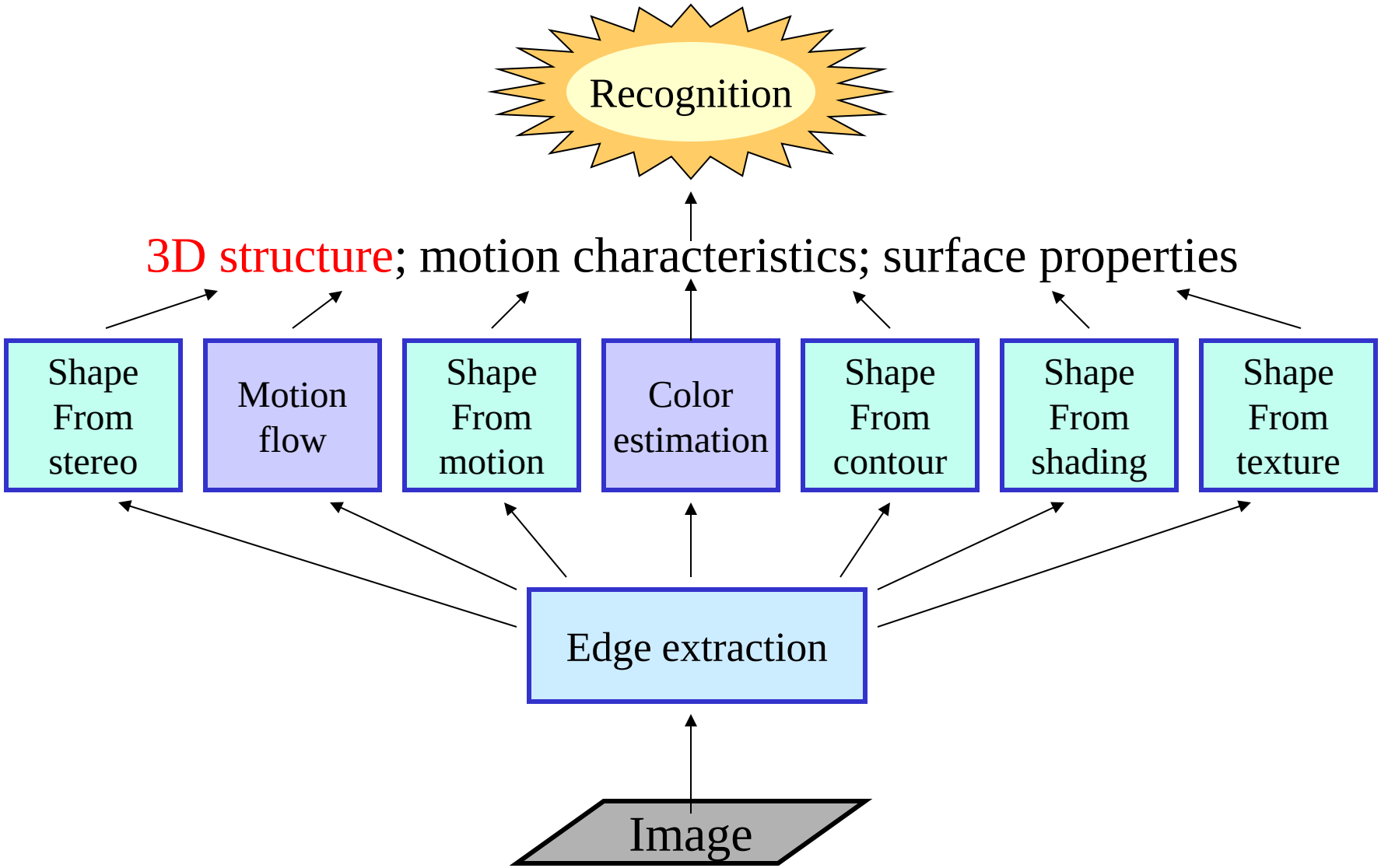
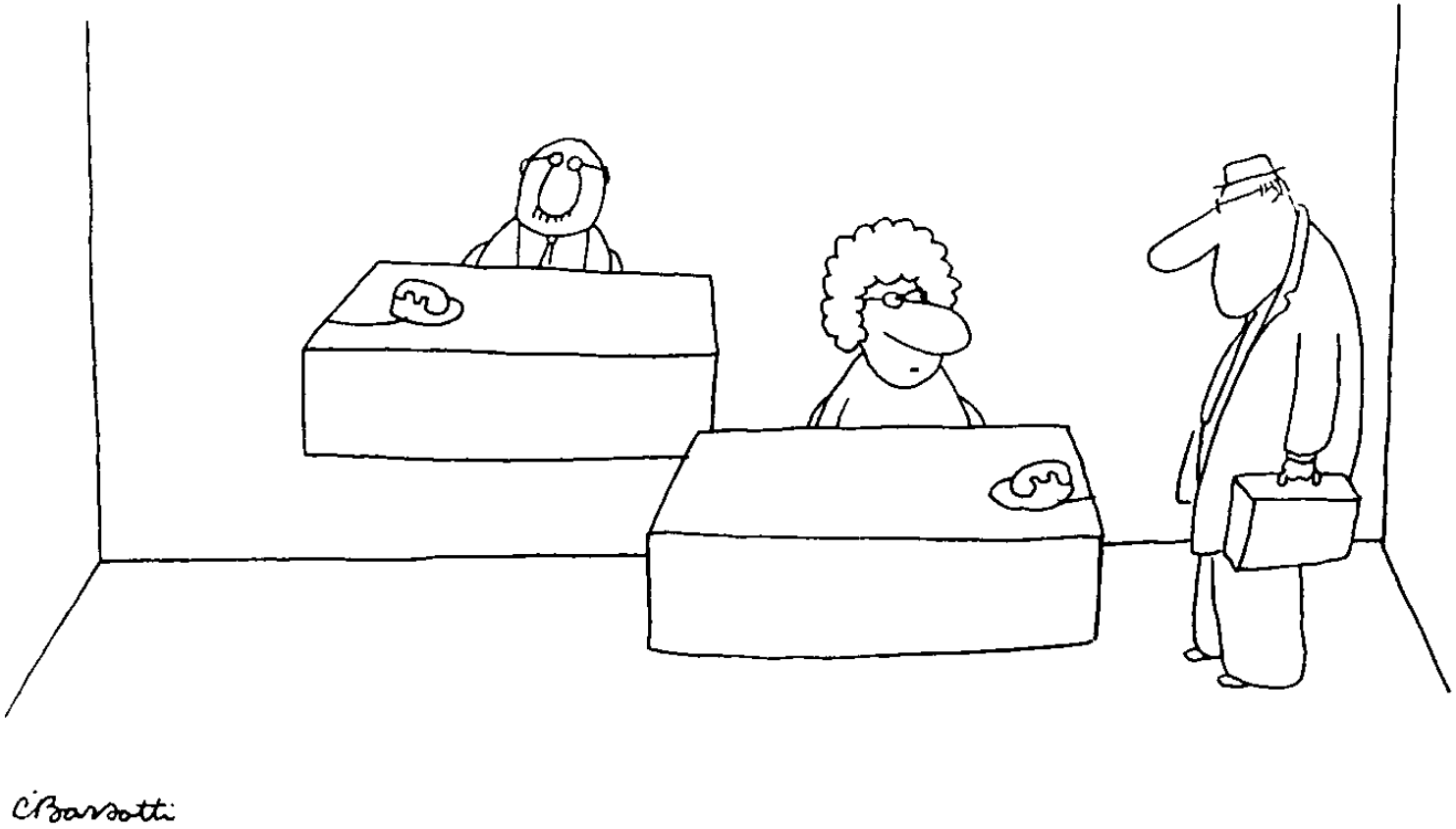
Bottom-up and Top-down processes in shape perception

Processing Framework Proposed by Marr

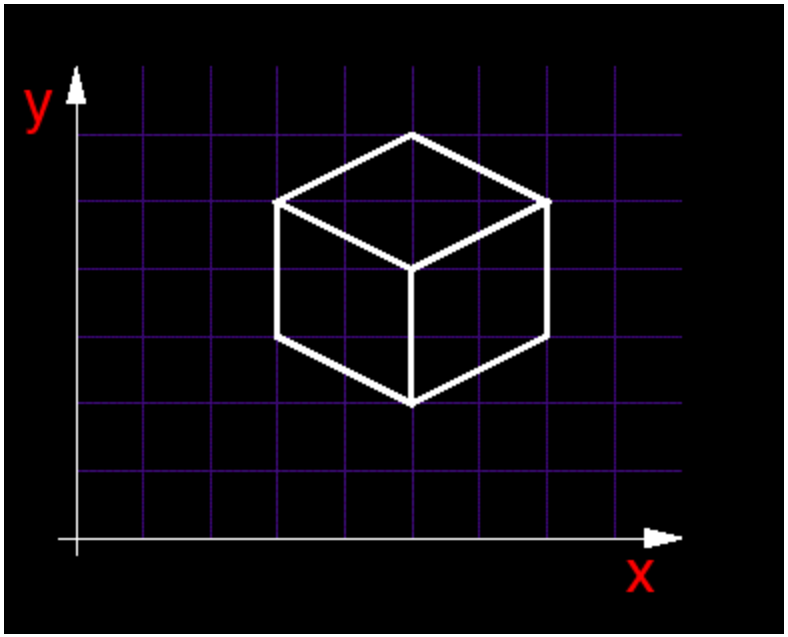


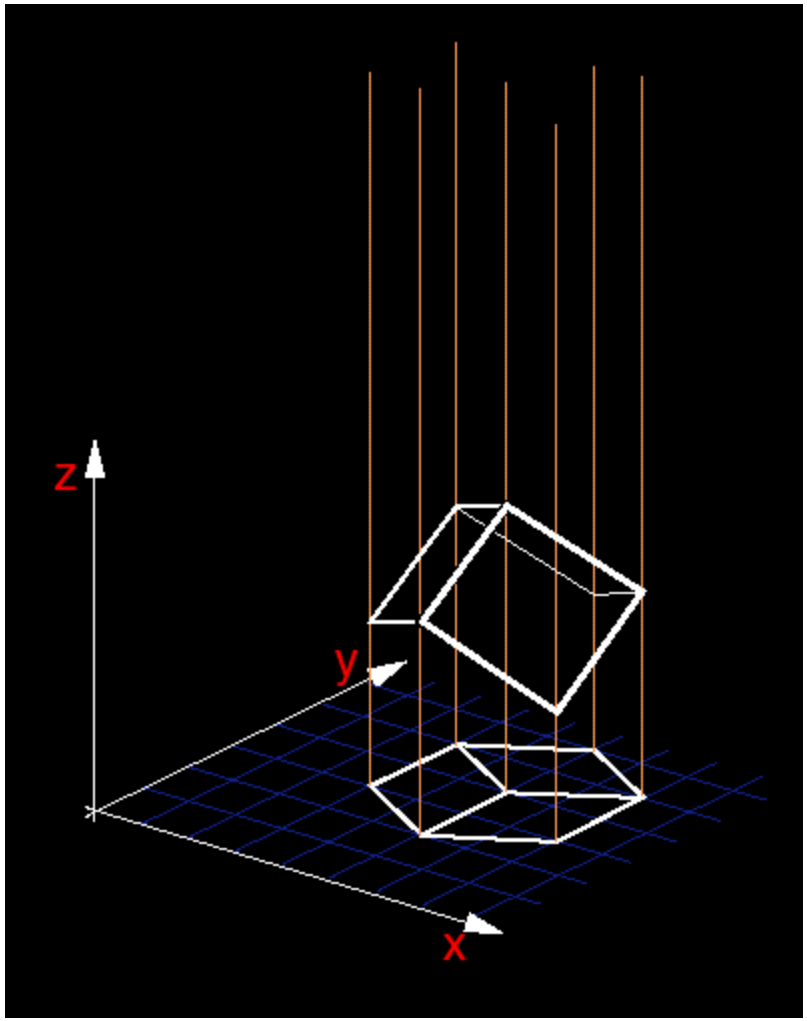
Shape from contour

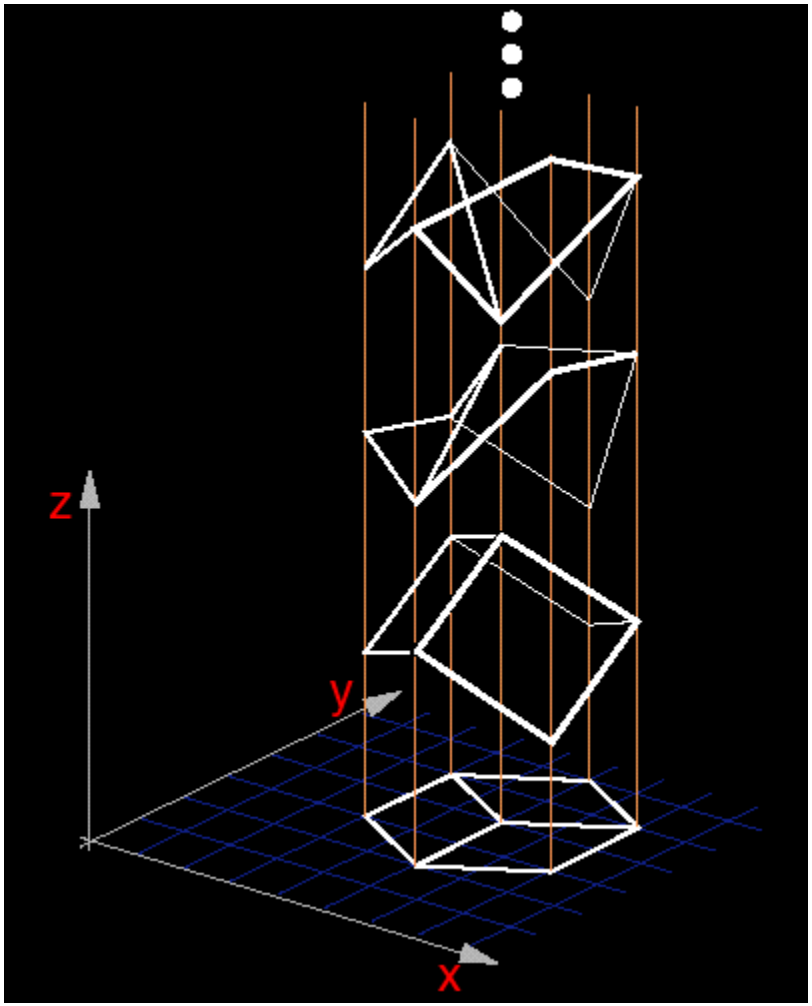


I'm sorry, Mr. Mitchell is only painted on the wall.

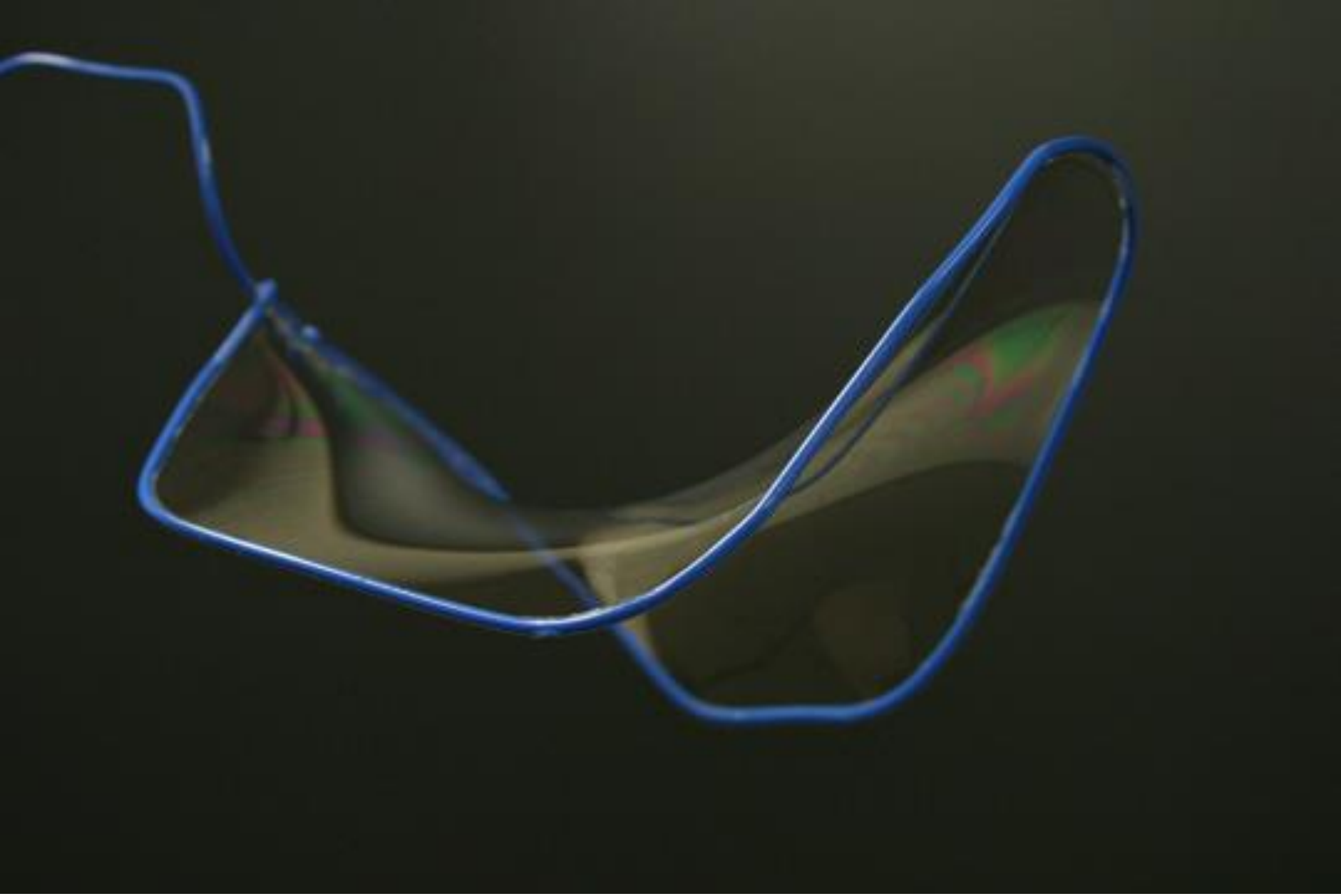
The perceptual task




z
y
x


z
y
x

A constraint based system



An implemented constraint-based system

Attneave & Frost, 1969
Mackworth, 1973
Perkins & Cooper, 1980
Kanade, 1980
Barrow & Tenenbaum, 1981
Marill, 1989
Fischler & Leclerc, 1992
⋮

Experimentation

Occam's razor and complexity

Sinha & Adelson

A 3D shape recovery system with 3 general constraints

What are the three constraints?

1. Regularity

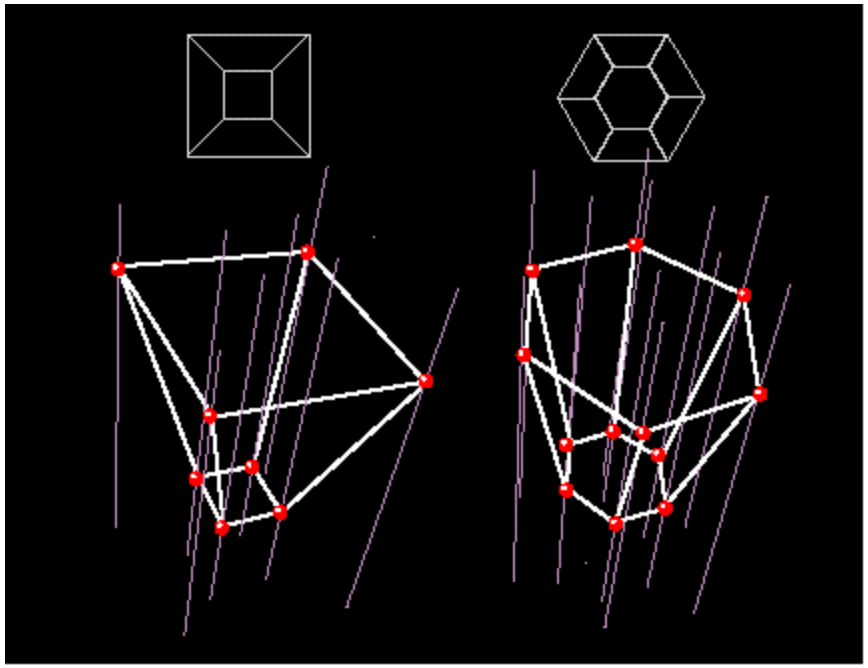
2. Planarity

3. Compactness

The system in action...

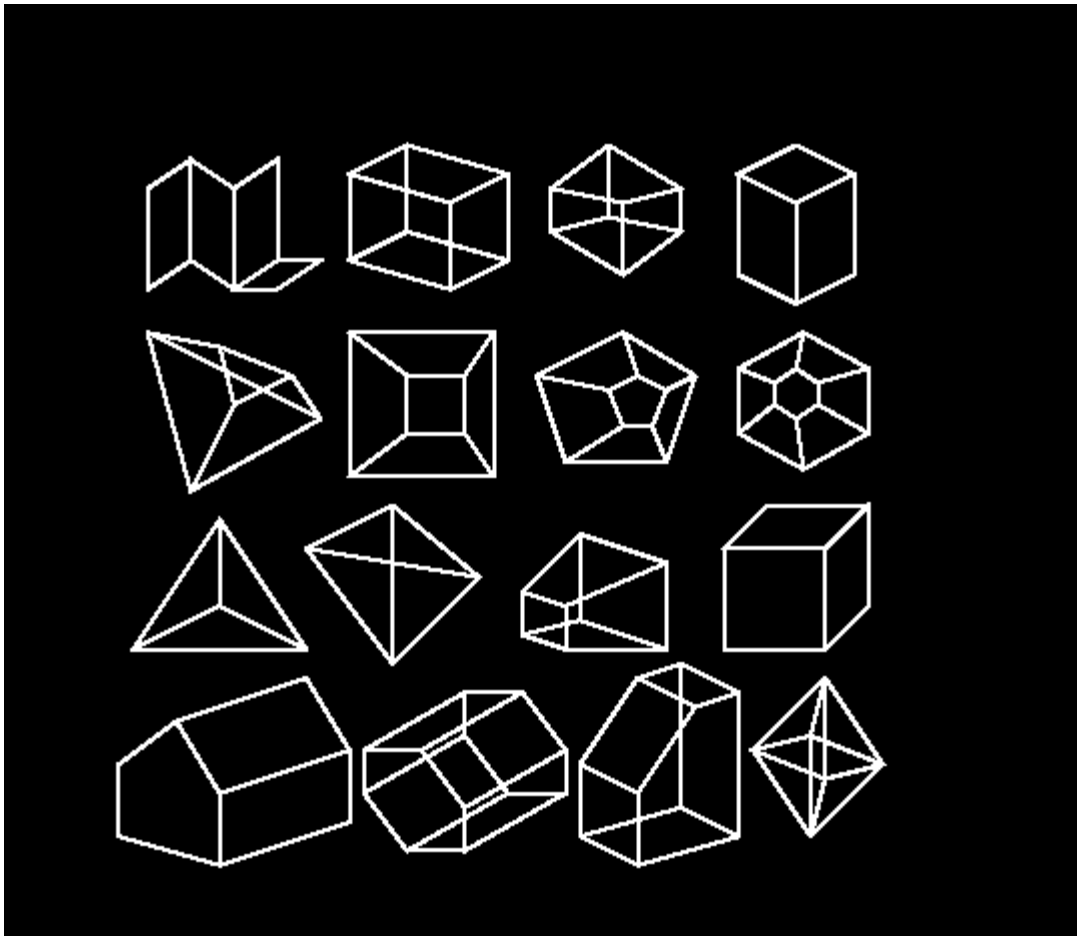
2D Inputs

Recovered
3D shapes

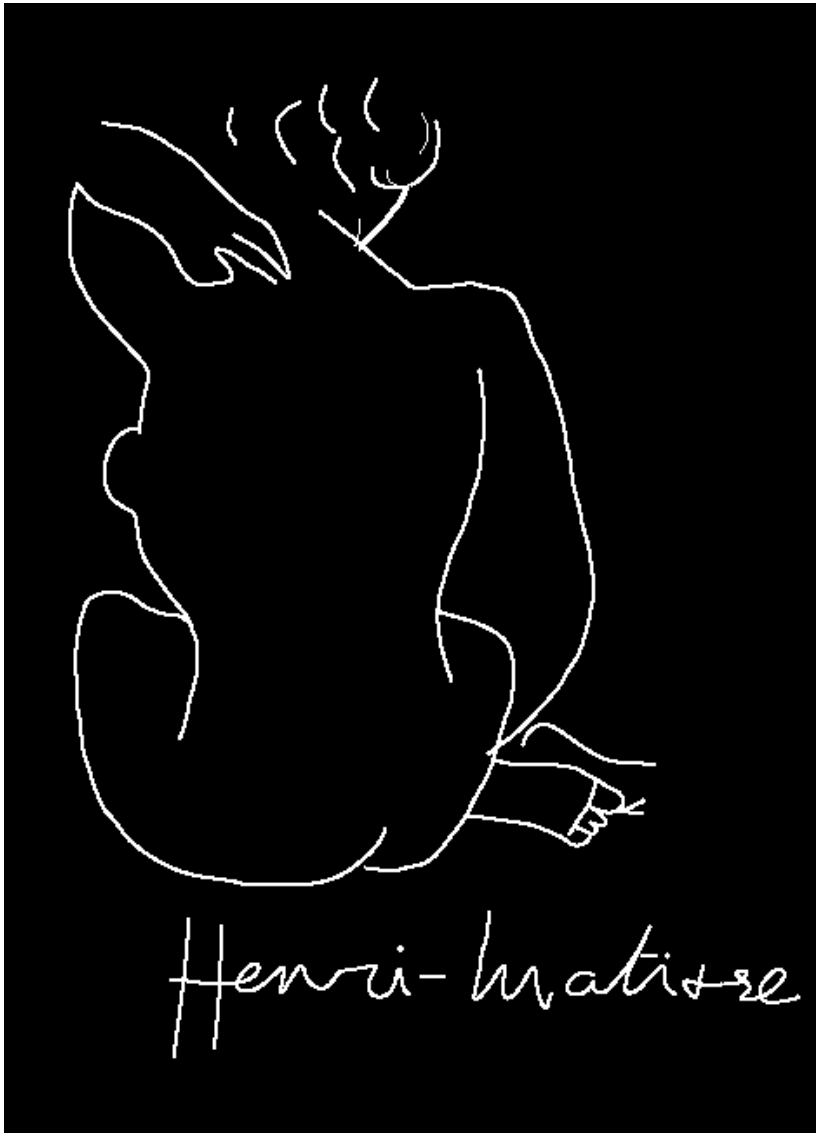


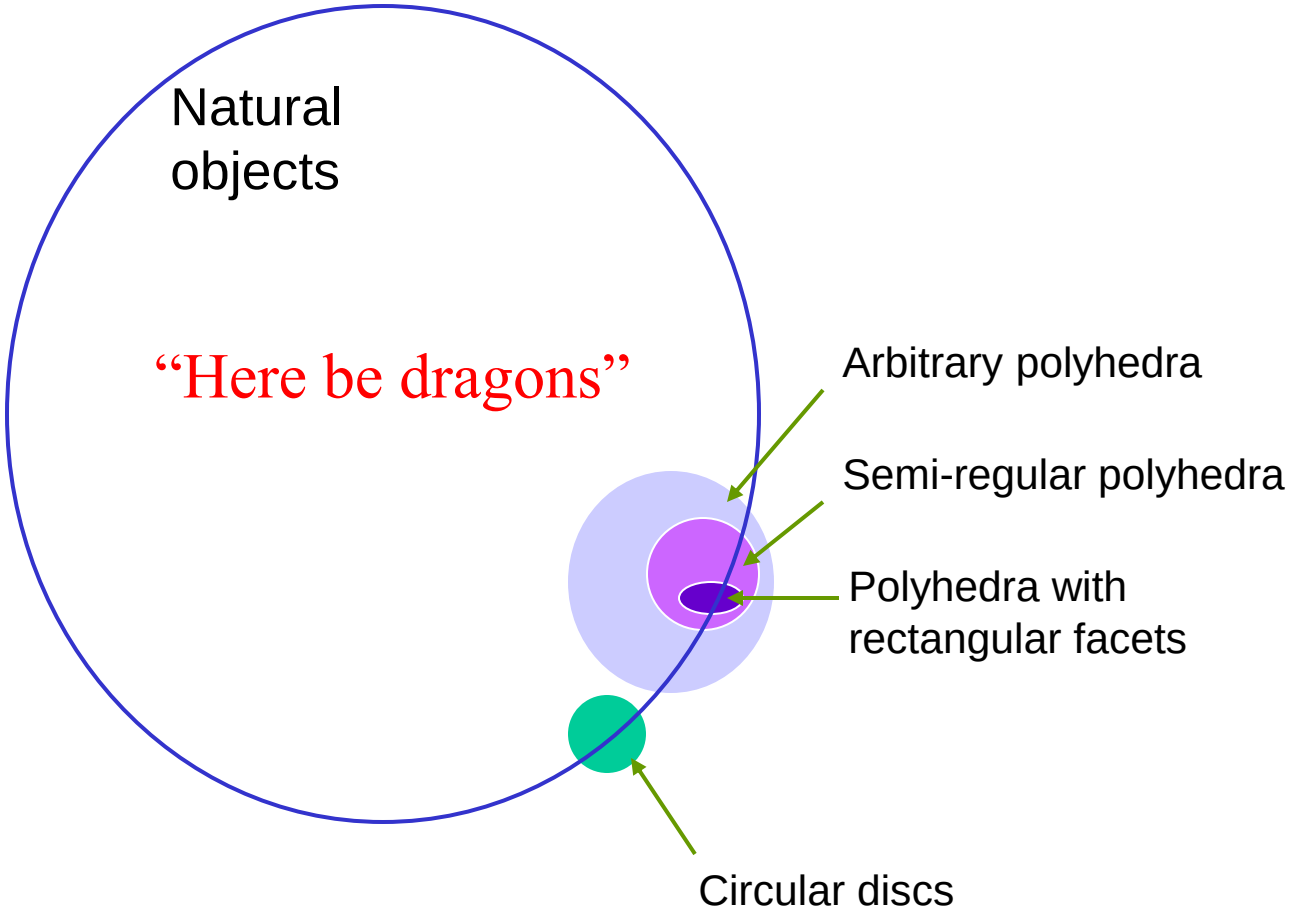
The system in action...

Where the system works...



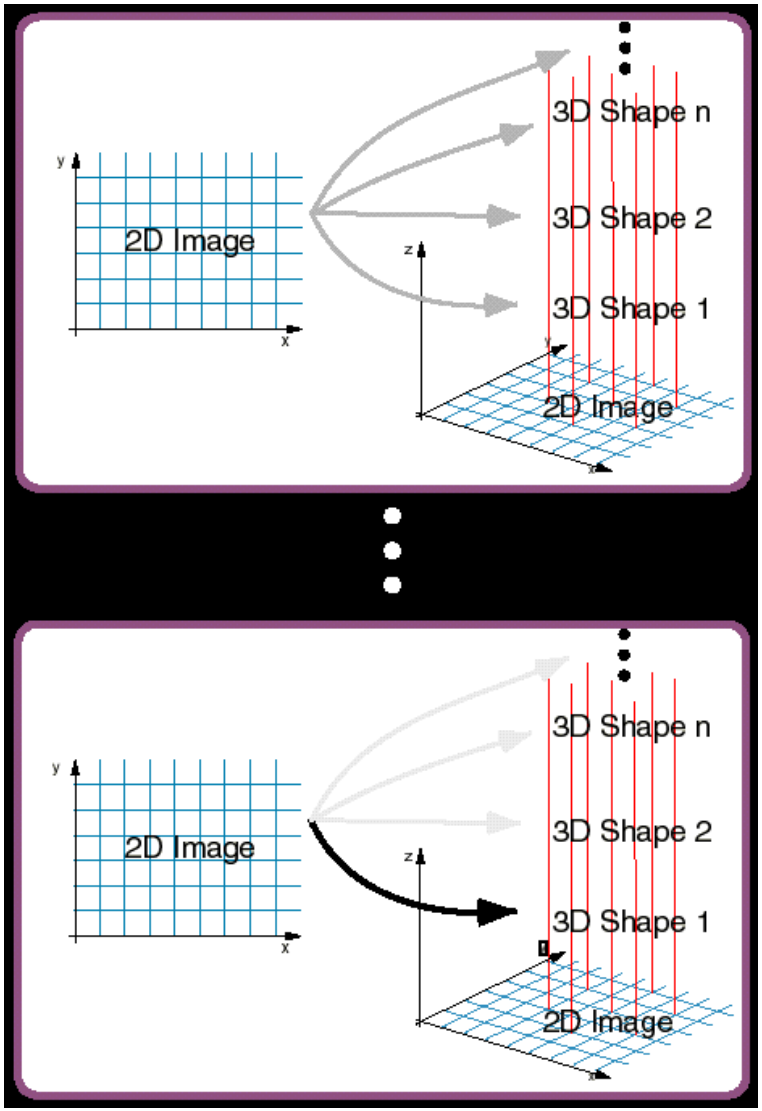
And where it runs into trouble...





Is there a more general approach to shape recovery?

Learning based hypothesis

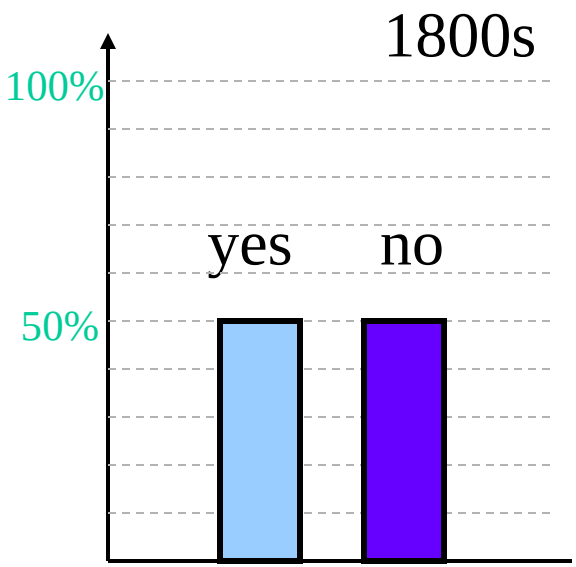


But, can learning really effect such a basic visual task?

Does learning influence perception?

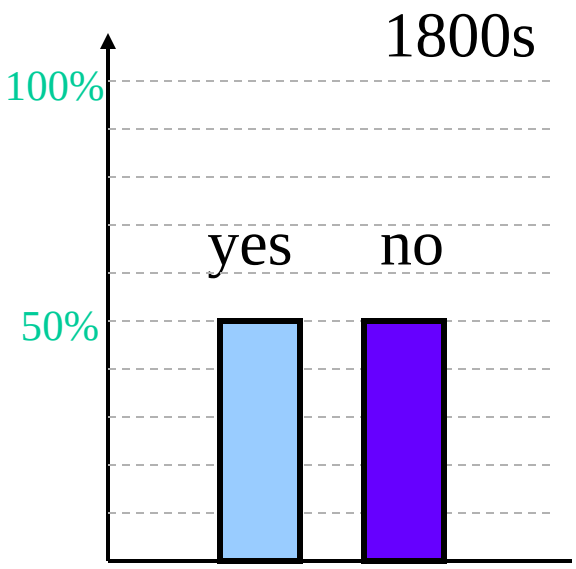
Computational and psychophysical investigations

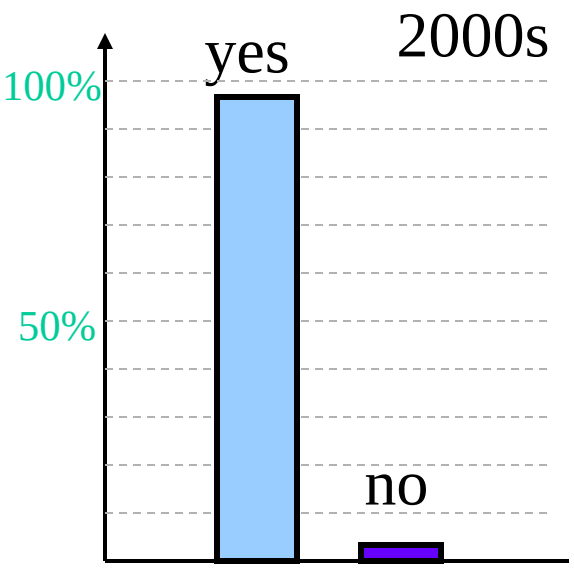
Does learning influence perception? Survey says...



Empiricists vs nativists

Does learning influence perception? Survey says...

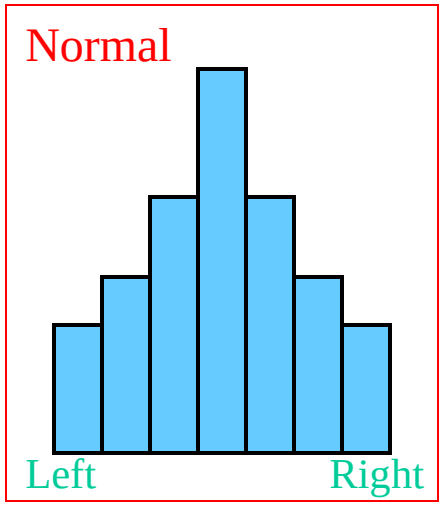


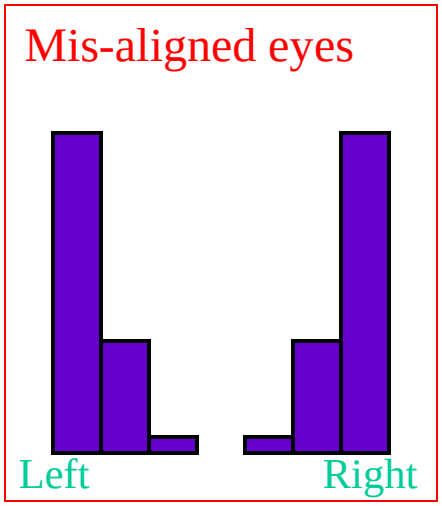


Does learning influence perception?

Evidence - I

Early experience and neural development

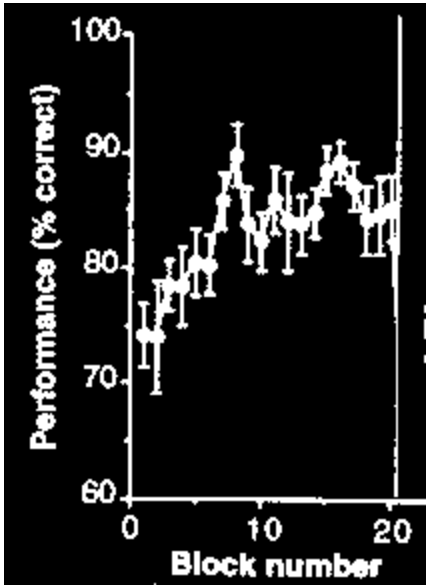


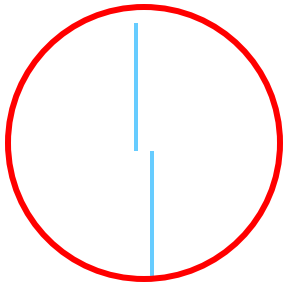


Wiesel & Hubel, J. Neurophys., 1963
Hubel & Wiesel, J. Neurophys., 1965
Olson & Freeman, Exp. Brain Res., 1980
...

Does learning influence perception?

Evidence - II



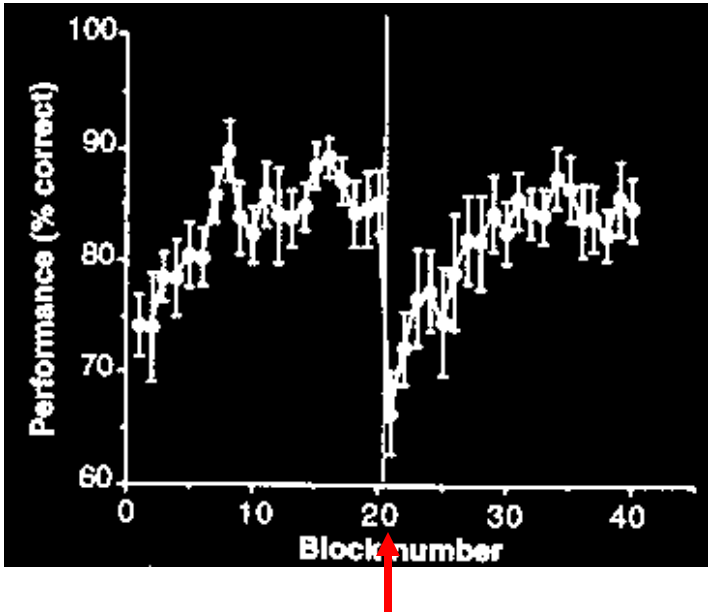


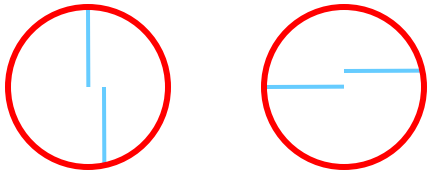
Fiorentini & Berardi, Nature, 1980
Poggio, Fahle & Edelman, Science, 1992
Karni & Sagi, Nature, 1993
Ahissar & Hochstein, Vis. Res., 1996
...

Does learning influence perception?

Yes.

Common characteristics of perceptual learning phenomena



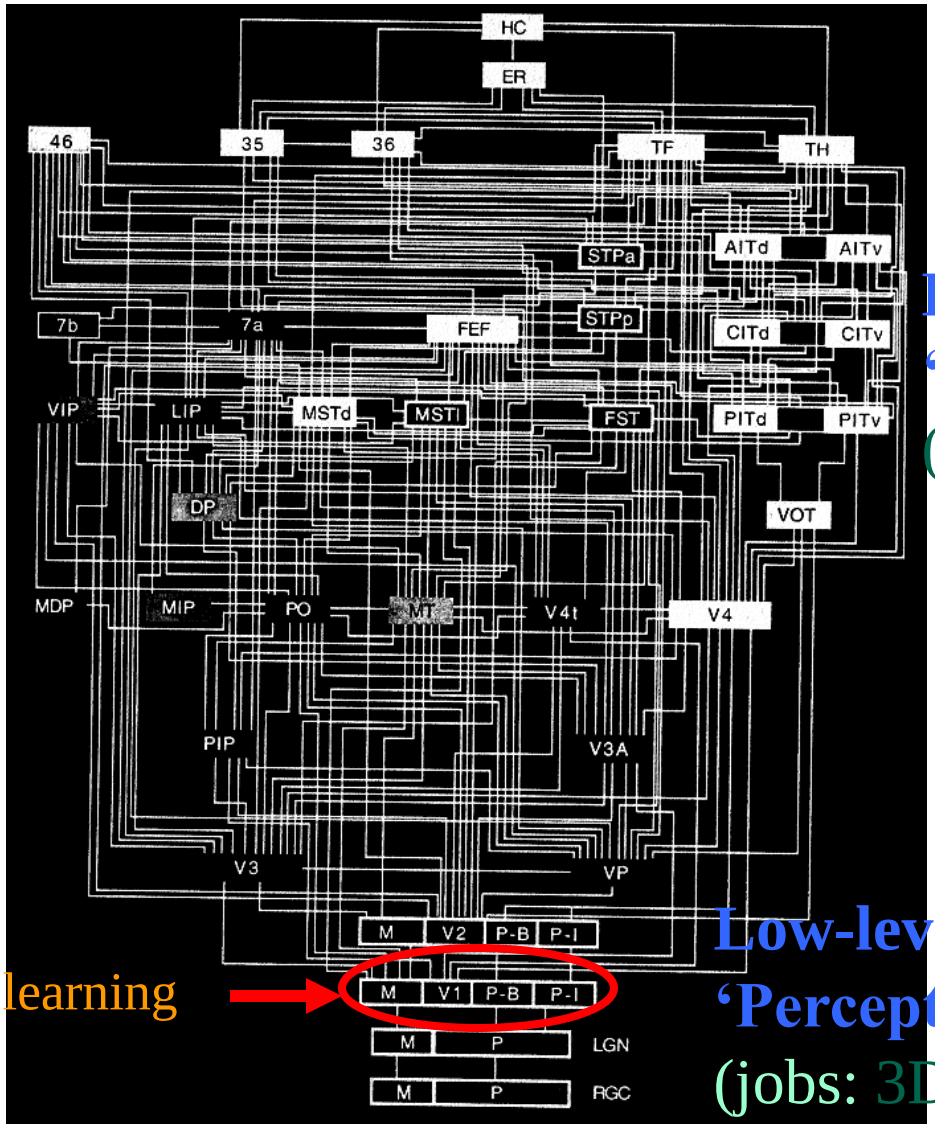


Change in a simple stimulus dimension

Perceptual learning is specific to:

- trained eye
- retinal location
- stimulus size and orientation

Implication



High-level
'Object' areas
(jobs: recognition)

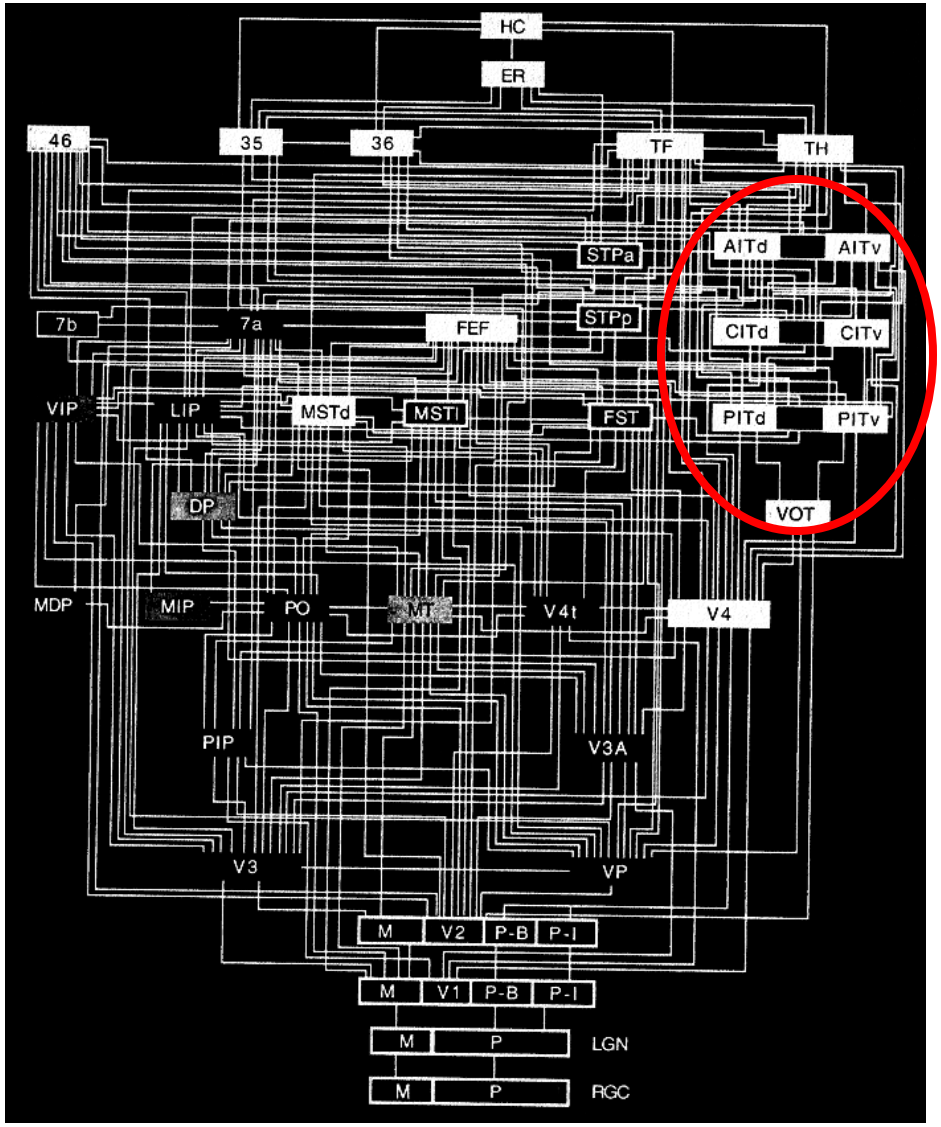
Low-level
'Perception' areas
(jobs: 3D recovery,
edge extraction)

Locus of learning

Open Question...

Influence on	Locus of learning: Low-level areas	Locus of learning: High-level areas
Low-level perception	✓	?
High-level perception	✓	✓

Open question

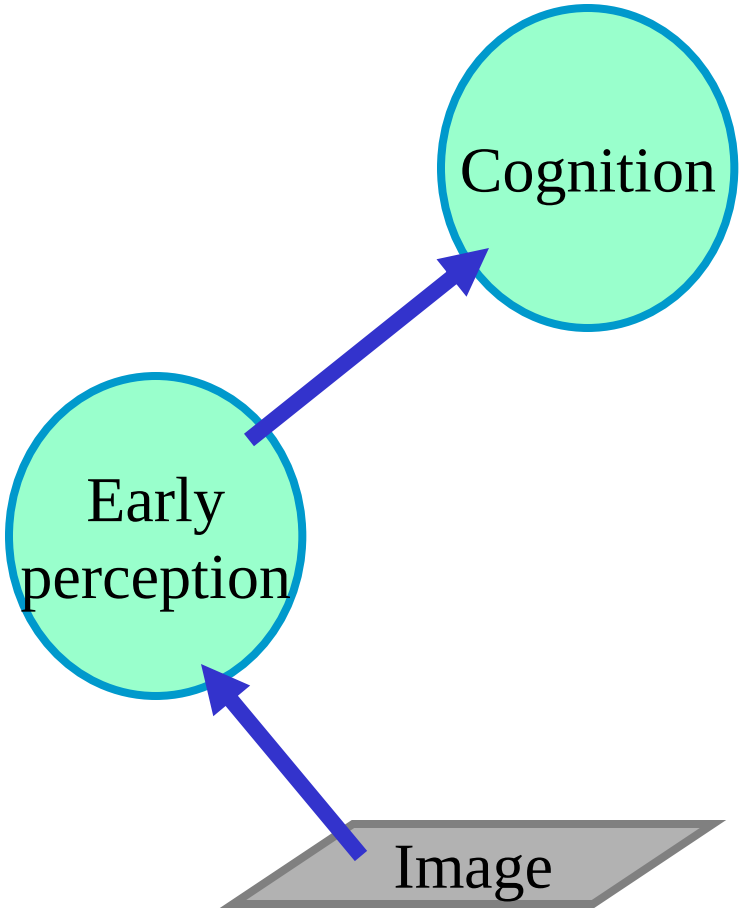


Can learning in ‘higher’ object-specific areas influence early perception?

Does high-level learning influence early perception?

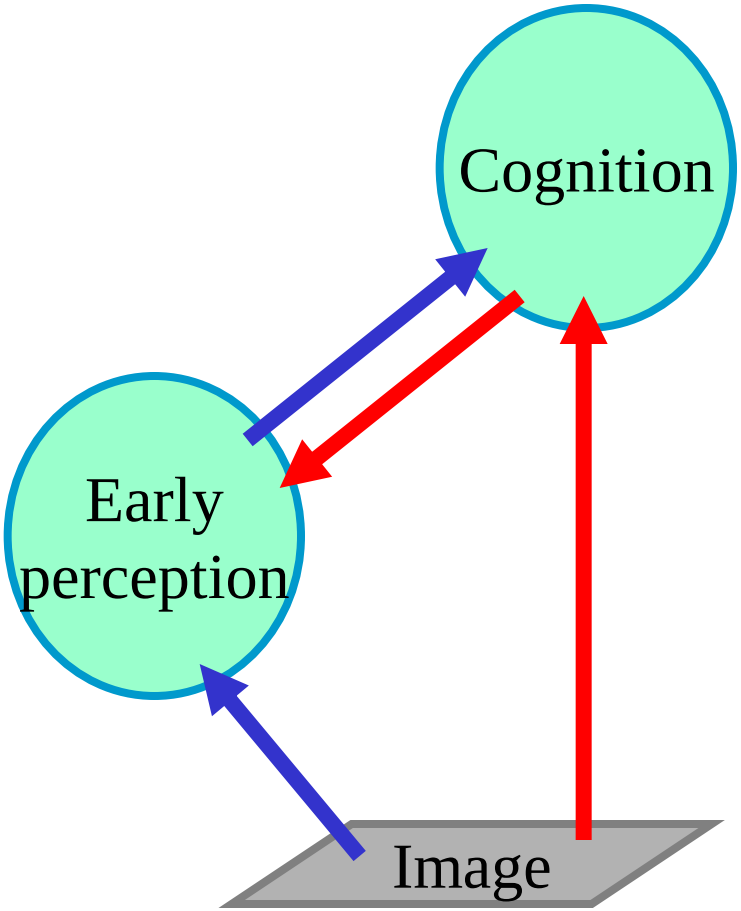
Why is this question interesting?

Marr's hierarchy



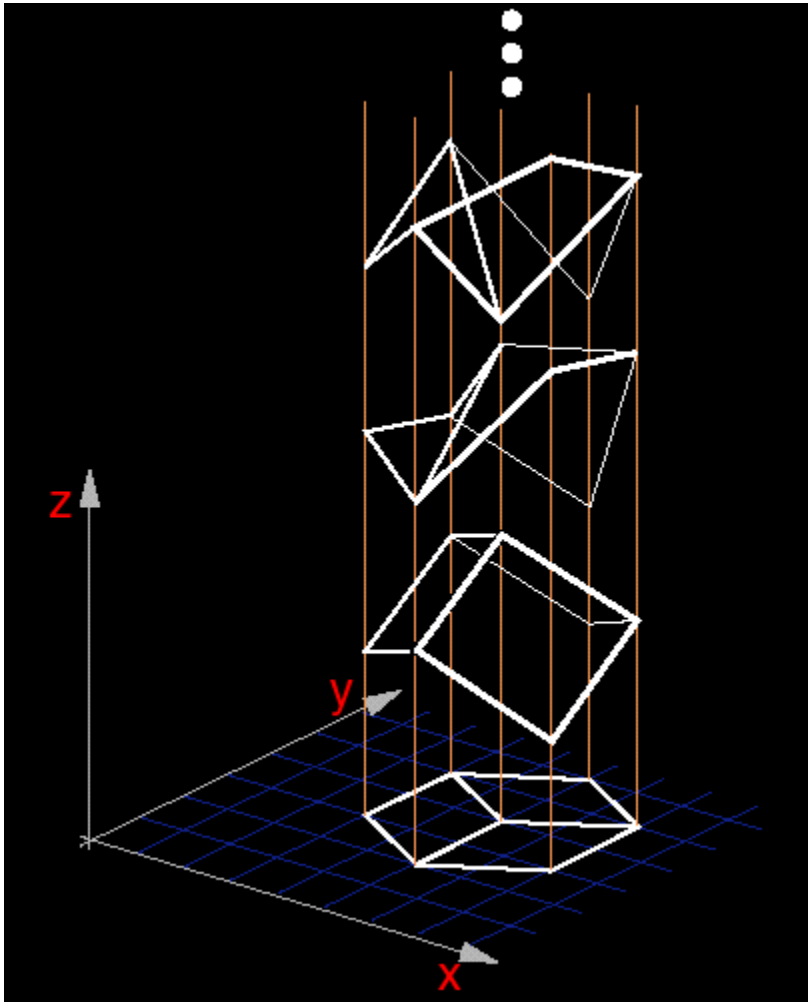
Does high-level learning influence early perception?

Why is this question interesting?



Does high-level learning influence early perception?

The perceptual task:



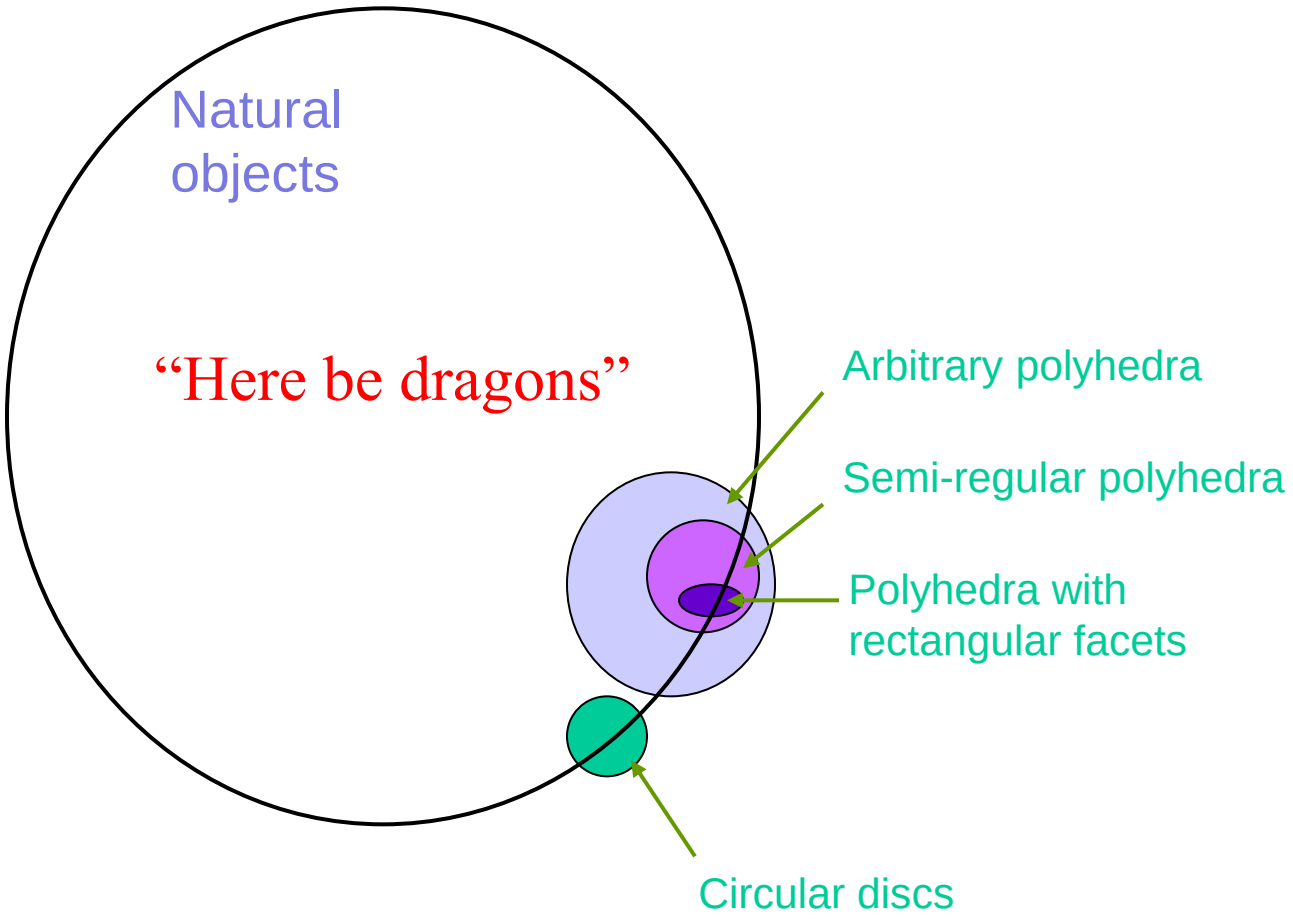
Why this task?

1. Traditionally considered one of the most fundamental early/mid-level perceptual tasks.

2. Past work is overwhelmingly in favor of constraint based explanations devoid of high-level learning.

Road map

1. A constraint-based model devoid of high-level learning



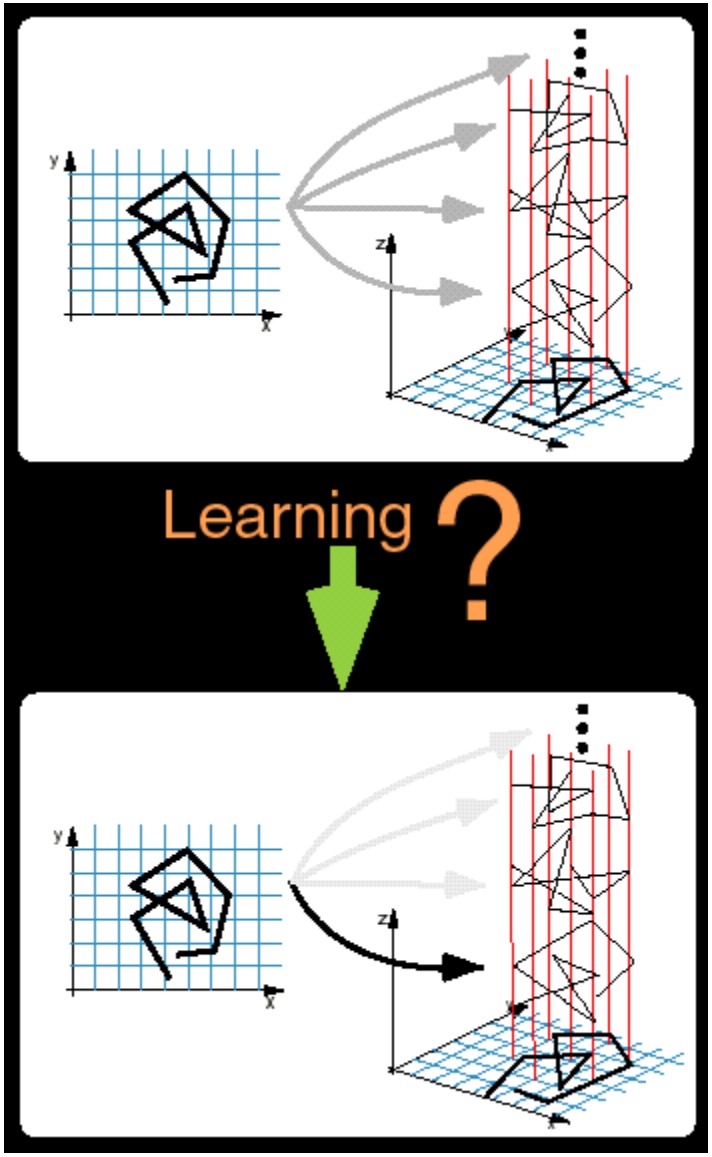
Road map

1. A constraint based model devoid of high-level learning

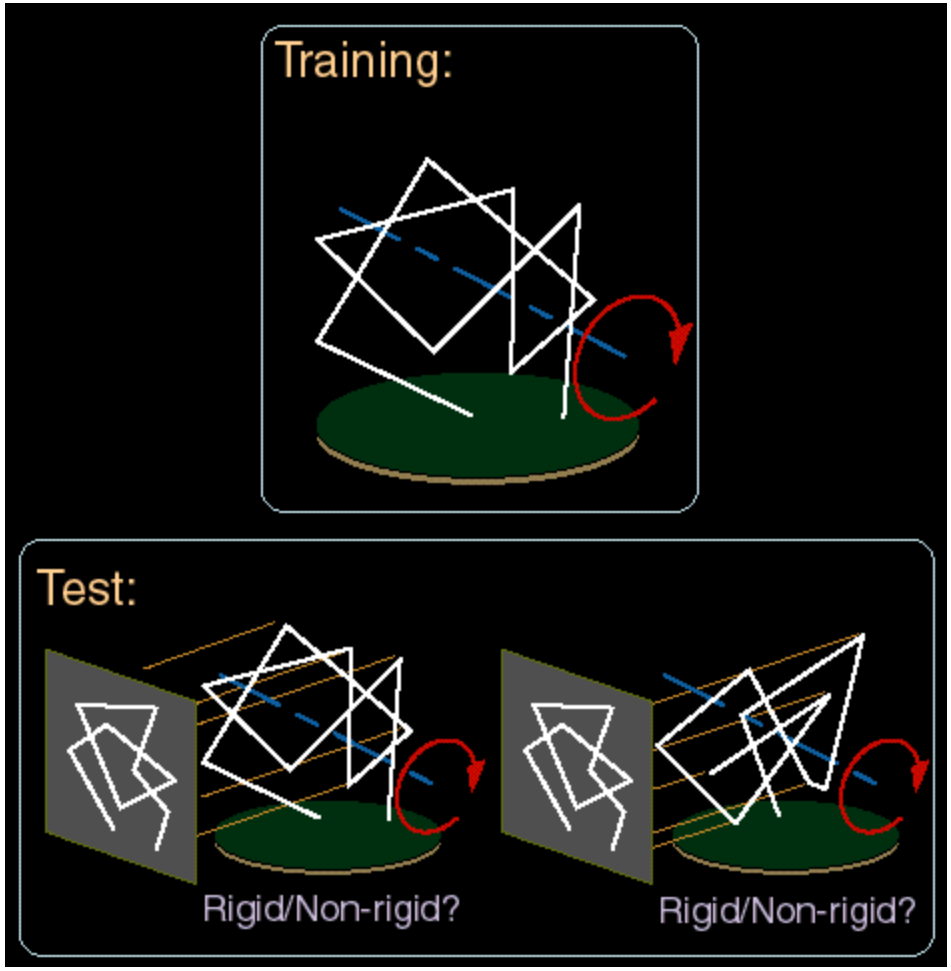
2. Experimental evidence for high-level learning

3. A model for incorporating high-level learning in early perception

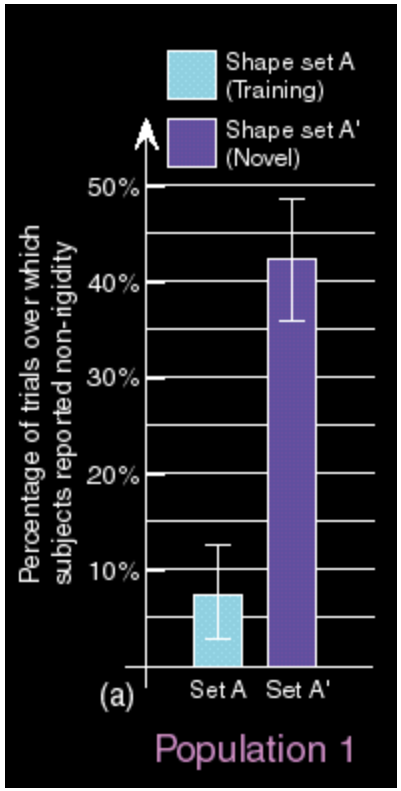
Experimental goal



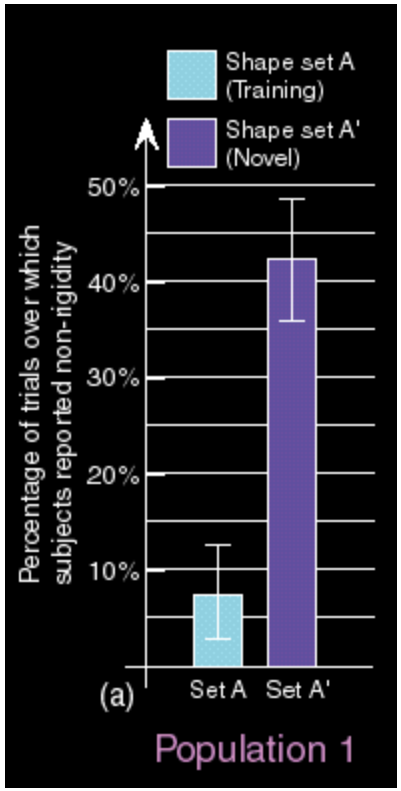
Experimental Paradigm



Results


Shape set A
(Training)
Shape set A'
(Novel)
Percentage of trials over which subjects reported non-rigidity
50%
40%
30%
20%
10%
(a)
Set A
Set A'
Population 1

Results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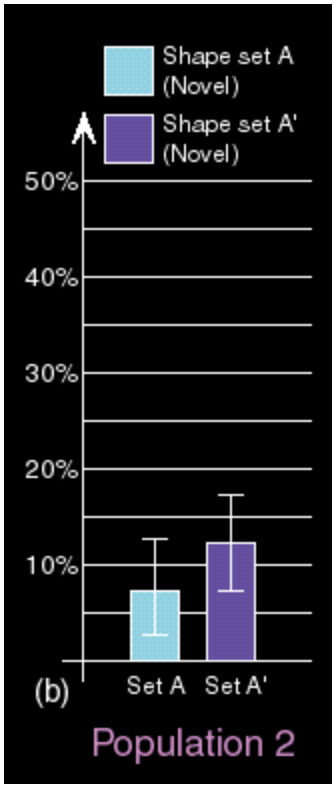
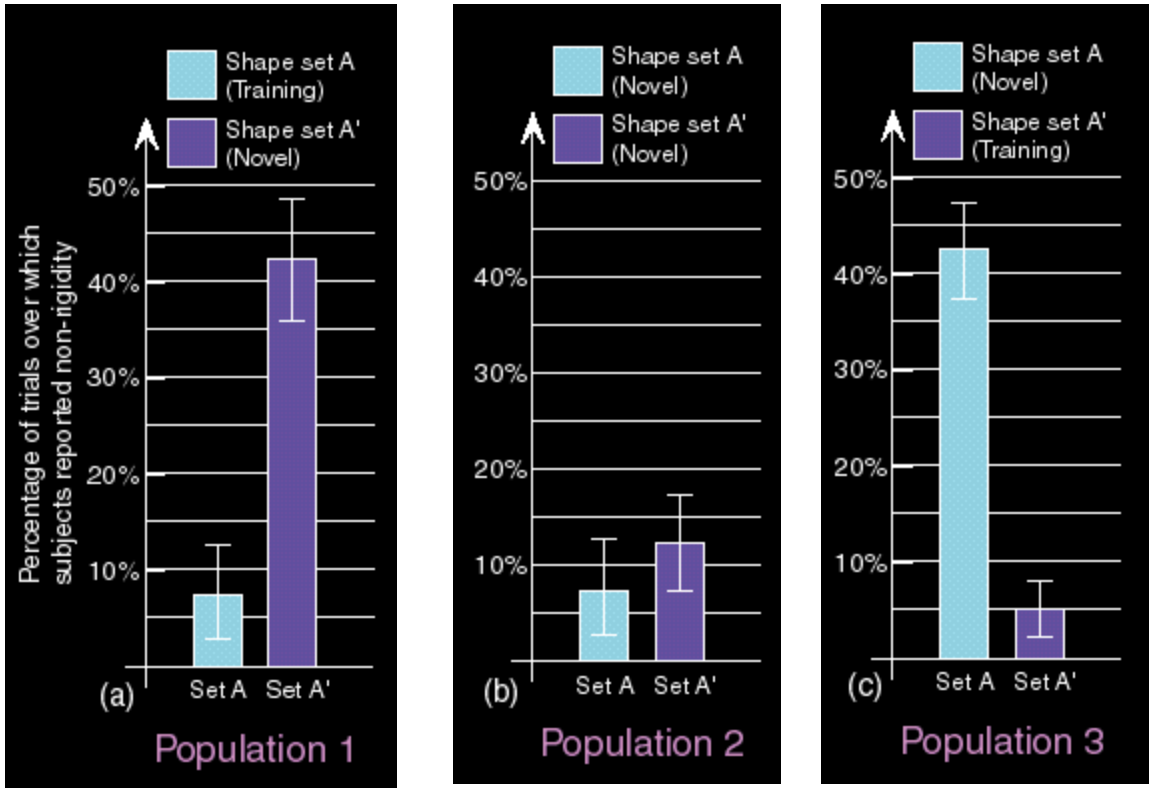
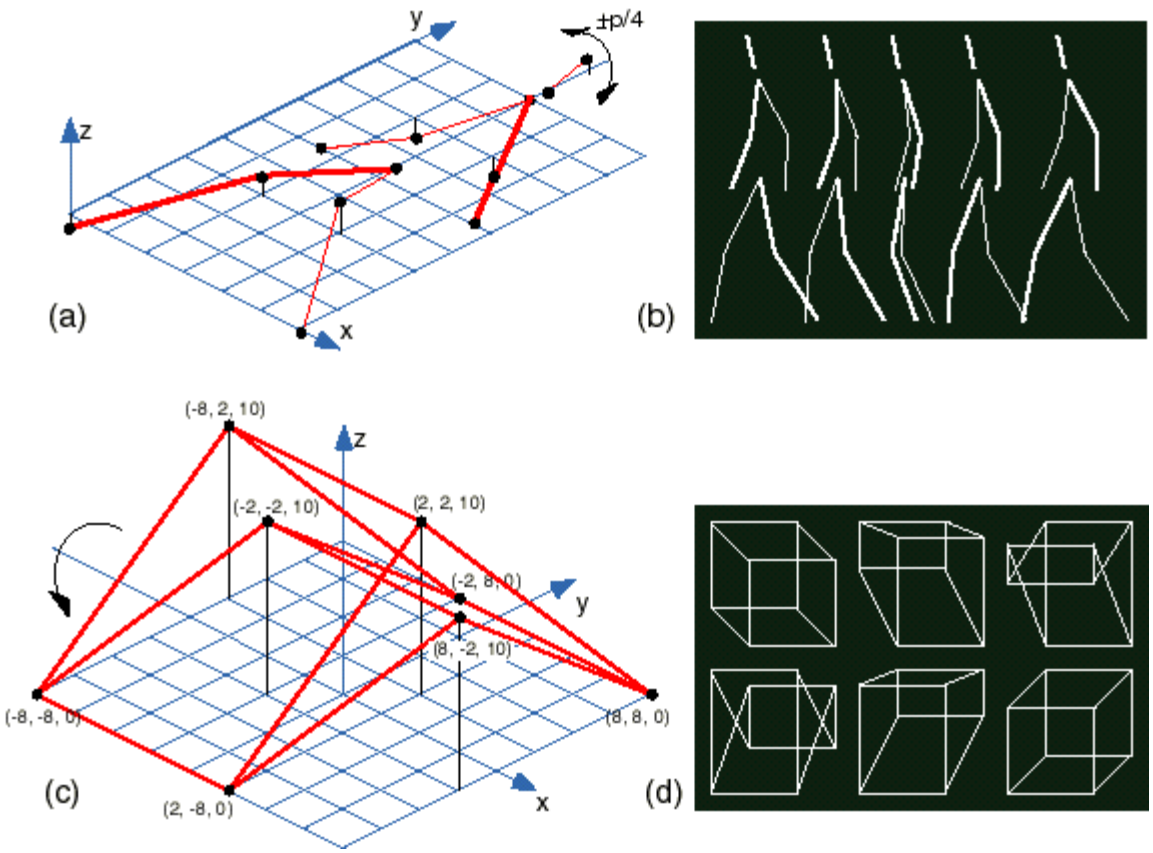
(Training)
Shape set A'
(Novel)
Percentage of trials over which subjects reported non-rigidity
50%
40%
30%
20%
10%
(a)
Set A
Set A'
Population 1


Shape set A
(Novel)
Shape set A'
(Novel)
50%
40%
30%
20%
10%
(b)
Set A
Set A'
Population 2

Results


Shape set A (Training)
Shape set A' (Novel)
Percentage of trials over which subjects reported non-rigidity
50%
40%
30%
20%
10%
(a)
Set A
Set A'
Population 1
Shape set A (Novel)
Shape set A' (Novel)
50%
40%
30%
20%
10%
(b)
Set A
Set A'
Population 2
Shape set A (Novel)
Shape set A' (Training)
50%
40%
30%
20%
10%
(c)
Set A
Set A'
Population 3

Illusions of non-rigidity

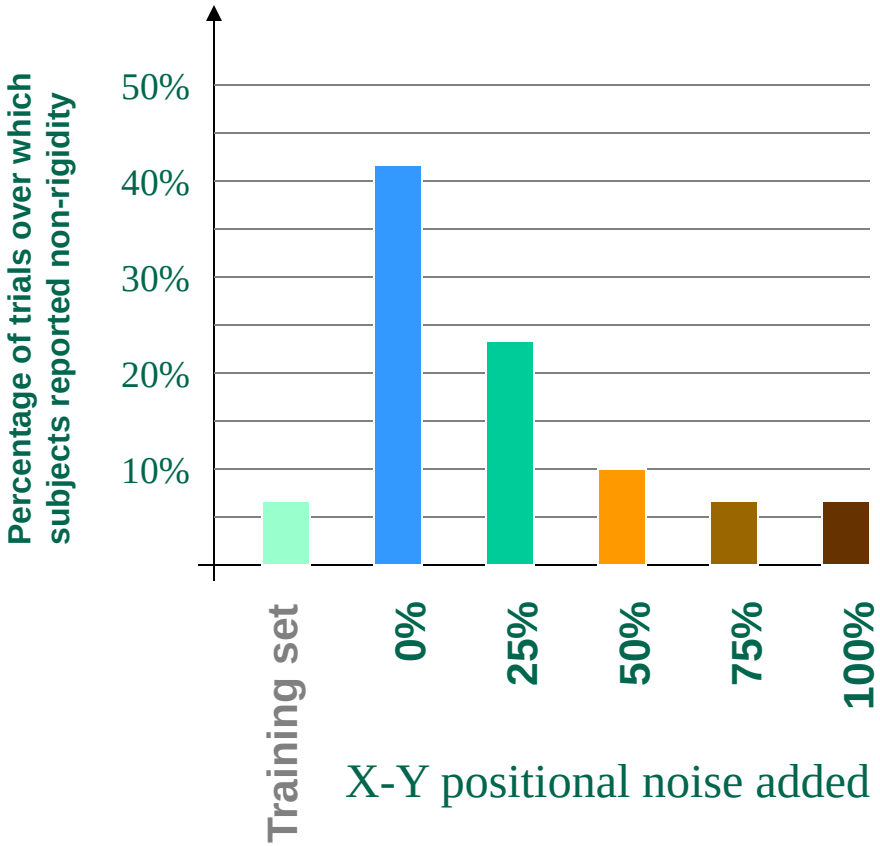


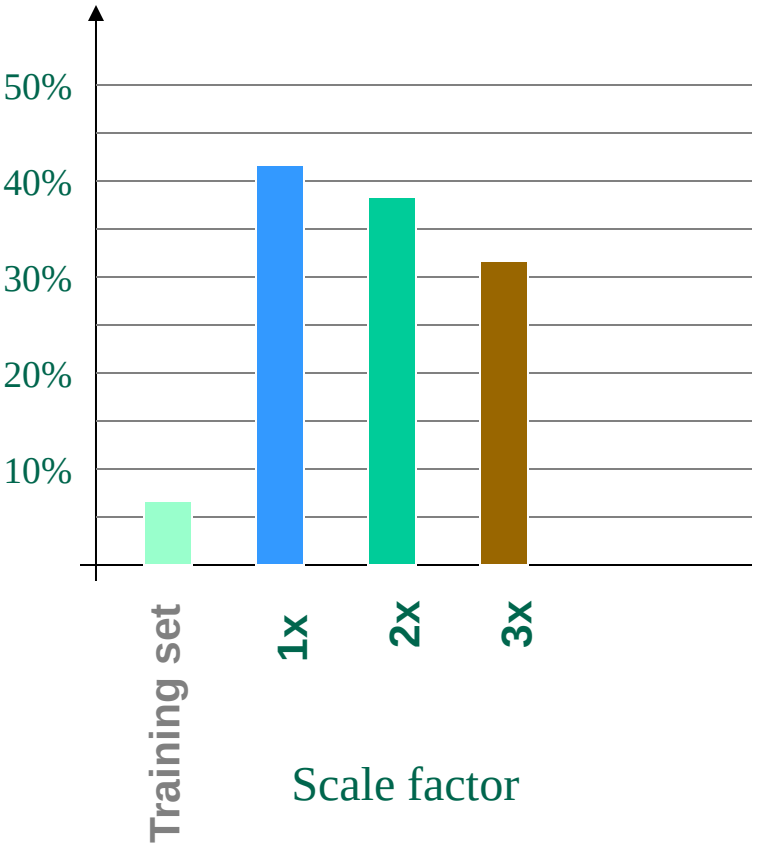
Illusions of non-rigidity

Illusions of non-rigidity

Results (contd.)

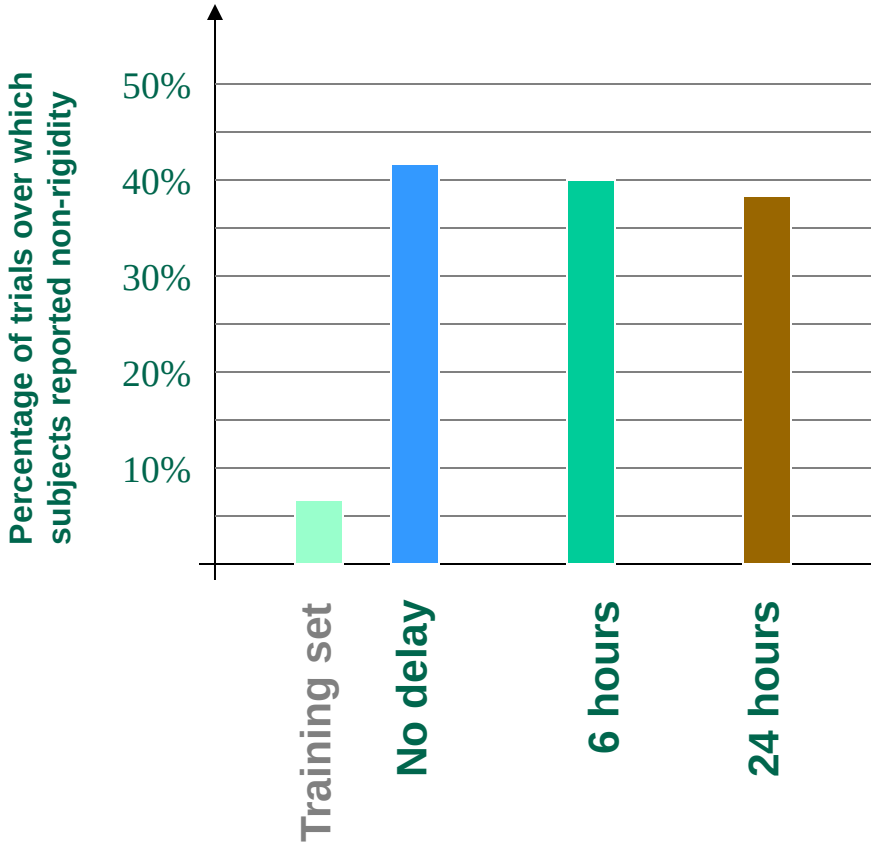
Learning is object-specific...





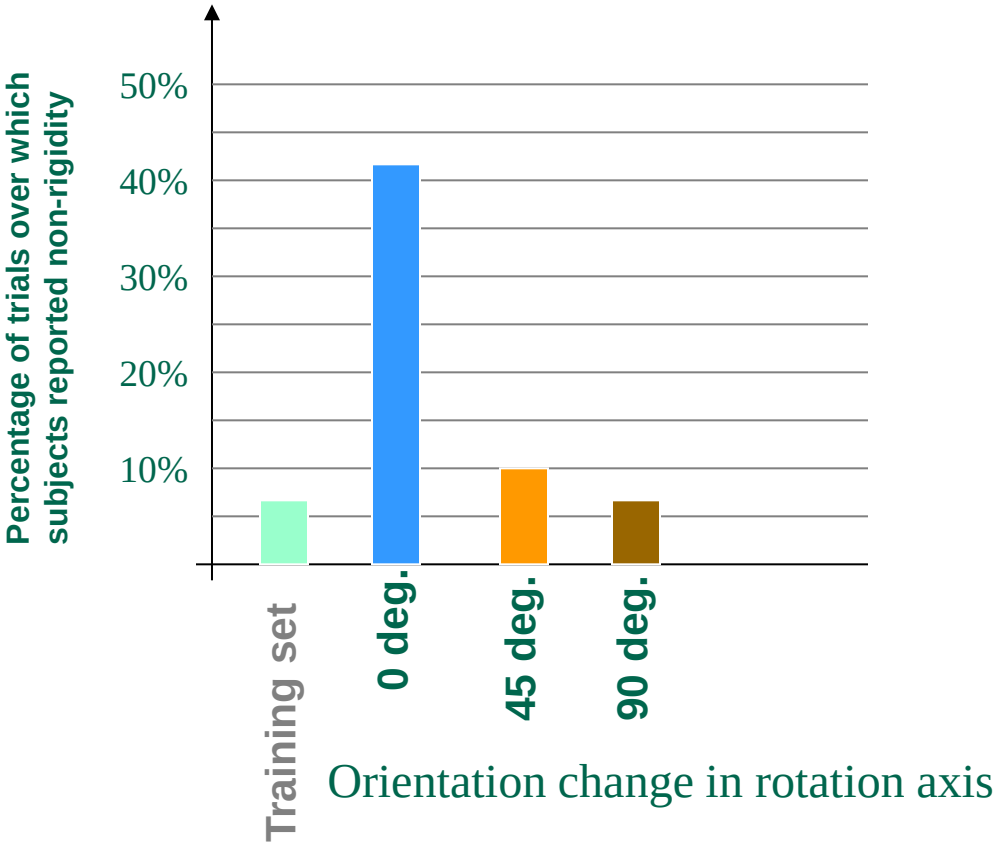
Results (contd.)

Learning is long lasting...



Results (contd.)

Learned shape may be represented implicitly...



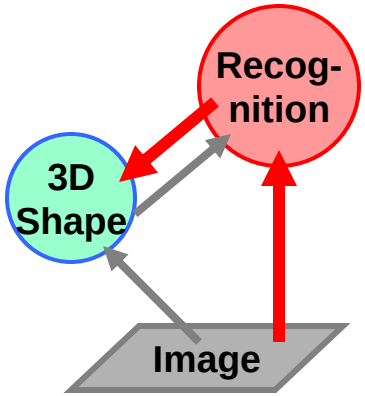
Objects may be represented as collections of temporally associated views

Inferences

1. Arbitrary associations between 2D and 3D structures can be learned.

2. Learning is object-specific.

3. Recognition may, in some circumstances, precede 3D shape perception.



Road map

1. A constraint based model devoid of high-level learning

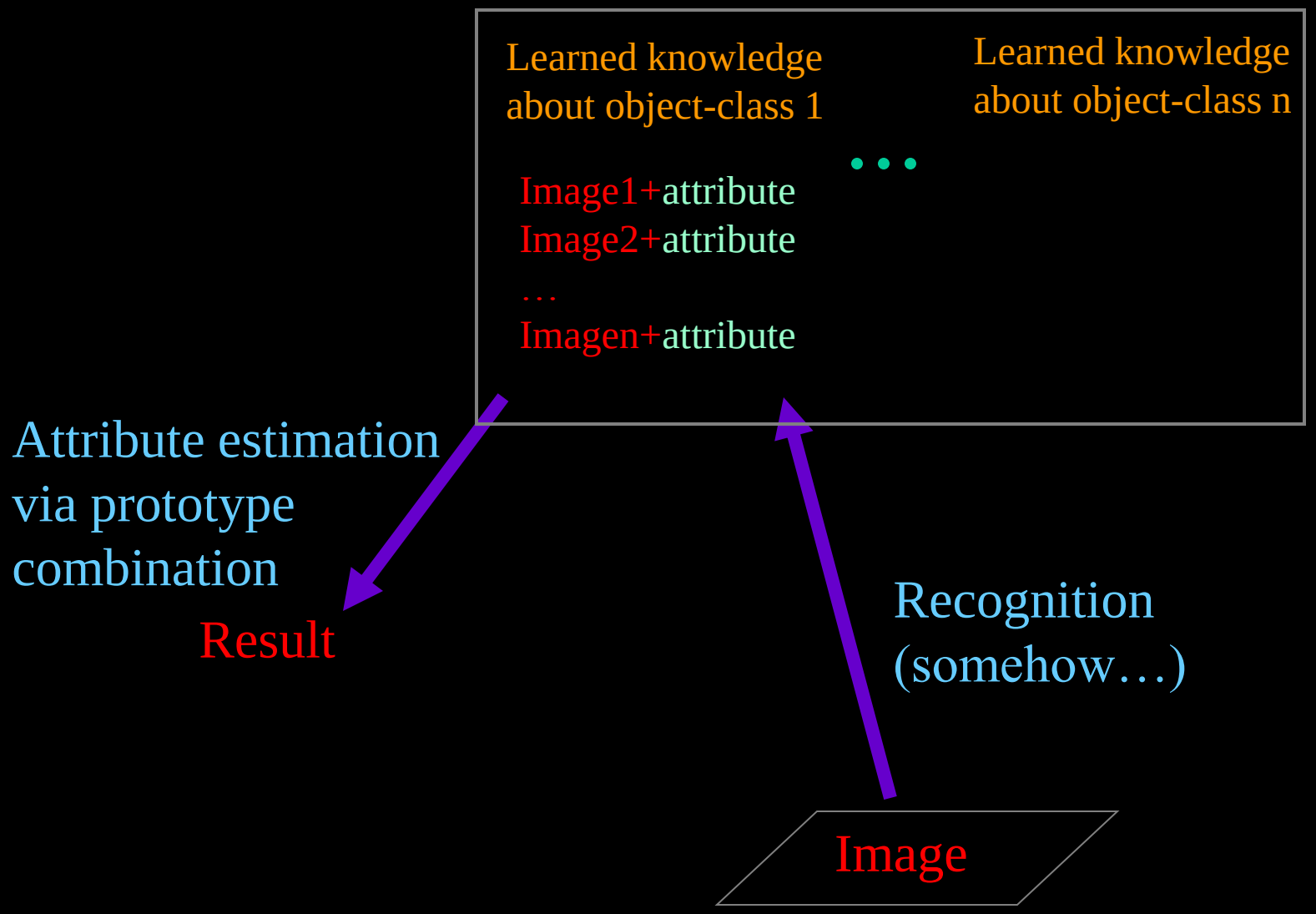
2. Experimental evidence for high-level learning

3. A model for incorporating high-level learning in early perception

Goal

Given an image, to estimate some attribute
(e.g. 3D shape, edge-map, tactile feel etc.)

The model schematically



Combining learned instances

Object class

$Image_0 + Attribute_0$

$Image_1 + Attribute_1$

• • •

$Image_n + Attribute_n$

image_new + ?

Step 1:

$$image_{new} = C0 * Image_0 + C1 * Image_1 \; \cdots \; + Cn * Image_n$$

Step 2:

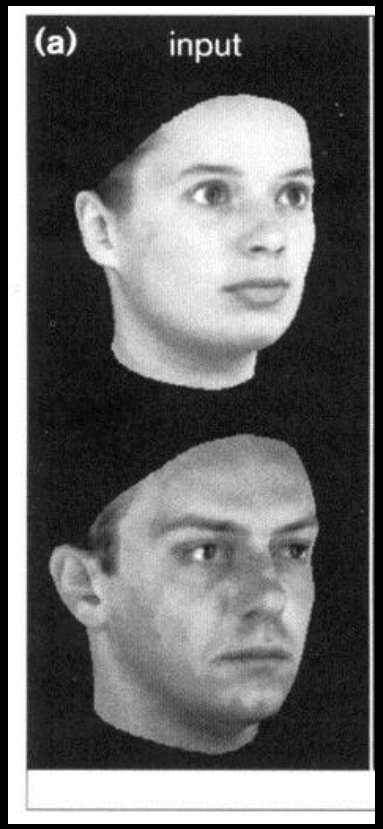
$$C0 * Attribute_0 + C1 * Attribute_1 \; \cdots \; + Cn * Attribute_n = Attribute_{new}$$

The model in action:

Example 1 - implicit 3D shape recovery

Image 45 degree face image

Attribute Frontal face image



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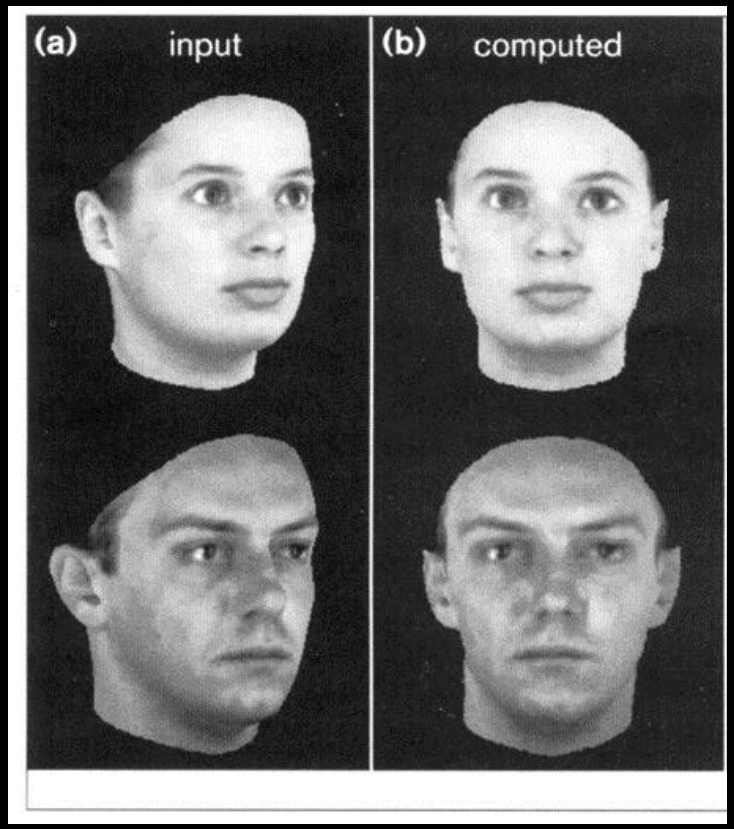

The model in action:

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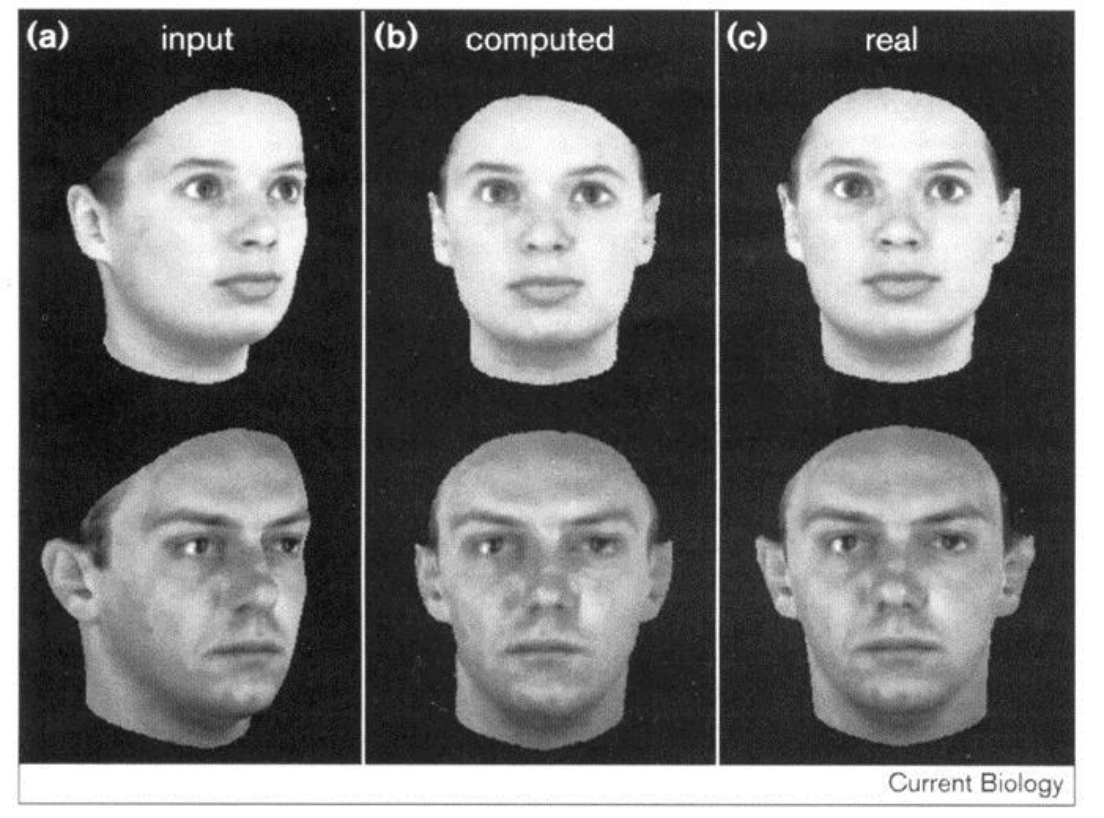
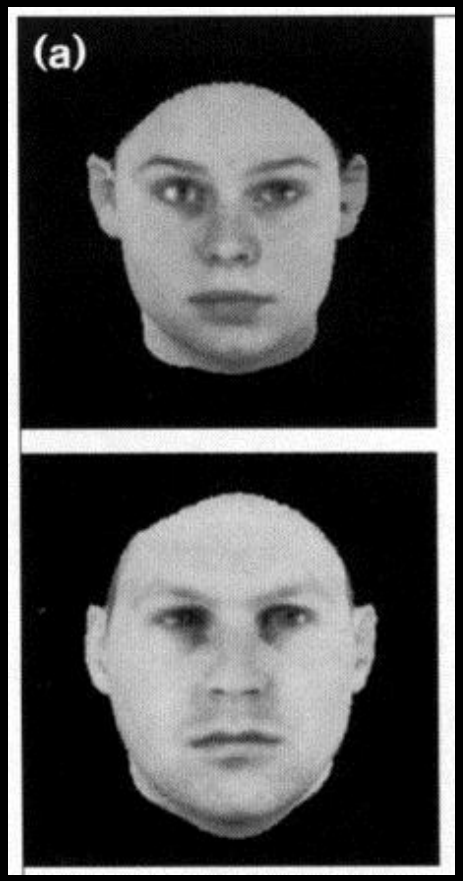


The model in action:

Example 2 - Clean edge-map extraction

Image frontal face image

Attribute Clean edge-map



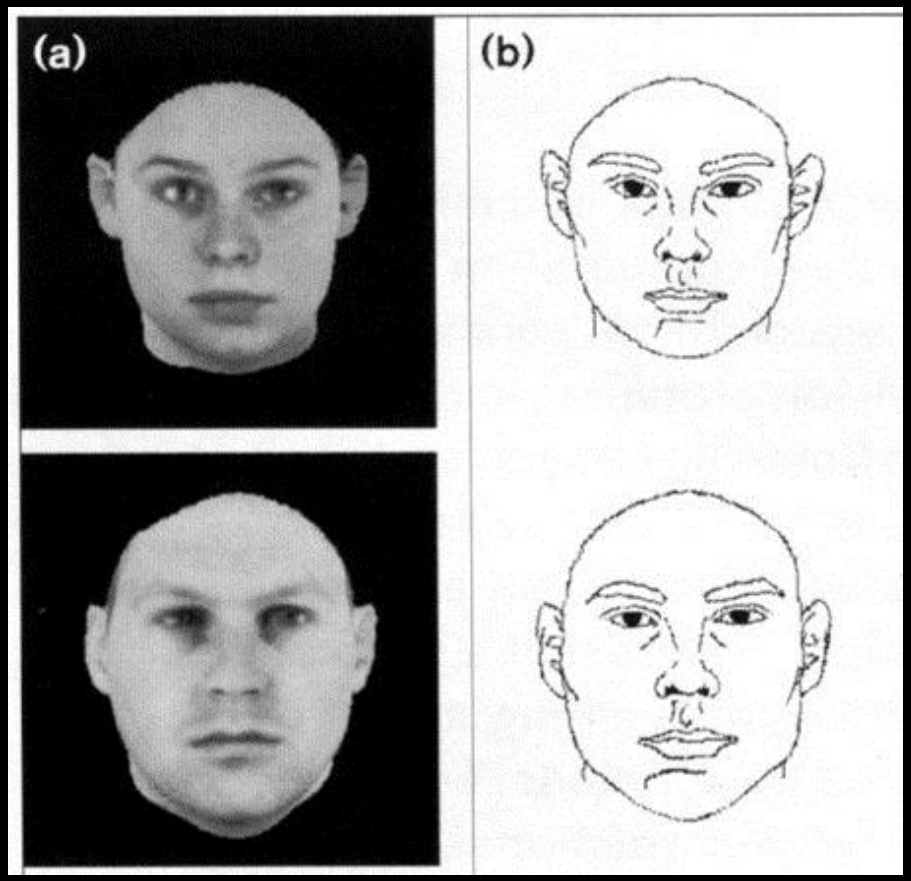
Input

The model in action:

Example 2 - Clean edge-map extraction

Image frontal face image

Attribute Clean edge-map



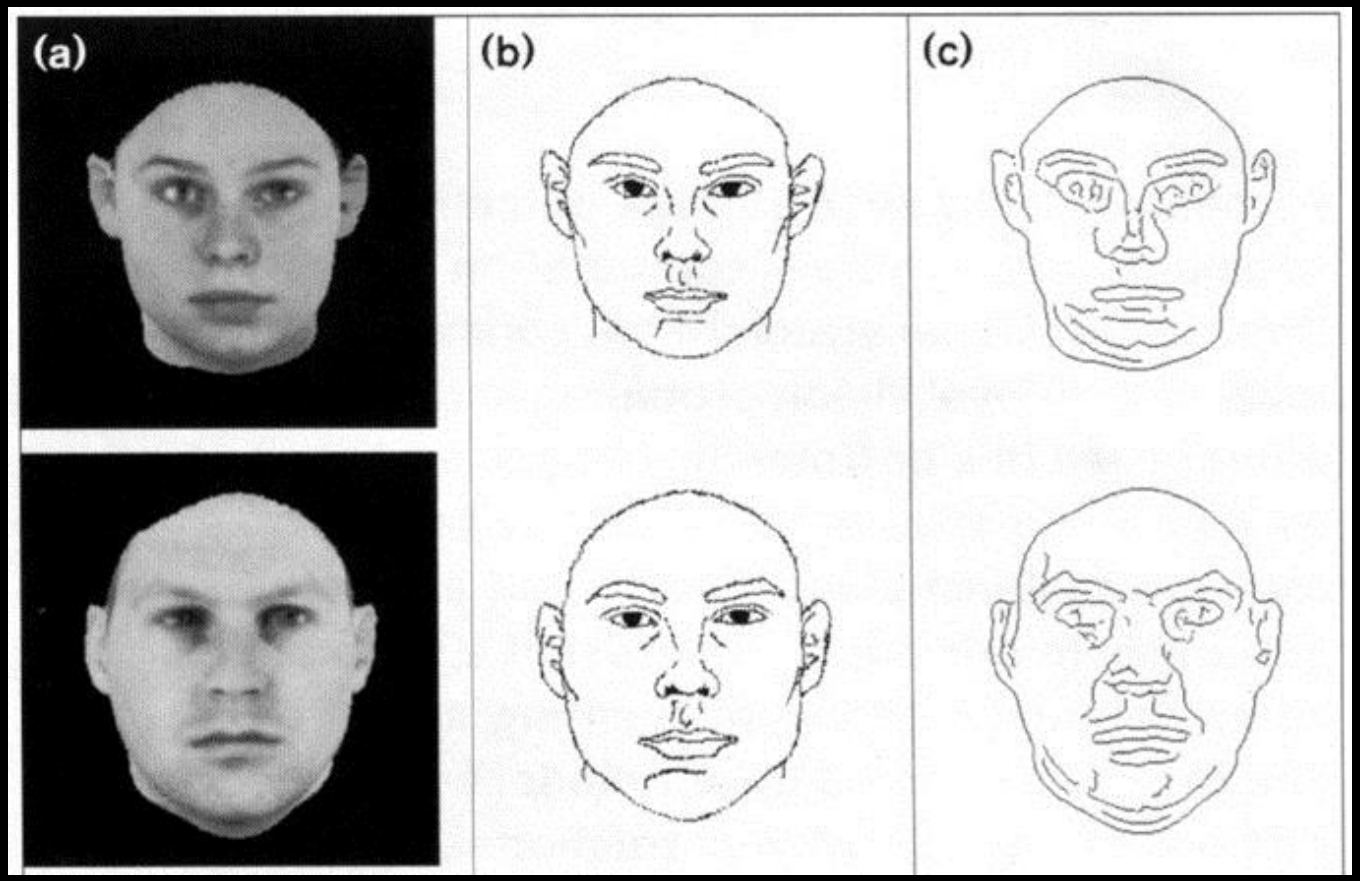
Input Model output

The model in action:

Example 2 - Clean edge-map extraction

Image frontal face image

Attribute Clean edge-map

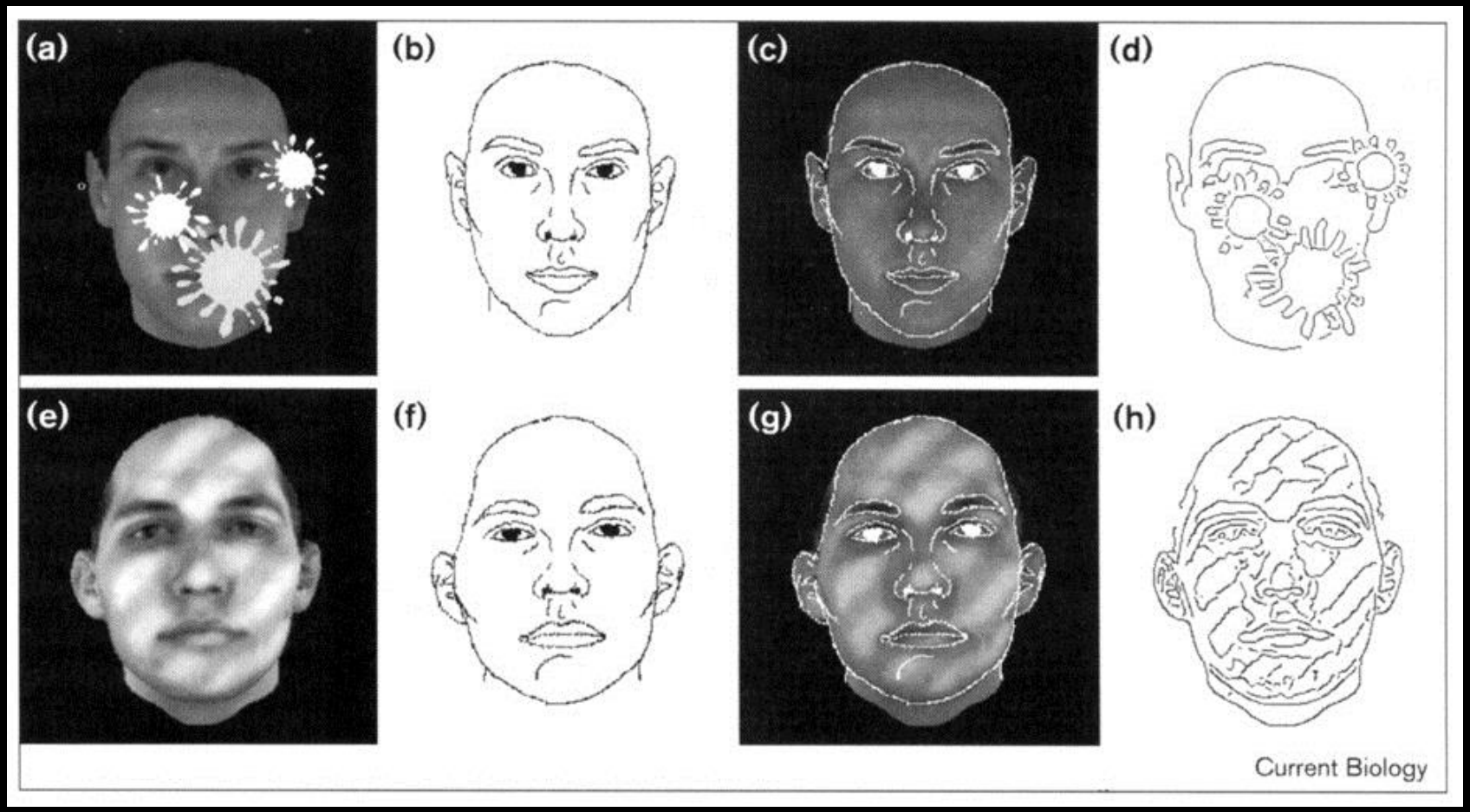


Input Model output Bottom-up output

Example 2 (contd.)

Strengths of high-level learning based model:

1. Ability to complete missing information
2. Ability to handle noise



Processing Framework Proposed by Marr