

Representing Shape and Structure



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Introduction



- Of all the properties we perceive about objects, shape is probably the most important.
 - Shape allows a perceiver to predict more facts about an object than any other property.
 - However, it is also the most complex.
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Shape Equivalence

- Defining Objective Shape
 - Invariant Features
 - Transformational Alignment
 - Object-Centered Reference Frames
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Shape Equivalence



- The problem of shape equivalence involves understanding the conditions under which people perceive two distinct objects as having the same shape.

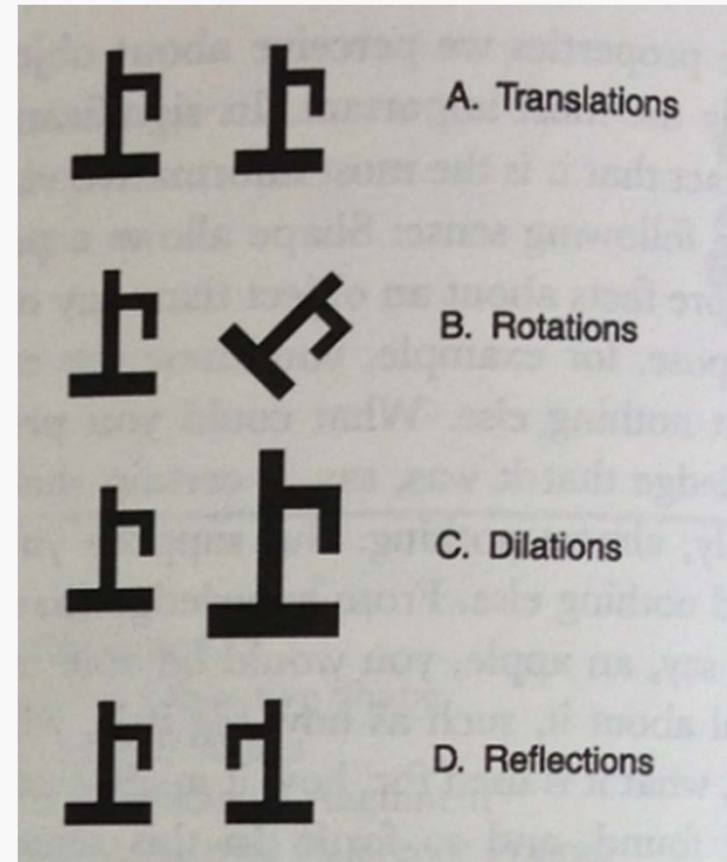
Shape Equivalence



- **Defining Objective Shape:**
- **The spatial structure of an object that does not change when the following spatial transformations are applied to it:**
- **Translations, rotations, dilations, reflections, any combination of these**

Shape Equivalence

- Pairs of figures that are related by these four types of transformation, or any combination of them, have the same objective shape.



Shape Equivalence



- Information and operations in determining that two object have the same shape:
 - **Invariant features hypothesis**
 - **Transformational alignment hypothesis**
 - **Object-centered reference frames hypothesis**

Invariant Features



- Those that do not change as a result of the transformation called **invariant features** and those that do called **variant features**.

Invariant Features

- This table shows which features vary and which are invariant with respect to transformations in the similarity group.

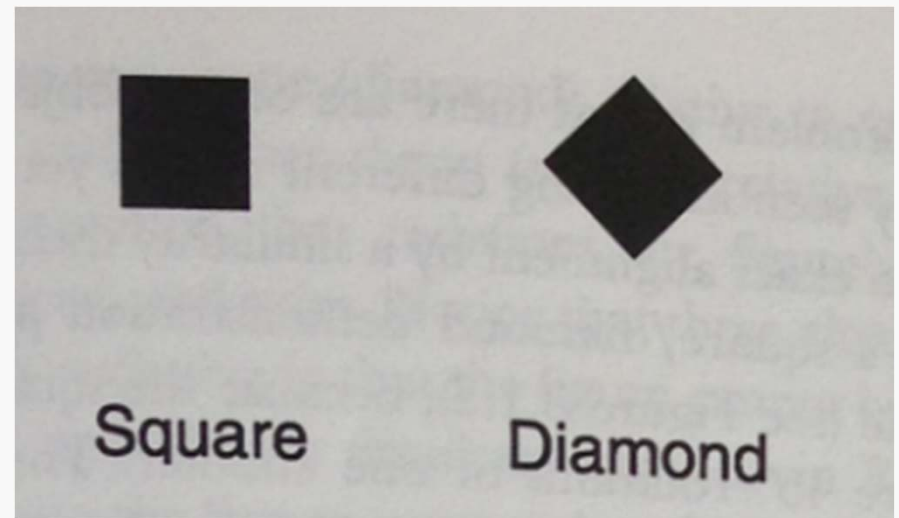
	Absolute Position	Relative Position	Absolute Orientation	Relative Orientation	Absolute Size	Relative Size	Number	Closedness	Connectedness
TRANSLATIONS	-	+	+	+	+	+	+	+	+
ROTATIONS	-	-	-	+	+	+	+	+	+
DILATIONS	-	+	+	+	-	+	+	+	+
REFLECTIONS	-	+	-	+	+	+	+	+	+
ALL COMBINATIONS	-	-	-	+	-	+	+	+	+

FEATURE CHANGE

(- = variant feature, + = invariant feature)

Invariant Features

- The ambiguous square/diamond. The same figure is perceived as a square when its sides are vertical and horizontal but as a diamond when its sides are diagonal.



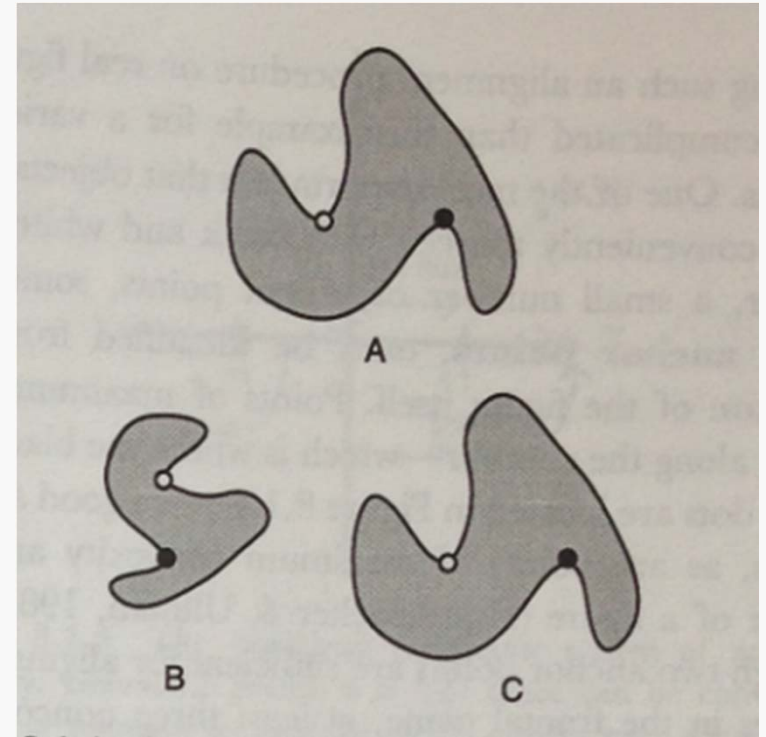
Transformational Alignment



- Two objects are equivalent in shape is to find a transformation that brings one into exact alignment with the other.


Transformational Alignment

- The two object(A B) can then be compared for shape equivalence by the following prcedure:
- 1.find the correspondence between dots: black to black and white to white.
- 2.determine the translation, rotation, reflection, and dilation required to exactly align the dots of B with the corresponding dots of A
- 3.apply the same transformation to figure B in its entirety, including all points rather than just the black and white one.
- 4.Determine whether the transformed version of figure B is identical to figure A.If it is, figure A and B have the same shape.



Transformational Alignment



- The transformational alignment hypothesis faces several difficulties.
 - One is that if the figures are complex and contain numerous potential anchor points, either some principled way must be found to eliminate all but a few possibilities or many different correspondences must be tried.
 - Second problem is the same set of anchor points must be visible in the two figures.
 - Third problem is that there are certain objects that are typically seen as having different shapes yet can be brought into exact alignment by a similarity transformation.
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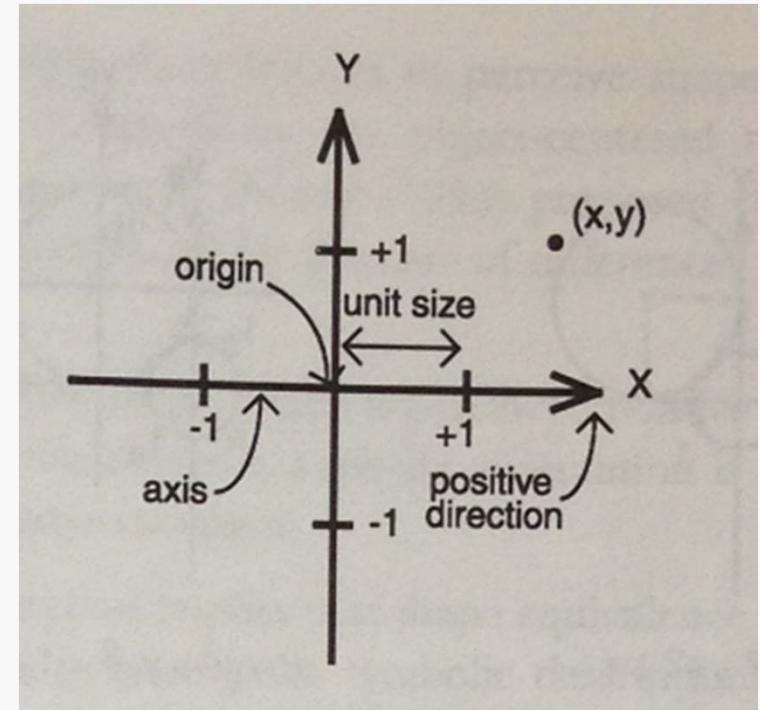
Object-Centered Reference Frames



- A third alternative to solving the problem of shape equivalence is to define shape relative to object-centered reference frames.

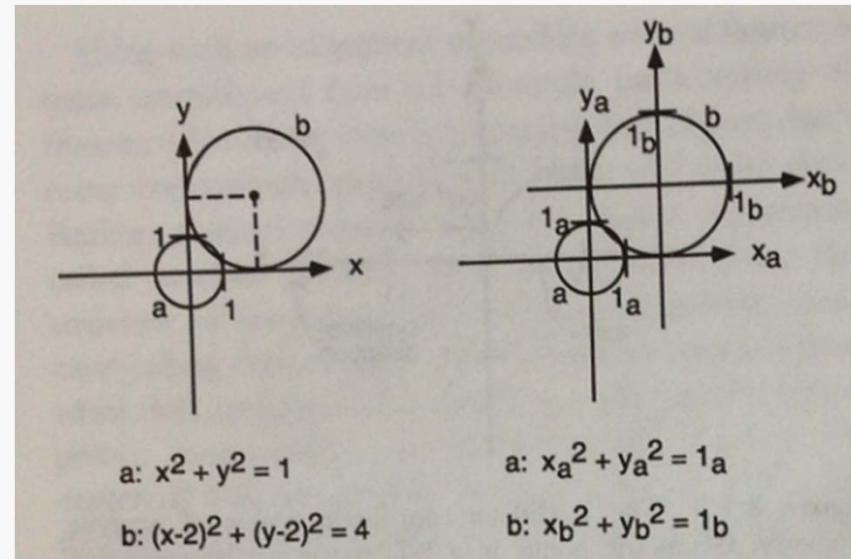
Object-Centered Reference Frames

- Geometric coordinate systems:
- The standards for each dimension of a Cartesian coordinate system include:
- 1.a reference location that defines its **origin**
- 2.a reference orientation that defines its **axis**
- 3.a reference distance that defines the **unit size**
- 4.a reference sense along the orientation that defines the **positive direction** along the axis




Object-Centered Reference Frames

- The right panel shows that when a different coordinate system is chosen for each circle, they have the same description relative to their own object centered reference frame.



Object-Centered Reference Frames



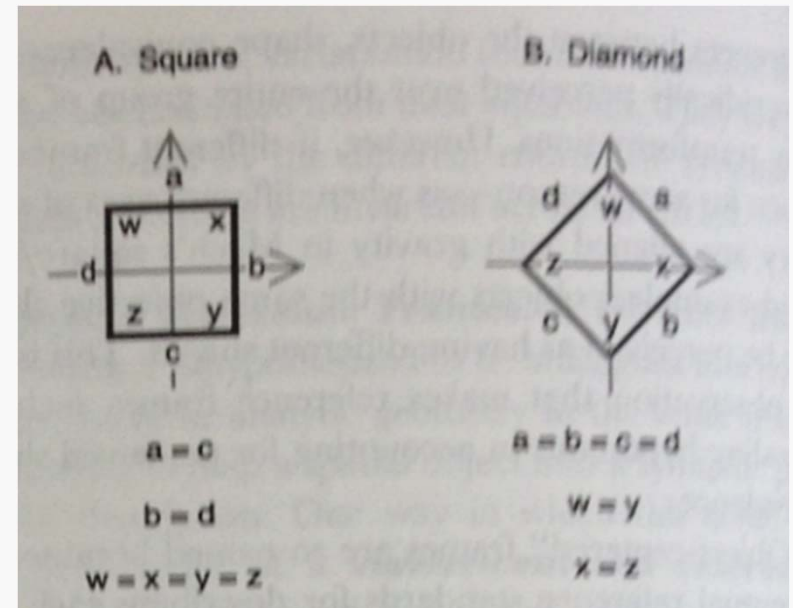
- Perceptual reference frames:
 - a reference frame in perception is hypothesized to be analogous to a coordinate system in analytic geometry in the sense that it can be used to map a spatial object into a symbolic perceptual description.
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Object-Centered Reference Frames

- Accounting for failures of shape equivalence:
- Three important assumptions for the case of differences in orientation
 - 1.relative description
 - 2.intrinsic biases
 - 3.extrinsic biases

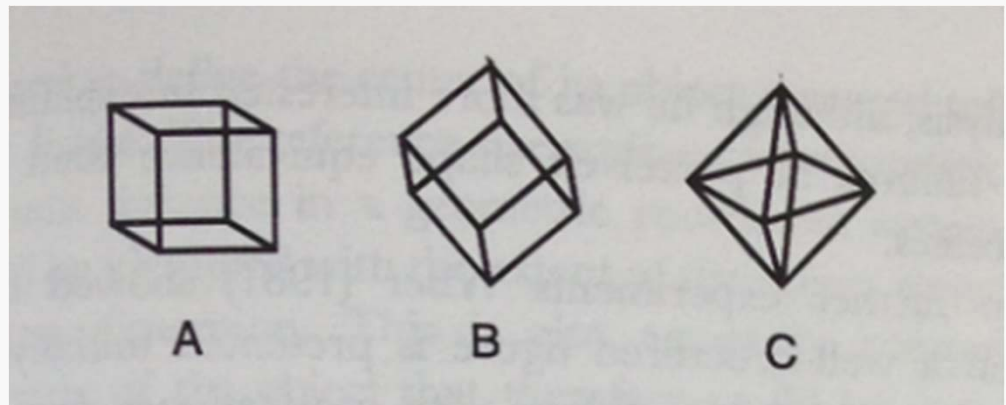
Object-Centered Reference Frames

- In squares, the equality of opposite sides and adjacent angles dominate perception. In diamonds, the equality of adjacent sides and opposite angles dominate perception.



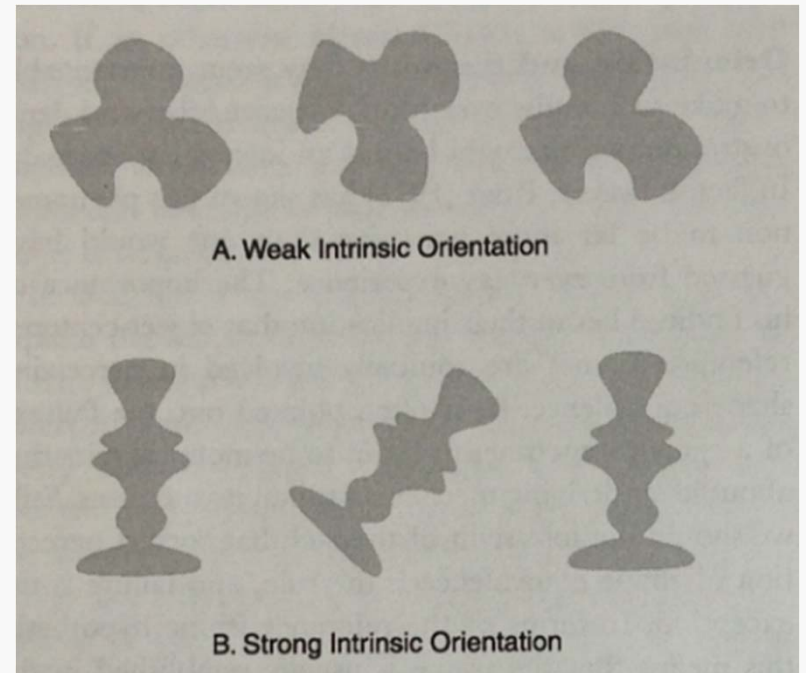
Object-Centered Reference Frames

- Reference frame effects in visual imagery.



Object-Centered Reference Frames

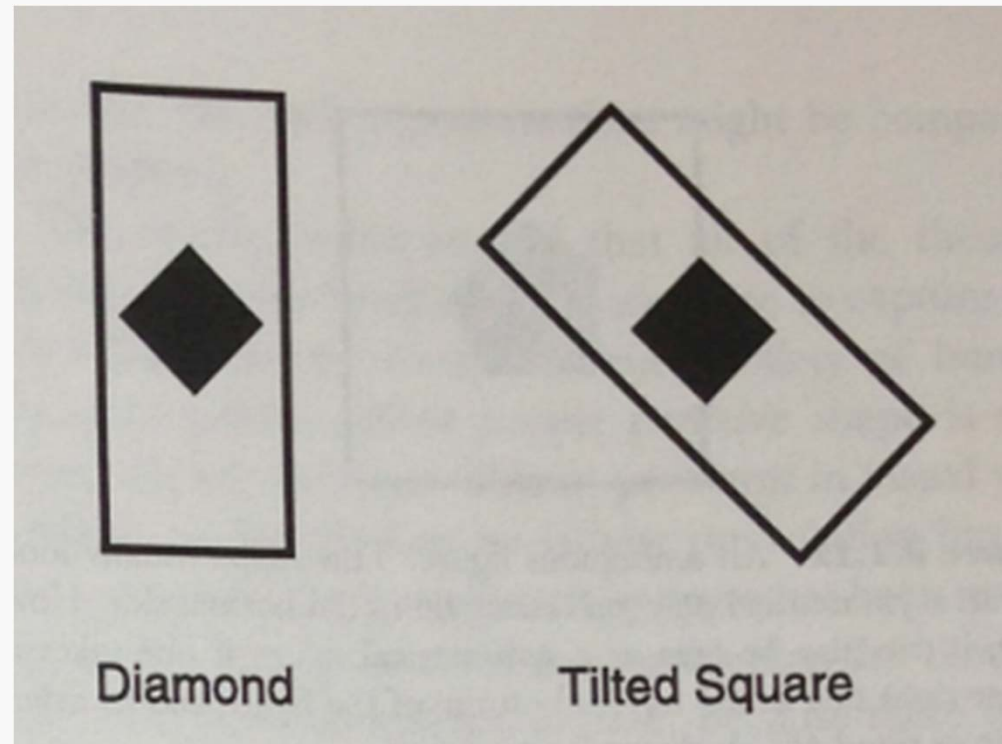
- Effects of orientation on perceived shape.
- They were much better at remembering when the figure's orientation was the same. Figures with good intrinsic axes (B) showed not such difference when orientation was changed at testing.



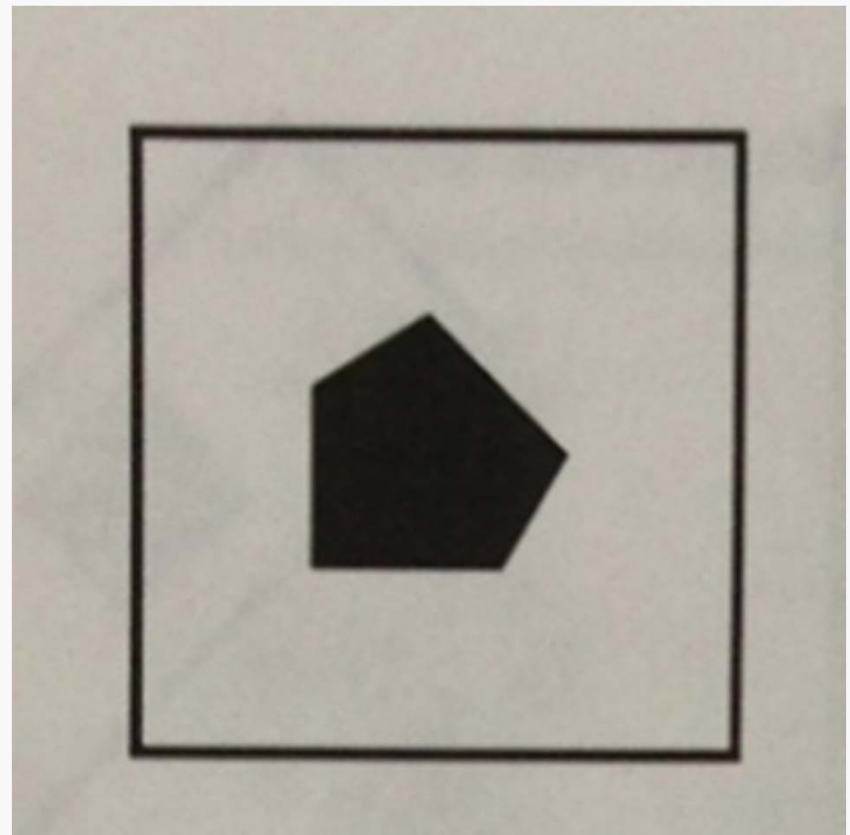
Object-Centered Reference Frames

- A number of stimulus factors seem to be important in determining intrinsic reference frame of an object:
- 1.Gravitational orientation.
- 2.Axes of reflectional symmetry
- 3.Axes of elongation
- 4.contour orientation
- 5.textural orientation
- 6.contextual orientation
- 7.motion

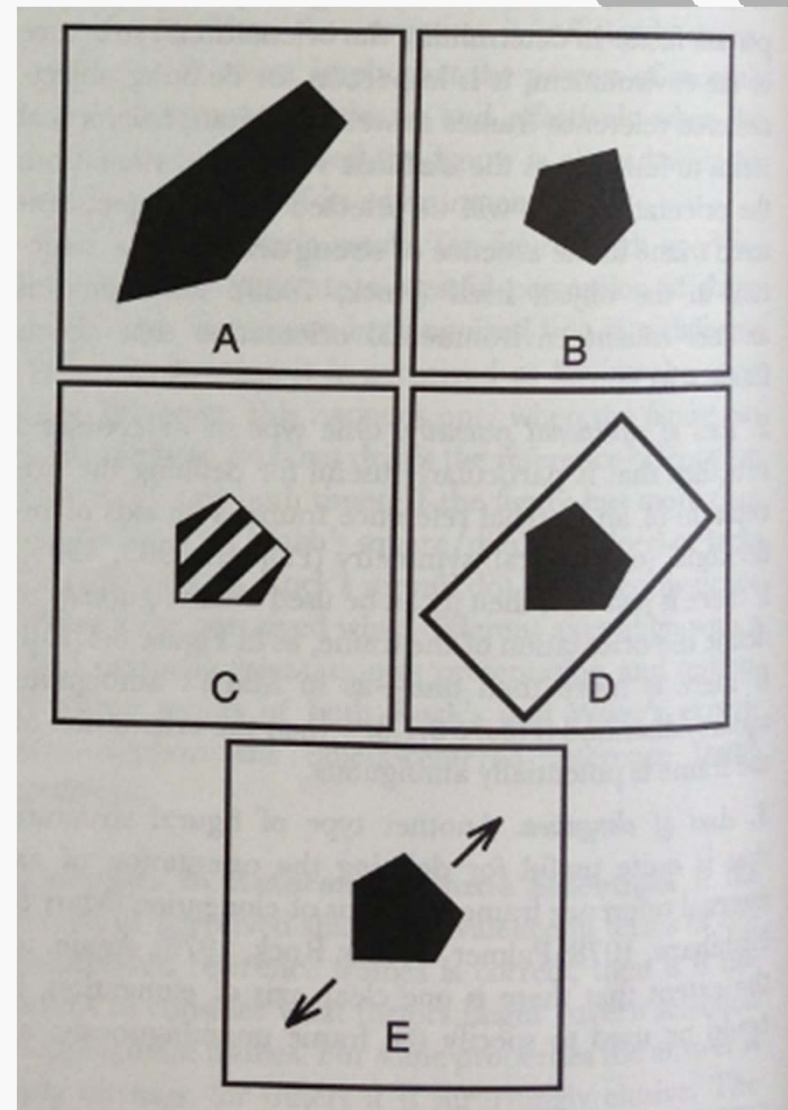
- Effects of frame orientation on perceived shape.



- An ambiguous figure.




- The perceived orientation of the pentagon can be influenced by elongation(A), gravitational stability(B), textural orientation(C), a surrounding frame(D), and motion(E)



Shape equivalence conclusion



- Transformational alignment is based on matching two images, whereas reference frame comparisons are based on symbolic descriptions of shape within the reference frame. In addition, alignment theories are often based on anchor point computation, whereas reference frame theories are usually based on finding an intrinsic orientation, via many factors.
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Theories of Shape Representation

- Templates
 - Fourier Spectra
 - Features and Dimensions
 - Structural Descriptions
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Theories of Shape Representation



- Shape similarity is a much more difficult problem because it requires a theory specifying how to represent shape in a way that will provide a graded measure corresponding to perceived similarity.
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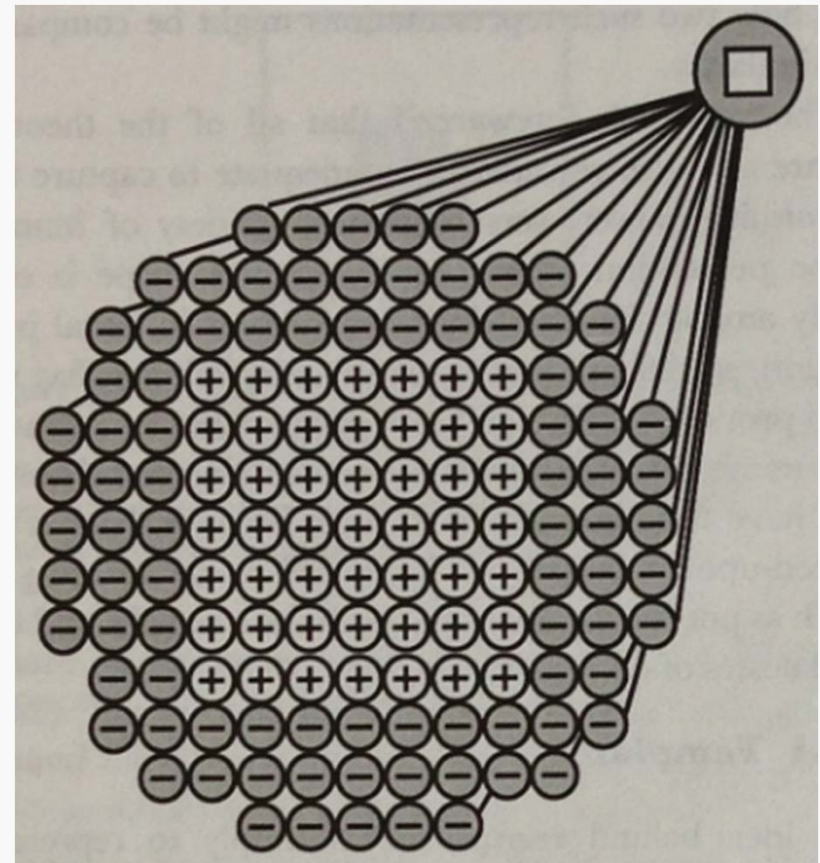
Templates



- The atomic elements of which templates are composed are typically represented as binary features corresponding to whether particular receptors are firing or not.
 - We will call such representations **standard templates** to differentiate them from more complex alternatives.
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Templates

- A template representation of a square.
- The square detector is excited by the receptors in the central region (white circles containing a "+") and inhibited by receptors in the surrounding region (dark circles containing a "-").



Templates



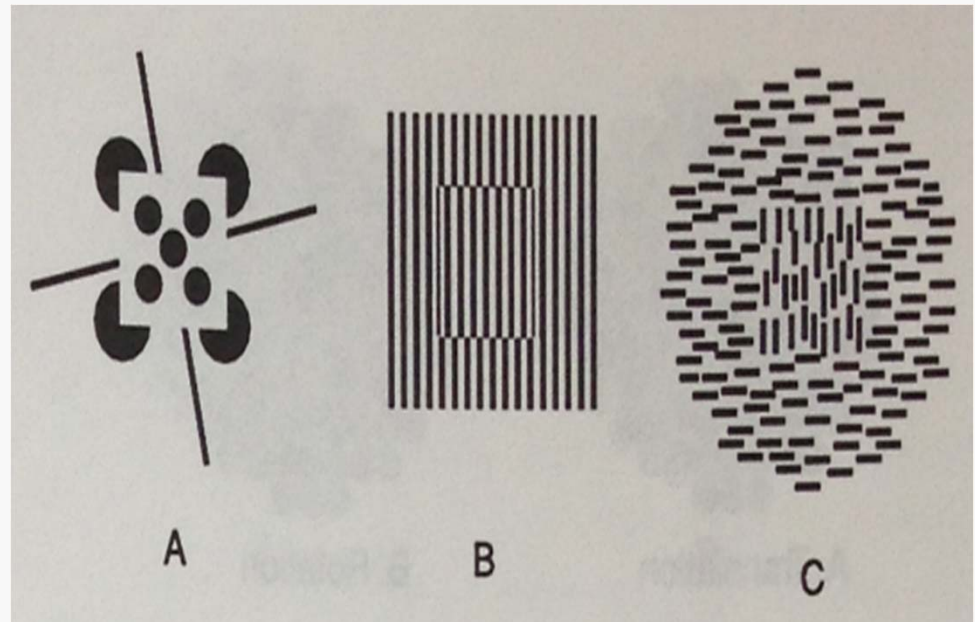
- To determine the similarity between two shapes, one needs a method to compare representations.
 - A particularly simple scheme for templates is to compute the correlation between the input image and the template. The expected value for two unrelated images is zero.
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Templates

- Strengths: Templates are always the starting point for discussions of shape representation for the simple reason that they are the most obvious mechanism for performing this conversion.
- Weakness:
 - 1.The problem of multiple sensory channels.
 - 2.The problem of spatial transformations.
 - 3.The problem of three- dimensionality.

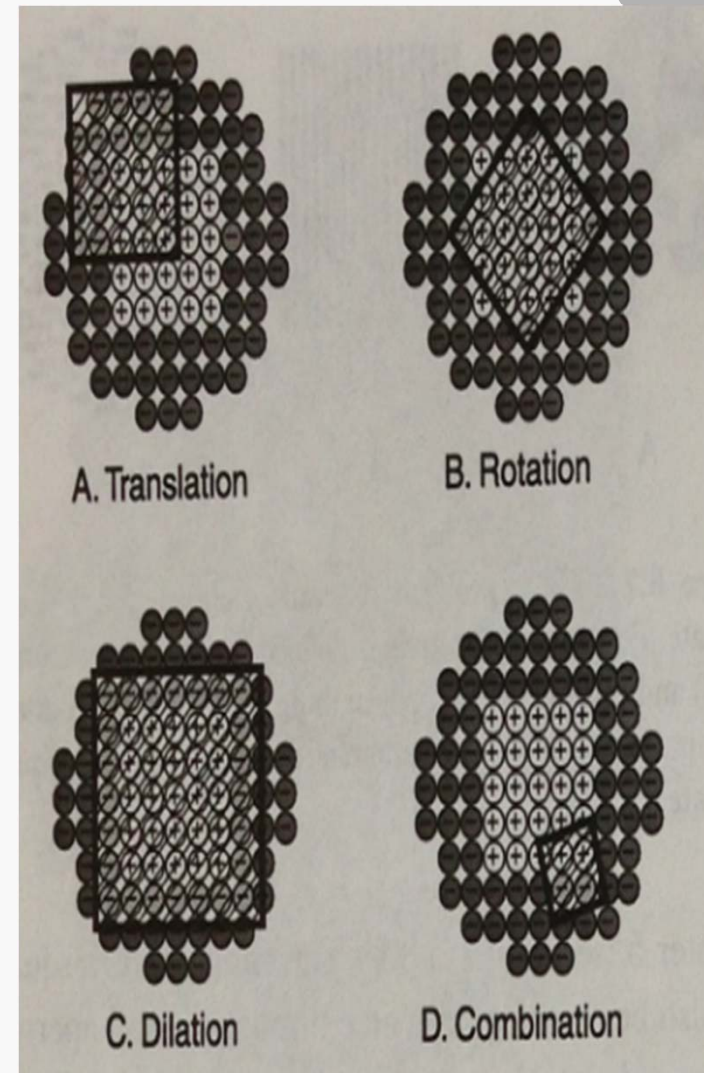
Templates

- People perceive squares defined by illusory contours A and B and texture edges C, even though none of these patterns will cause high levels of activation in the luminance-based square template.



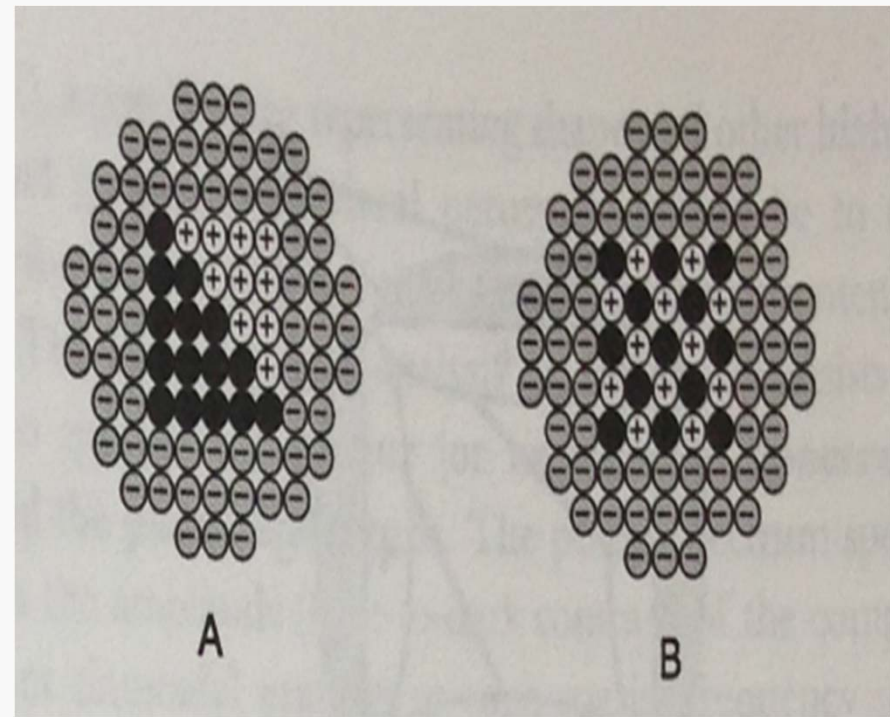
Templates

- People perceive the shaded areas in parts A, C, and D as square, despite the fact that they overlap poorly with the template. Moreover, people do not perceive the diamond in part B as square, despite the fact that its overlap with the template is reasonably good.



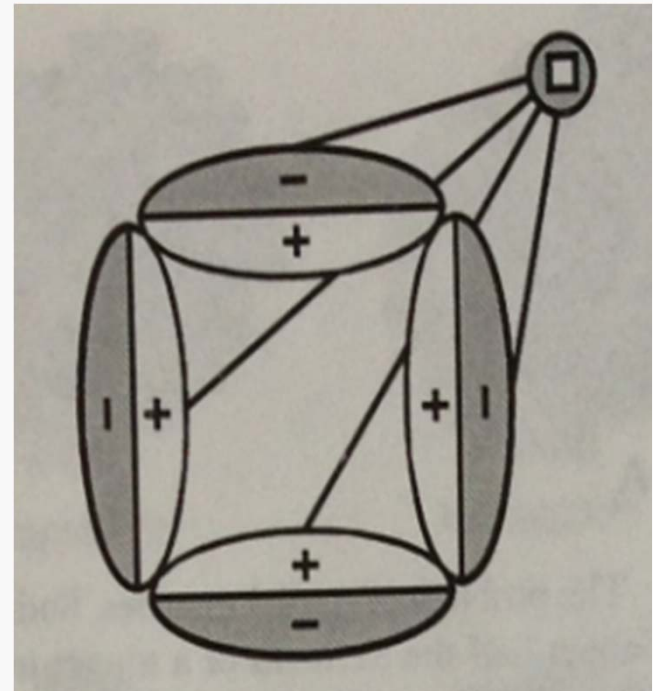
Templates

- Both figures depict overlap of about half the elements of a square template, yet the dark figure in part A is perceived as a triangle rather than a square, whereas that in part B is perceived as a square made of loosely spaced dots.



Templates

- A **hierarchical template** for a square. The square detector at the upper right receives input from other templates rather than from individual receptors.



Fourier Spectra



- The global fourier analysis of an image consists of two spectra: **the power spectrum** and the **phase spectrum**.
- Most Fourier approaches to shape perception have therefore focused on the power spectrum.

Fourier Spectra



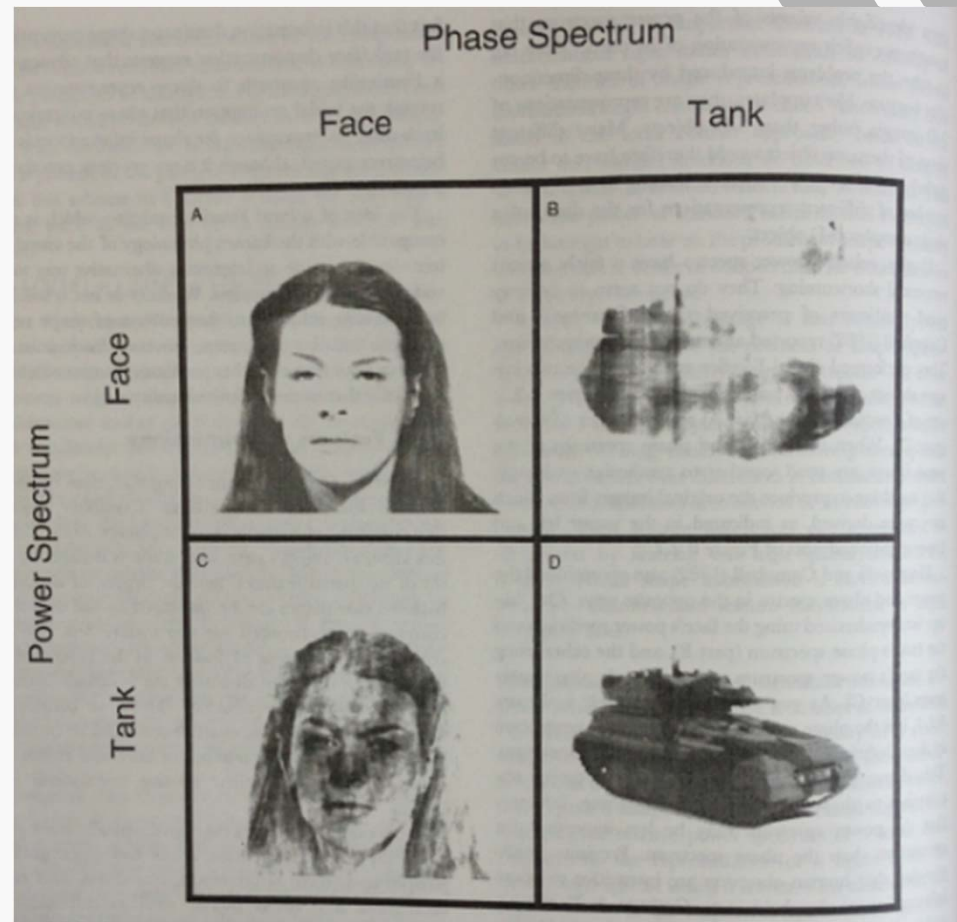
- One of the attractions of using the power spectrum as the basis for shape perception is that it automatically solves the problem of shape equivalence over changes in position.

Fourier Spectra

- Strengths:
- it not only is consistent with, but was actually derived from, a prominent theory of low-level vision.
- Fourier approach to shape is its formal mathematical status.
- A more tangible advantage is that relative power spectra appear to solve the problem of shape equivalence over the similarity transformations.
- Weaknesses:
- A global Fourier analysis an entire, uninterpreted image rather than individual objects.
- Object-relative power spectra also fail to solve, or even to provide insight into, the problems of part structure and three-dimensionality.

Fourier Spectra

- When properly combined, the original picture are reproduced. When mismatched, the phase information clearly dominates perception.



Fourier Spectra



- The idea of a local Fourier analysis--which is most compatible with the known physiology of the visual system--may provide an interesting alternative way to encode positional information.

Features and Dimensions



- The most popular class of shape representation was **feature lists**: a symbolic description consisting of a simple set of attributes.
- The features that have typically been proposed for representing shape are of two types: **global properties**, such as symmetry, closedness, and connectedness and **local parts**, such as containing a straight line, a curved line, or an acute angle.

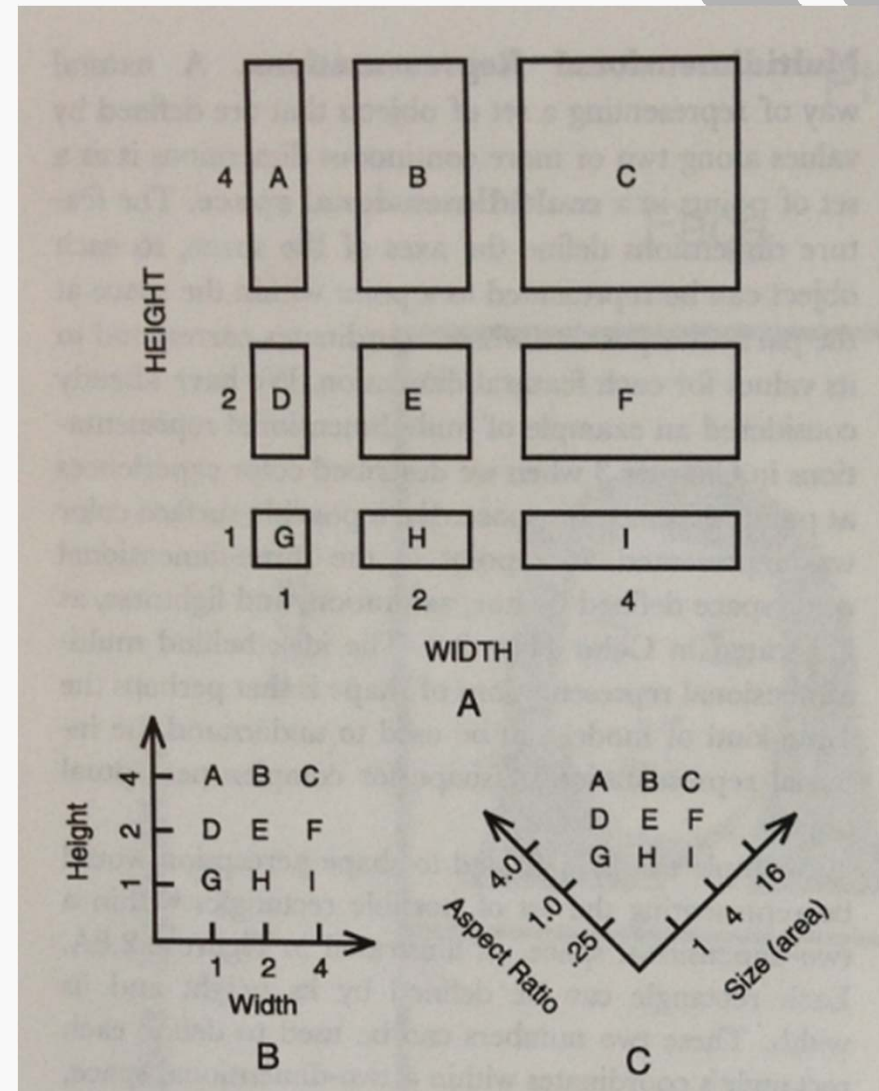
Multidimensional Representations



- A natural way of representing a set of objects that are defined by values along two or more continuous dimensions is as a set of points in a **multidimensional space**.


Multidimensional Representations

- A set of nine rectangles is defined by three values of height and width(A). These rectangles can therefore be represented in a multidimensional space defined by orthogonal axes of height and width(B) or axes of aspect ratio and size(C)



Multidimensional scaling(MDS)programs



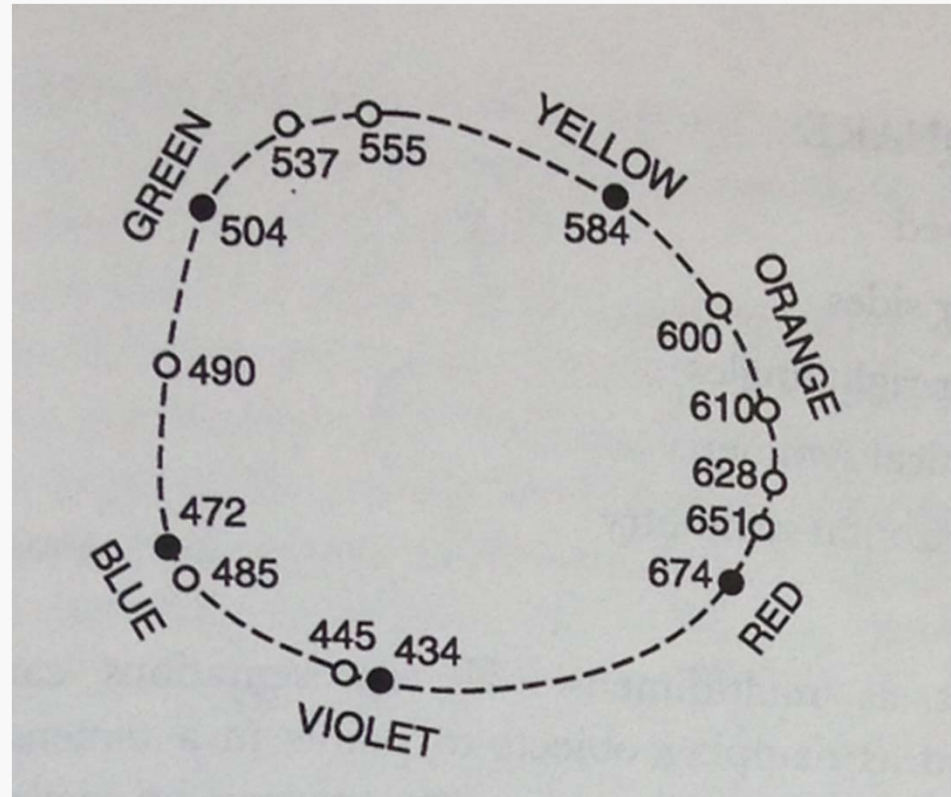
- The heart of an MDS program is a method for adjusting the locations of the objects within the space according to a formula that systematically decreases **stress** with each successive adjustment.
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Multidimensional scaling(MDS)programs

- Stress:
- It usually called stress, of how badly the distances between pairs of points in that spatial configuration fit the rated similarity of corresponding objects in the proximity matirx.

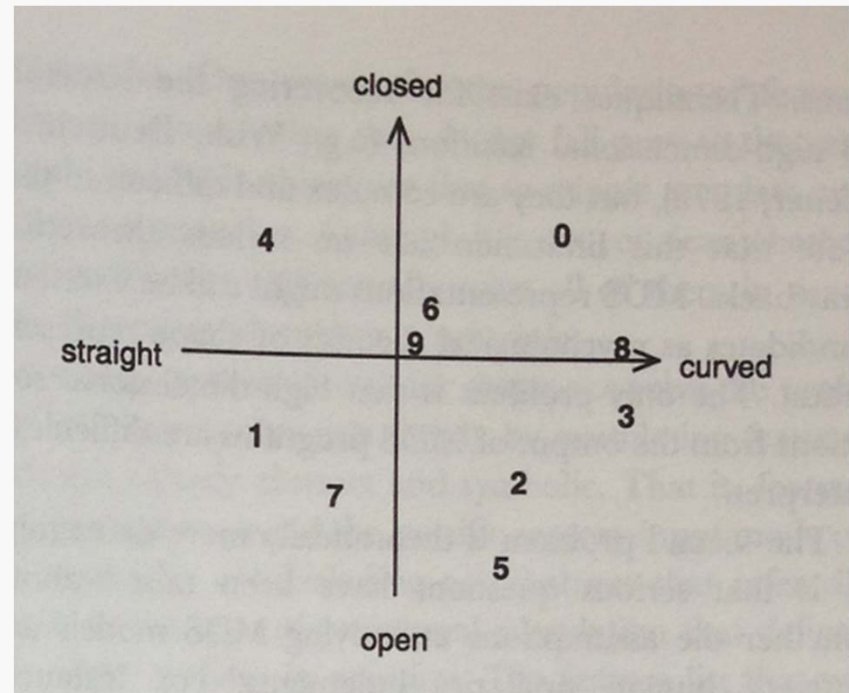
Multidimensional scaling(MDS)programs

- A reconstruction of the color circle using **multidimensional scaling**. By using a 14×14 proximity matrix, MDS algorithm recovered the nearly circular configuration shown here.



Multidimensional scaling(MDS)programs

- A multidimensional scaling solution for the shape of single numerals. The two dimensions were interpreted as straightness/curvature and open/closed.



Multidimensional scaling(MDS)programs

- MDS representations have two major limitations.
- First, their usefulness is pragmatically limited to solutions in three dimensions or fewer.
- The second problem is theoretically more damaging. It is questions about whether the assumptions underlying MDS models are true of human similarity judgments.

Multifeatural Representations

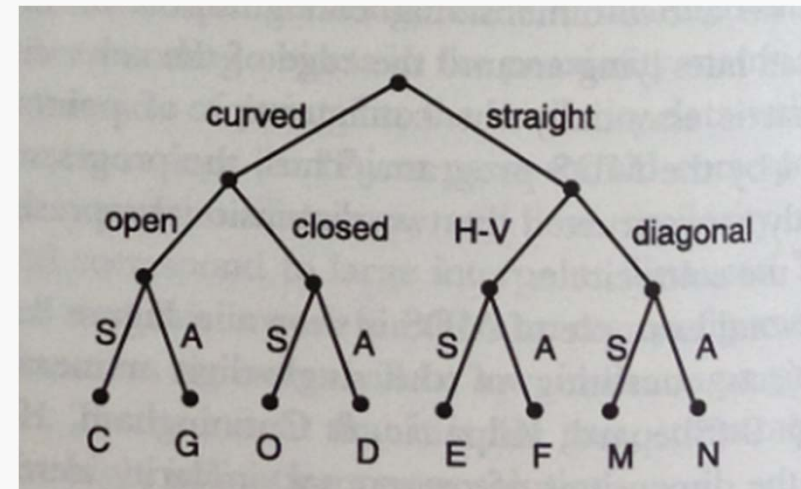
- The representation of an object within a multifeatural approach is typically conceived as **a set of its features**. It is another approach to representing complex perceptual objects.

Mutifeatural Representations

- A square, for example, might be represented by the following set of discrete features:
- closed
- four sides
- four right angles
- vertical symmetry
- horizontal symmetry

Mutifeatural Representations

- Just as multidimensional representations can be viewed as mapping objects to points in a dimensional space, multifeatural representations can be viewed as mapping objects to terminal nodes in a tree structure.



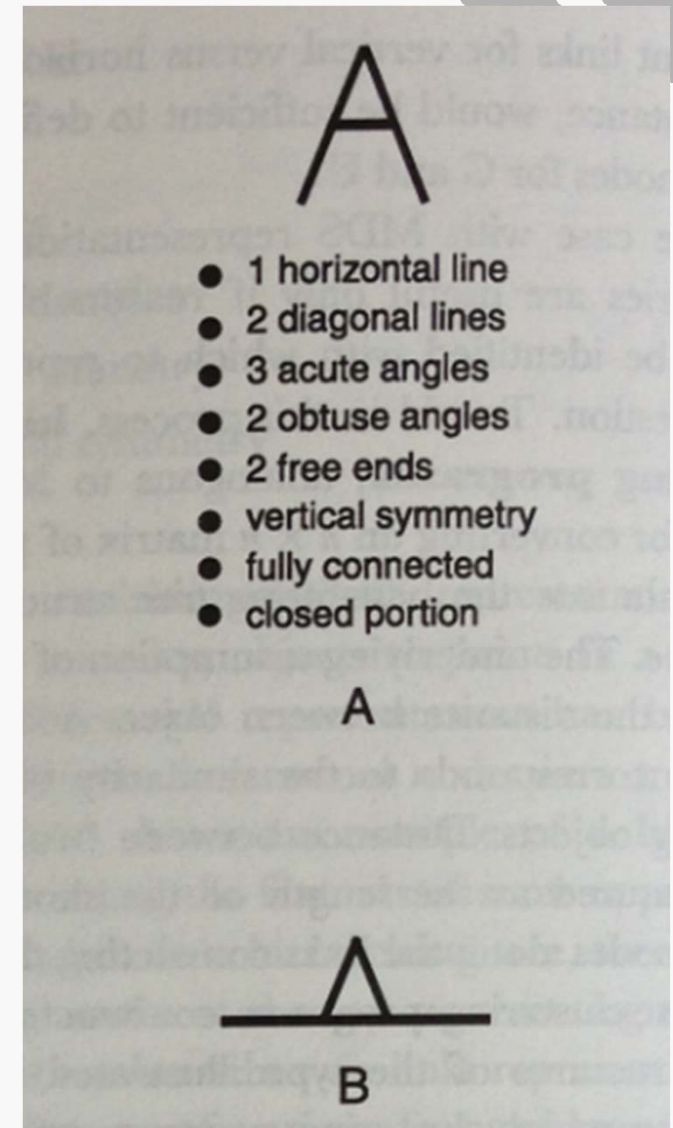
Multifeatural Representations



- Strengths: Feature representations can solve the problem of sensory channels simply by postulating features that are already abstract and symbolic.
- And also able to solve the problem of part structure simply by including the different parts of an object in its feature list.
- It also solving the problems resulting from three-dimensionality, at least in principle.

Mutifeatural Representations

- Weakness: Features of an A. Part A shows a feature list for the shape of a prototypical A containing many of the standard features for alphanumeric symbols. Part B shows a figure that has every feature listed in part A yet has a very different shape.

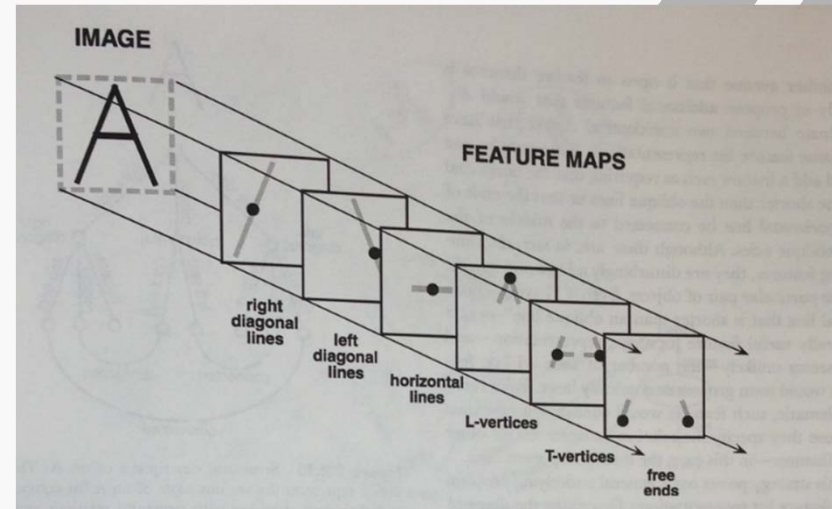


Mutifeatural Representations

- Weakness: it is often unclear how to determine computationally whether a given object has the features that are proposed to make up its shape representation and it still very difficult problem of specifying what the proper features for a shape representation might be.

Mutifeatural Representations

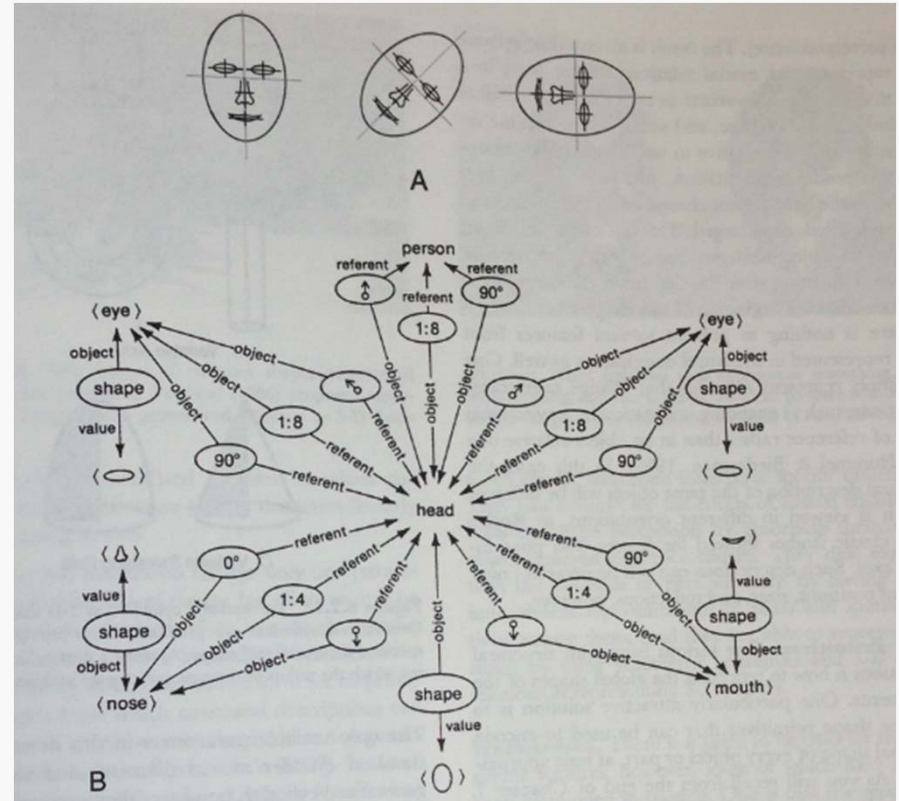
- Solution:
- A **feature map** representation of an A. The various features of an A, consisting of its component lines, vertices and free ends, are associated with their locations in a set of spatially defined feature maps.



- [illegible]


Structural Descriptions

- Part A illustrates the invariance of the relation between the intrinsic frame of the head and those of eyes, nose, and mouth over rotations. Part B shows a structural description that encodes such invariant relations by specifying the translation, rotation and dilation that relate the reference frames for each component of the description.



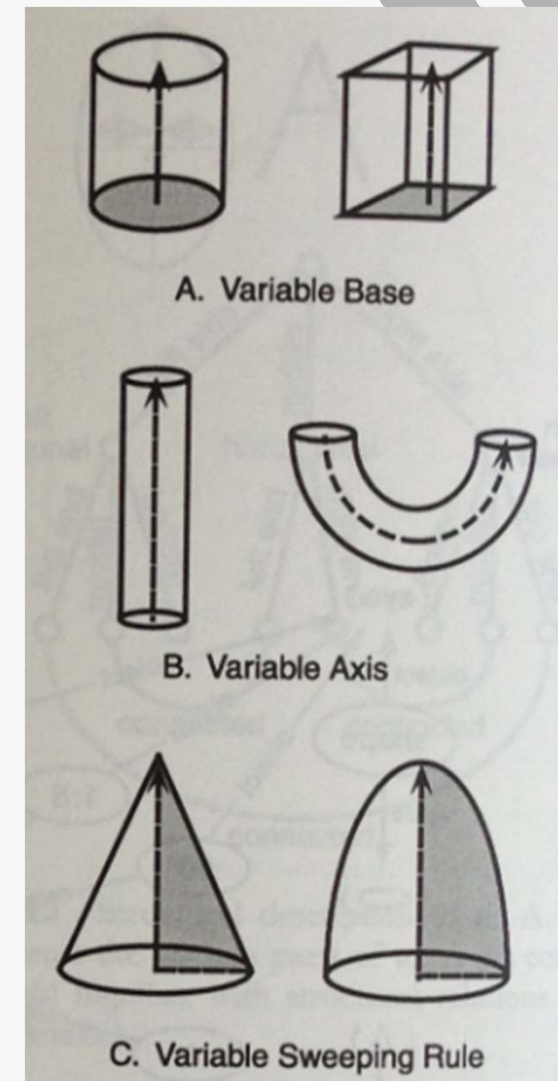
Shape Primitives



- How to represent the global shapes of the components.
 - One particularly attractive solution is to postulate shape primitives that can be used to encode the global shape of every object or part, at least approximately.
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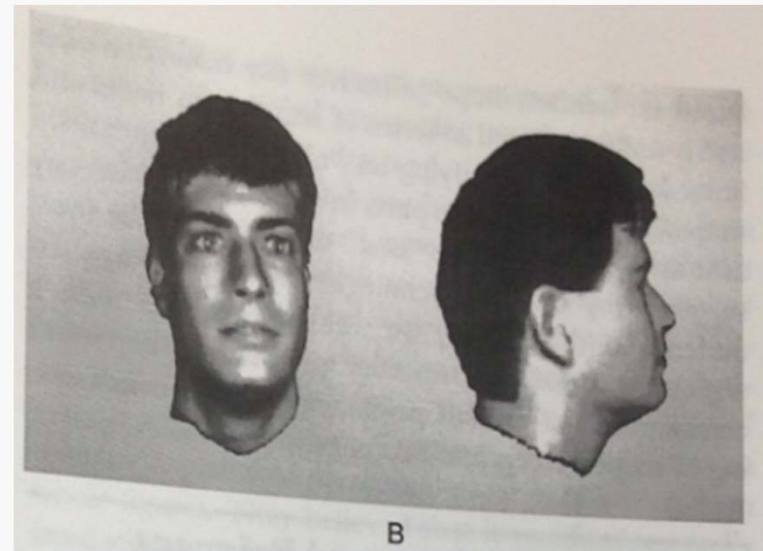
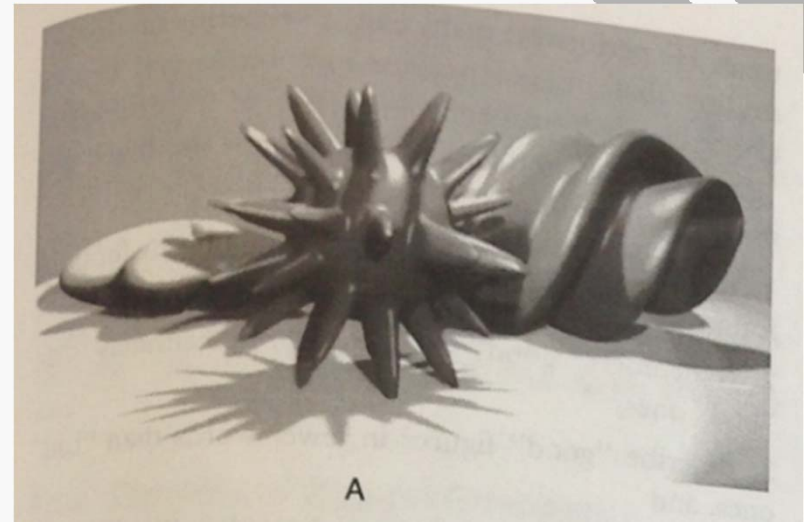
Shape Primitives

- Generalized cylinders are produced by sweeping a base of a specified cross-sectional shape(A) along a particular axis(B), during which the radius of the base can change in different ways(C)
- It can have 1.variable base, 2.variable axis, 3.variable sweeping rule



Shape Primitives

- Two images of complex shapes constructed from super quadric primitives.
- It seems fully up to the task of representing the shape of all the complex objects people are able to recognize.



Shape Primitives

- Strengths:
- Structural descriptions overcome many of the difficulties with templates, Fourier spectra, and feature.
- They are invariant over different sensory channels-such as edges defined by luminance, texture, and motion-because the primitives of which they are composed can be abstracted from these specific dimensions.
- Weaknesses: One is that the representations become quite complicated and sufficiently powerful set of primitives and relations must be identified.

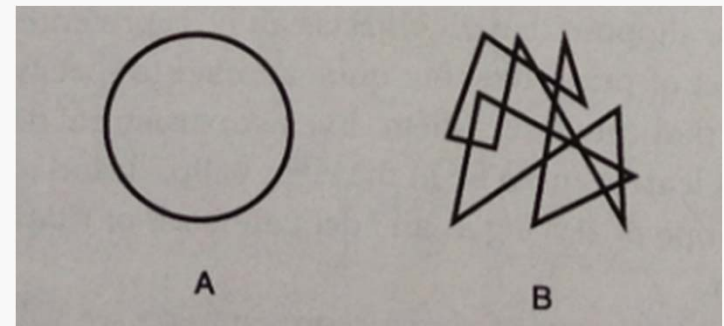


Figural Goodness and Pragnanz

- Theories of Figural Goodness
 - Structural Information Theory
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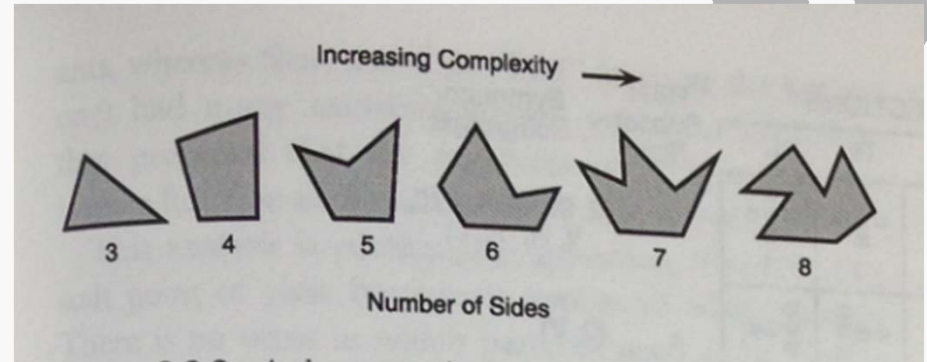
Figural Goodness and pragnanz

- **Figural goodness** is the aspect of perceptual experience that is perhaps **best described** as a composite of the simplicity, order, and regularity of an object.



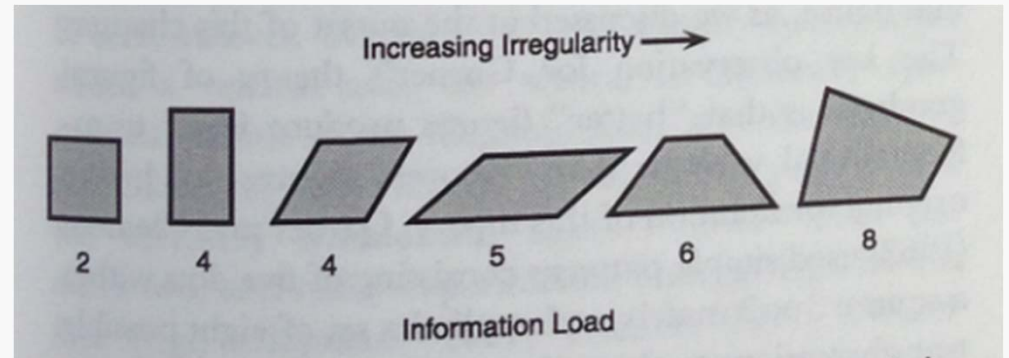
Figural Goodness and pragnanz

- One obvious factor that influences figural goodness is the number of component parts an object has. All else being equal, figures with fewer sides tend to be perceived as "better" than figures with more sides.











































Figural Goodness and pragnanz

A demonstration of how increasing irregularity affects figural goodness.



Figural Goodness and pragnanz

- **Information theory:**
- It analysis of figural goodness was based on breaking figures down into local component and analyzing them for structural regularities.

ROTATIONS				REFLECTIONS				R&R Subset Size	Symmetry Subgroups
0	90	180	270	V	H	R	L		
 1	 1	 1	 1	 1	 1	 1	 1	1	(0, 90, 180, 270, V, H, R, L)
 1	 2	 3	 4	 1	 3	 2	 4	4	(0, V)
 1	 2	 3	 4	 4	 2	 1	 3	4	(0, R)
 1	 2	 1	 2	 3	 3	 4	 4	4	(0, 180)
 1	 2	 3	 4	 5	 6	 7	 8	8	(0)

Figural Goodness and pragnanz

- **Rotation and reflection subsets:**
- Figures are "good" to the extent that they are the same as transformed versions of themselves. This notion is called rotation and reflection(R&R) subsets.
- **Symmetry subgroups:**
- A given figure can therefore be characterized as the subset of spatial transformations that leave it invariant.

Structural Information Theory



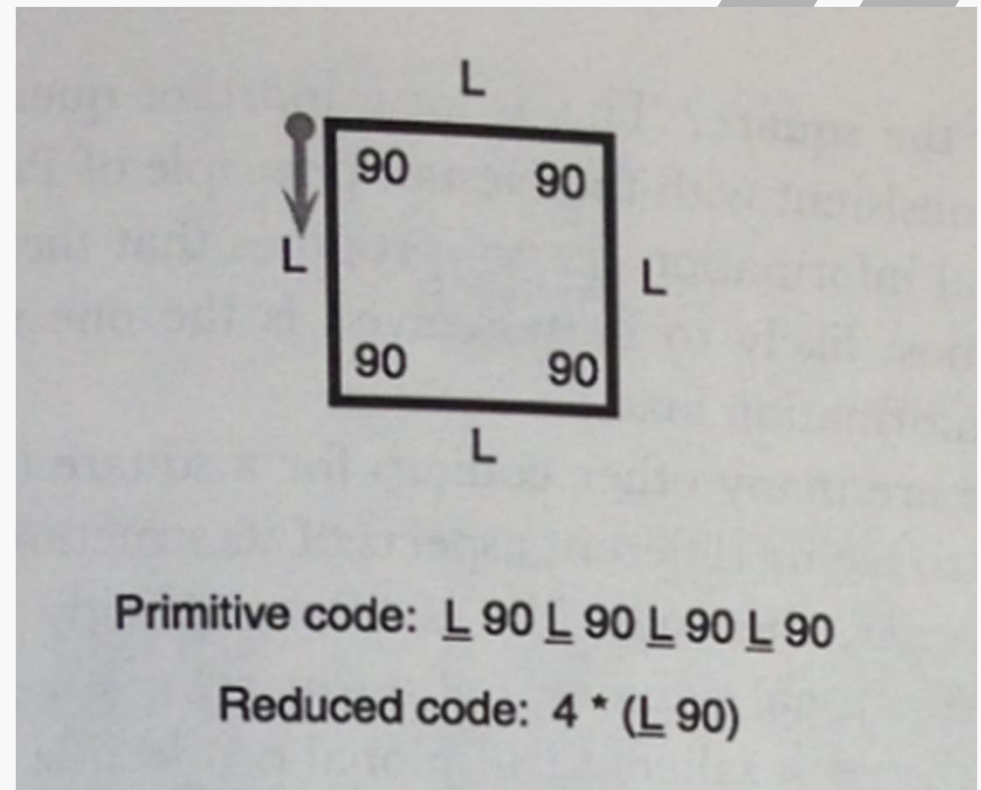
- Shape descriptions are derived in **structural information theory** by generating and then simplifying perceptual descriptions called **codes** that are sufficient to generate the figure. Figural goodness and pragnanz are then introduced into the theory through a measure called **information load**.

Structural Information Theory

- outline of structural information theory:
- 1. construct a primitive code by tracing the contour of the figure and describing it symbolically as a sequence of line segment lengths and the angles between them.
- 2. use a set of sematic operators to simplify the primitive code by removing as many structural redundancies as possible.
- 3. compute the information load of each reduced code by counting the number of parameters it contains
- 4. the reduced code with the lowest information load, called the **minimum code**, is the one that structural information theory predicts will be perceived most often.

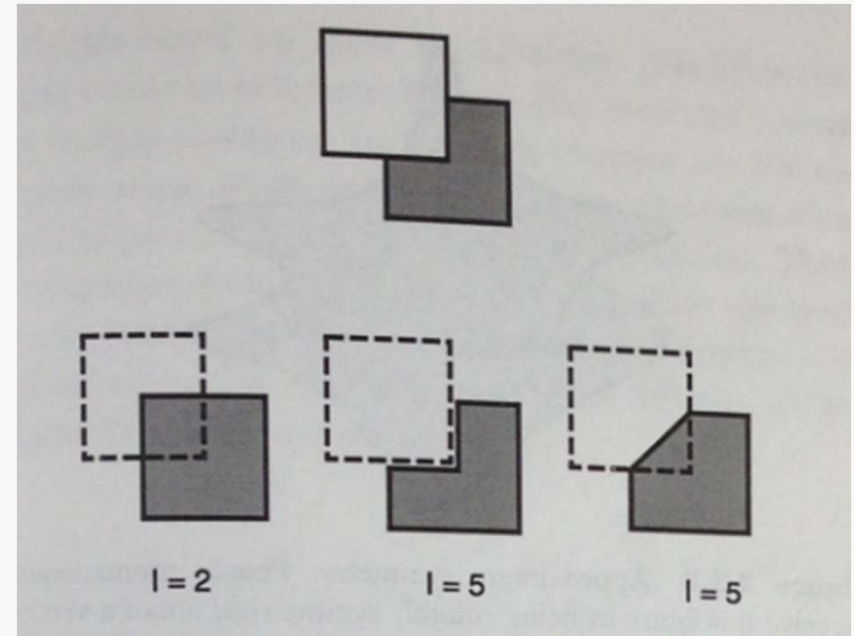
Structural Information Theory

- Reduced codes can then be derived by applying rules to eliminate redundancies.



Structural Information Theory

- The figure at the top is generally perceived as dark square behind a light one. Structural information theory explains the shape of the **completed square** because it has the lowest information load of any alternative consistent with the stimulus.



Structural Information Theory

- Strengths: Structural information theory can easily deal with the problem of similarity transformations. And it close connection to figural goodness and its ingenious way of explaining a number of important perceptual phenomena by analyzing the codability of different shape interpretations.
- Weaknesses: It cannot be applied directly to gray-scale images. It does not contain any explicit encoding of parts other than simple lines or curves. It is more difficult for 3D volumes.

Structural Information Theory

- Structural information theory is the best defined and most successful extension of ideas about figural goodness and Pragnanz to the representation of shape.

Conclusion



- We have now surveyed a sampling of major theories of shape representation and found none to be without difficulties.
- Perhaps not surprisingly, the most promising approach appears to be the most complex.

Review



- Shape Equivalence
 - Defining Objective Shape
 - Invariant Features
 - Transformational Alignment
 - Object-Centered Reference Frames
- Theories of Shape Representation
 - Templates
 - Fourier Spectra
 - Features and Dimensions
 - Structural Descriptions
- Figural Goodness and Pragnanz
 - Theories of Figural Goodness
 - Structural Information Theory



Thanks for watching

