16-899: Visual World as seen by Neurons and Machines

Administrative

- Signups – Starts Wednesday after Class.
- Read 2 papers on Object Recognition in Human Brain over next 2 weeks.
- Doodle Poll and Google Survey..
- Other Questions?

Introductions?

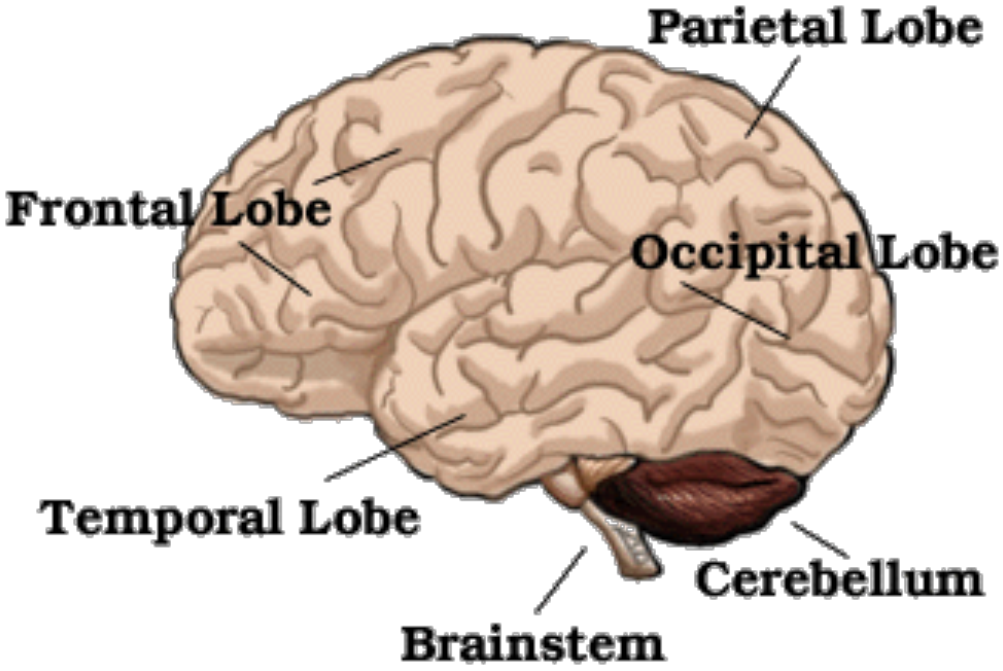
- Name
- Department/Research/Advisor

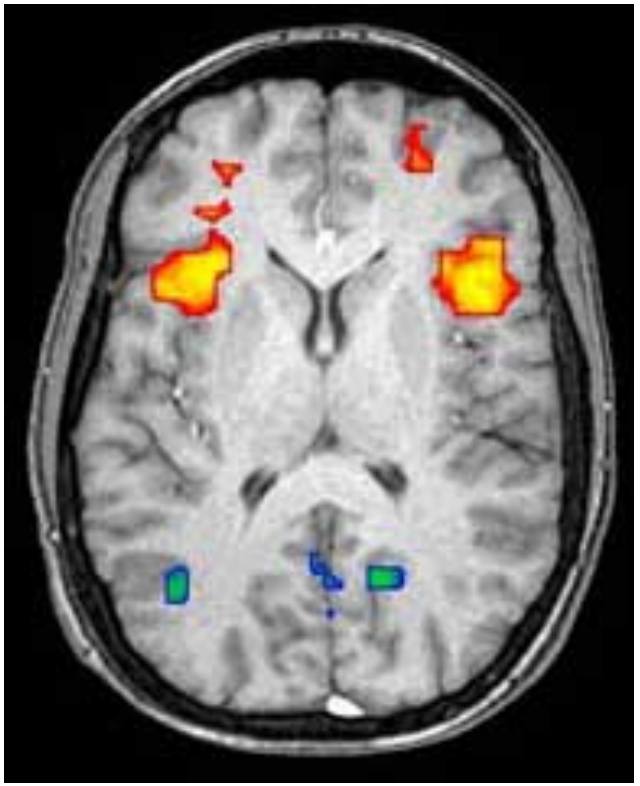
- What do you want to learn in this class?

Or

- What question about human vision/cognition intrigues you the most ?

Human Brain


Parietal Lobe
Frontal Lobe
Occipital Lobe
Temporal Lobe
Cerebellum
Brainstem



Technology

- FMRI – 1990s
- MEG – 1970/80s

But our interest in understanding human vision and cognition is quite old…

Greek Philosophers

Understanding Human Vision

Pre-Neuroscience Era

Most Slides from Palmer

Goal: Understand Perception

Approach 1: Discover all the facts related to perception !

Is that even possible?

Understanding a process as complex as perception requires more than listing facts

Theories

What is a Theory?

Theory

An integrated set of related hypotheses about underlying mechanisms or principles that not only organizes and explain known facts, but also makes prediction about new ones.

What is a Theory?

Three important functions of a theory:

- Integrate “old” facts
- Predict “new” facts
- Lead to “understanding”

Three criteria for evaluating a theory:

- Logical consistency
- Empirical adequacy
- Parsimony (“Occam’s razor”)

Theories of Vision

Categorization of Theories of Vision

- "*Why do things looks as they do?*"

  -- Kurt Koffka (1935)

- Nativism vs. Empiricism
  - "Because we were born *(evolved)* to see them that way" vs.
  - "Because we have learned to see them that way"
- Atomism vs. Holism
  - "because of the way each pixel appears" vs.
  - "because of the way the entire scene appears"
- Organism vs. Environment
  - "Because we are the way we are" vs.
  - "Because the world is the way it is"

4^{th} Axis

- How do you derive the theory?
  - Introspection (Conscious Inference)
  - Behavior (Measurement of Human Performance)

  - -Koffka: why do the things look the way they do?
  - -What does vision enable us to do?

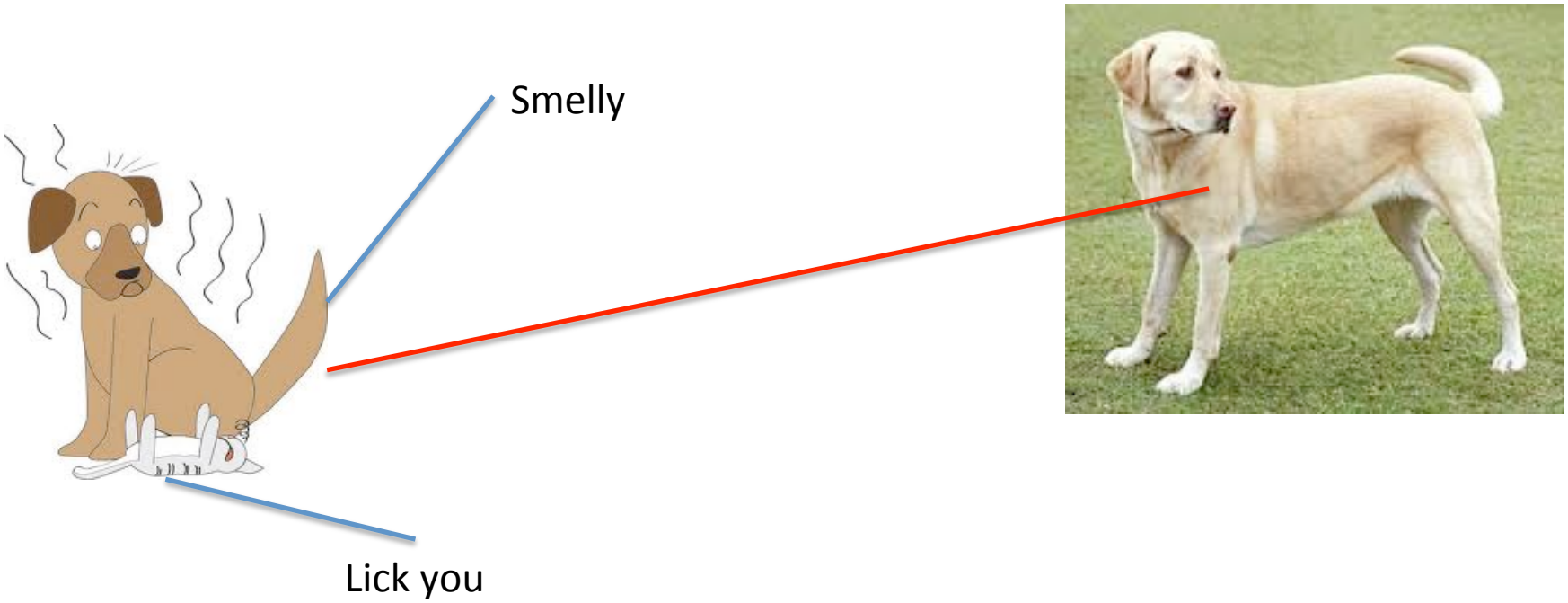
Structuralism

THEORY	NATIVISM vs. EMPIRICISM	ATOMISM vs. HOLISM	ORGANISM vs. ENVIRONMENT	PRINCIPAL ANALOGY	METHOD
Structuralism					
Gestaltism					
Ecological Optics					
Constructivism					

Structuralism

Structuralism:

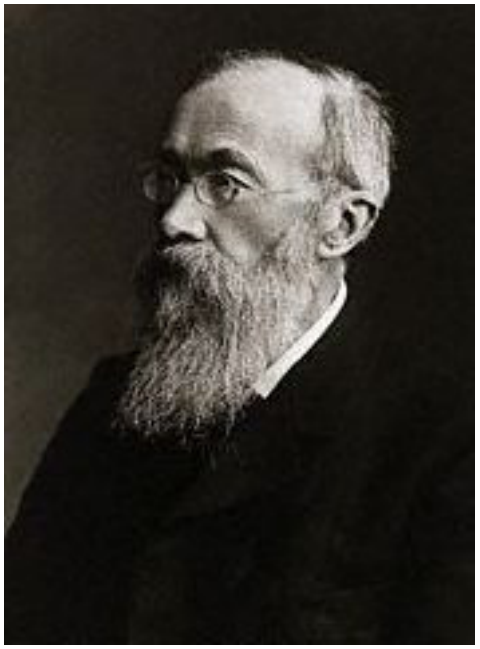
Perception results from the association of basic sensory atoms in memory via repeated, prior joint occurrences.



Structuralism

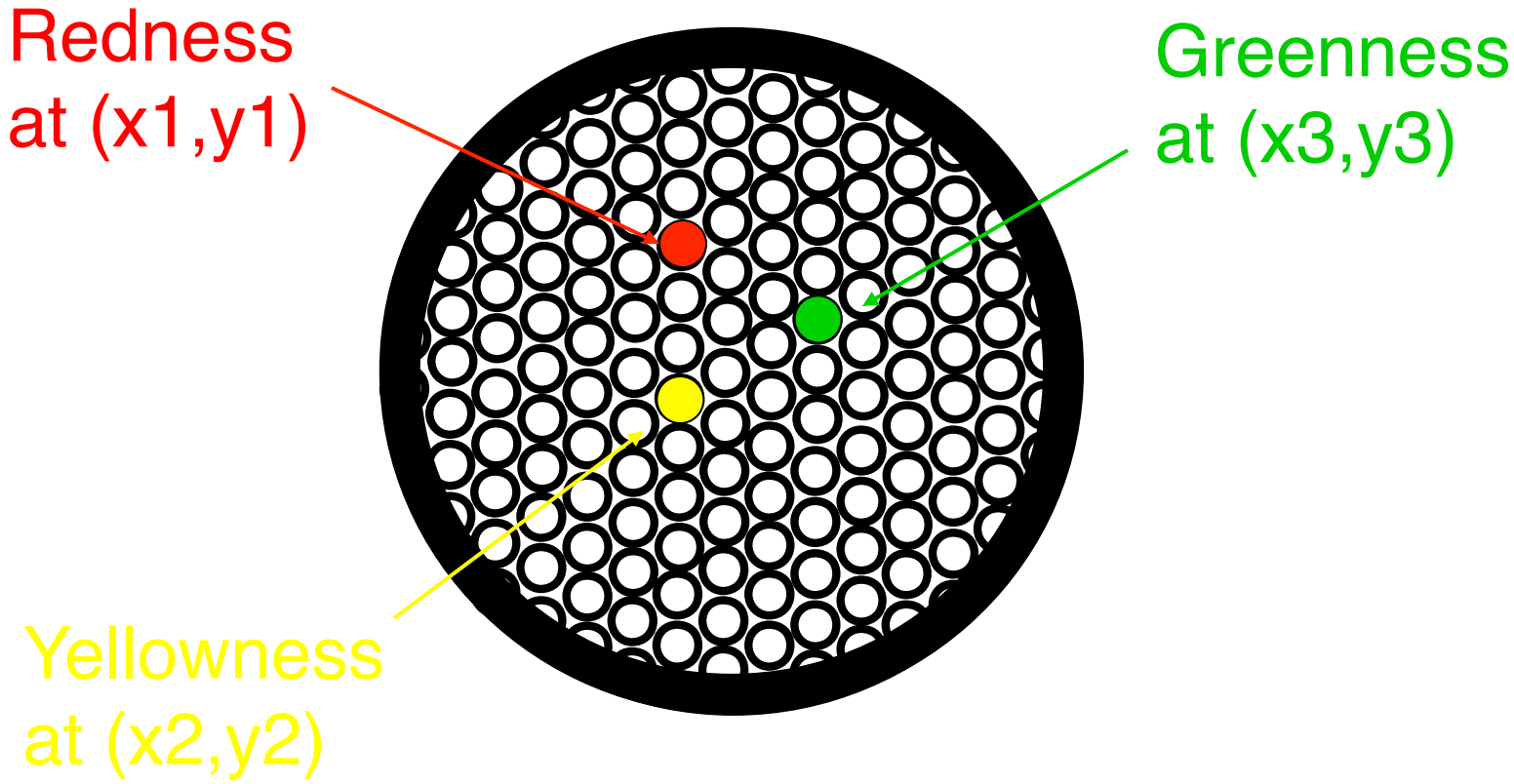
Derived from philosophy of British Empiricists (e.g., Locke, Berkeley, Hume, and Mills).

Proposed by Wilhelm Wundt, the father of modern Psychology.



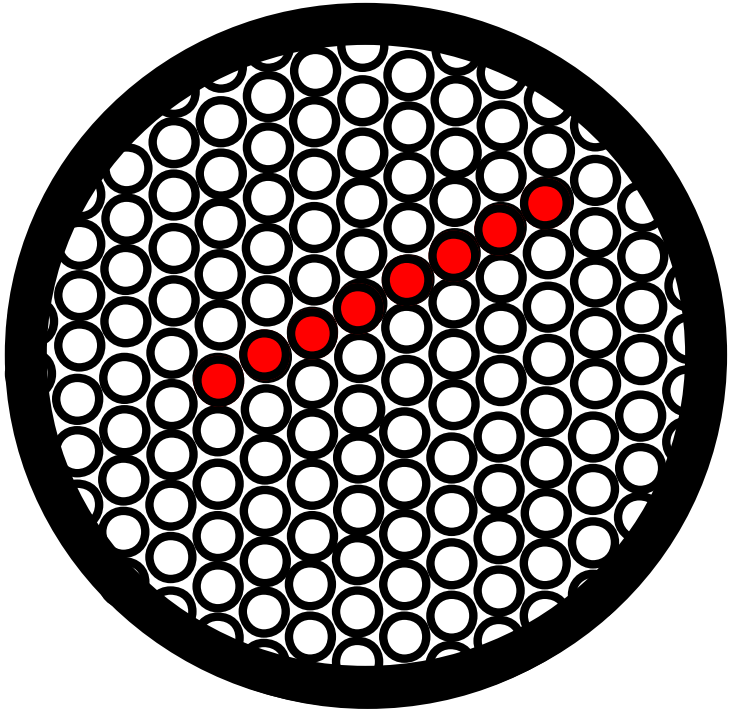
Structuralism

Sensory Atoms



Structuralism

Perceptual Complexes

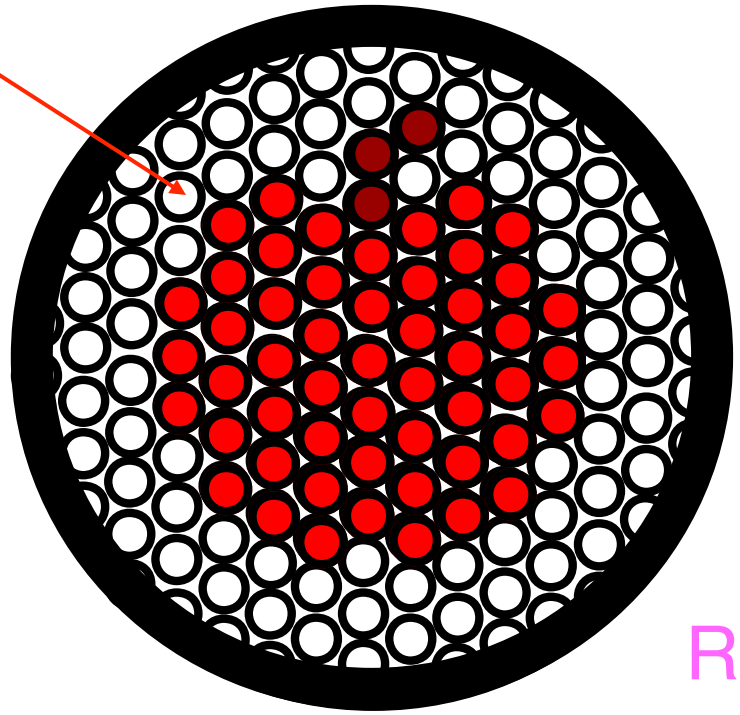


Retinal mosaic

Structuralism

Perceptual Complexes

Red apple
at (x0,y0)



Retinal mosaic

Structuralism

Perceptual Complexes

Red apple
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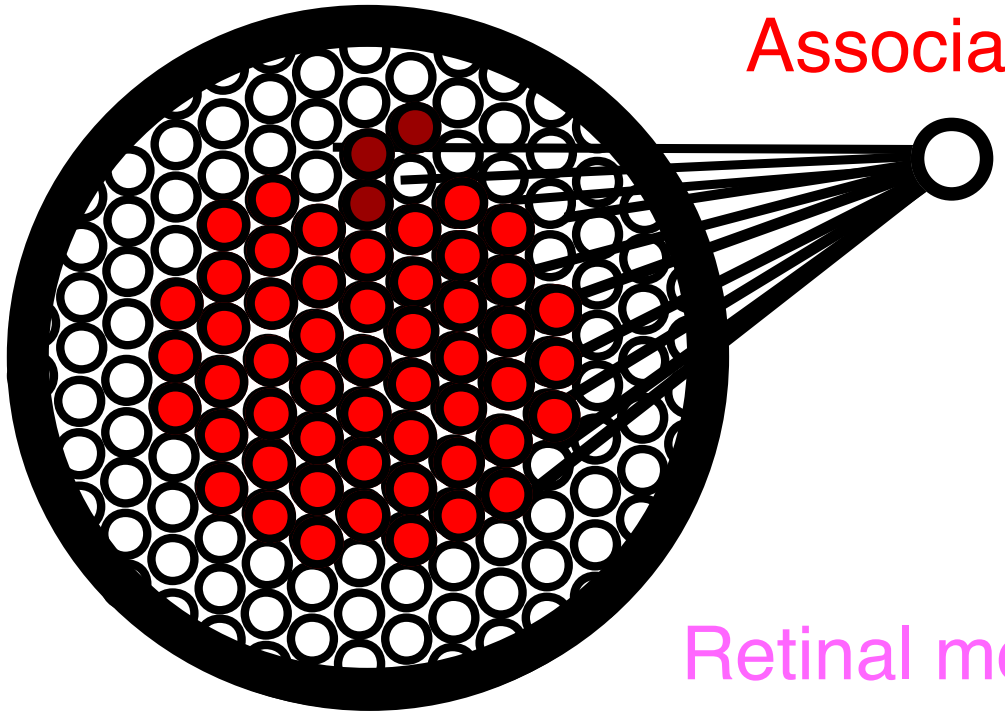


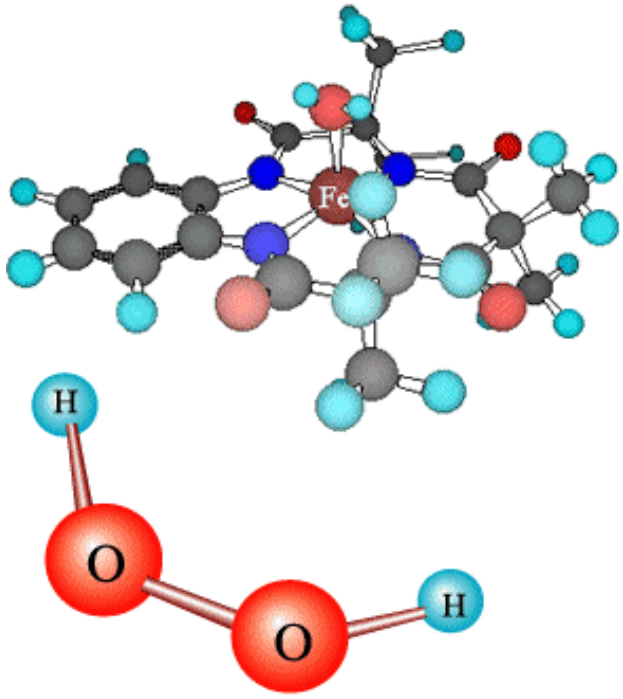
Association

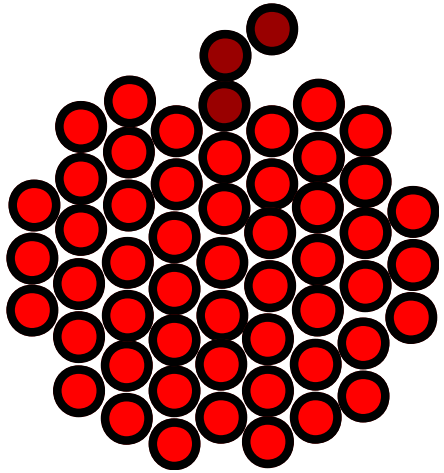
Retinal mosaic

Structuralism

Chemical Analogy

Perceptions are made of basic sensory experiences just as molecules are made of basic atoms.





Structuralism

Training Experts to discover the elementary units of perception

Nature of training led to different conclusions – One of the reasons for the downfall

Structuralism

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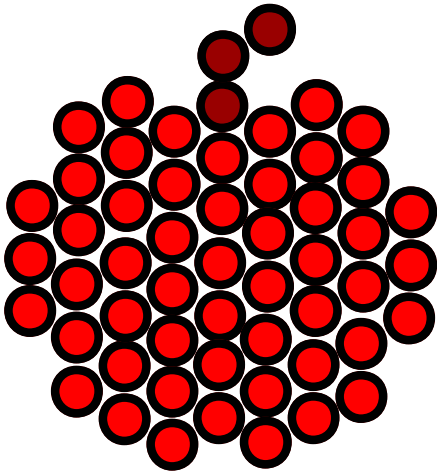
Ecological Optics					
Constructivism					

Gestaltism

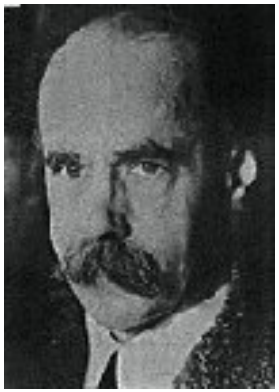
Whole is different from sum of its parts



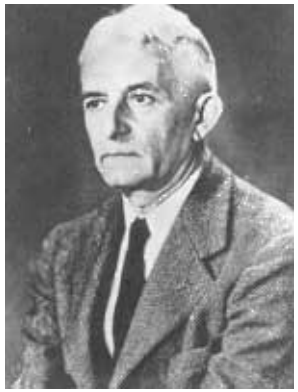
Gestaltism

Gestaltism:

Perception results from the interaction between the intrinsic structure of the stimulus and the intrinsic structure of the brain.



Max Wertheimer



Wolfgang Köhler

Kurt Koffka

Gestaltism

The Gestalt movement in perceptual theory was primarily a reaction against Structuralism:

Rejected atomism
Rejected empiricism
Rejected associationism

Successful in arguing against Structuralism, but less successful in promoting its own theoretical agenda.

Gestaltism

Principles of Gestalt Theory

Holism:

The whole is different from the sum of its parts.

Prägnanz:

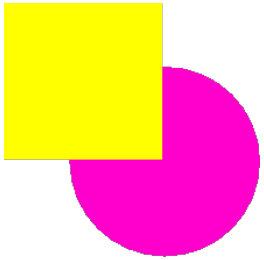
The percept will be as "good" as the prevailing conditions allow, I.e. simplest explanation

Nativism:

Not a total rejection of learning, but rejection of its primacy.

Gestaltism

Prägnanz: the percept will be as "good" as the prevailing conditions allow



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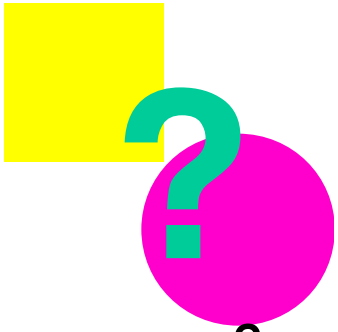
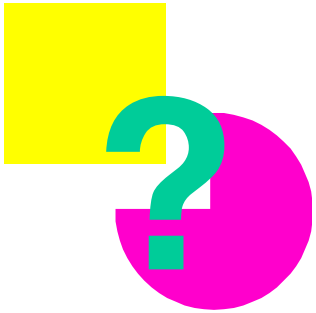


square & circle?



square & pacman?

squigit & pacman?

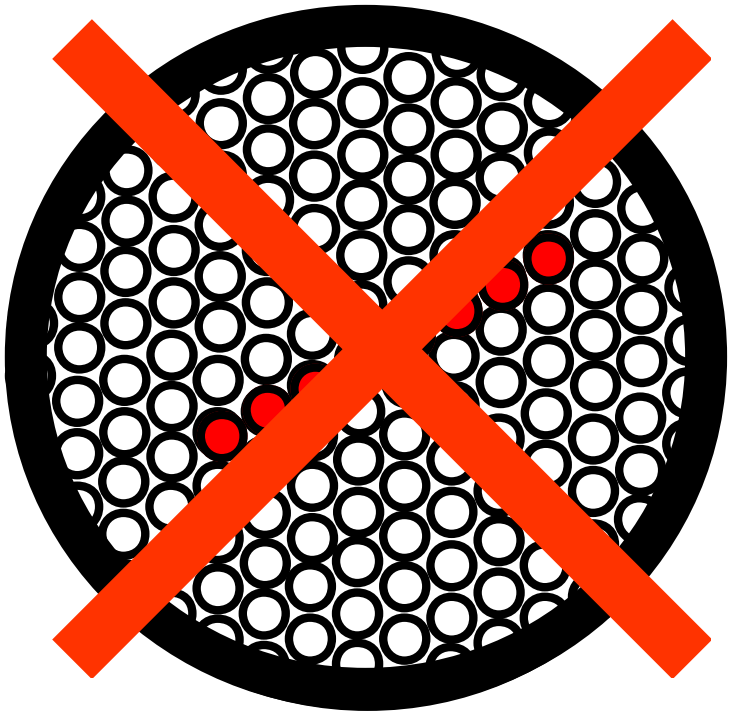
etc….

Gestaltism

Holism: The whole is <u>different</u> from the sum of its parts.

<u>Emergent properties:</u>
Features of a configuration that are not features of its components, e.g.:

- length
- orientation
- curvature
- closure
- connectedness



Emergent Properties

The Problem of Organization

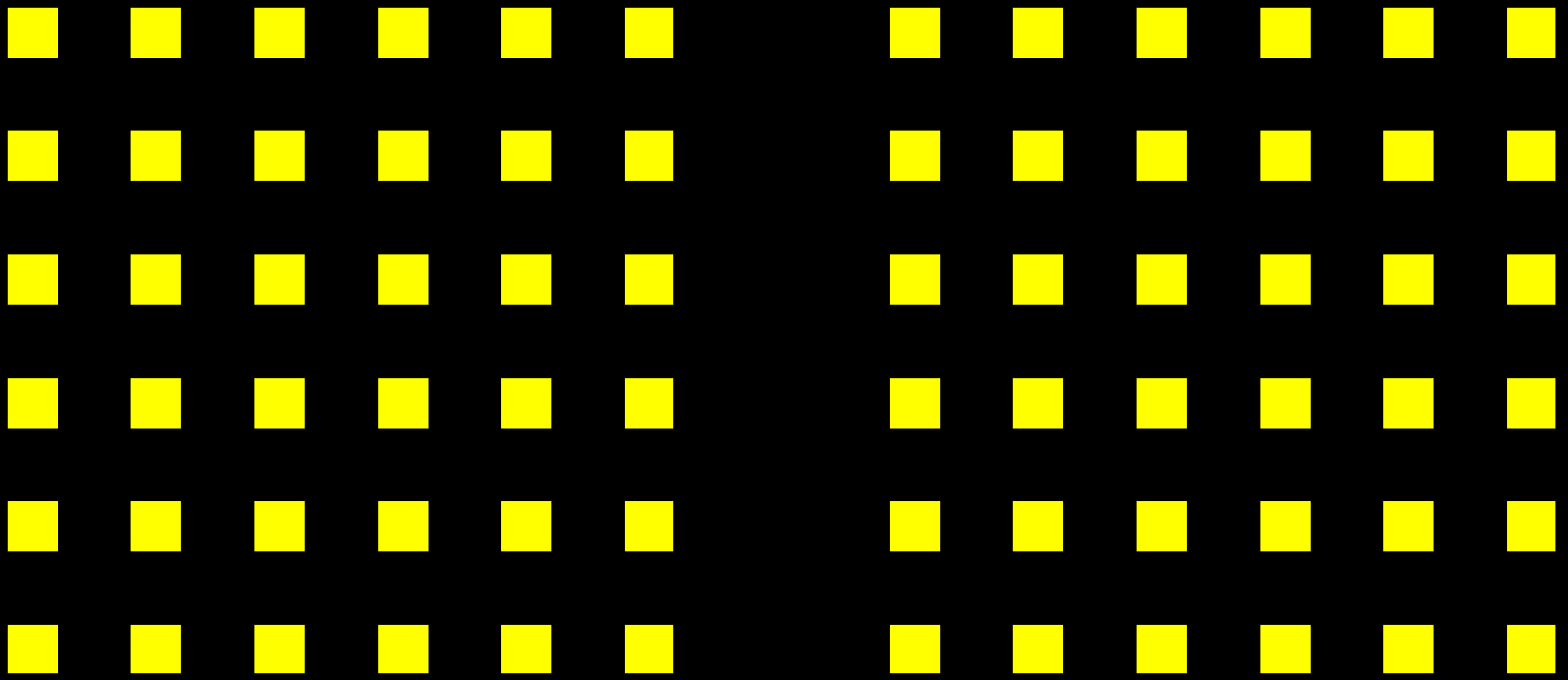
The problem of grouping:

"I stand at the window and see a house, trees, sky."

Theoretically, I might say that there were 327 brightnesses and nuances of color. Do I have "327"? No. I have sky, house, and trees. (Wertheimer, 1923)

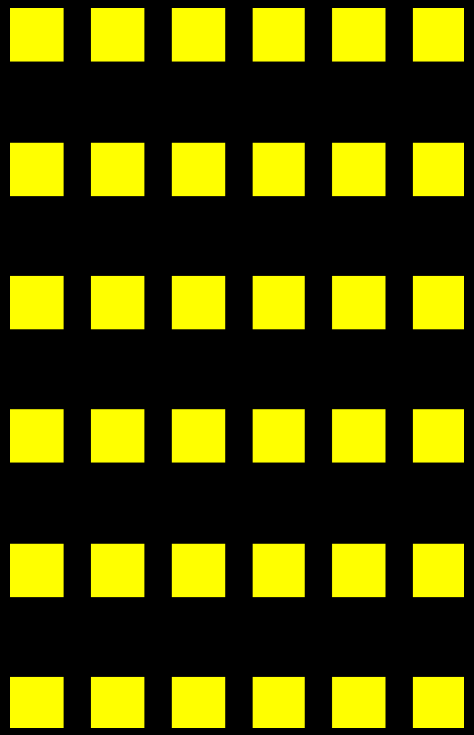
Perceptual Grouping

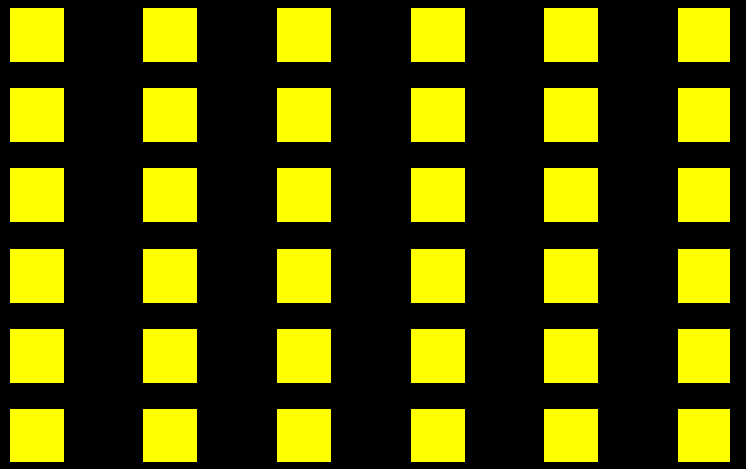
Wertheimer's "laws" of grouping



Perceptual Grouping

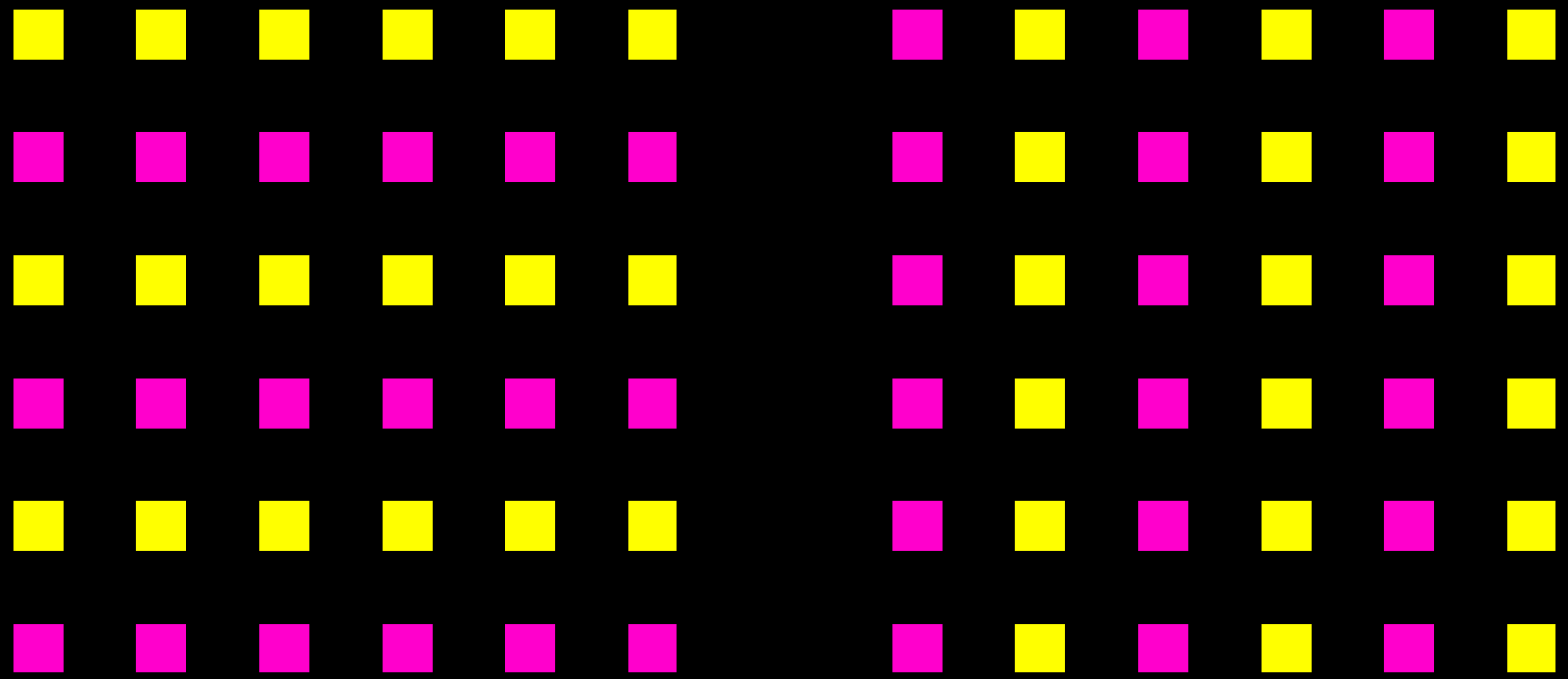
Proximity





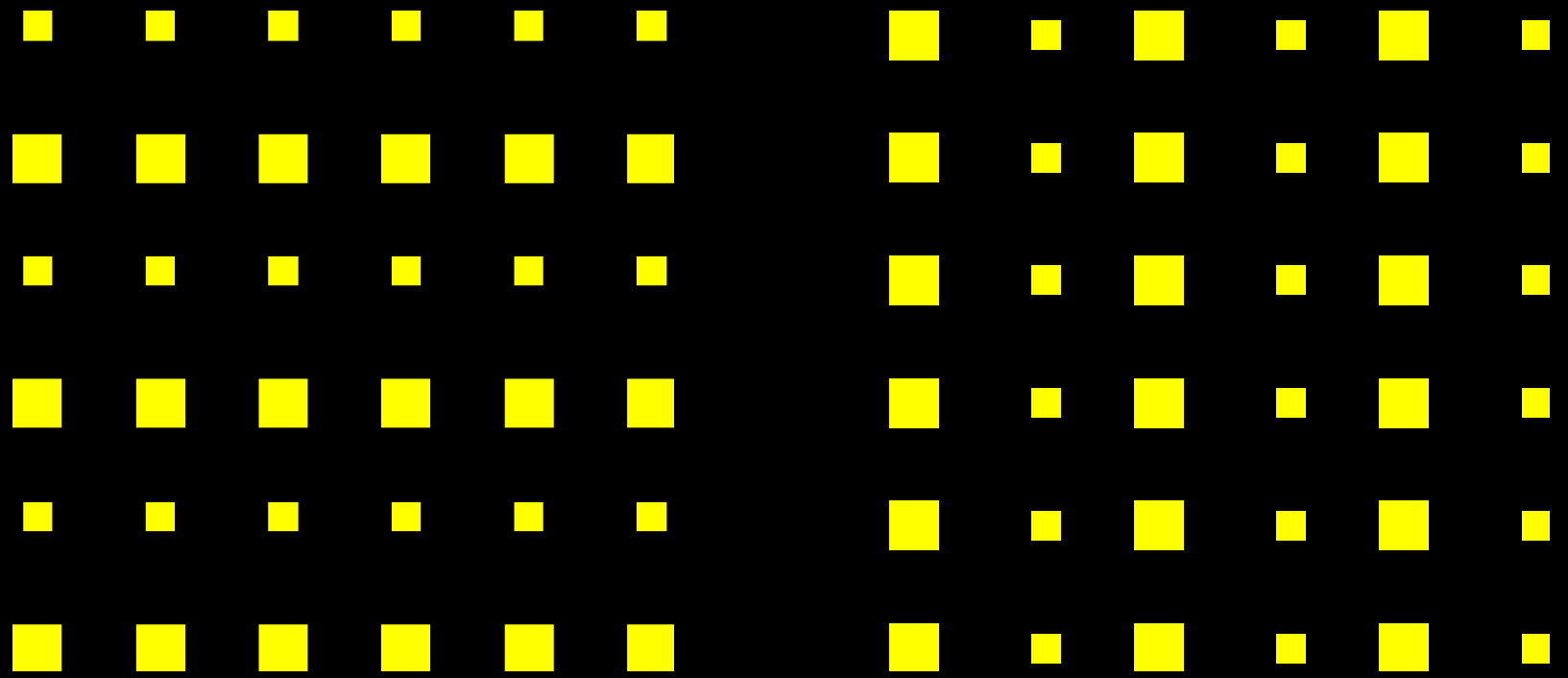
Perceptual Grouping

Color Similarity



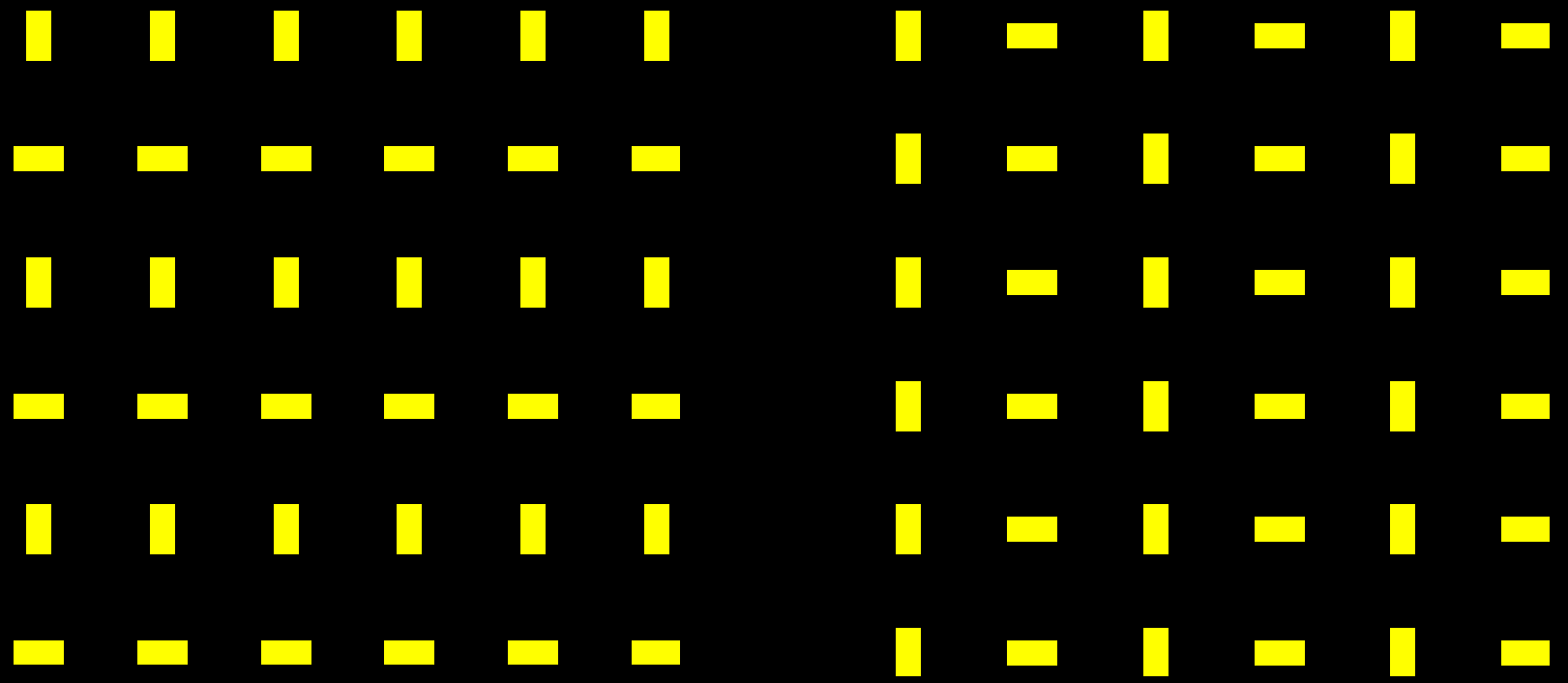
Perceptual Grouping

Size Similarity



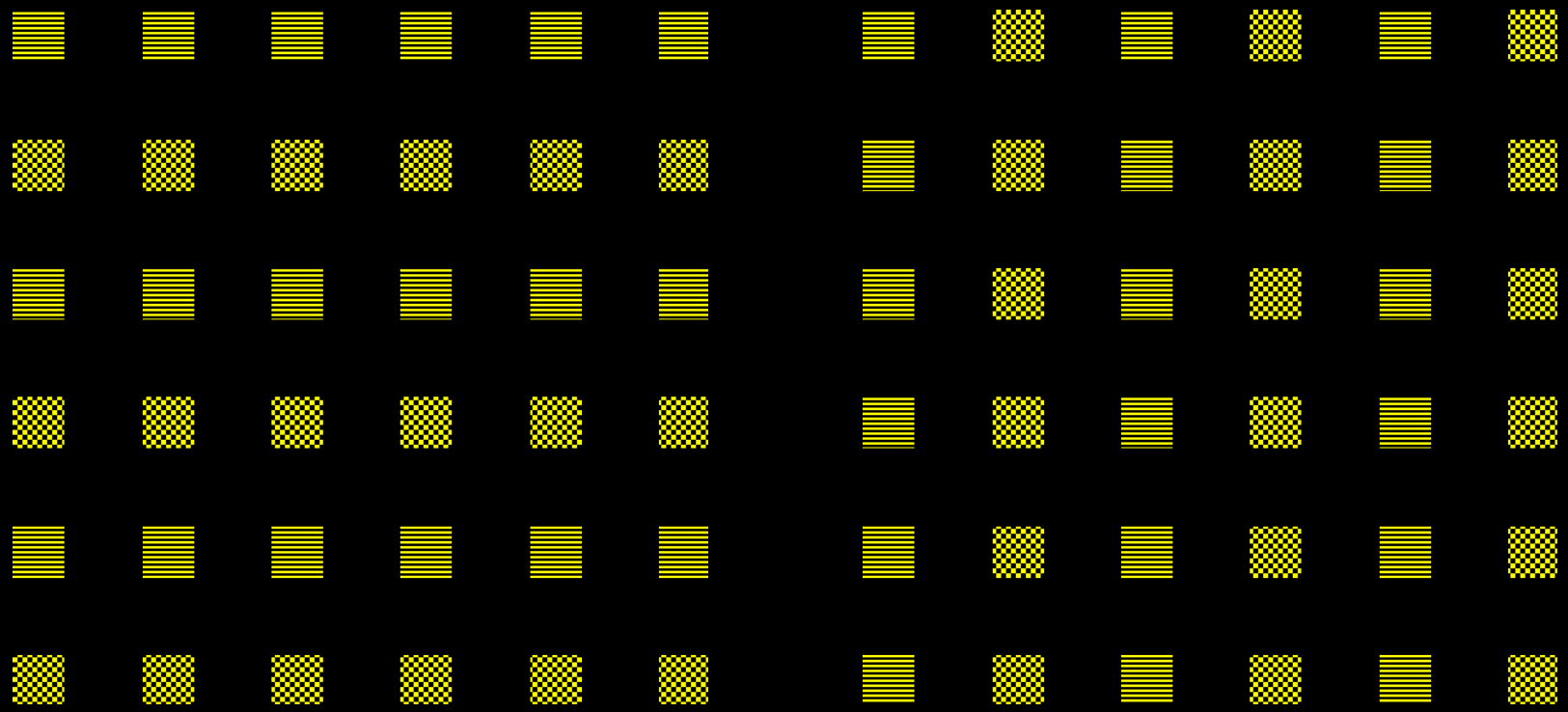
Perceptual Grouping

Orientation Similarity



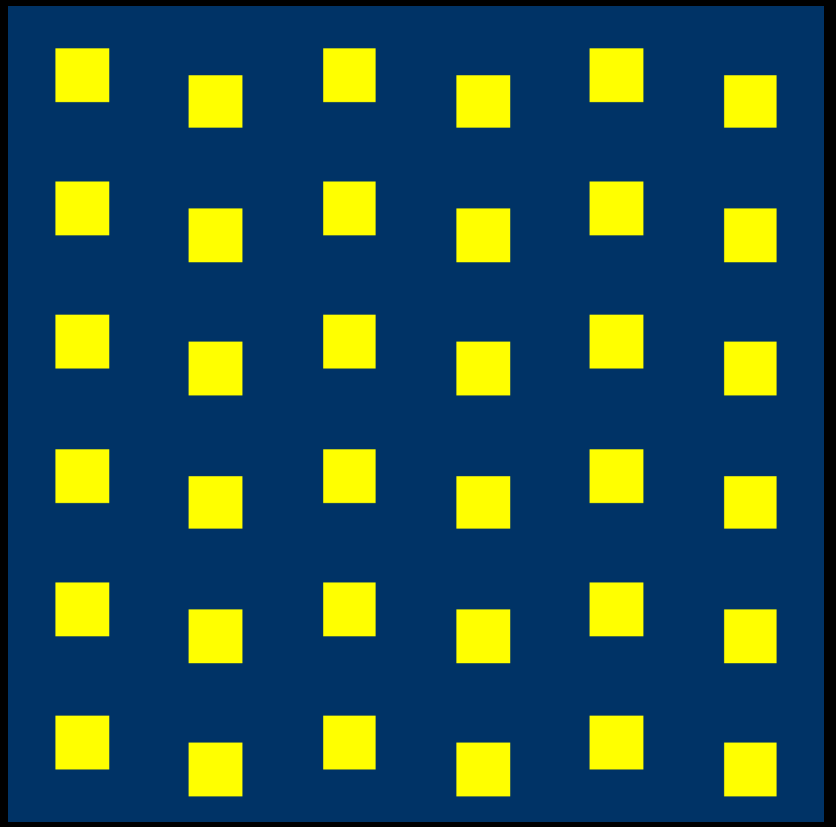
Perceptual Grouping

Similarity of texture



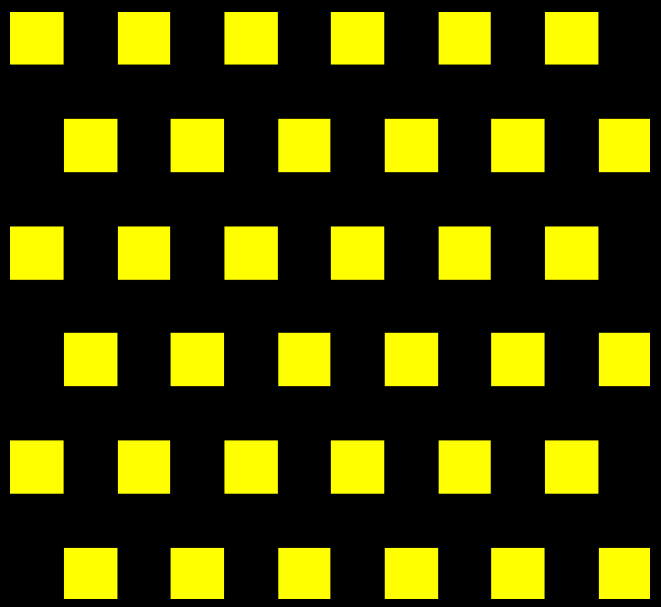
Perceptual Grouping

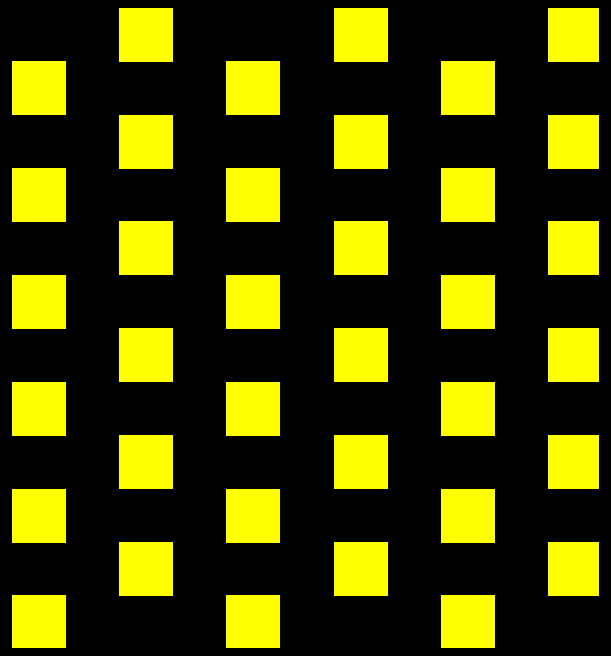
Common Fate



Perceptual Grouping

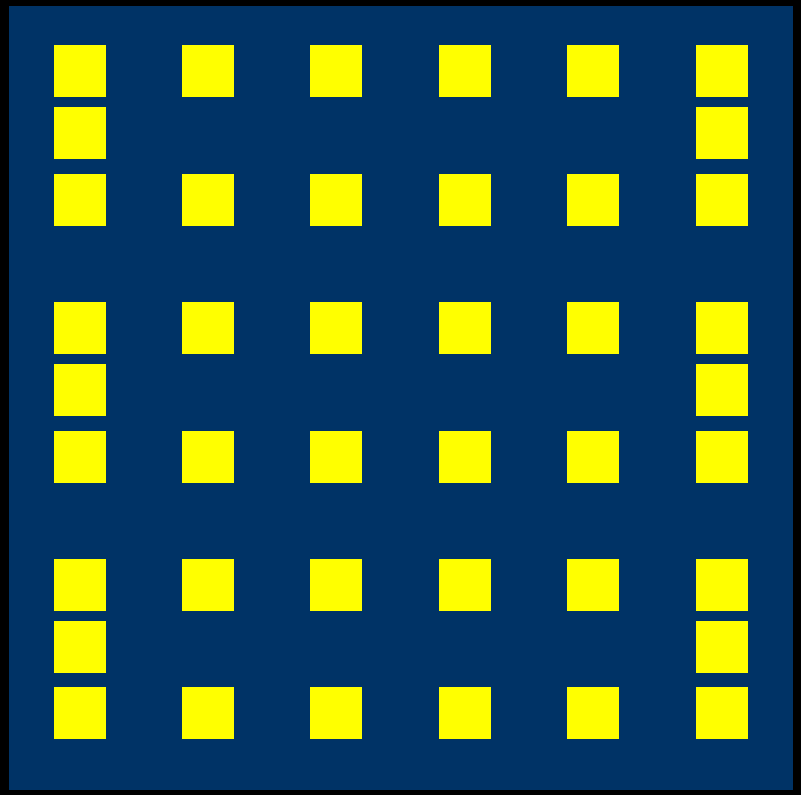
Good Continuation

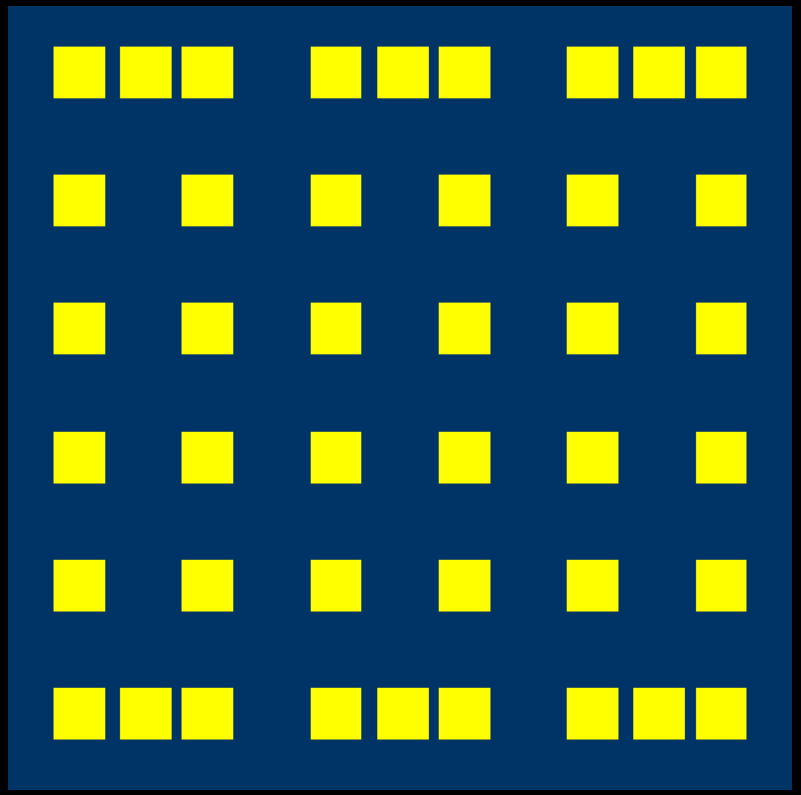




Perceptual Grouping

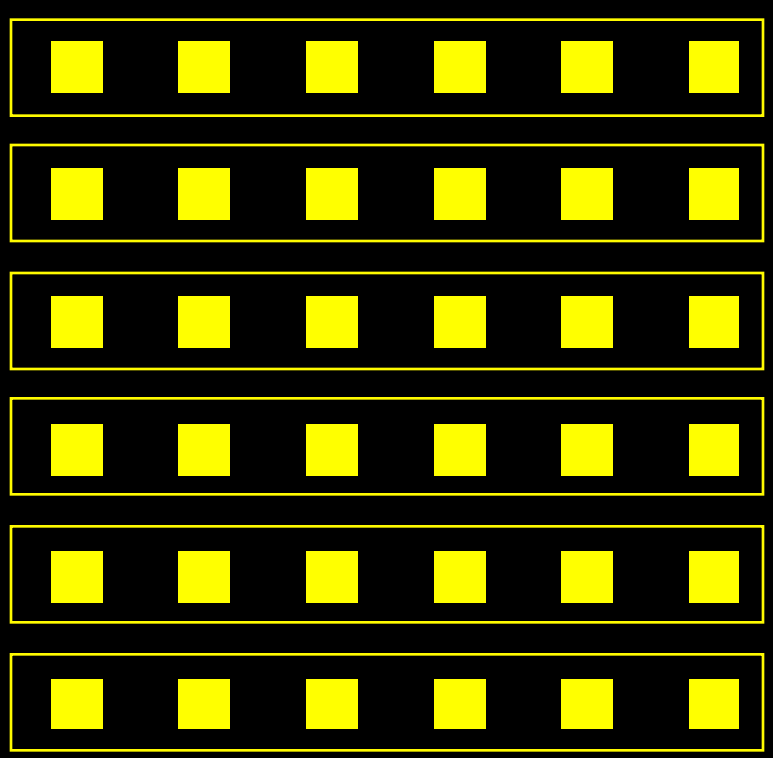
Closure

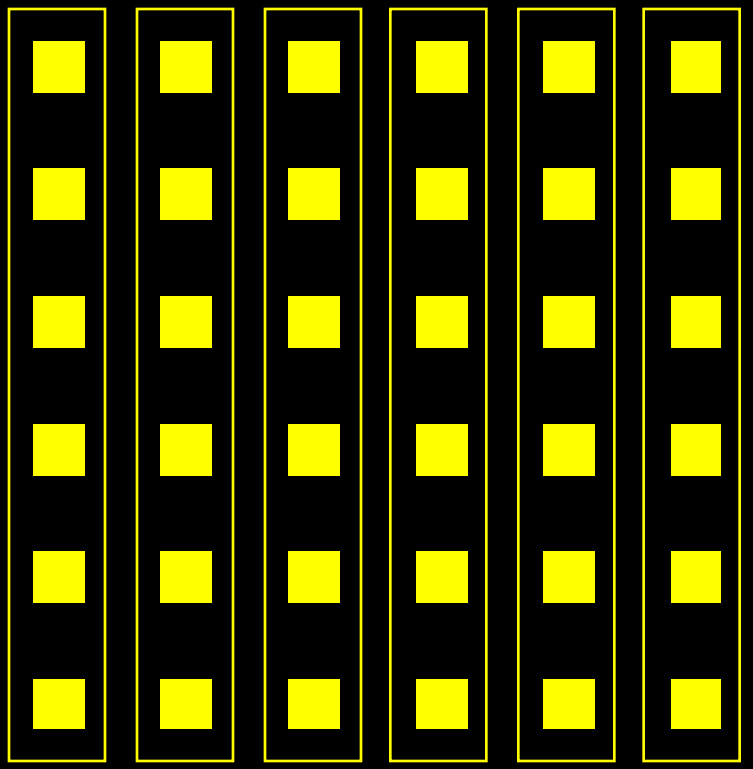




Perceptual Grouping

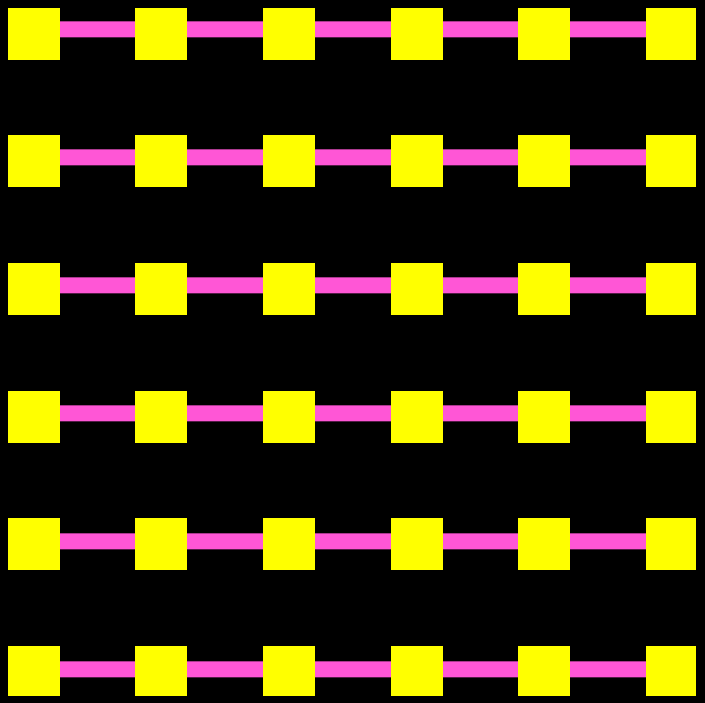
Common Region

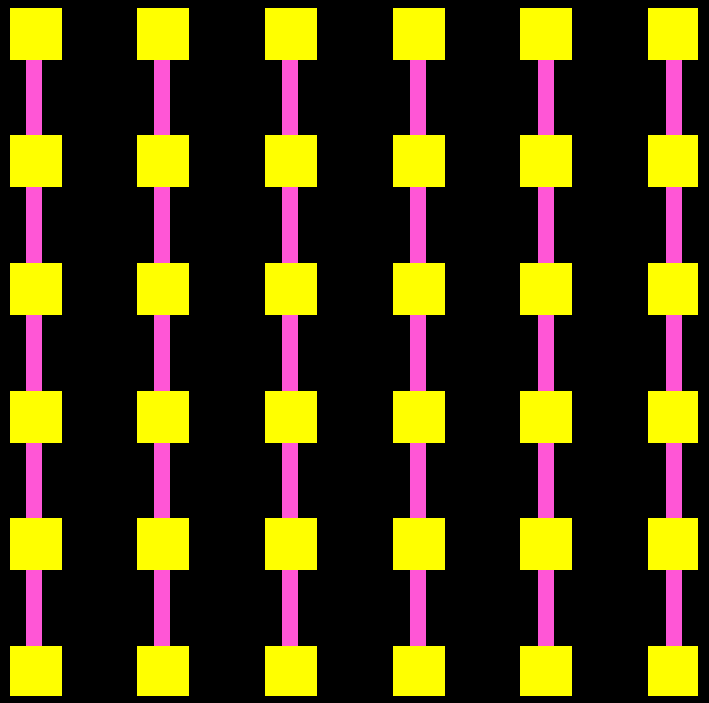




Perceptual Grouping

Element Connectedness



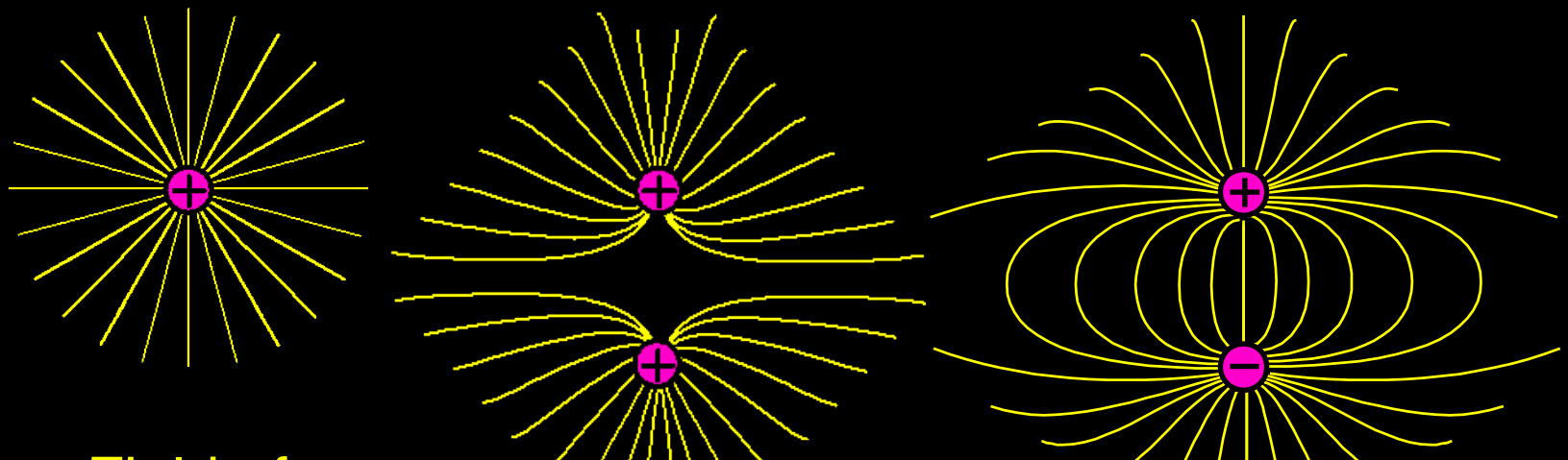


Perceptual Grouping

Past Experience

Gestaltism

Field Theoretic Analogy



Field of a single positive charge

Field of a pair of positive charges

⇓

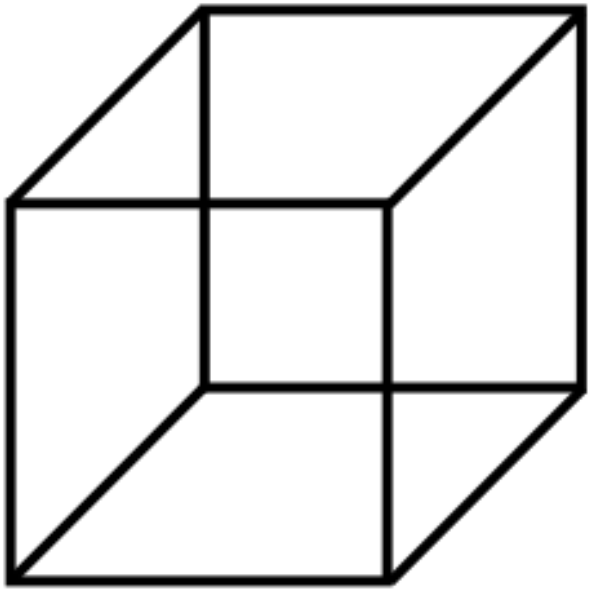
Repulsion

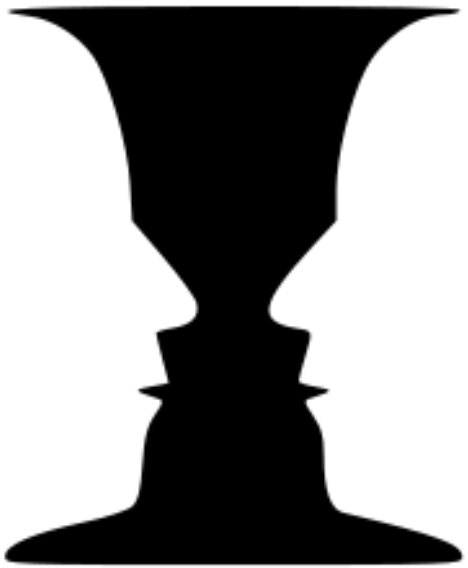
Field of a positive & a negative charge

⇓

Attraction

Gestaltism – Multi-stability





Gestaltism

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Structuralism	Empiricism	Atomism	Organism	Chemistry	Trained Introspection
Gestaltism	Nativism	Holism	Organism	EM Fields	Naïve Introspection
Ecological Optics					
Constructivism					

Ecological Optics

Ecological Optics: Perception is the direct apprehension of the visible environment by extracting invariants in the dynamic ambient optic array and the affordances of objects.

James J. Gibson: Ask not what's inside your head, but what your head's inside of! (Ecological optics is a theory of stimulus structure.)

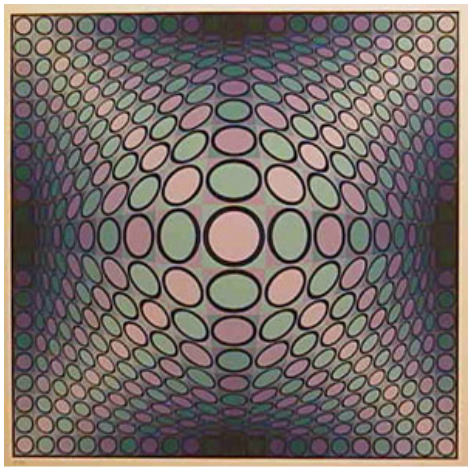
How does the world structure the light stimulus received by the brain?

Ecological Optics

Texture Gradients are gradual changes in the size & shape of texture elements in an image when a plane recedes in depth.

Tile floor

Wheat field

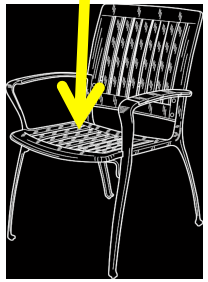


Geometric surface

affordances

- **Affordances:** Opportunities of interaction in the scene.
- Infer functions rather than identities.

Sittable



Ecological Optics

Direct Perception: Perception is not mediated by processes like unconscious thinking

Perception of the 3-D world is NOT ambiguous for an actively exploring organism.

Ecological

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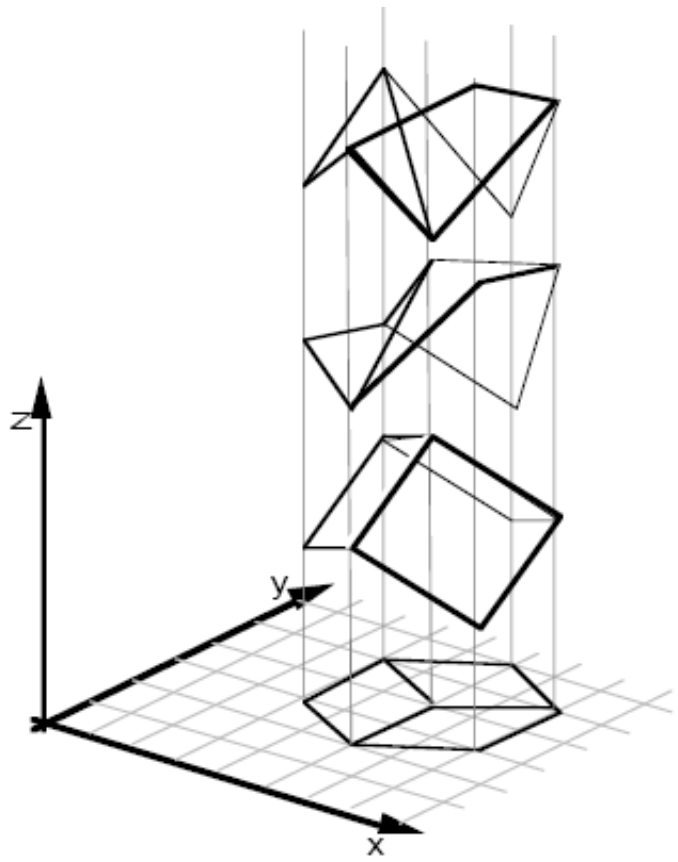
Ecological Optics	Nativism	Holism	Environment	Resonance	Ecological Analysis
Constructivism					

Visual Inference is Ambiguous



Constructivism

Constructivism: Perception is the result of unconscious inferences about the scene most likely to have caused the retinal image or event.

Hermann von Helmholtz originated the idea of unconscious inference and the likelihood principle.

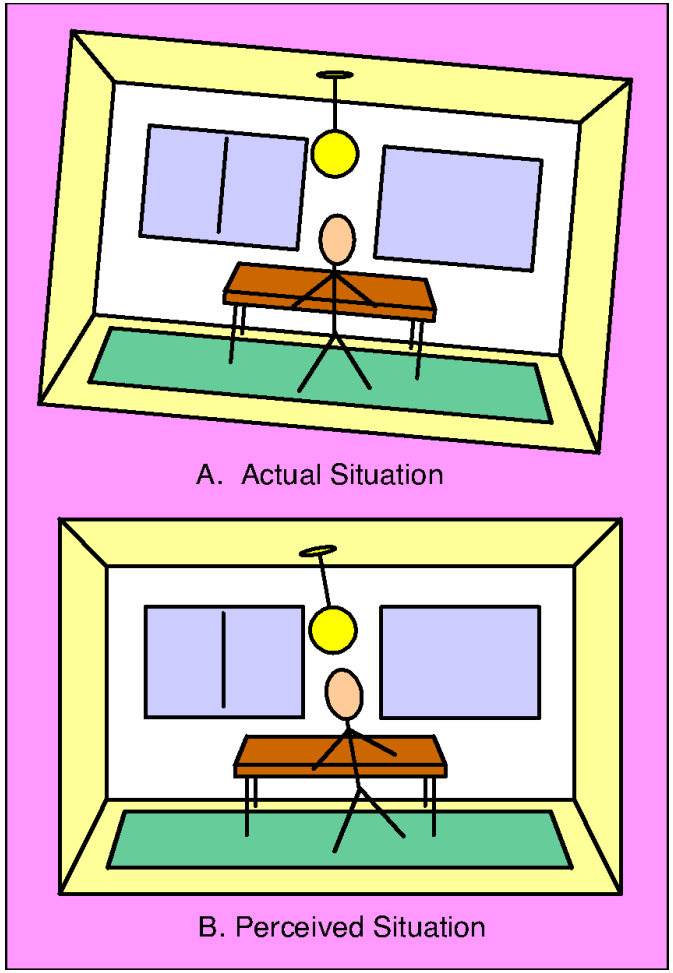
Constructivism

Unconscious Inference: the process of recovering environmental information by logically combining retinal information with heuristic assumptions.

Tilted room illusion:
If you assume that the walls and floor of the room are vertical and horizontal, then you must be tilted —and you feel that way!

Constructivism

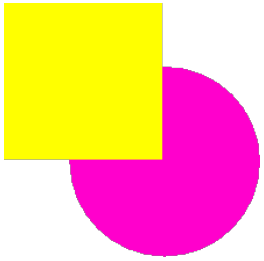
Tilted room illusion



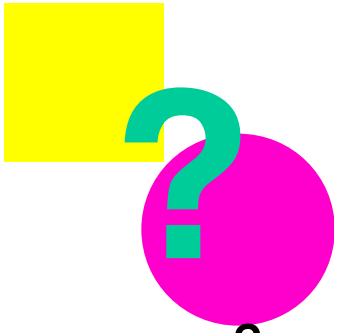
Constructivism

Prägnanz vs. Likelihood

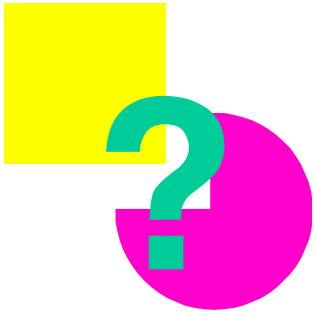
What governs what we see: goodness or probability?



What is this?



square & circle?



square & pacman?

squigit & pacman?

etc….

Constructivsm

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Ecological Optics	Nativism	Holism	Environment	Resonance	Ecological Analysis
Constructivism	both	both	both	Logical Inference	Behavior

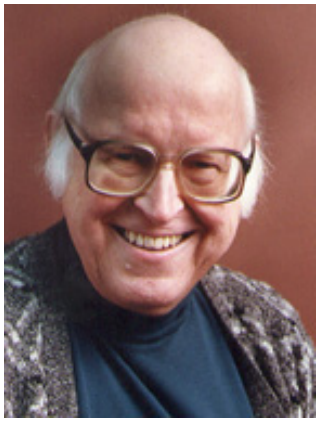
So which theory is correct?

Probably none of them!

Or maybe all of them, to some degree!

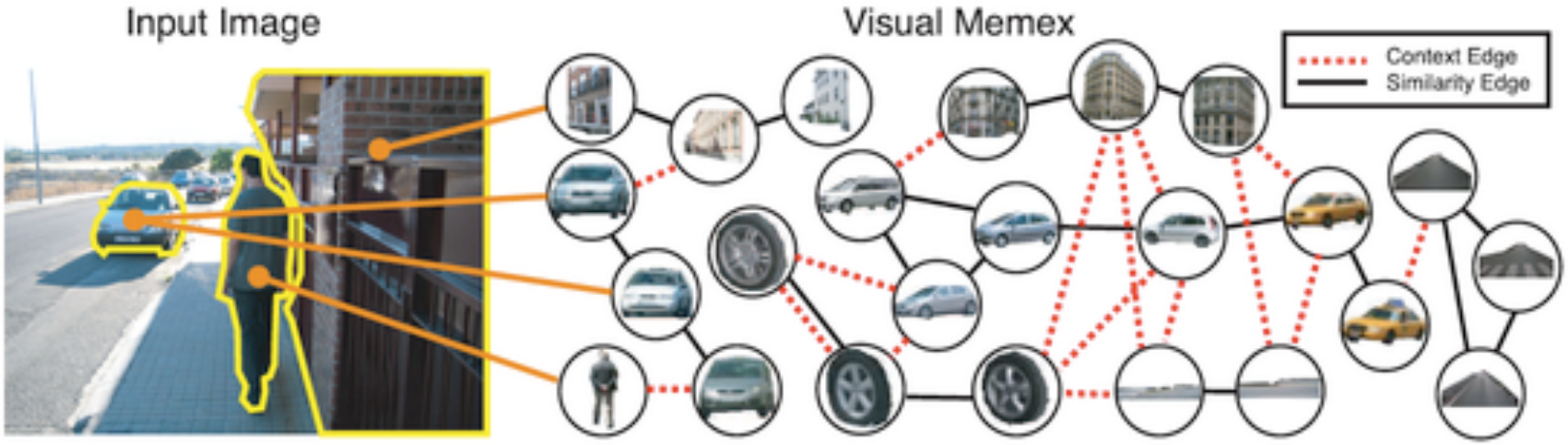
It's good to keep them in mind, when designing your algorithms!

"You can't play 20-questions with nature and win!"
(Allen Newell, 1973)

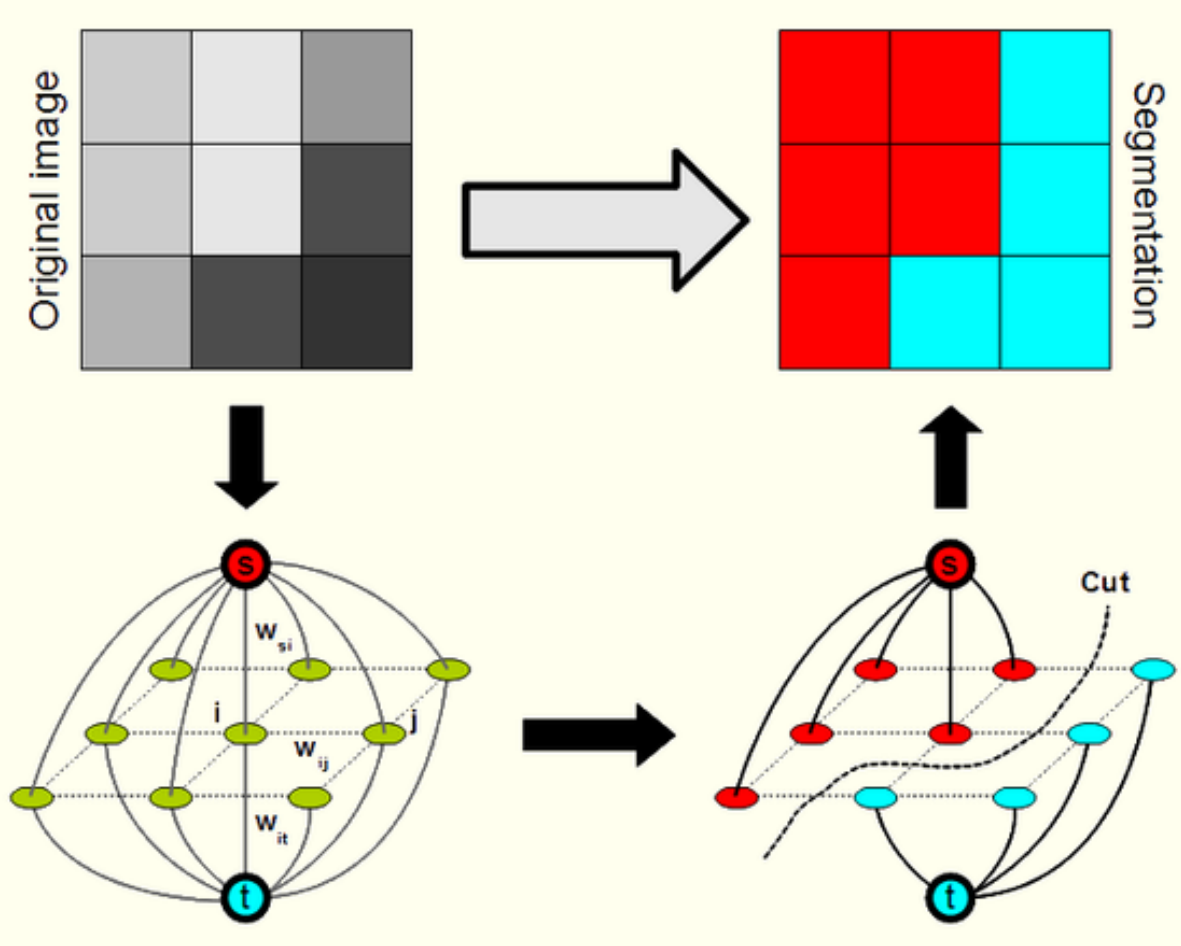


Where do you see these principles in current vision techniques?

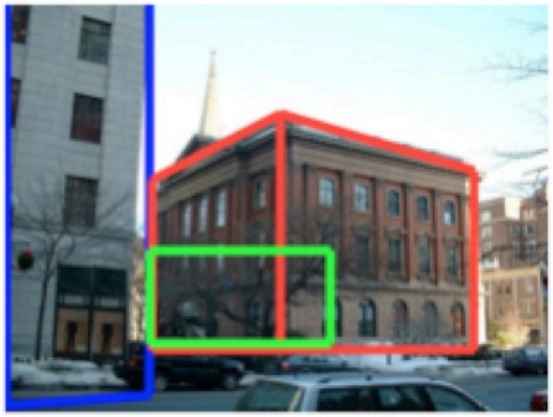
Structuralism

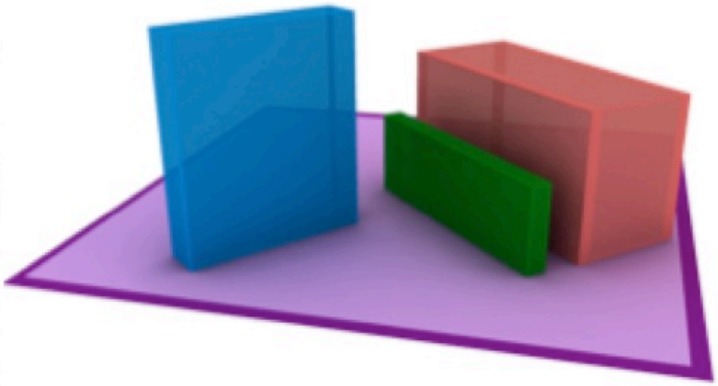


Gestaltism

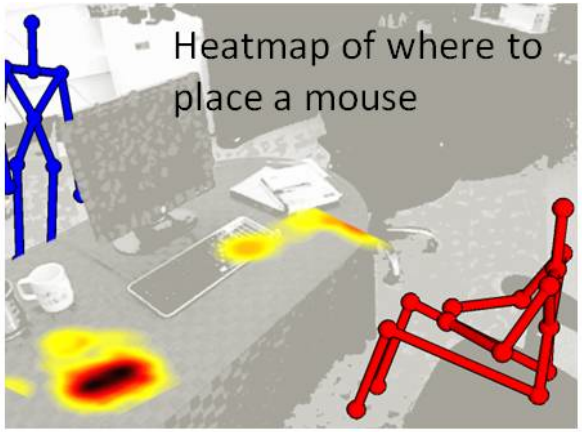


Ecological Theory of Vision





Blocks World Revisited



3D Object detection using Hallucinated Humans

Arranging Objects using Hallucinated Humans

Constructivism

Everywhere! – Context to Graphical Model etc.

Enter the computers

Computational Thinking

+ Real Images rather than made up Stimuli

+ No more vague theories. Needed more details.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROJECT MAC

Artificial Intelligence Group July 7, 1966
Vision Memo. No. 100.

THE SUMMER VISION PROJECT

Seymour Papert

The summer vision project is an attempt to use our summer workers effectively in the construction of a significant part of a visual system. The particular task was chosen partly because it can be segmented into sub-problems which will allow individuals to work independently and yet participate in the construction of a system complex enough to be a real landmark in the development of "pattern recognition".

Computational Thinking

+ Real Images rather than made up Stimuli

+ No more vague theories. Needed more details.

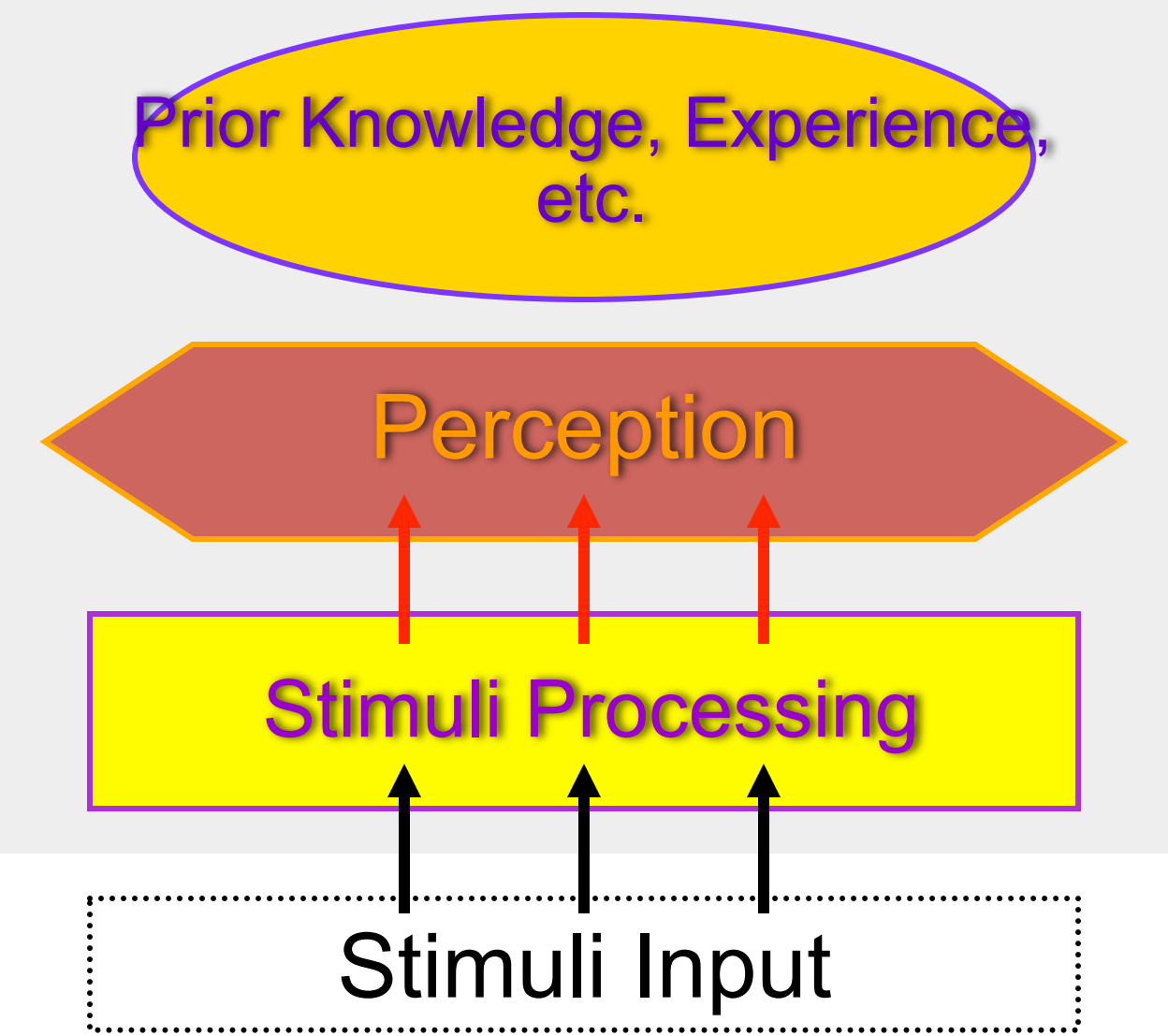
+ Principles of Information Processing

Top-down vs. Bottom-up

Top-Down versus Bottom-Up Perception

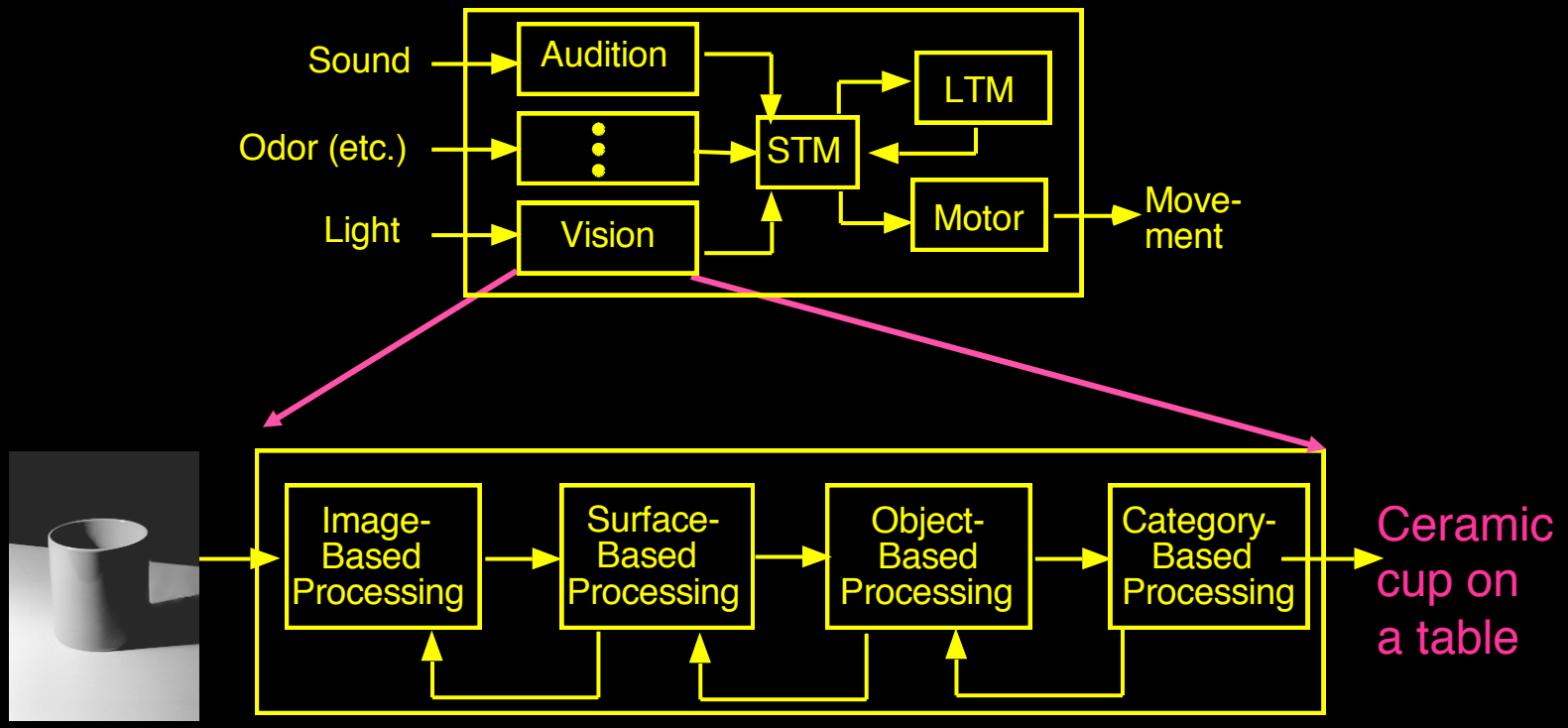
- **Top-Down**
  - Perceive the whole and then individual parts as needed.
  - Experience-driven as opposed to stimulus or input-data driven.
  - Quick and highly inferential but also a source of misperception.
- **Bottom-up**
  - Perceive the individual parts and organize them into a whole, if possible.
  - Information available in the stimulus itself.

Bottom-Up Processing



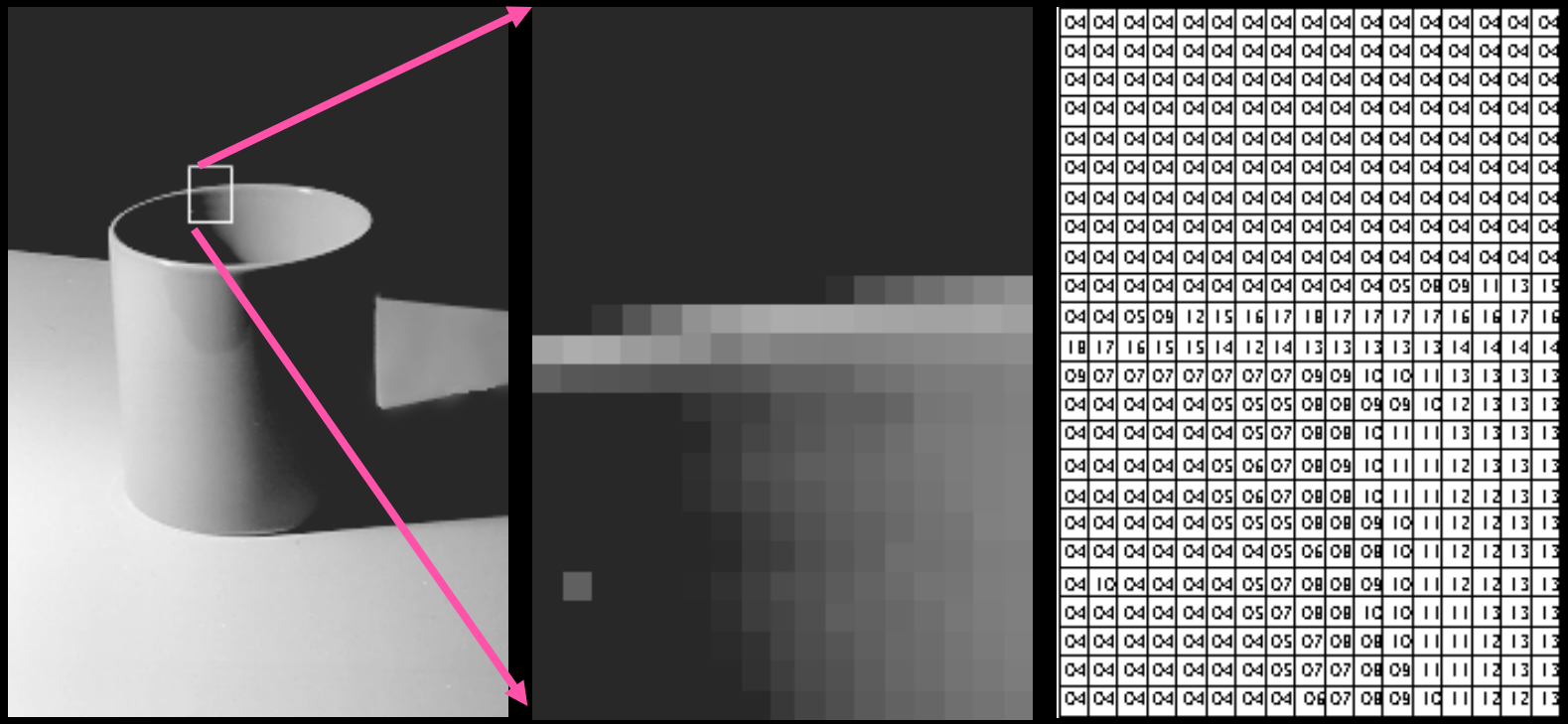
David Marr’s Theory

Four Stages of Visual Perception



Four Stages of Visual Perception

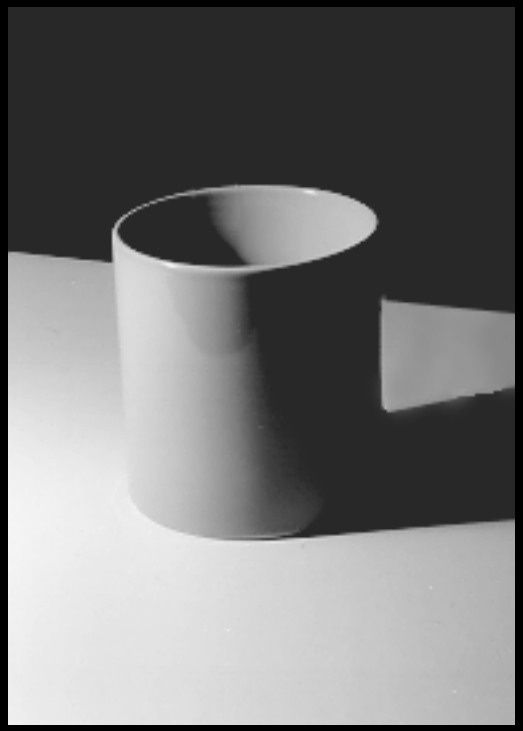
The Retinal Image



An Image (blowup) Receptor Output

Four Stages of Visual Perception

Retinal Image

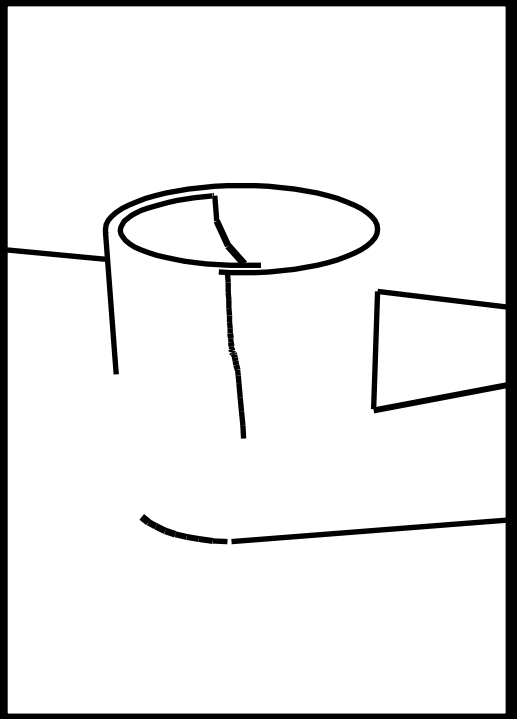


An Image

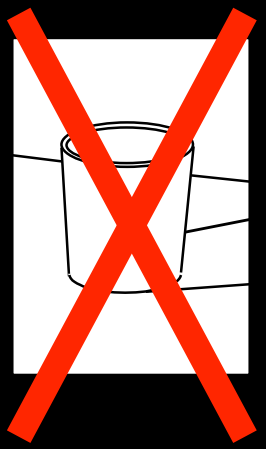
Image-based processes

Edges
Lines
Blobs
etc.

Image-based Representation



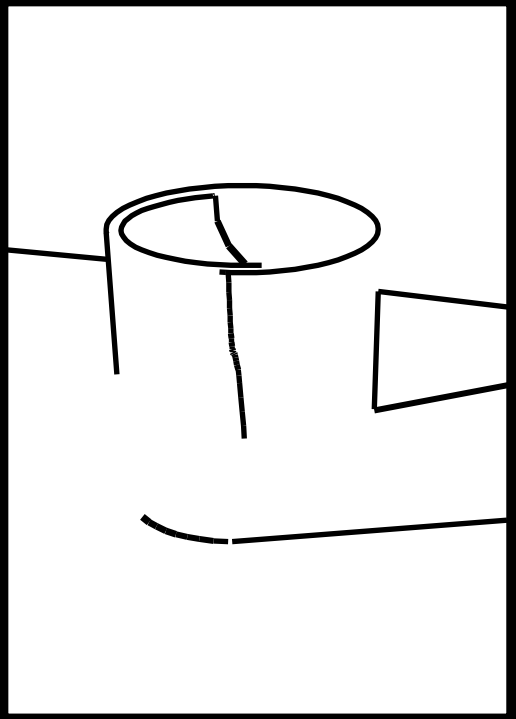
Primal Sketch (Marr)



(Line Drawing)

Four Stages of Visual Perception

Image-based Representation

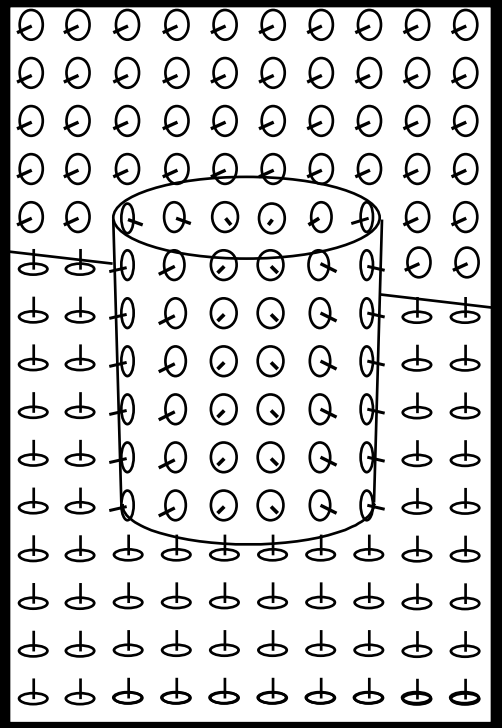


Primal Sketch

Surface-based processes

Stereo
Shading
Motion
etc.

Surface-based Representation



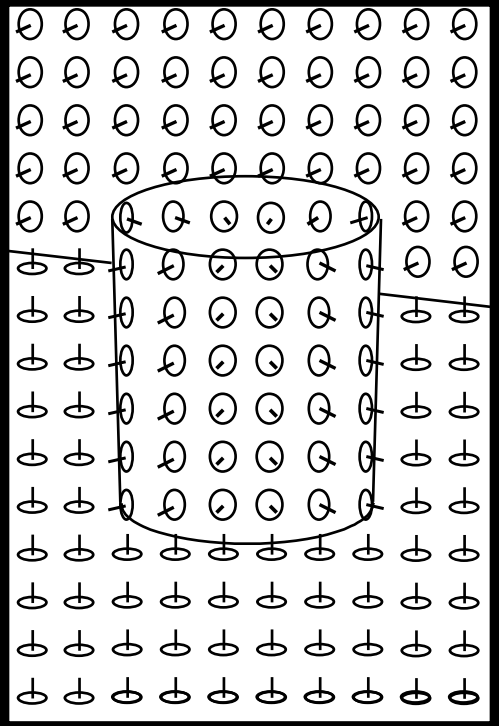
2.5-D Sketch

Surfaces etc.

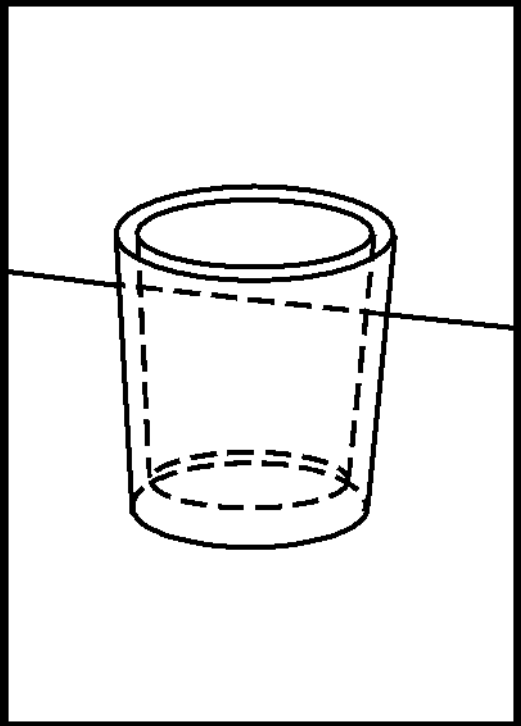
- Initially proposed by Gibson (1950).
- Departure from Object-based 3-D representations.
- But what is this 2.5D and how it is inferred (especially in 2D images).

Four Stages of Visual Perception

Surface-based Representation



Object-based Representation



Object-based processes

Grouping
Parsing
Completion
etc.

2.5-D Sketch

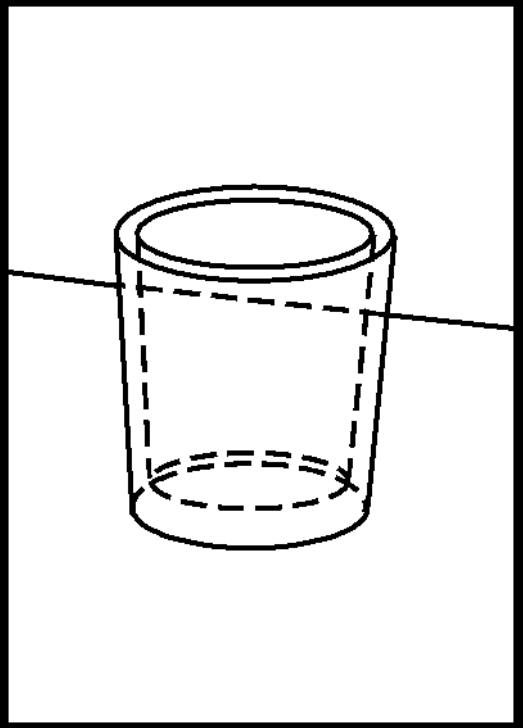
Volumetric Sketch

Object-based

- **Move from surfaces to volumes.**
- **Seeing the hidden layer.**
- **But how do you move from surface to volumes? Bottom-up or Top-down?**

Four Stages of Visual Perception

Object-based Representation



Volumetric Sketch

Category-based processes

Pattern-Recognition

Spatial-description

Category-based Representation

Category: cup

Color: light-gray

Size: 6”

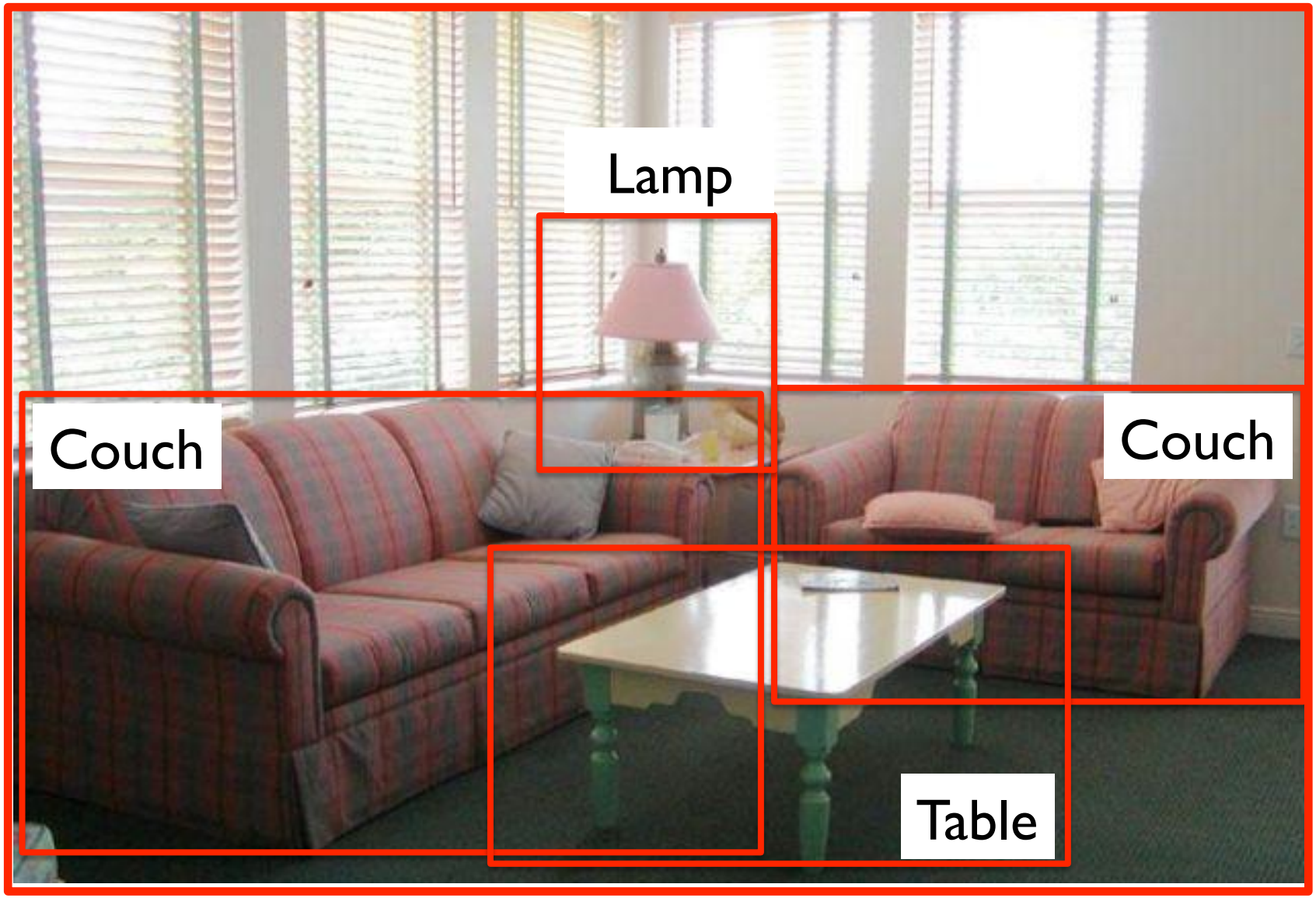
Location: table

Basic-level Category

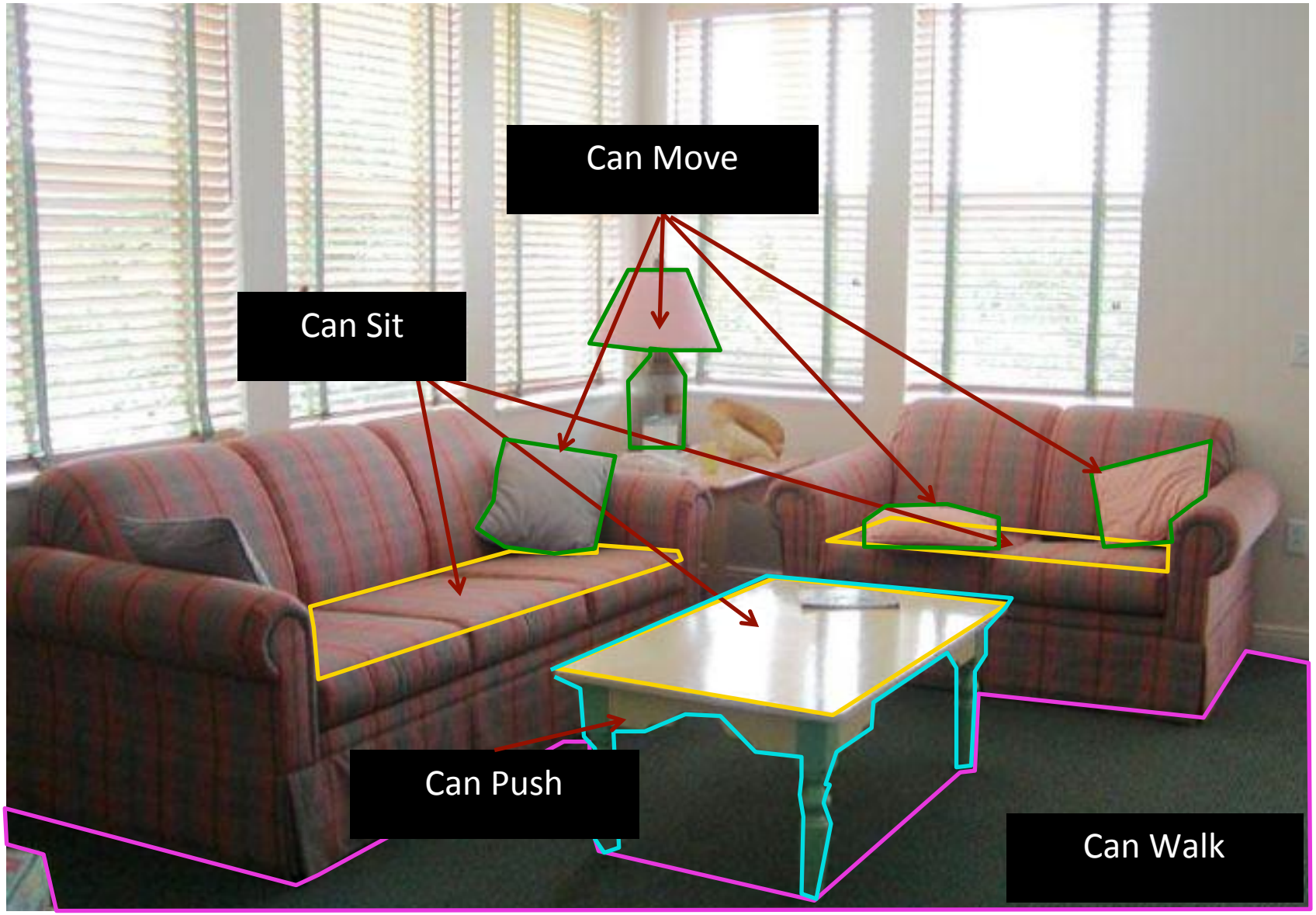
Category-based

- **Move from volumes to categories.**
- **Essentially this step relates to association of object with memory elements.**
- **But what are the right categories?**

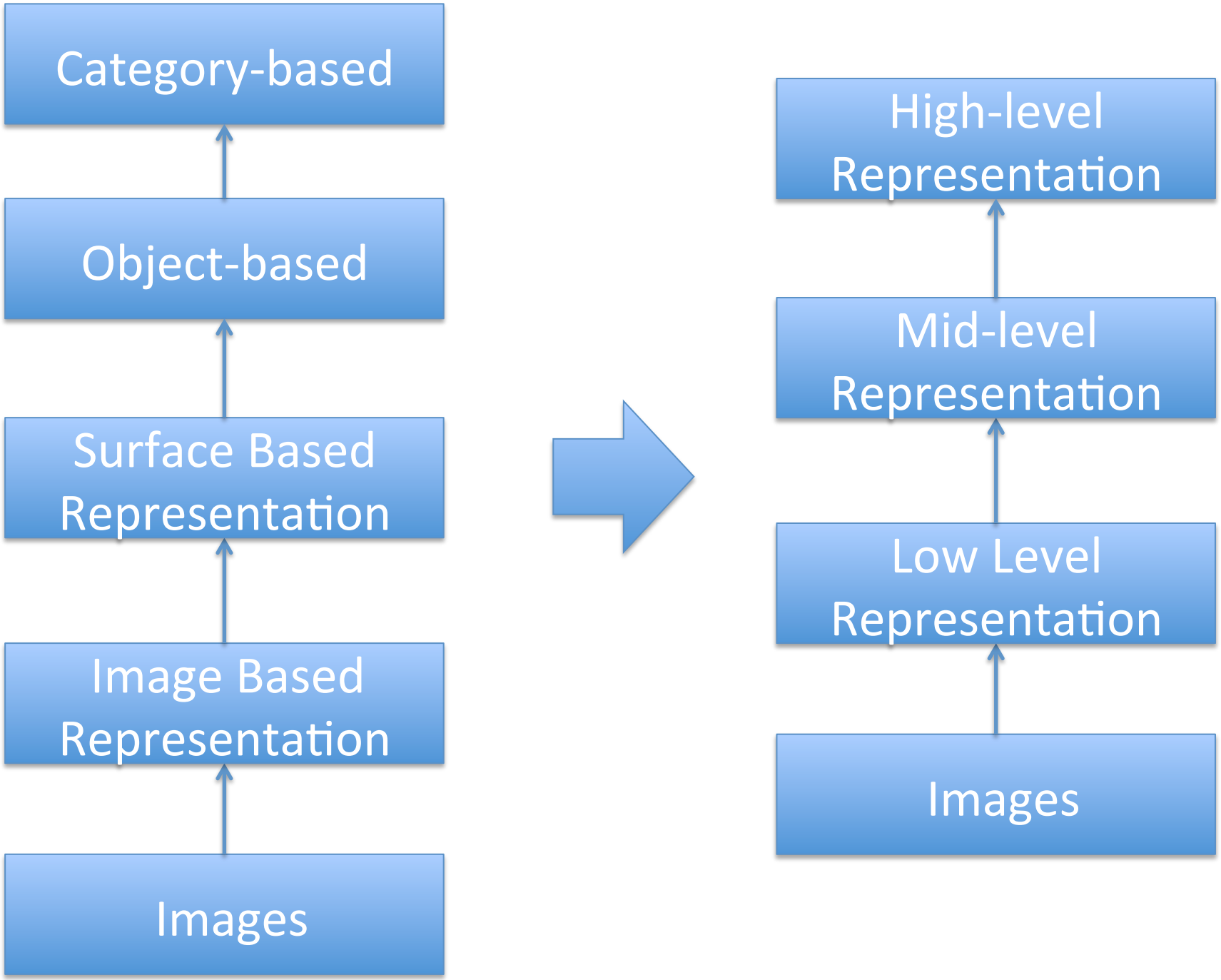
Semantic?



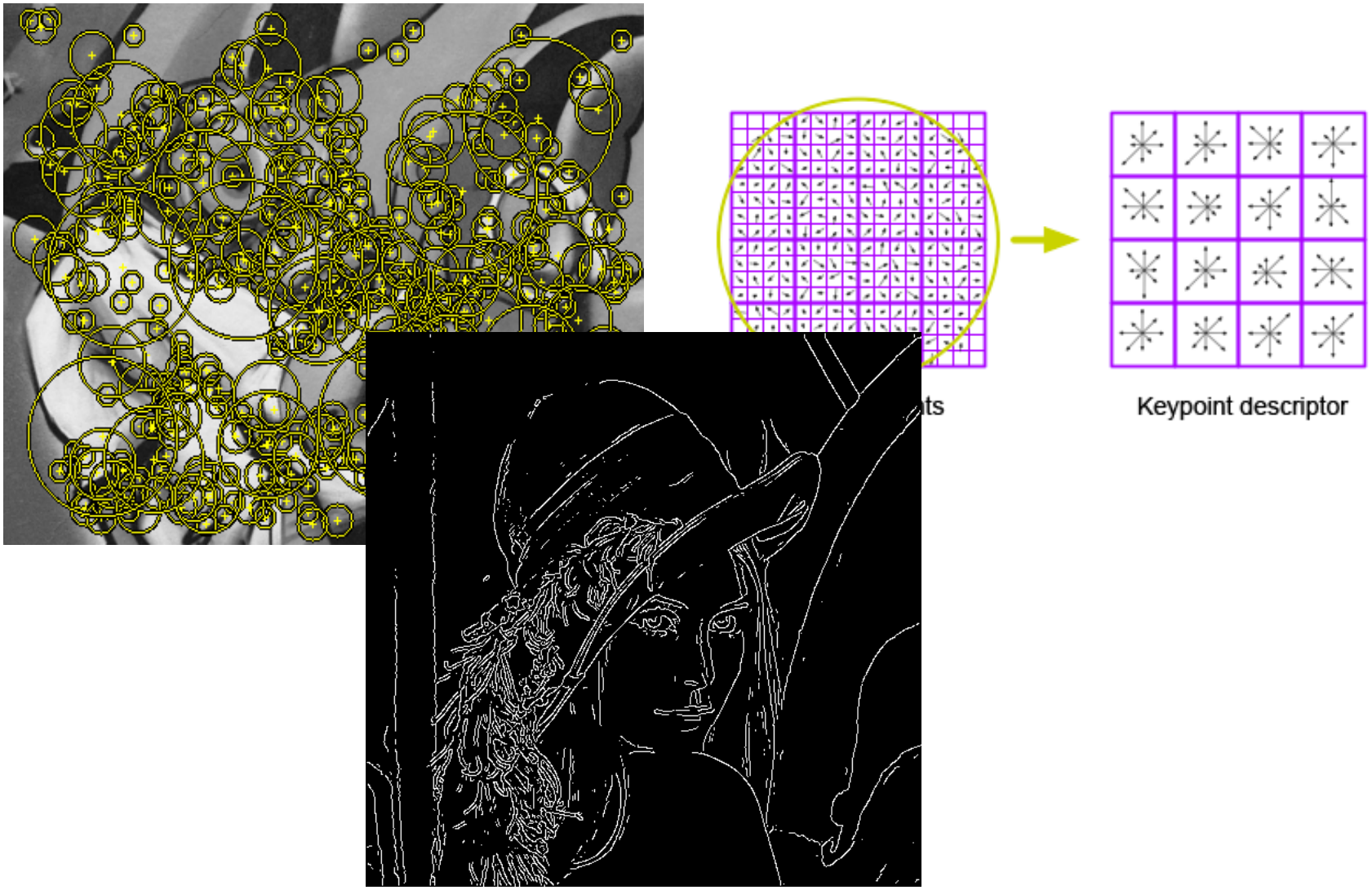
Functional?



Exemplars maybe?

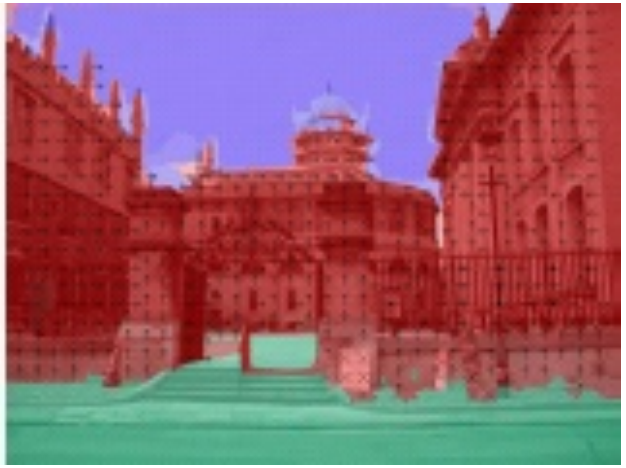

Category-based
Object-based
Surface Based Representation
Image Based Representation
Images
High-level Representation
Mid-level Representation
Low Level Representation
Images

Low-Level Representation

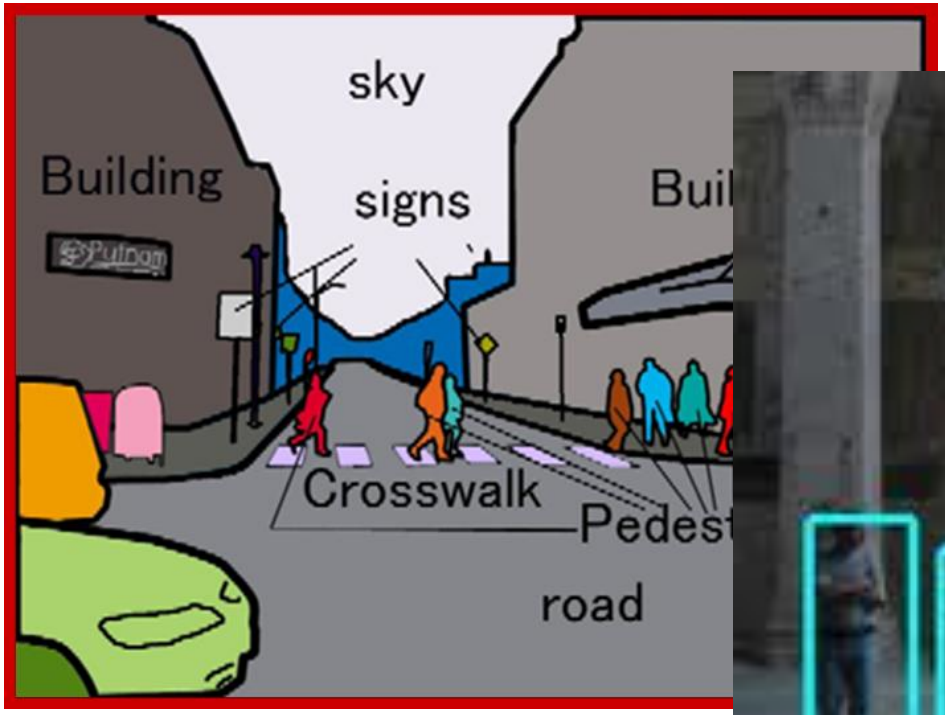


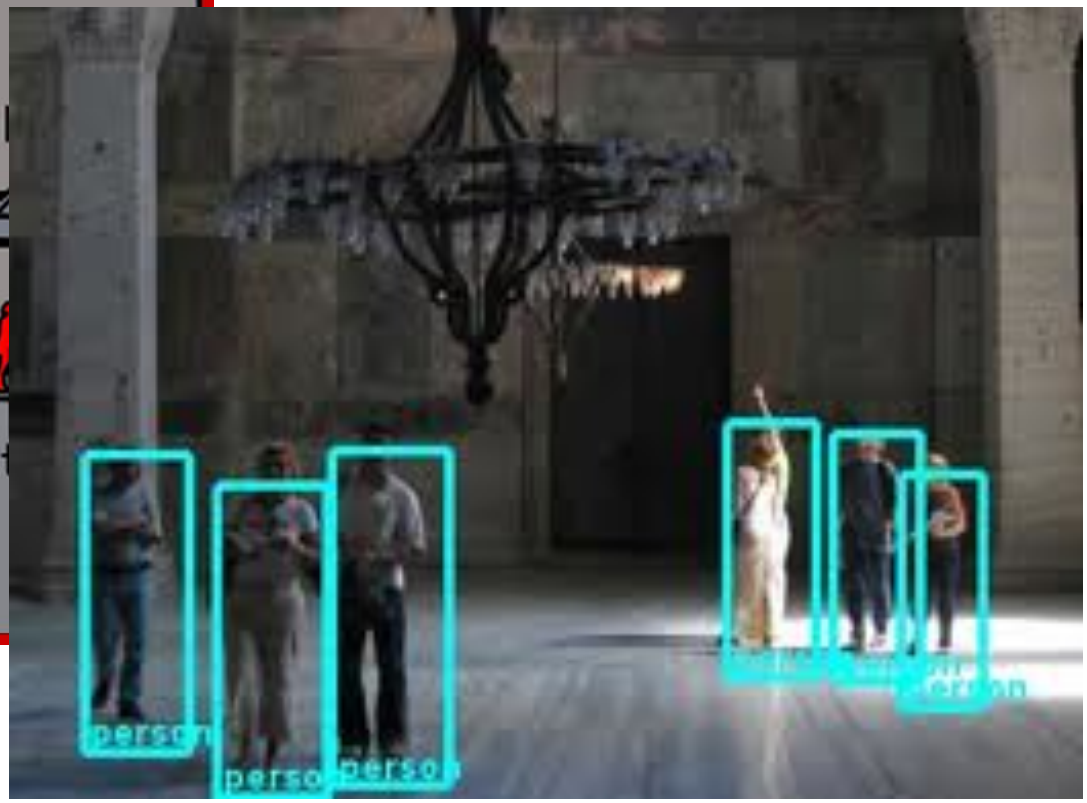
Mid-level Representations

- Grouping, 3D Properties



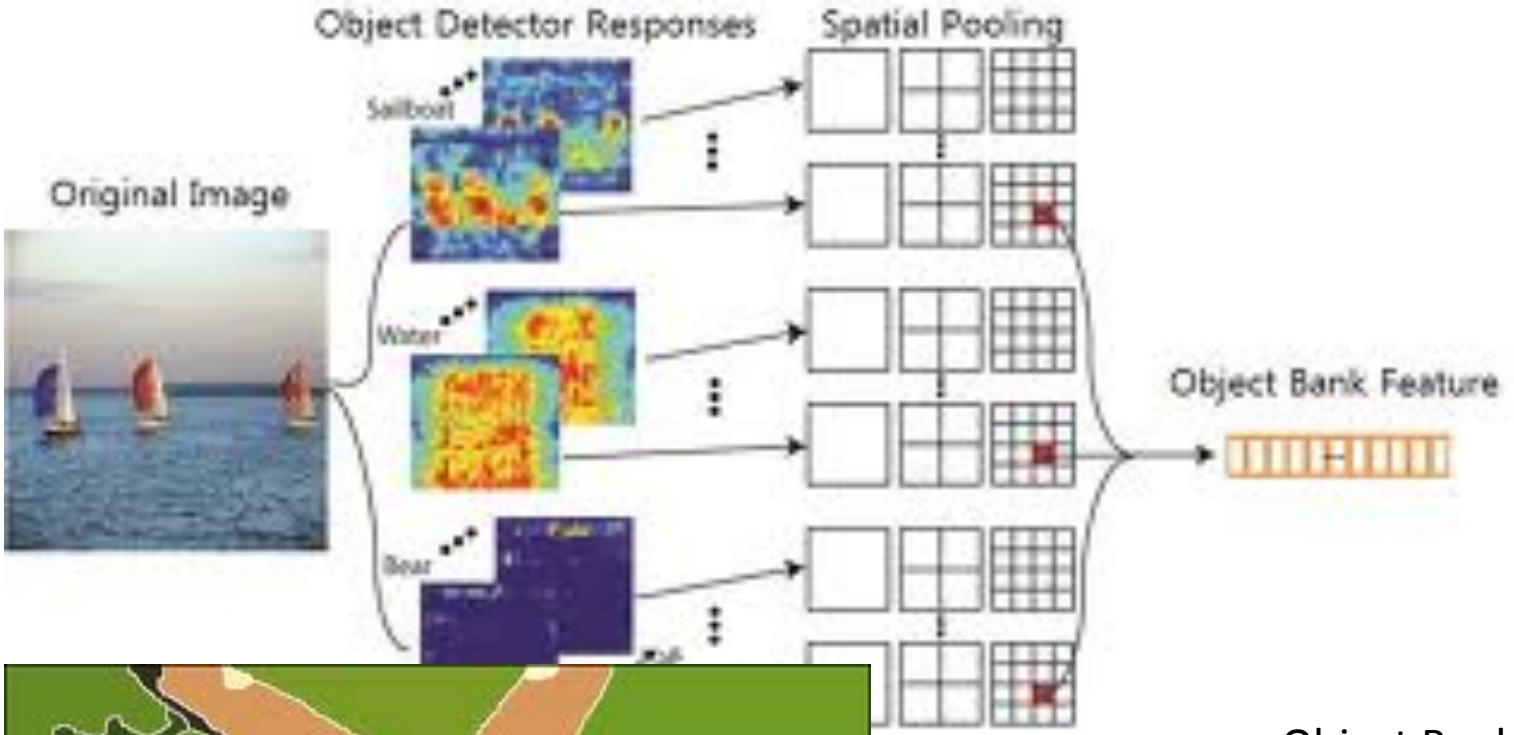
High-level Representation





- But what are the boundaries?

- How does the information flow?



Object Bank

gPb

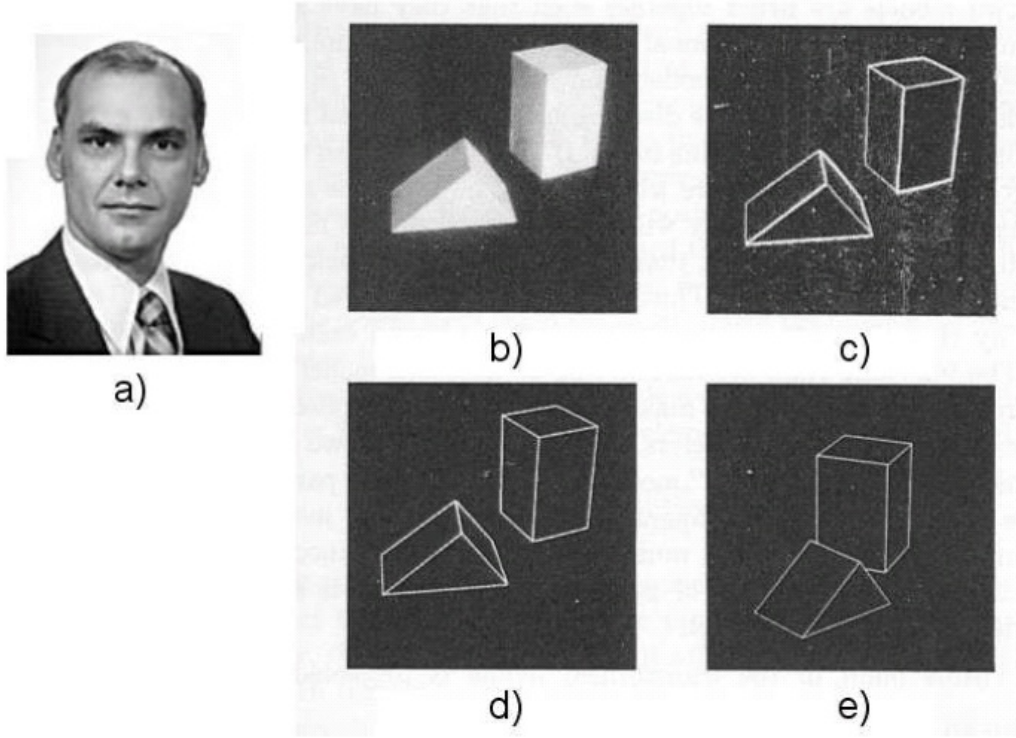
In Search of Objects: 50 years of wondering

Geometric Era

- Influenced by Ecological theory: Computer Vision started by geometric modeling the Visual World (Objects).

  - Invariance to Viewpoint (Geometric Modeling allowed prediction under perspective).
  - Invariance to Illumination (Matching was based on edges which were robust to illumination variations.
  - Man-made World: Most objects are designed by humans using CAD..therefore rightly modeled using geometric primitives
  - Well formed theories in geometry.

Blocks World at MIT



L. G. Roberts, *Machine Perception of Three Dimensional Solids*, Ph.D. thesis, MIT Department of Electrical Engineering, 1963.

Fig. 1. A system for recognizing 3-d polyhedral scenes. a) L.G. Roberts. b)A blocks world scene. c)Detected edges using a 2x2 gradient operator. d) A 3-d polyhedral description of the scene, formed automatically from the single image. e) The 3-d scene displayed with a viewpoint different from the original image to demonstrate its accuracy and completeness. (b) - e) are taken from [64] with permission MIT Press.)

J. Mundy, Object Recognition in the Geometric Era: a Retrospective, 2006

Why Blocks World?

start with a simplification of the world so that the mathematical models can apply rigorously

Line Labeling and Reasoning

- Essentially there was no learning because there was not enough data.
- Edges were labeled convex and concave and the way these edges combine are using rules.

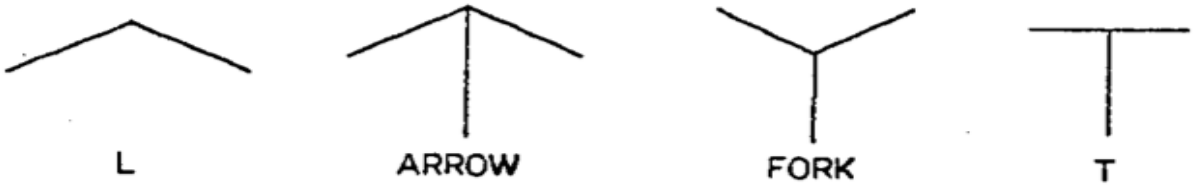
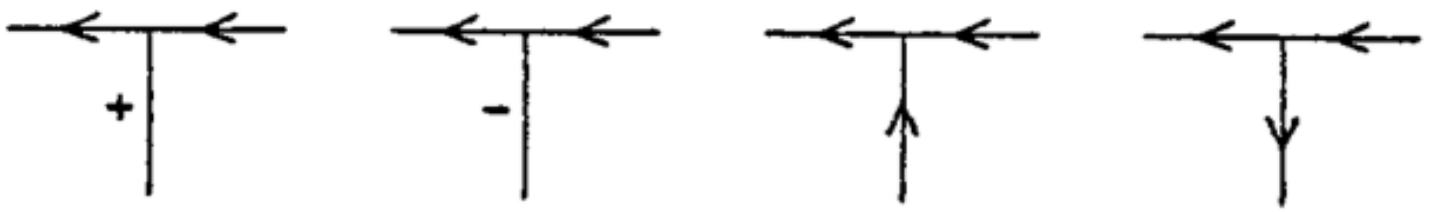
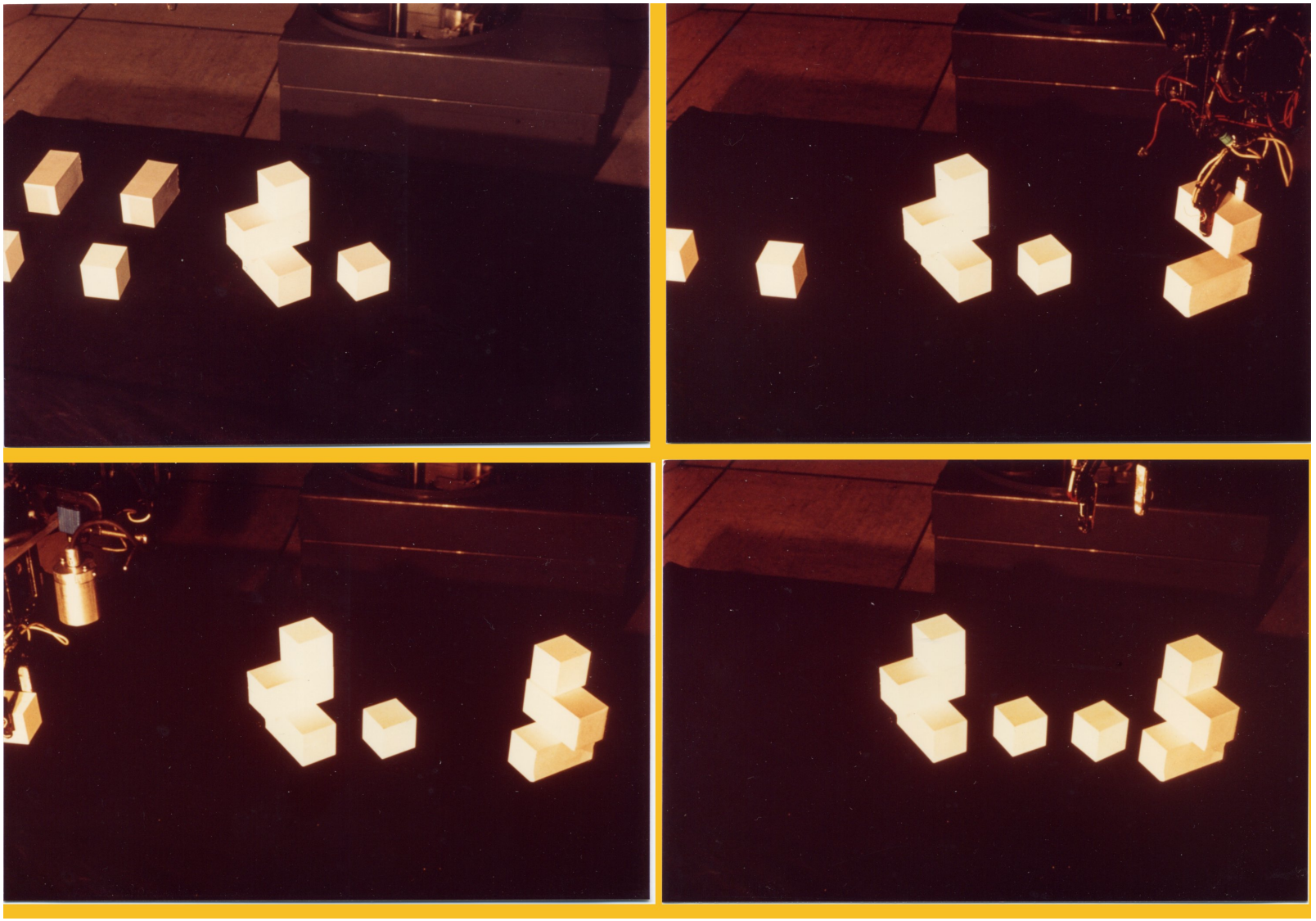


Figure 8 Junction types treated in this paper.



MIT Copy Demo



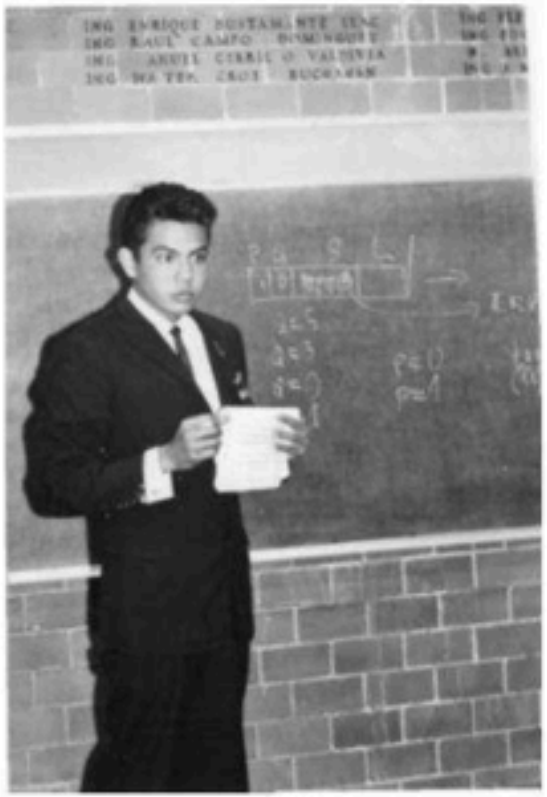
Why Blocks World?

Decade of Research but culminated soon…assumptions did not translate to real world

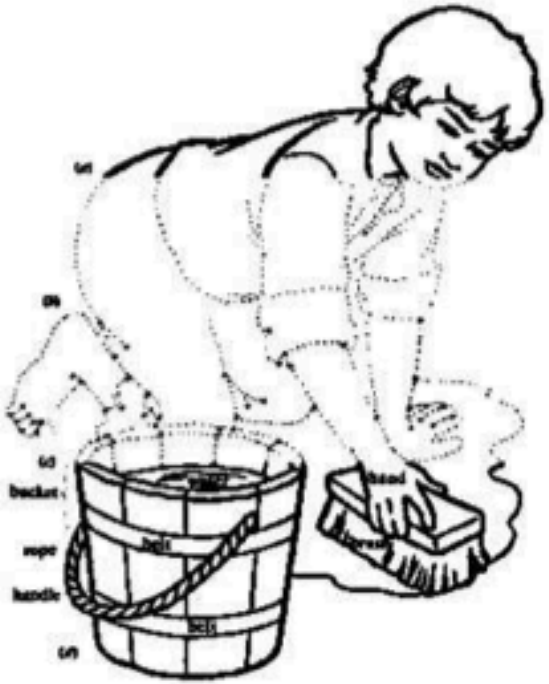
- Modeling Assumptions
  - Curved surfaces and boundaries;
  - articulated and moving objects;
- Edge Detection and Segmentation
  - complex background and 3-d texture such as foliage; – specular or mutually illuminating surfaces;
  - multiple light sources and remote shadowing; – transparent or translucent surfaces.
- Occlusion by unknown shapes;

Modeling Generalizations

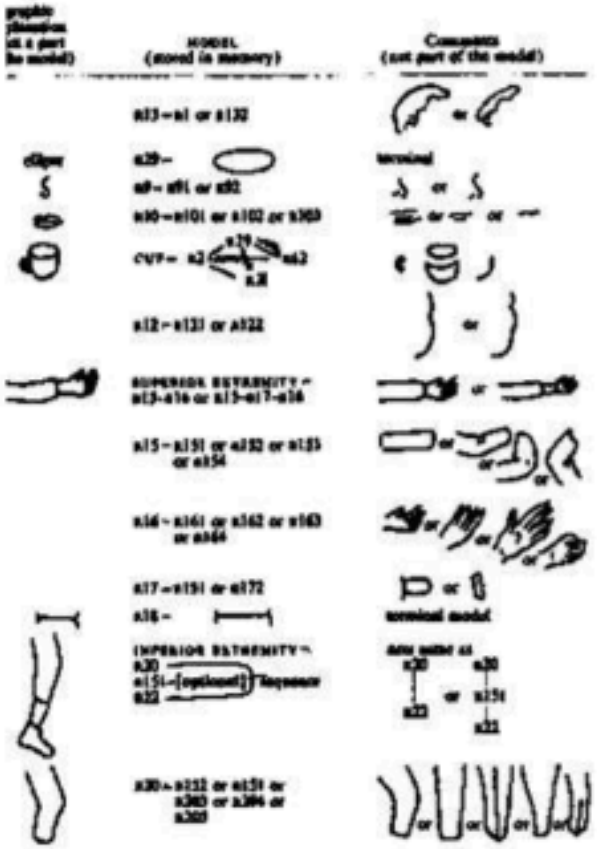
From Blocks World



a)

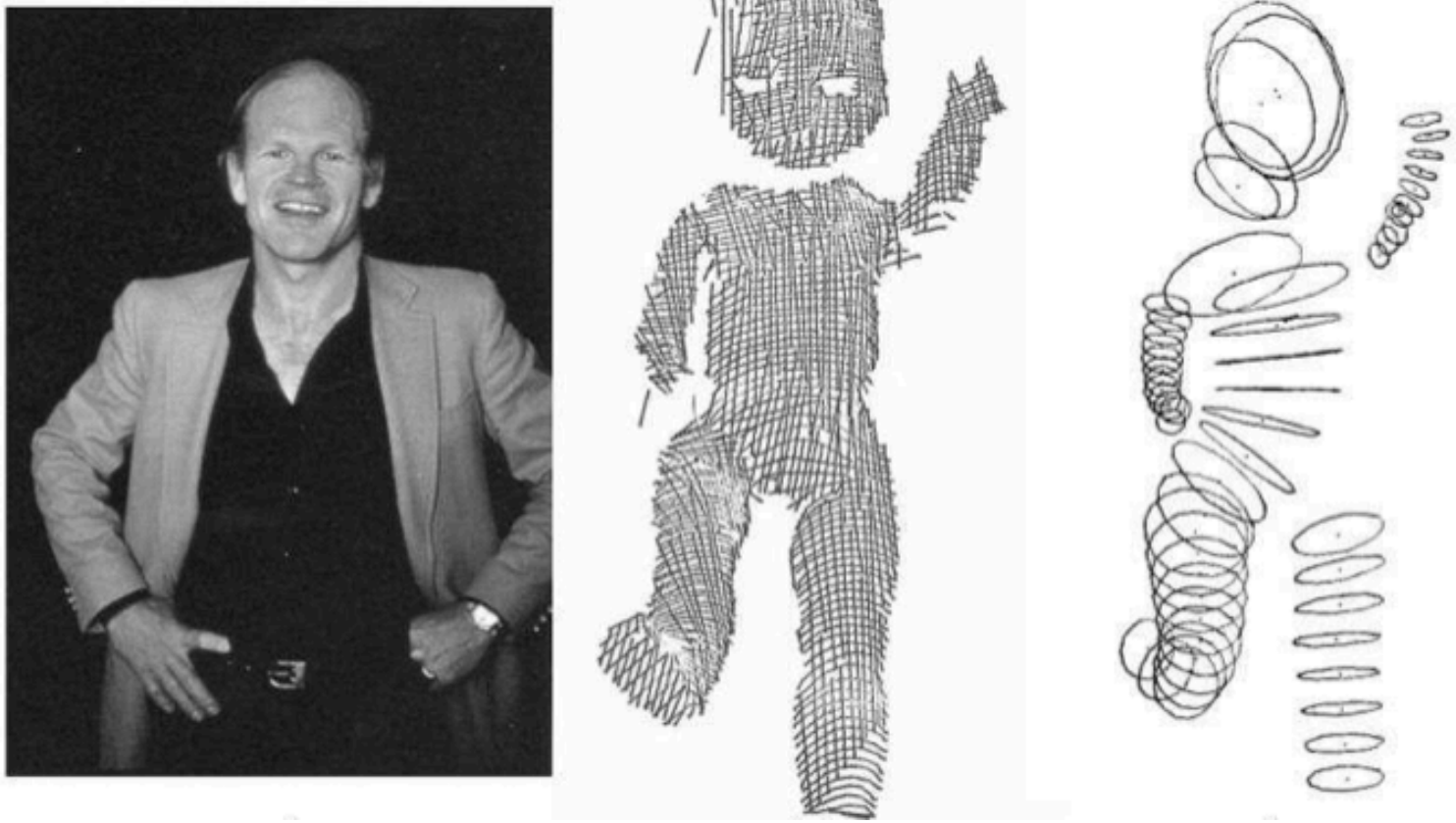


b)



c)

Generalized Cylinders

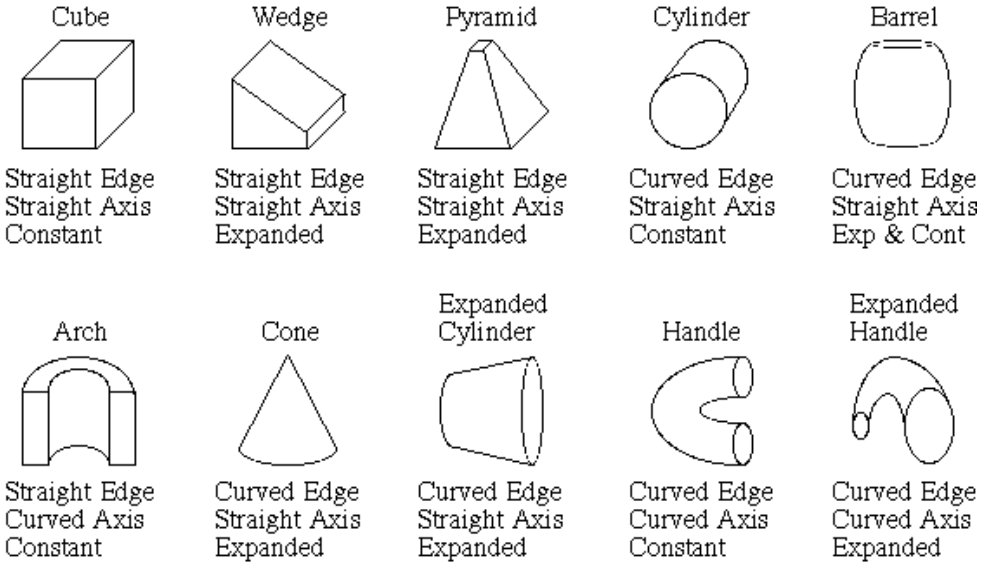


curved shapes can be expressed as a sweep of a variable cross section along a curved axis.

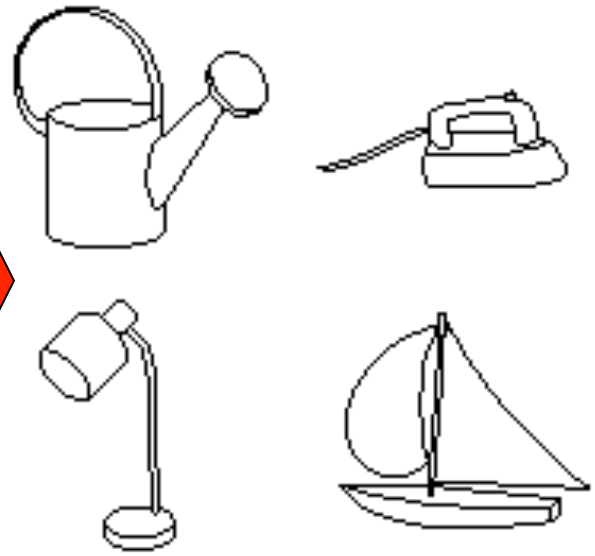
Recognition by components - Geons

Biederman (1987)

Primitives (geons)



Objects



http://en.wikipedia.org/wiki/Recognition_by_Components_Theory

View-Centered

Aspect Graph

- Until 1970-80's, research focused on object-centered representation.
- No focus on modeling image intensity variations (model every-thing from edges)
- Alternative to 3D representation of objects
- How would appearance change under different viewpoint?

Aspect Graph

- Network of object appearances under different viewpoint.
- The nodes of the graph represent object views that are adjacent to each other on the unit sphere of viewing directions but differ in some significant way.
- the aspect graph arise from transitions in the graph structure relating vertices, edges and faces of the projected object.
- pre-compiling 2-d views into an efficient recognition plan.
- Did not carry forward due to high complexity!!

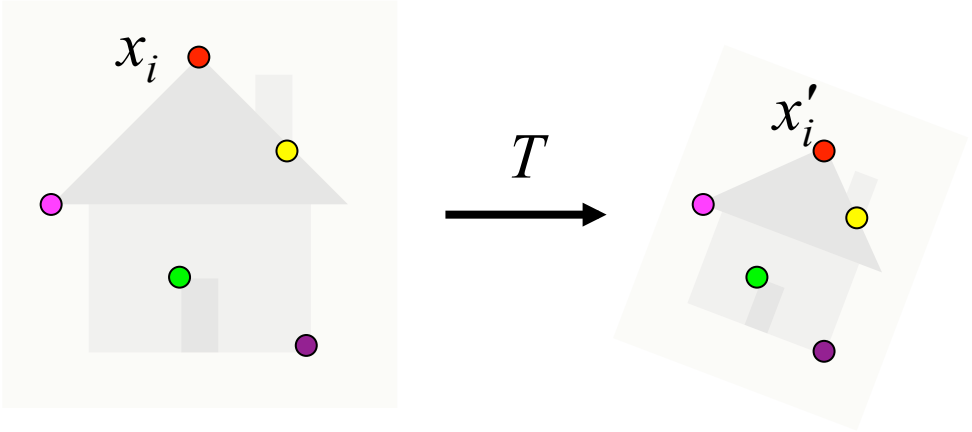
Perceptual Grouping

- Previous Geometric Approaches assumed grouping problem as solved
  - Objects in Isolation
  - No background clutter
  - Contours easy to estimate

Alignment

Alignment

- Alignment: fitting a model to a transformation between pairs of features (*matches*) in two images

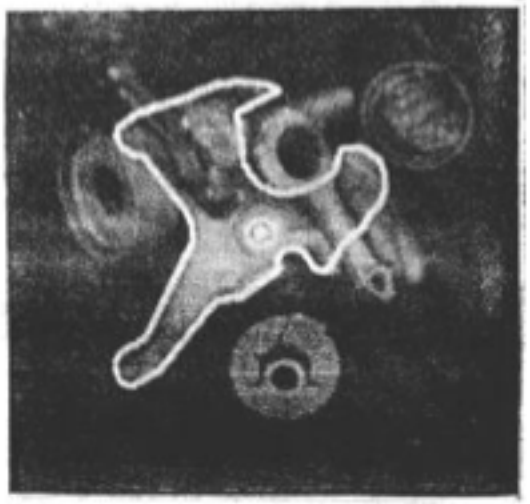


Find transformation T that minimizes

$$\sum_i \text{residual}(T(x_i), x_i')$$

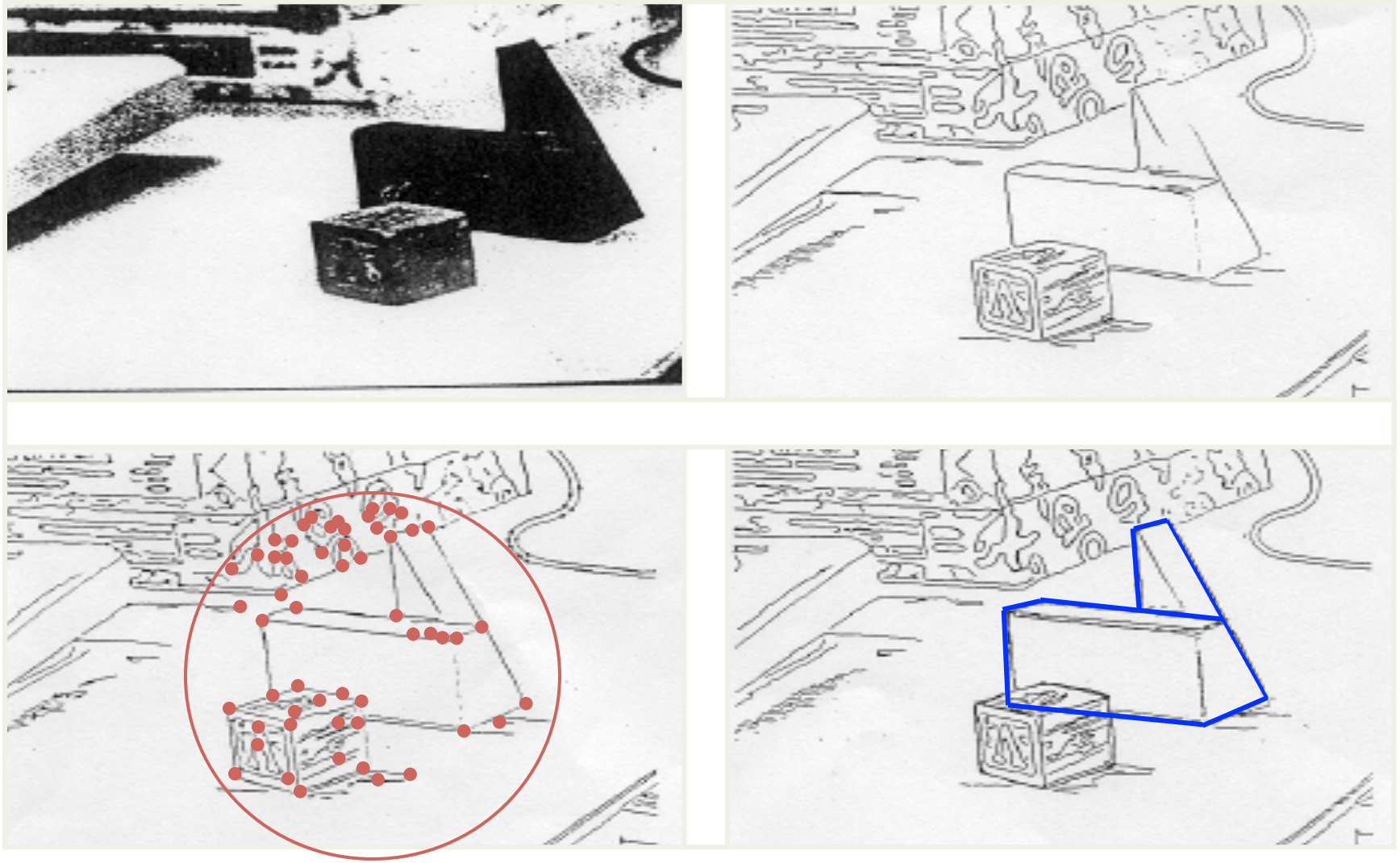
a)

b)



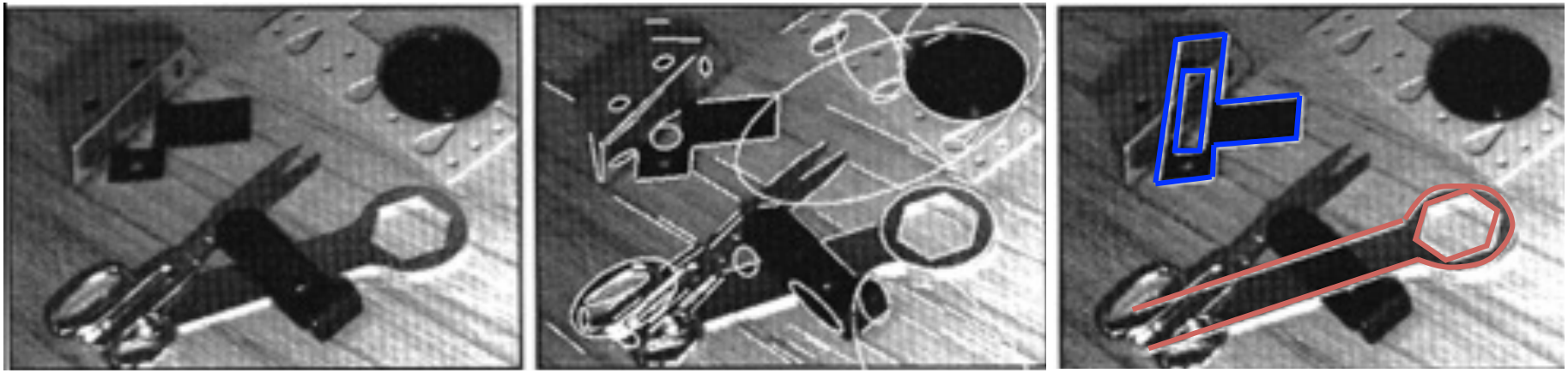
c)

Alignment: Huttenlocher & Ullman (1987)



Geometric Invariants such as cross-ratios and ratio of area ratios.

Projective invariants (Rothwell et al., 1992):

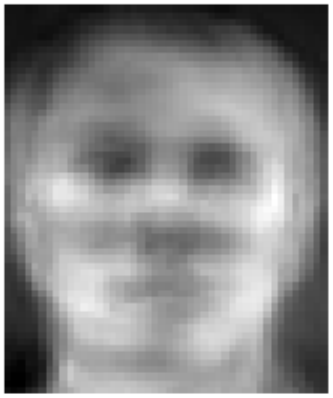


General 3D objects do not admit monocular viewpoint invariants (Burns et al., 1993)

History of ideas in recognition

- 1960s – early 1990s: the geometric era
- 1990s: appearance-based models

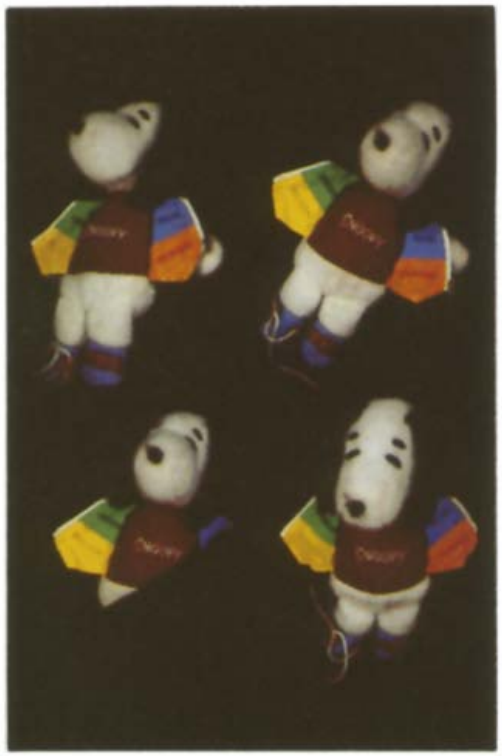
Eigenfaces (Turk & Pentland, 1991)

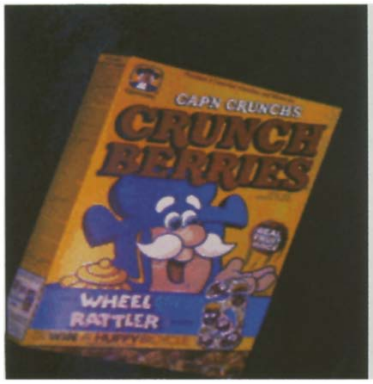


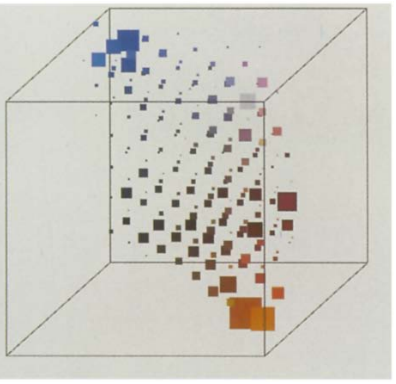
Experimental	Correct/Unknown Recognition Percentage		
Condition	Lighting	Orientation	Scale
Forced classification	96/0	85/0	64/0
Forced 100% accuracy	100/19	100/39	100/60
Forced 20% unknown rate	100/20	94/20	74/20

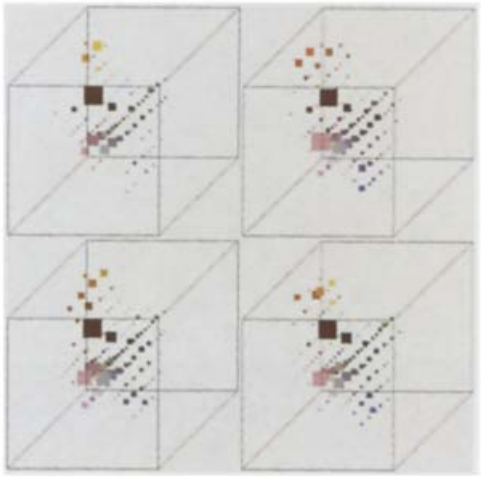
Svetlana Lazebnik

Color Histograms









Swain and Ballard, Color Indexing, IJCV 1991.

Limitations of global appearance models

- Requires global registration of patterns
- Not robust to clutter, occlusion, geometric transformations

Svetlana Lazebnik

Modeling Local Appearances

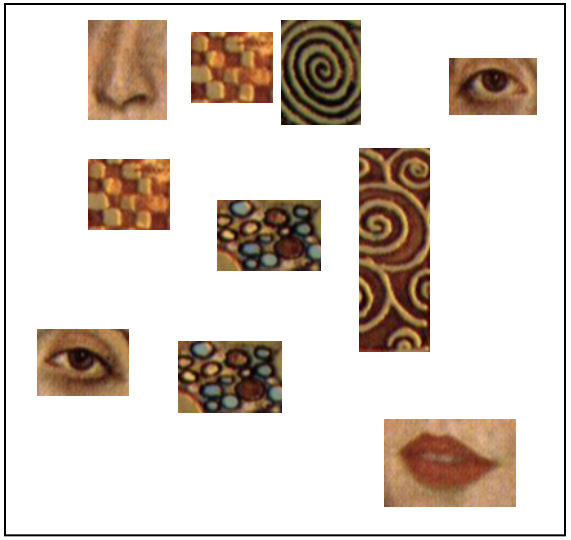
Bag-of-words models

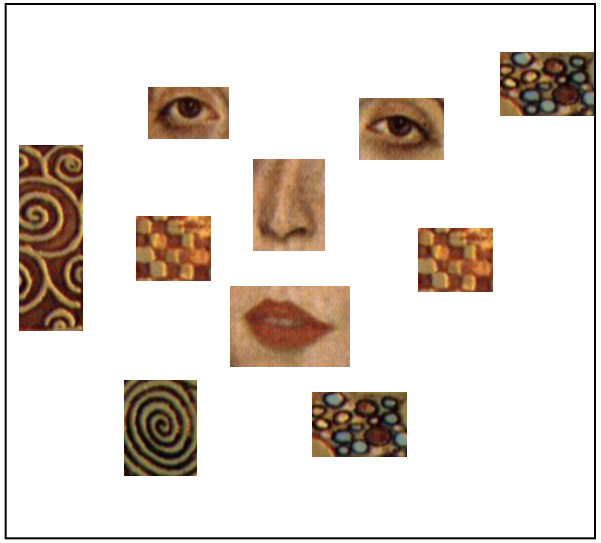
Object → **Bag of ‘words’**

Svetlana Lazebnik

Objects as texture

- All of these are treated as being the same





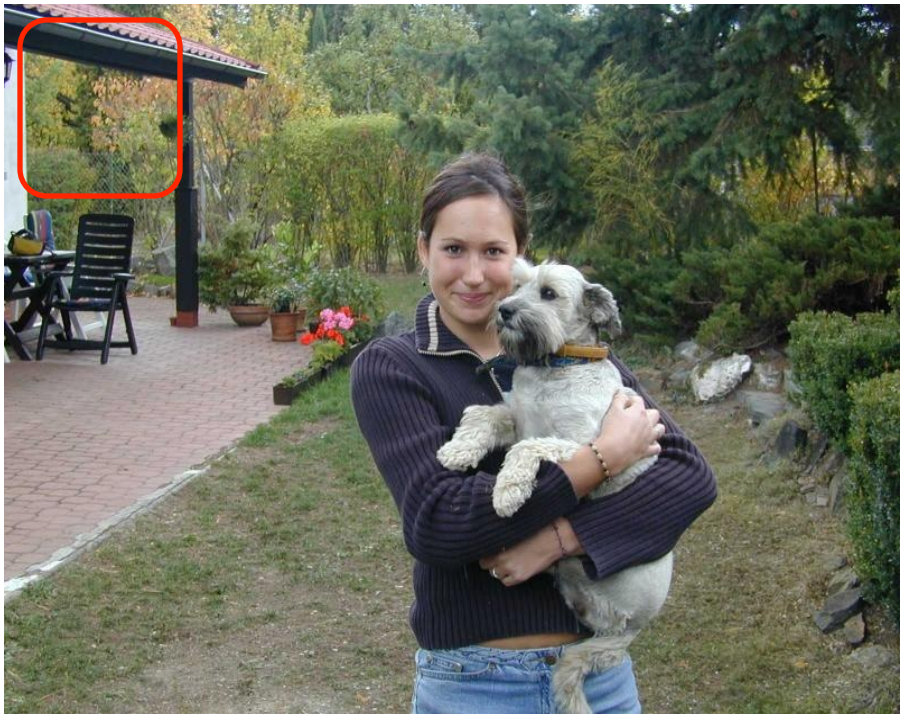
- No distinction between foreground and background: scene recognition?

Sliding-Window Paradigm

History of ideas in recognition

- 1960s – early 1990s: the geometric era
- 1990s: appearance-based models
- 1990s – present: sliding window approaches

Sliding window approaches



Sliding window approaches

- Turk and Pentland, 1991
- Belhumeur, Hespanha, & Kriegman, 1997
- Schneiderman & Kanade 2004
- Viola and Jones, 2000

- Schneiderman & Kanade, 2004
- Argawal and Roth, 2002
- Poggio et al. 1993

History of ideas in recognition

- 1960s – early 1990s: the geometric era
- 1990s: appearance-based models
- Mid-1990s: sliding window approaches
- Early 2000s: parts-and-shape models

Parts-and-shape models

- Model:
  - Object as a set of parts
  - Relative locations between parts
  - Appearance of part

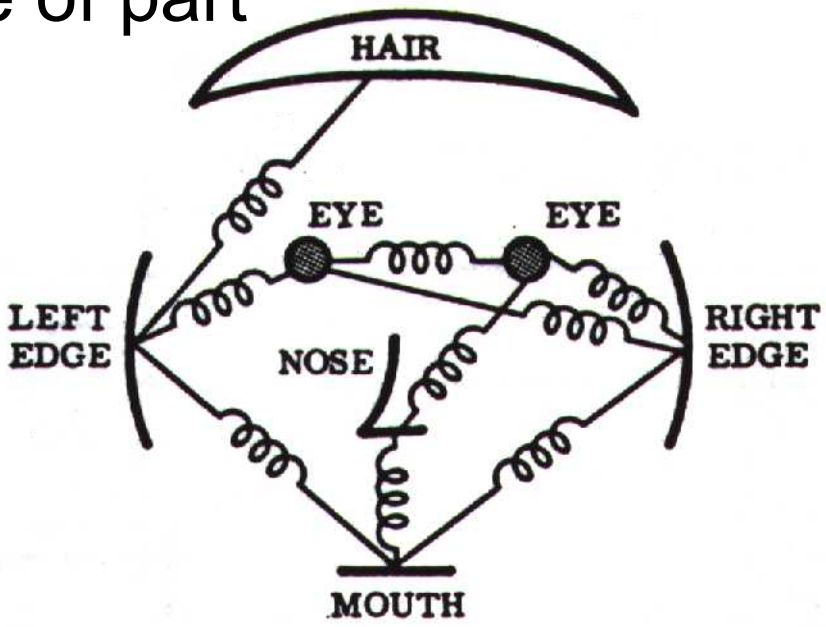
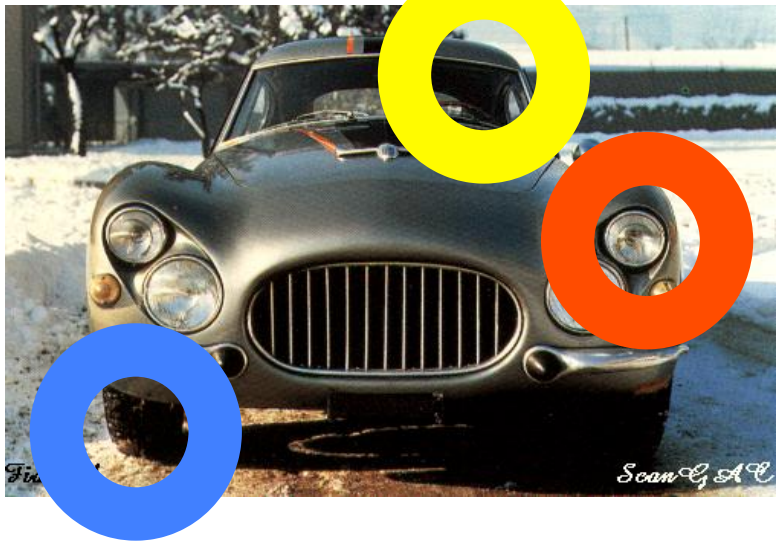
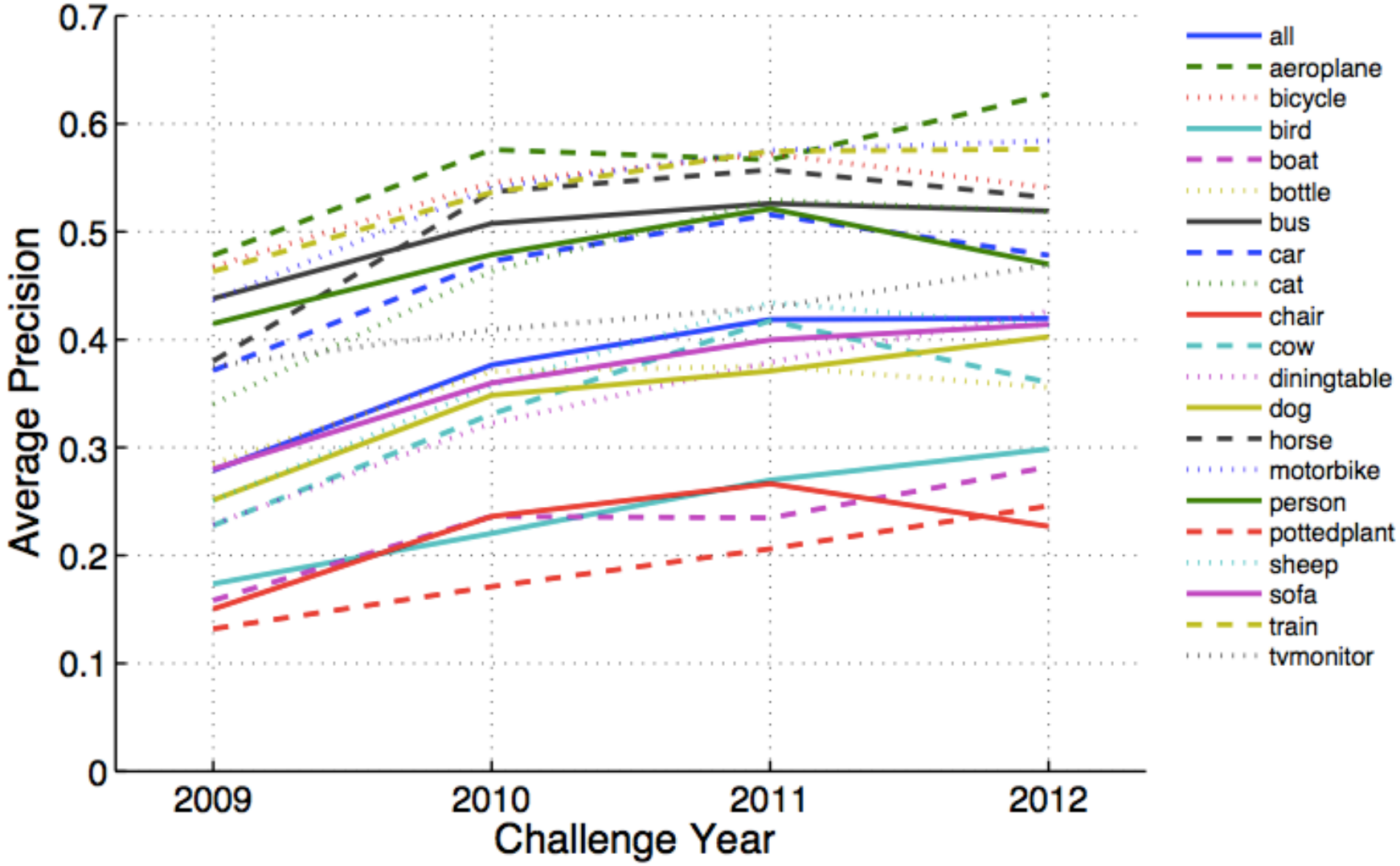


Figure from [Fischler & Elschlager 73]

Constellation models



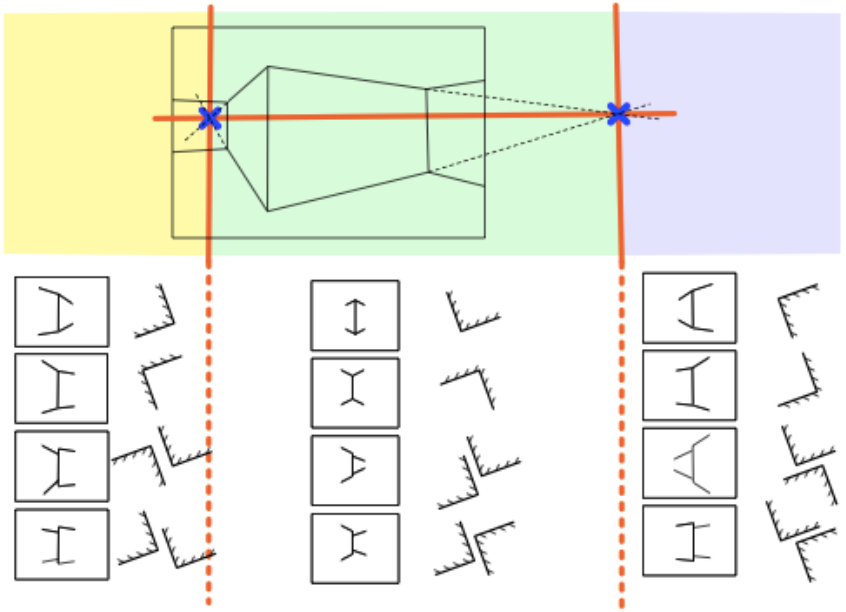
Weber, Welling & Perona (2000), Fergus, Perona & Zisserman (2003)



VOC Benchmark Dataset

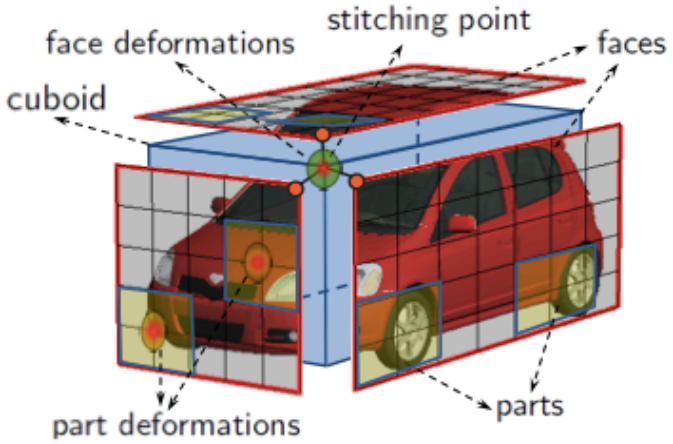
History of ideas in recognition

- 1960s – early 1990s: the geometric era
- 1990s: appearance-based models
- 1990s-Present: sliding window approaches
- Early 2000s-Present: parts-and-shape models
- Return of Geometric Models – with the Power of Data!

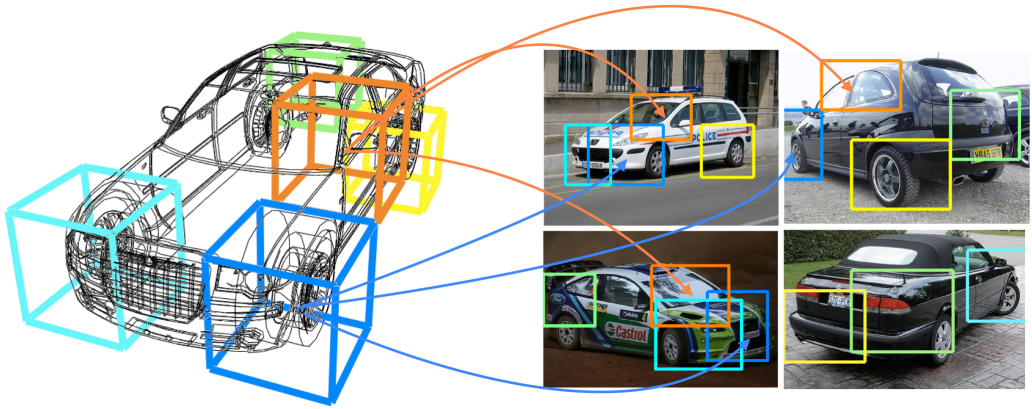


Geometric Layout (CVPR'09)

ECCV 2010



NIPS 2012



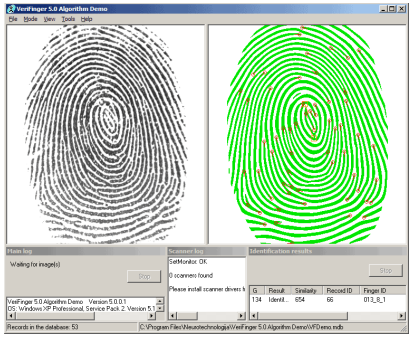
CVPR 2012

What “works” today

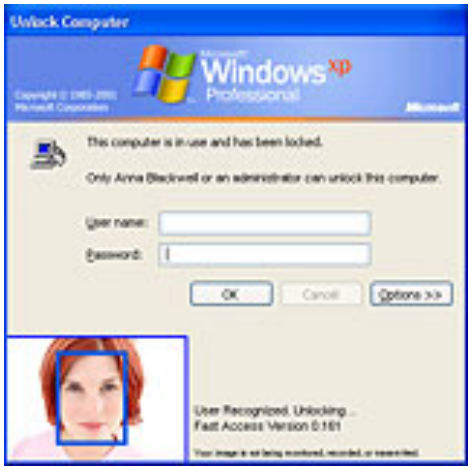
- Reading license plates, zip codes, checks

Svetlana Lazebnik

Biometrics



Fingerprint scanners on many new laptops, other devices



Face recognition systems now beginning to appear more widely
http://www.sensiblevision.com/

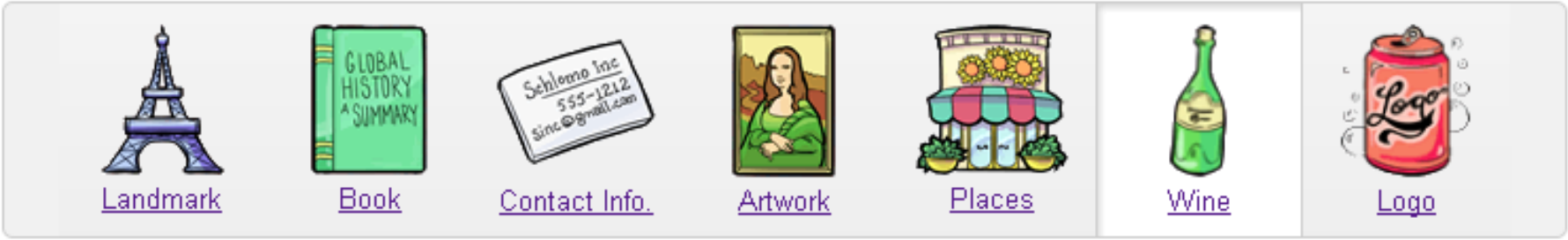
Source: S. Seitz

Mobile visual search: Google Goggles

Google Goggles in Action

Click the icons below to see the different ways Google Goggles can be used.

Google goggles labs

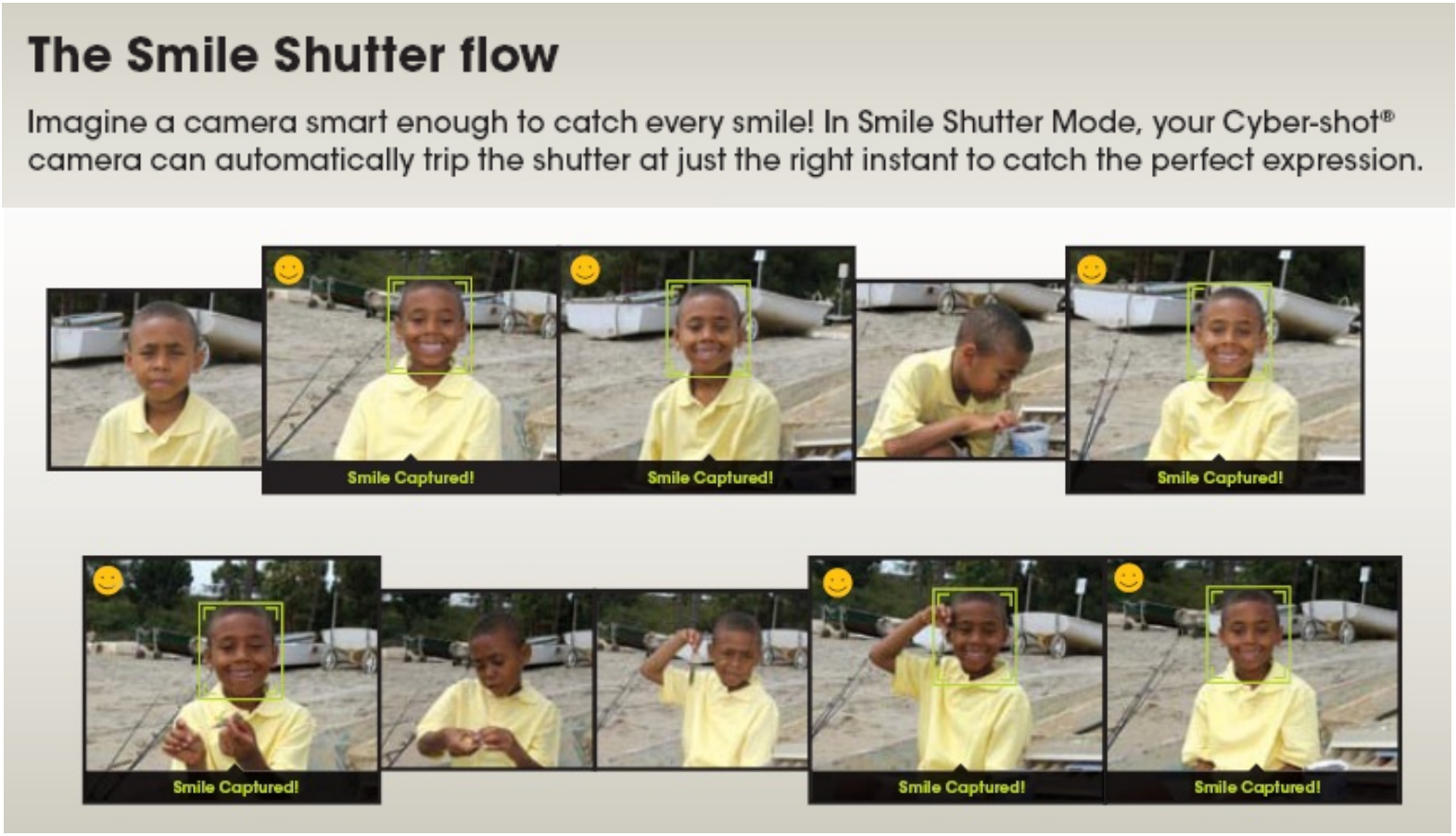


Face detection

- Many new digital cameras now detect faces
  - Canon, Sony, Fuji, …

Source: S. Seitz

Smile detection



Sony Cyber-shot® T70 Digital Still Camera

Source: S. Seitz

Face recognition: Apple iPhoto, Facebook, Google, etc

Object recognition (in supermarkets)

LaneHawk by EvolutionRobotics

“A smart camera is flush-mounted in the checkout lane, continuously watching for items. When an item is detected and recognized, the cashier verifies the quantity of items that were found under the basket, and continues to close the transaction. The item can remain under the basket, and with LaneHawk,you are assured to get paid for it… “

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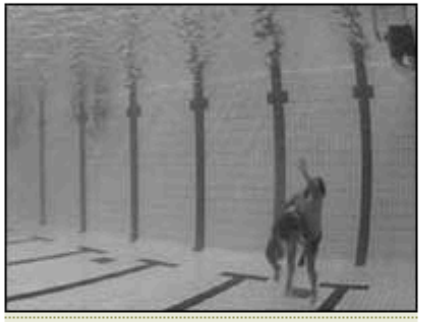
Computer alert for drowning girl

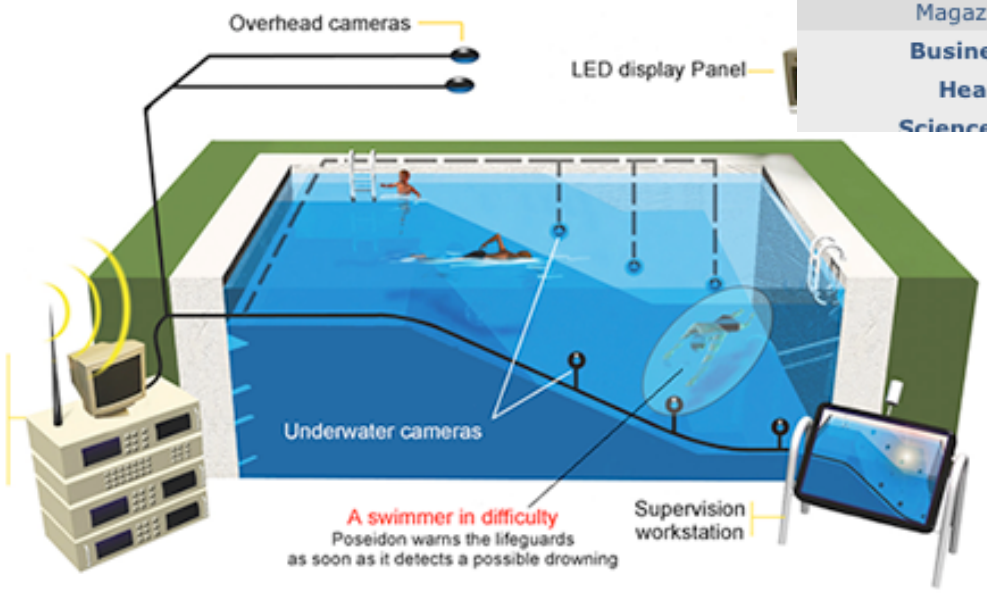
A 10-year-old girl has been saved from drowning by a computer system designed to raise the alarm when swimmers get into difficulties.



VIDEO Watch the rescue

The girl, from Rochdale, was at the deep end of the pool in Bangor, north Wales, when she sank to the bottom.

The £65,000 system, called Poseidon, detected her on the pool floor and sounded the alarm. A lifeguard pulled her out and she recovered in hospital.



Security

Local

Cameras help confirm Scott suicide ruling

Friday, December 04, 2009

TAGS: local, paul meincke

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Paul Meincke
More: Bio, News Team

December 4, 2009 (CHICAGO) (WLS) -- Chicago police have closed the case in the death of Chicago School Board President Michael Scott.

Police Supt. Jody Weis says investigators used police cameras in the city to trace Scott's last steps in the hours before his body was found in November.

Scott's death has been ruled a suicide. The medical examiner's office concluded --not long after Scott's body was found -- that he had committed suicide. Police did not dispute the finding but wanted to pursue all the investigative leads they could. They say they have done that and have now reached the same conclusion.

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Automotive safety

- Mobileye: Vision systems in high-end BMW, GM, Volvo models
  - Pedestrian collision warning
  - Forward collision warning
  - Lane departure warning
  - Headway monitoring and warning

Source: A. Shashua, S. Seitz

Google cars

Oct 9, 2010. "Google Cars Drive Themselves, in Traffic". *The New York Times*. John Markoff
June 24, 2011. "Nevada state law paves the way for driverless cars". *Financial Post*. Christine Dobby
Aug 9, 2011,
"Human error blamed after Google's driverless car sparks five-vehicle crash". *The Star* (Toronto)

Vision-based interaction: Xbox Kinect