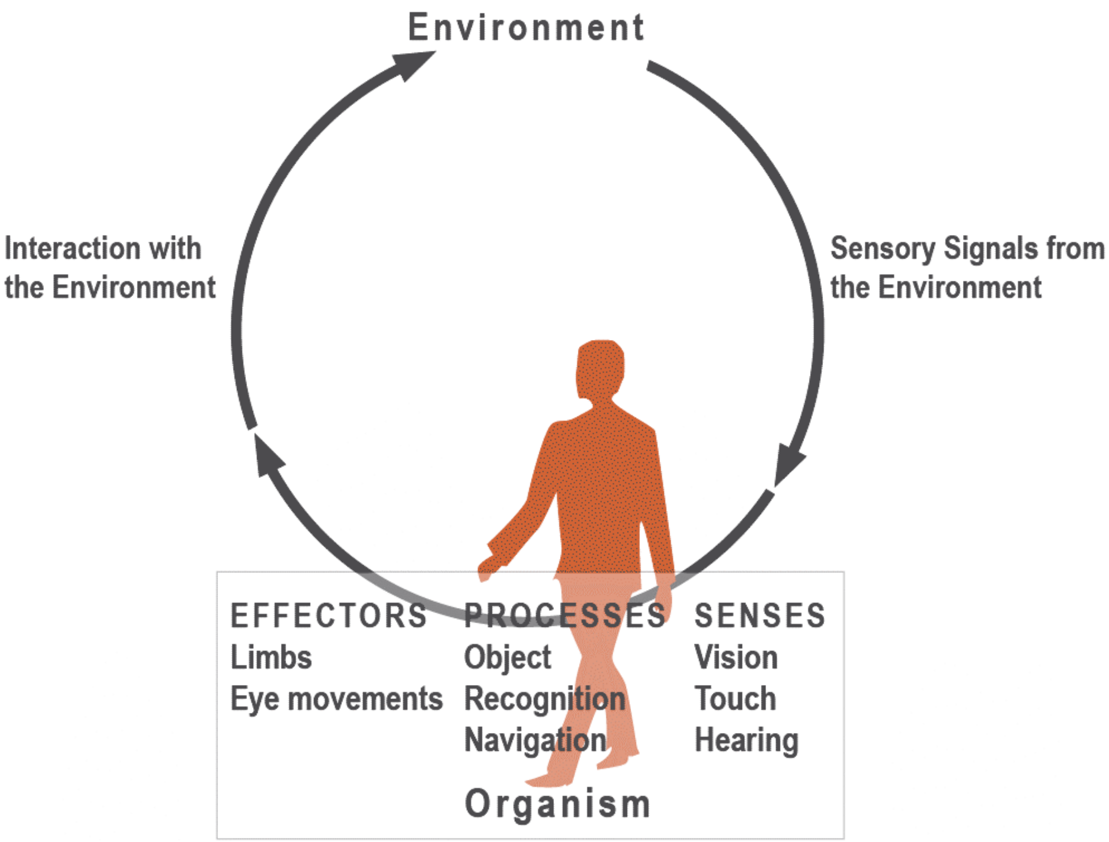


Learning multi-modal Object Representations

Natale, Rao, Sandini & Wallraven [*CogVis Project*, 2004],
Wallraven & Bülthoff [*Object Recognition, Attention, Action*, 2007]

“How can
Proprioception, Vision and Active Control
make object recognition more robust?”

Self-terminating Learning

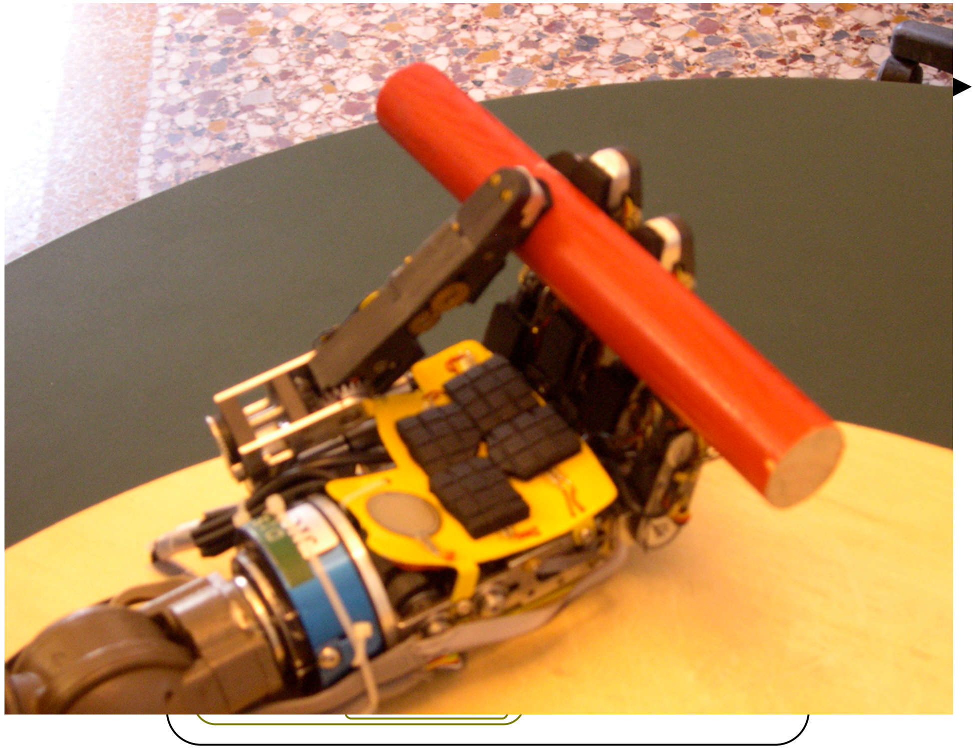
Proprioceptive View-Transition Map

Object Recognition

Learning multi-modal Object Representations

Natale, Rao, Sandini & Wallraven [*CogVis Project*, 2004],
Wallraven & Bülthoff [*Object Recognition, Attention, Action*, 2007]

- A robot with stereo-cameras, an arm equipped with proprioceptive sensors
  (LiraLab *Baby-Bot*)
- A simple, view-based visual recognition framework that learns object representations from image sequences
  (Wallraven & Bülthoff [*CVPR*, 2001])
- Coupling of proprioceptive information (joint angles) with views for learning **and** recognition

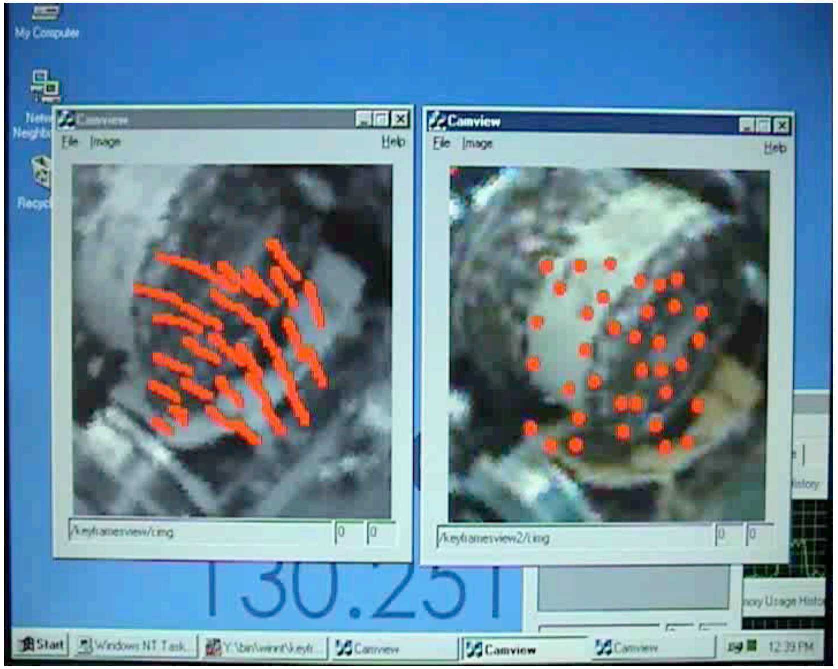


Learning multi-modal Object Representations

Natale, Rao, Sandini & Wallraven [*CogVis Project*, 2004],
Wallraven & Bülthoff [*Object Recognition, Attention, Action*, 2007]

- Robot performs explorative motor-program for any given object to learn the multi-sensory representation

External View

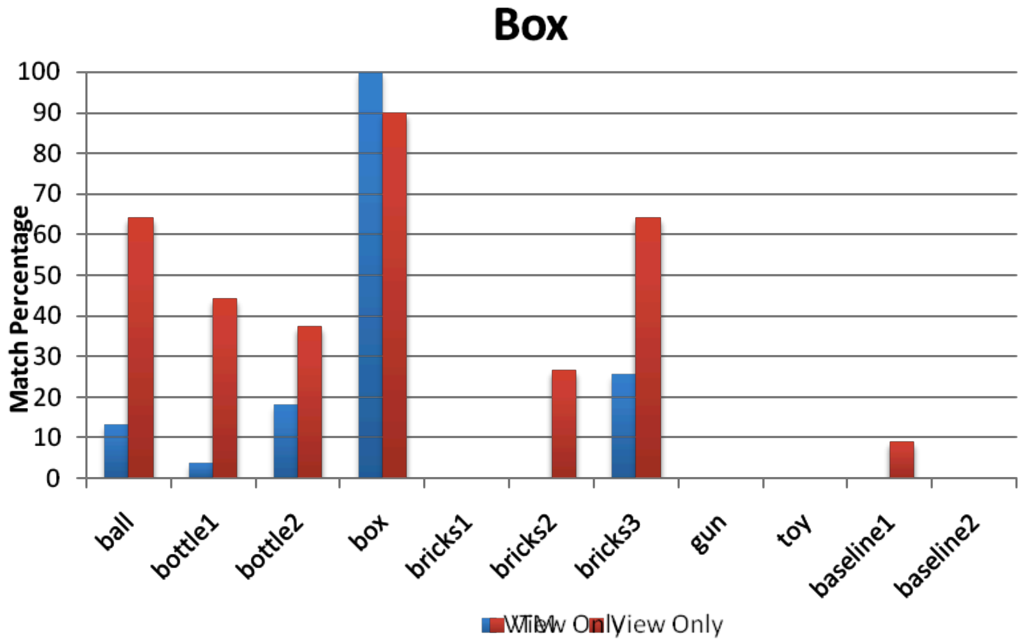


Keyframes Tracking

Learning multi-modal Object Representations

Natale, Rao, Sandini & Wallraven [*CogVis Project*, 2004],
Wallraven & Bülthoff [*Object Recognition, Attention, Action*, 2007]

- **Visual matching** is sufficient to predict the best model but is **not** very discriminatory
- **Multi-modal matching** profile is more **“sharply tuned”**
- The integration of proprioceptive information adds viewer-centered **3D information**



Quick summary (Sensory Integration)

- Object representations can incorporate multi-sensory information
- Common representation for vision and haptics (?)
  - Cross-modal transfer between vision and haptics
    Newell, F., M. O. Ernst, B. S. Tjan and H. H. Bülthoff *Psychological Science* [2001]
- Exploitation of common representation to develop more efficient object learning and recognition algorithms for embodied agents

Some open questions

- Computer vision
  - Can we go beyond image fragments (“bags of words”)?
  - Do the current approaches scale to 1000s of categories?
  - How do we incorporate other modalities?
- Computer graphics
  - What is perceptual realism?
  - How can we make better animations?
  - Can we learn graphics?
- Perception research
  - Can we come up with a quantitative model for object recognition?
  - Does optimal integration hold everywhere – where does it break?
  - What is the psychophysics of higher-level cognitive functions?

Challenges

- The "Chair" challenge

Challenges

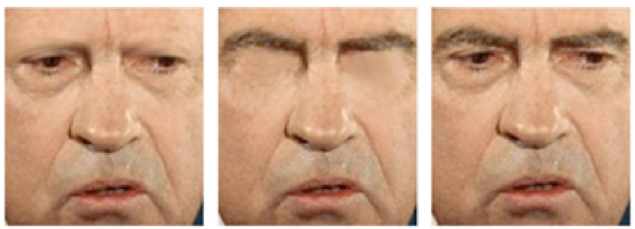
- The "Art" challenge: build a computer vision system that learns to interpret art images
  - Such a system would need to deal with abstraction

?

Images (c) by Robert Pepperell, see Wallraven et al. [*APGV,* 2007]

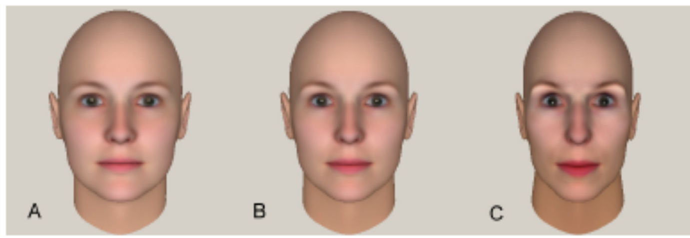
Challenges

- The "Pawan Sinha" challenge
  - build a computer vision system that integrates the 20 results every CV researcher should know about face recognition
    http://web.mit.edu/bcs/sinha/papers/20Results_2005.pdf

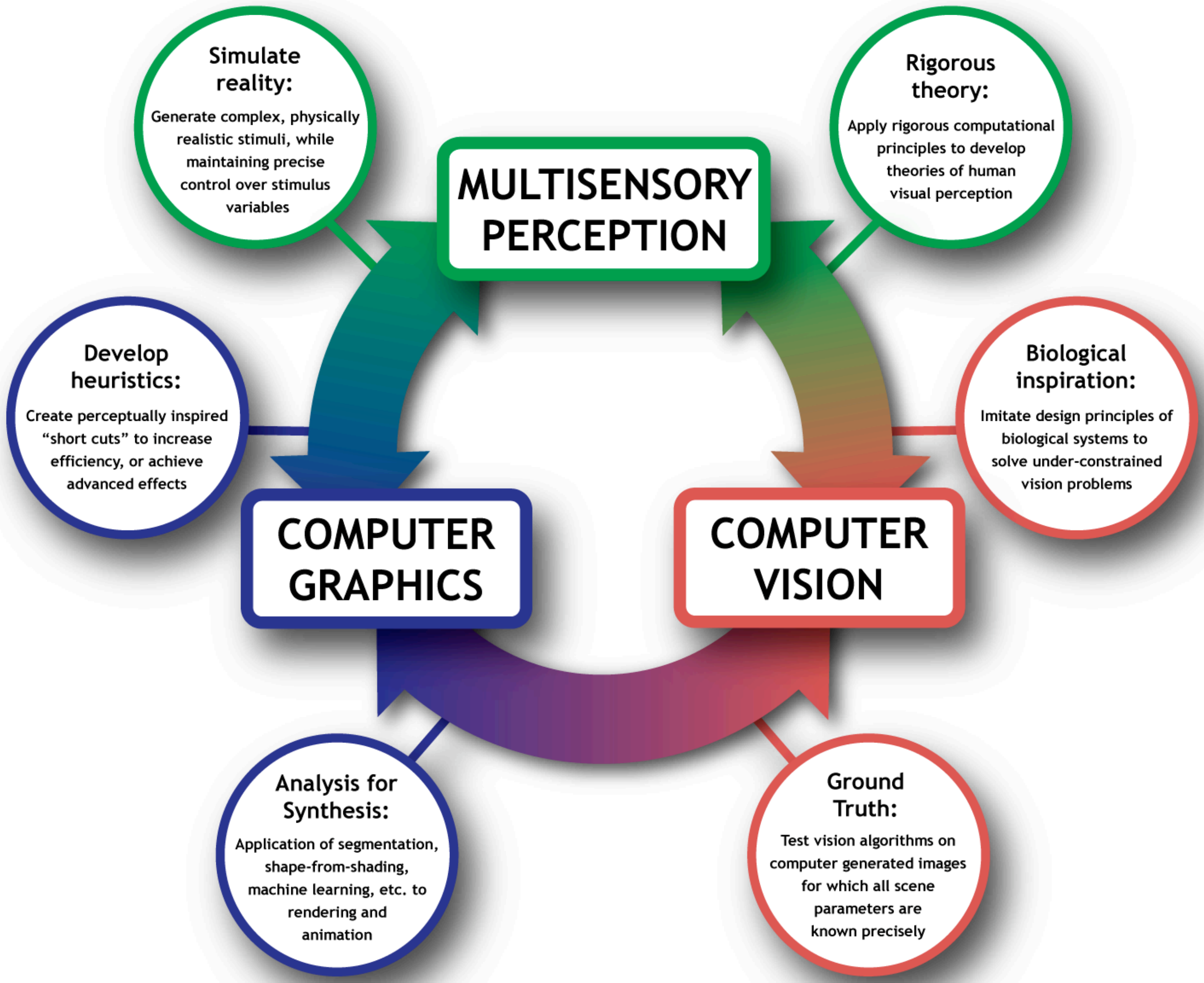


Eyebrows as important features

Recognition under distortions



Caricature effect for recognition


MULTISENSORY PERCEPTION
COMPUTER GRAPHICS
COMPUTER VISION
Simulate reality:
Generate complex, physically realistic stimuli, while maintaining precise control over stimulus variables
Rigorous theory:
Apply rigorous computational principles to develop theories of human visual perception
Develop heuristics:
Create perceptually inspired "short cuts" to increase efficiency, or achieve advanced effects
Biological inspiration:
Imitate design principles of biological systems to solve under-constrained vision problems
Analysis for Synthesis:
Application of segmentation, shape-from-shading, machine learning, etc. to rendering and animation
Ground Truth:
Test vision algorithms on computer generated images for which all scene parameters are known precisely