UNIT-2

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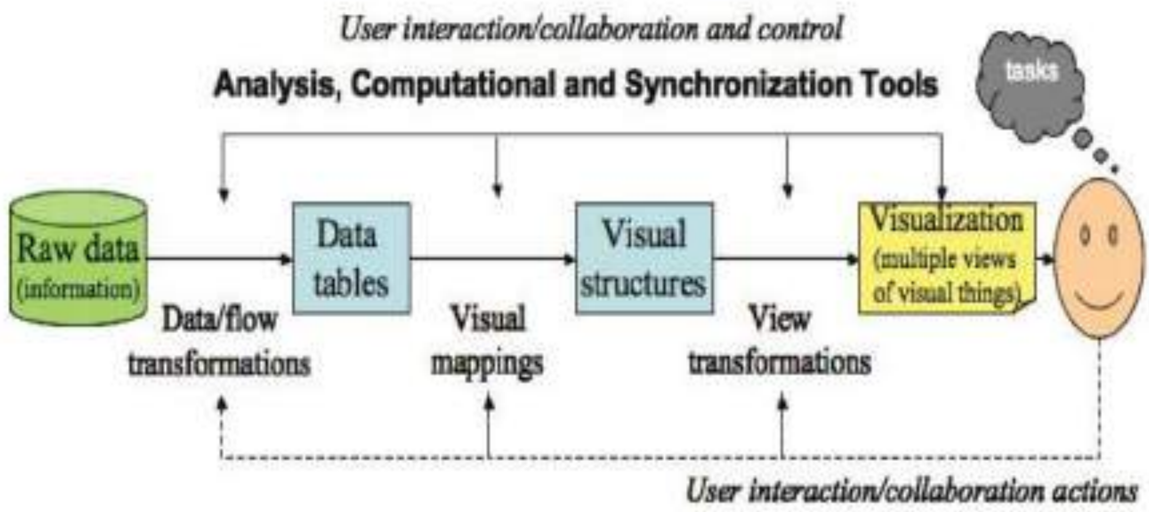
Foundations for Visualization: Visualization stages - Semiology of Graphical Symbols - The Eight Visual Variables - Historical Perspective - Taxonomies - Experimental Semiotics based on Perception, Gibson's Affordance theory – A Model of Perceptual Processing.

References:
1.Matthew Ward, Georges Grinstein and Daniel Keim, : Interactive Data Visualization Foundations, Techniques, Applications ",2010

2.Colin ware: Information Visualization Perception for Design",2nd edition , Margon Kaufmann Publishers,2004

2.1 Visualization stages :



Above Figure represents visualization process. Most visualization pipelines and systems map easily to these stages. Any transformation or computation can be placed at any of the stages.

We also note two key points: user interaction ideally takes place at any point in this pipeline (nodes and links), and each link is a many-to-many mapping. For example, many visualization systems have multiple visualizations at the same time on the screen, and thus have multiple representation mappings and corresponding renderings. We now focus on the transformations and processes that alter the data.

1.Data preprocessing and transformation.

The starting point is to process the raw data into something usable by the visualization system.

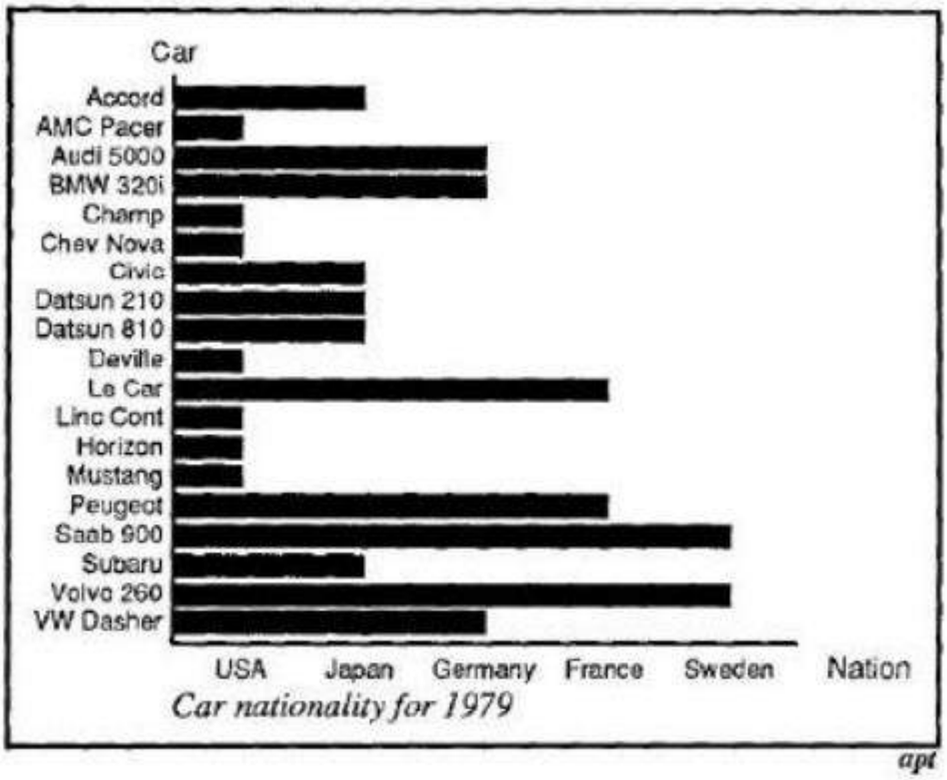
The first part is to make sure that the data are mapped to fundamental data types for computer ingestion.

The second step entails dealing with specific application data issues such as missing values, errors in input, and data too large for processing. The data may be simulated or sampled. Missing data may require interpolation. Large data may require sampling, filtering, aggregation, or partitionining.

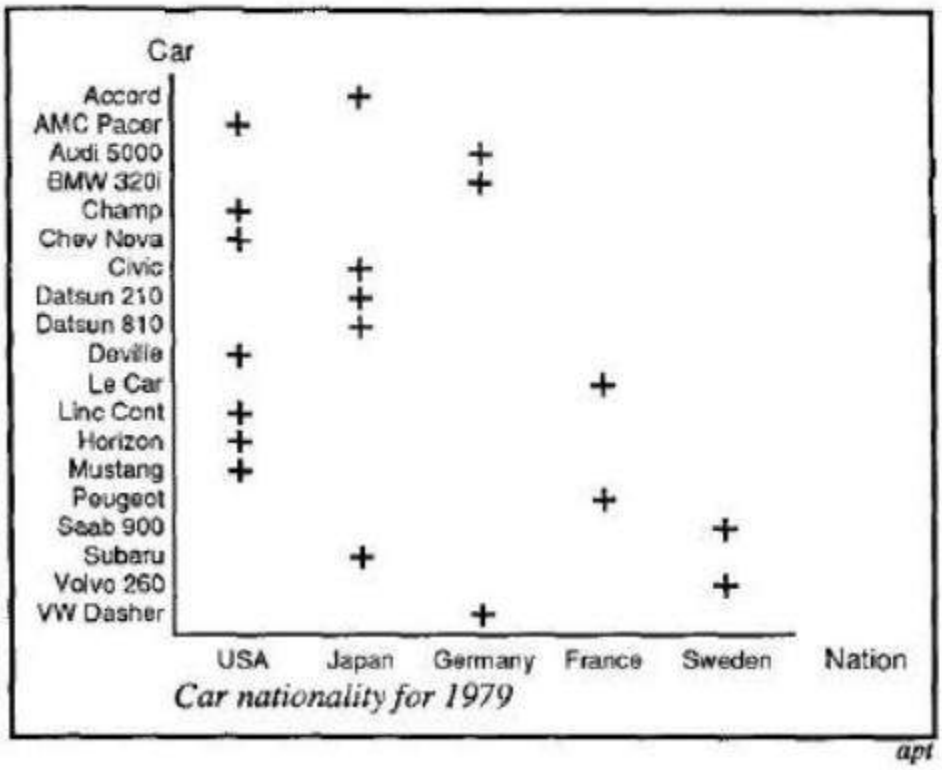
2. Mapping for visualizations.

Once the data are clean, we can decide on a specific visual representation.

This requires representation mappings: geometry, color, and sound, for example. It is easy to simply develop a nonsense visualization, or one that conveys the wrong information.



Above Figure shows an improper use of a bar chart. By having the bars extend over each of the x-coordinate tick marks, there is an implication that the x-coordinate is involved, when no such association occurs. For example, the Volvo, second row from the bottom, cuts across several x-values (USA, Japan, Germany, . . .) until it gets to Sweden.



A better representation is the one in above Figure (scatter plot) , but even that one can be significantly improved.

Crucial influences on the visualization of data sets are expressiveness and eff

ectiveness. It is an interesting exercise to develop measures or metrics for expressiveness and effectiveness; after all, we do use them as measures.

3. Rendering transformations.

The final stage involves mapping from geometry data to the image.

This includes interfacing with a computer graphics Application Programmer's Interface (API). We need to select the viewing parameters, shading technique if 3D, device transformations (for display, printers, . . .).

This stage of the pipeline is very dependent on the underlying graphics library.

2.2 Semiology of graphical symbols:

A visual object is called **a graphical symbol**. Symbols often make up parts of visualizations (arrows, labels, . . .). The science of graphical symbols and marks is called **semiology.**

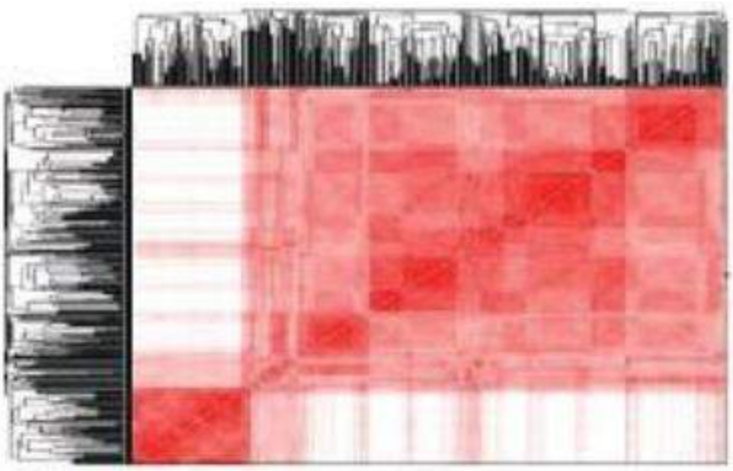
Every possible construction in the Euclidean plane is a graphical representation made up of graphical symbols. This includes diagrams, networks, maps, plots, and other common visualizations.

Semiology uses the qualities of the plane and objects on the plane to produce similarity features, ordering features, and proportionality features of the data that are visible for human consumption.

There are numerous characteristics of visualizations, of images, or of graphics made up of symbols.

1.Symbols and Visualizations

Above Figure contains an image that is universally recognizable (yield sign). Such images become preattentively recognizable with experience. It is perceived in one step, and that step is simply an association of its meaning.



Above Figure on the other hand, requires a great deal of attention to understand; the first steps are to recognize patterns within that figure.

It takes two steps for understanding. The first identifies the major elements of the image, with the second identifying the various relationships between these.

With attentive effort, the symbols are perceived (transferred from long-term memory). Patterns, mostly subsets of groups or information having perceptual or cognitive commonality, are extracted from the overall image. The last step is identifying the most interesting things (such as the most interesting point clusters, genes, countries, or products), that is, those having the most interesting or special features.

Without external (cognitive) identification, a graphic is unusable.

The external identification must be directly readable and understandable.

Since much of our perception is driven by physical interpretations, meaningful images must have easily interpretable x-, y-, and z-dimensions and the graphics elements of the image must be clear.

2.Features of Graphics

Graphics have three (or more) dimensions.

Every point of the graphic can be interpreted as a relation between a position in x and a position in y. The points vary in size, providing a third dimension or variable to interpret.

In effect, this can be considered a value in z. This produces a one-to-one correspondence between a 3D view with height and a 2D view with size, thus different interpretations for the z value.

The set of all points either in the 2D or 3D image represents the totality of the relations among the three dimensions x, y, and z, and any patterns present imply a pattern in the data.

3. Rules of a graphic.

1. The aim of a graphic is to discover groups or orders in x, and groups or orders in y, that are formed on z-values;

2. (x, y, z)-construction enables in all cases the discovery of these groups;

3. Within the (x, y, z)-construction, permutations and classifications solve the problem of the upper level of information;

4. Every graphic with more than three factors that differs from the (x, y, z)-construction destroys the unity of the graphic and the upper level of information; and 5. Pictures must be read and understood by the human.

4.Analysis of a graphic:

When analyzing a graphic, we first perceive groups of objects (preattentively). We then attempt to characterize these groups (cognitively).

Finally, we examine special cases not within the groups or relationships between the groups (combination of both). This process can be done at many levels and with many different visualizations.

Supporting analysis plays a significant role (for example, we can cluster the data and show the results of the computation, hence speeding up the likely perception of groups)

2.3. Eight Visual Variables:

In total there are eight ways in which graphical objects can encode information, i.e**., eight visual variables: position, shape, size, brightness, color, orientation, texture, and motion**. These eight variables can be adjusted as necessary to maximize the effectiveness of a visualization to convey information.

1. Position

The first and most important visual variable is that of position, the placement of representative graphics within some display space, be it one-, two-, or three-dimensional.

Position has the greatest impact on the display of information, because the spatial arrangement of graphics is the first step in reading a visualization.

In essence, the maximization of the spread of representational graphics throughout the display space maximizes the amount of information communicated, to some degree.

The visualization display with the worst case positioning scheme maps all graphics to the exact same position.

consequently, only the last-drawn graphic is seen, and little information is exchanged.

The best positioning scheme maps each graphic to unique positions, such that all the graphics can be seen with no overlaps.

2. **Mark**

   The second visual variable is the mark or shape: points, lines, areas, volumes, and their compositions.
   Marks are graphic primitives that represent data.
   Any graphical object can be used as a mark, including symbols, letters, and words .
   When working purely with marks, it is important not to consider differences in sizes, shades of intensity, or orientation.
   When using marks, it is important to consider how well one mark can be differentiated from other marks.

Several examples of different marks or glyphs that can be used.

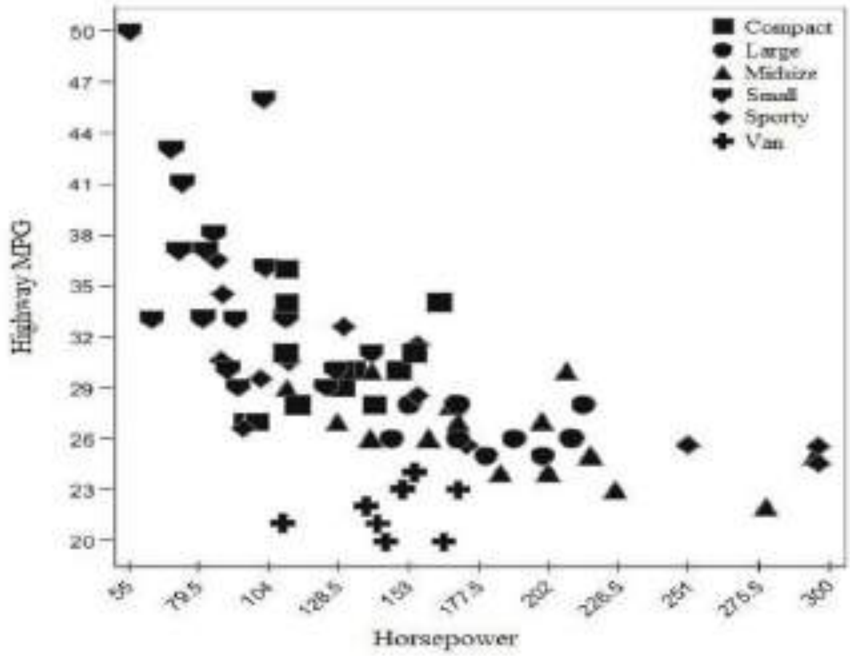


Fig: This visualization uses shapes to distinguish between different car types in a plot comparing highway MPG and horsepower.

Within a single visualization there can be hundreds or thousands of marks to observe; therefore, we try not to select marks that are too similar.
The goal is to be able to easily distinguish between different marks quickly, while maintaining an overall view of the projected data space.
Also, different mark shapes in a given visualization must have similar area and complexity, to avoid visually emphasizing one or more of them inadvertently.

3.Size (Length, Area, and Volume)

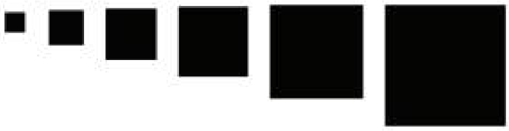
The previous two visual variables, position and marks, are required to define a visualization. Without these two variables there would not be much to see. The remaining visual variables affect the way individual representations are displayed; these are the graphical properties of marks other than their shape.

The third visual variable and first graphic property is size.

Size determines how small or large a mark will be drawn .

Size easily maps to interval and continuous data variables, because that property supports gradual increments over some range.

And while size can also be applied to categorical data, it is more difficult to distinguish between marks of near similar size, and thus size can only support categories with very small cardinality.



Example sizes to encode data.

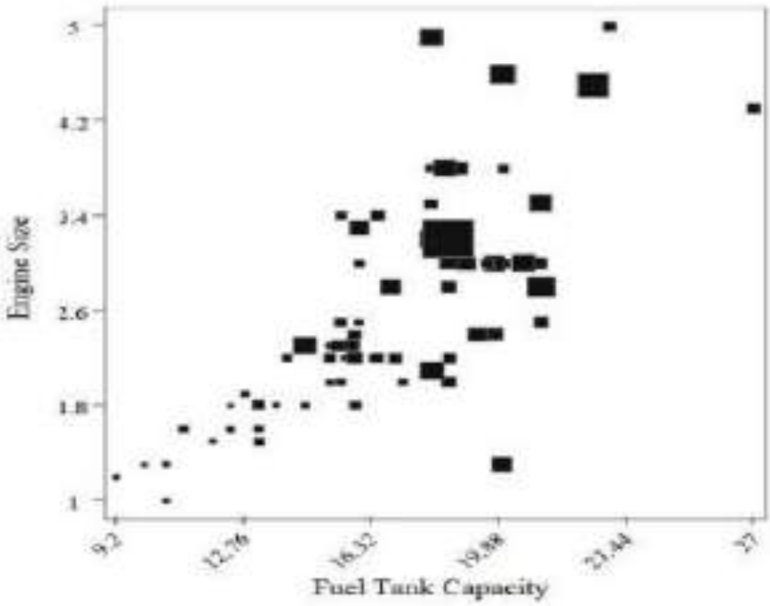


Fig: **This is a visualization of the 1993 car models data set, showing engine size versus fuel tank capacity. Size is mapped to maximum price charged**.

4. **Brightness or luminance**

   The fourth visual variable is brightness or luminance.
   Brightness is the second visual variable used to modify marks to encode additional data variables.
   While it is possible to use the complete numerical range of brightness values, human perception cannot distinguish between all pairs of brightness values.

Consequently, brightness can be used to provide relative difference for large interval and continuous data variables, or for accurate mark distinction for marks drawn using a reduced sampled brightness scale.

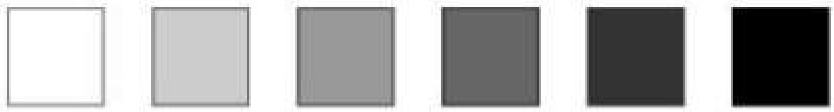


Fig: **Brightness scale for mapping values to the display.**

Furthermore, it is recommended that a perceptually linear brightness scale be used, which defines a step-based brightness scale that maximizes perceived.

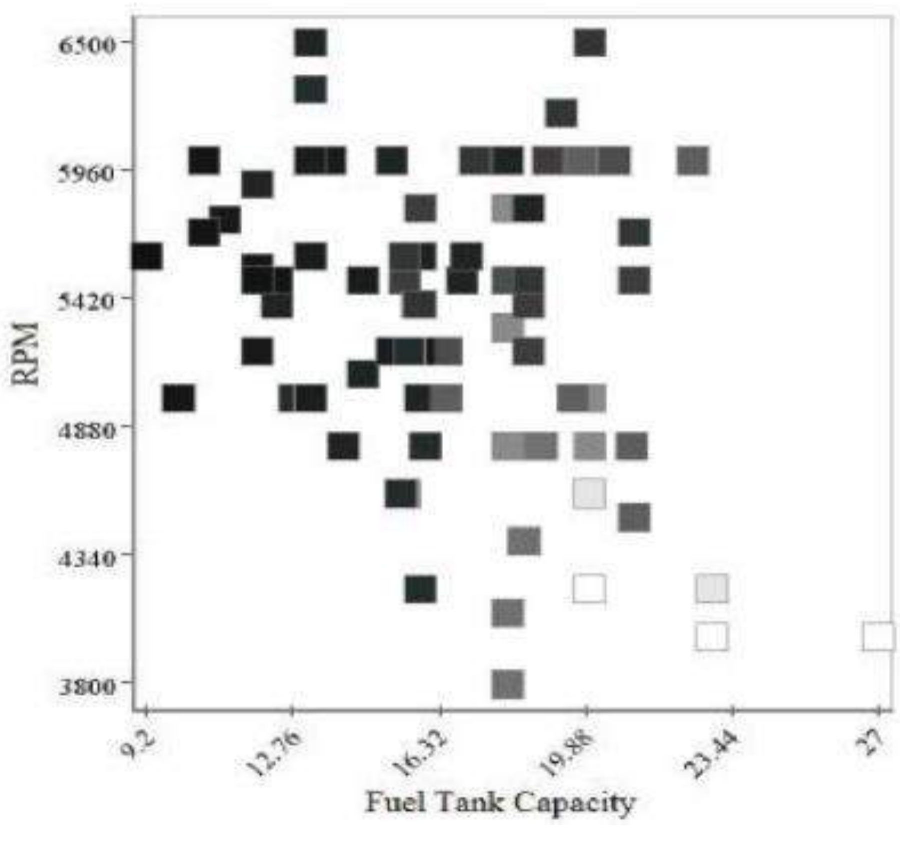


Fig: Another visualization of the 1993 car models data set, this time illustrating the use of brightness to convey car width (the darker the points, the wider the vehicle).

5.Color

The fifth visual variable is color. While brightness affects how white or black colors are displayed, it is not actually color. **Color can be defined by the two parameters, hue and saturation.** .Hue provides what most think of as color: the dominant wavelength from the visual spectrum. Saturation is the level of hue relative to gray, and drives the purity of the color to be displayed.

The use of color to display information requires mapping data values to individual colors. The mapping of color usually entails defining color maps that specify the relationship between value ranges and color values. Color maps are useful for handling both interval and continuous data variables, since a color map is generally defined as a continuous range of hue and saturation values.

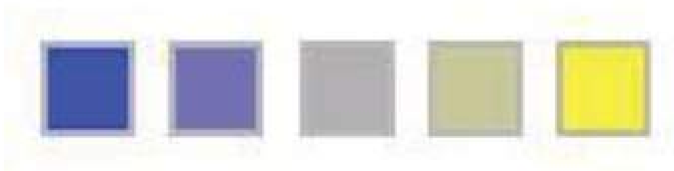


Fig: Example color map that can be used to encode a data variable.

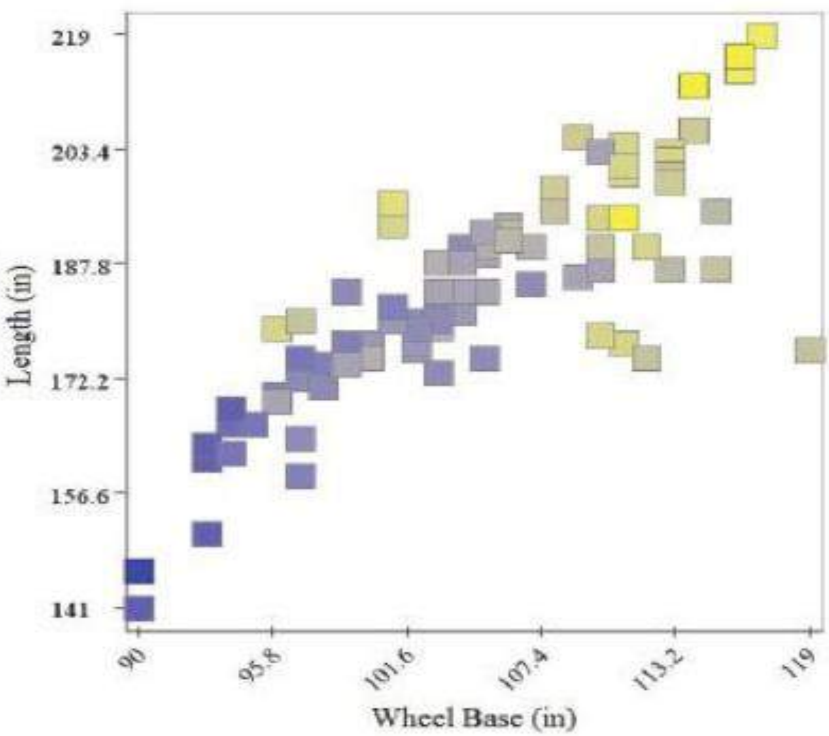


Fig: A visualization of the 1993 car models, showing the use of color to display the car's length. Here length is also associated with the y-axis and is plotted against wheelbase. In this figure, blue indicates a shorter length, while yellow indicates a longer length.

6. **Orientation**

   The sixth visual variable is orientation or direction. Orientation is a principal graphic component behind iconographic stick figure displays, and is tied directly to preattentive vision.

   This graphic property describes how a mark is rotated in connection with a data variable. Clearly, orientation cannot be used with all marks; for instance, a circle looks the same under any rotation. The best marks for using orientation are those with a natural single axis; the graphic exhibits symmetry about a major axis. These marks can display the entire range of orientations.

Fig:Example orientations of a representation graphic, where the lowest value maps to the mark pointing upward and increasing values rotate the mark in a clockwise rotation

7. **Texture**

The seventh visual variable is texture. **Texture can be considered as a combination of many of the other visual variables, including marks (texture elements), color (associated with each pixel in a texture region), and orientation (conveyed by changes in the local color).** Dashed and dotted lines, which constitute some of the textures of linear features, can be readily differentiated, as long as only a modest number of distinct types exist. Varying the color of the segments or dots can also be perceived as a texture.

Texture is most commonly associated with a polygon, region, or surface. In 3D, a texture can be an attribute of the geometry, such as with ridges of varying height, frequency, and orientation. Similarly, it can be associated with the color of the graphical entity, with regular or irregular variations in color with different ranges and distributions.

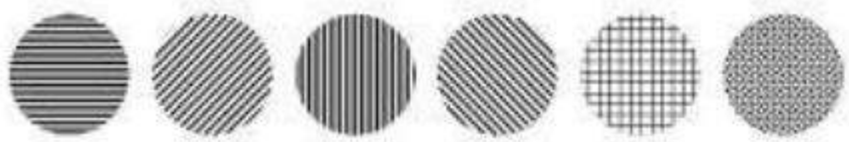


Fig:Six possible example textures that could be used to identify different data values.

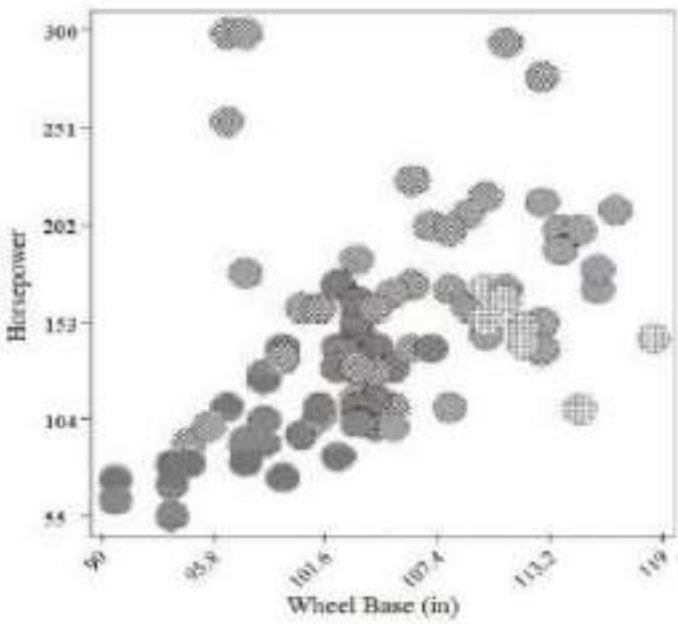


Fig: Example visualization using texture to provide additional information about the 1993 car models data set, showing the relationship between wheelbase versus horsepower (position) as related to car types, depicted by different textures.

8. Motion

The eighth visual variable is motion. In fact, **motion can be associated with any of the other visual variables, since the way a variable changes over time can convey more information.** One common use of motion is in varying the speed at which a change is occurring (such as position change or flashing, which can be seen as changing the opacity). The eye will be drawn to graphical entities based not only on similarities in behavior, but also on outliers. The other aspect of motion is in the direction; for position, this can be up, down, left, right, diagonal, or basically any slope, while for other variables it can be larger/smaller, brighter/dimmer, steeper/shallower angles, and so on.

2.4 Historical Perspective:

Robertson first proposed this need for formal models as a foundation for visualization systems . In this section, we look at a number of efforts over the years to formalize the field of visualization.

1.Bertin (1967) Semiology of Graphics:

In 1967, Jacques Bertin, possibly the most important figure in visualization theory, published his S´emiologie Graphique .

This was the first rigorous attempt at defining graphics and its application to the portrayal of information. Bertin presents the fundamentals of information encoding via graphic representations as a semiology, a science dealing with sign systems.

His first key point is the strict separation of content (the information to encode) from the container (the properties of the graphic system). To fully comprehend a sign system, one must first completely understand the primitive elements that define such a system. Consequently, Bertin embarks on defining a graphical vocabulary.

Marks	Points, lines, and areas
Positional	Two planar dimensions
Retinal	Size, value, texture, color, orientation, and shape

Bertin's graphical vocabulary.

2. Mackinlay (1986) APT

Mackinlay introduced a design for an automated graphical presentation designer of relational information, named **APT (A Presentation Tool) .**

APT was designed to extract some information from a database and to render a graphical design that presented this information.

A graphical design is an abstract description of the graphical techniques encoding information.

Marks	Points, lines, and areas
Positional	1D, 2D, and 3D
Temporal	Animation
Retinal	Color, shape, size, saturation, texture, and orientation

Mackinlay's graphical vocabulary, extended from Bertin.

Encoding Technique	Primitive Graphical Language
Retinal-list	Color, shape, size, saturation, texture, orientation
Single-position	Horizontal axis, vertical axis
Apposed-position	Line chart, bar chart, plot chart
Map	Road map, topographic map
Connection	Tree, acyclic graph, network
Misc. (angle, contain, ...)	Pie chart, Venn diagram, ...

Mackinlay's basis set of primitive graphical languages.

3. Bergeron and Grinstein (1989) Visualization Reference Model

The Visualization Reference Model by Bergeron and Grinstein defines an abstraction of the visualization problem, which establishes a mapping from the underlying data space to a physical representation .

Based on the conventional graphics system's viewing pipeline, the model is represented by a conceptual visualization pipeline.

This pipeline is organized into four stages.

The first stage identifies the source and provides appropriate information about the data structure.

Standardized data from the previous stage enters the model transformation stage which defines appropriate projections of the source data space to a usable representation data space.

Next, the view specification stage identifies the appropriate mappings from the transformed data space to visual representations.

Finally, an association stage performs the generation of graphics defined by the representations and encoded with the data, resulting in the perceptual stimulation of the data, including both graphic and sound representations.

4. Wehrend and Lewis (1990)

Wehrend and Lewis also defined a mechanism for automatically defining visualizations . They constructed a large catalog of encoding techniques

and their effective uses.

The catalog is arranged as a two-dimensional matrix classified as objects and operations.

The objects identify the problems and are grouped together based on their target domains, while the operations identify groups of similar goals. The catalog is filled with problems (tasks to perform) and solutions (visualization techniques that provide answers)

5. Robertson (1990) Natural Scene Paradigm

The Natural Scene Paradigm introduced by Robertson aims to visually display data represented by identifiable properties of realistic scenes.

Robertson reasoned that people have highly developed skills for analyzing multiple aspects of natural scenes, and aimed to exploit these skills for multivariate analysis.

Natural scene views are defined as two- or threedimensional spatial surfaces with spectral and temporal variables.

Visual properties such as surface height, material, density, phase, and wetness are defined and ranked, based on perceptual characteristics.

6. Roth (1991) Visage and SAGE

Roth et al. created Visage , a prototype user-interface environment for exploring information, which incorporates SAGE, a knowledge-based automatic graphic design tool, and extends the ideas of Mackinlay for general two-dimensional graphics .

The primary contribution of Visage is its “information-centric” approach, where the central focus of user interaction is connected directly to the data elements (graphic representations).

The whole environment is based on two basic object types: elements and frames.

Data Objects	**Position**	Axis, table, keys, network nodes
	Labels	Size, color, length
Correspondence Objects	Points, bars, links, lines, and spatial offsets	

SAGE's graphical objects.

7.Casner (1991) BOZ

BOZ, developed by Stephen Casner, is an automated graphic design and presentation tool to assist in performing specific tasks .

The main focus of BOZ is to replace logical task descriptions with perceptually equivalent tasks by encoding logical inferences (mental arithmetic or numerical comparisons) with perceptual inferences (shortest distance and average size), from which solutions can be visually obtained.

BOZ can be used to design different presentations of the same information customized to the requirements of different tasks.

Horizontal Position (100)	Area (10)	Line Thickness (3)
Vertical Position (100)	Shading (4)	Line Dashing (2)
Height (50)	Connectivity (8)	Shape (5)
Width (50)	Color (12)	Visibility (2)
Line Length (50)	Labels (∞)	Tabular (∞)

Casner's primitive graphical languages. The numbers indicate Casner's original upper limits on the number of distinct values that each primitive can practically encode.

8.Beshers and Feiner (1992) AutoVisual

AutoVisual is an automatic system for designing visualizations within the n-Vision visualization system .

The n-Vision system implements the worlds-within-worlds visualization technique that recursively defines subspace coordinate systems, and is defined as a hierarchy of interactors consisting of four components: encoding objects, encoding spaces, selections, and a user interface .

9. Senay and Ignatius (1994) VISTA

Senay and Ignatius extended the work of Mackinlay, but focused on scientific data visualization. They developed VISTA (Visualization Tool Assistant), a knowledge-based system for visualization design .

VISTA incorporates human perceptual experimental results, plus heuristic rules defining a visualization’s effectiveness.

Simple marks	Points, lines, areas, and volumes
Compound marks	Contour lines, glyphs, flow ribbons, and particles

VISTA’s visualization marks.

10. Hibbard (1994) Lattice Model

Hibbard presents a lattice model for describing visualizations .

Unlike the previous graphical models that focused on the graphic primitives, the lattice model focuses on data to display transformations.

Hibbard notes, “data objects are approximations to mathematical objects and real displays are approximations to ideal displays”.

10.Golovchinsky (1995) AVE

AVE (Automatic Visualization Environment) is an automatic graphical presentation system based on a generative theory of diagram design, the construction of diagrams from basic components corresponding to relations present in the data .

Diagrams are composed of graphical elements— only rectangles in this implementation—that have attributes and are related to other elements through graphical relations based on the underlying data relations.

The resulting graphics are trees and graphs depicting nodes as rectangles and relationships with lines or arrows.

11. Card, Mackinlay, and Shneiderman (1999) Spatial Substrate

Card et al. present a reference model for visualizations describing three primary transformations for mapping data to visual form that also support human interaction: data transformations, visual mappings, and view transformations.

Their spatial substrate, an integral part of the visual structures, deals with the use of spatial positioning for encoding data within the display.

11.Kamps (1999) EAVE

EAVE (Extended Automatic Visualization Engine) by Kamps is an extension of AVE .

EAVE takes arbitrary relations as input and generates diagram visualizations.

While the diagrams generated by this system primarily depend on data characteristics and graphical knowledge, user preferences are also taken into account.

This system only generates traditional types of diagrams that are commonly used in publications. Kamps introduces a language for defining diagrams internal to EAVE.

12.Wilkinson (1999) Grammar of Graphics

Wilkinson's Grammar of Graphics, based on his original Graphics Algebra, specifies the construction of statistical graphics .

This grammar of graphics is actually a grammar of statistical visualizations, a subclass of data visualizations readily used for statistical analyses.

Each individual component of these graphics is defined as instances of various graphical objects; the combination of individual components defining the resulting display.

Data	a set of data operations that create variables from data sets
Trans	data variable transformations
Frame	a set of variables, related by operators, that define a space
Scale	scale transformations
Coord	a coordinate system
Graph	graph (points) and their aesthetic attributes
Guide	one or more guides

Wilkinson's seven specifications [460].

13.Hoffman (2000) Table Visualizations

The formal model for Table Visualizations developed by Hoffman was the first attempt at defining a generalized space of data visualizations .

The aim was the encapsulation of the primitive-graphic properties that define individual visualization techniques, and then the inference of the space of these techniques as the combination of graphic elements within some geometric layout. This research combined four specific visualization techniques: survey plots, scatterplots, RadViz, and parallel coordinates.

P_1	size of the scatterplot points
P_2	length of the perpendicular lines extending from individual anchor points in a scatterplot
P_3	length of the lines connecting scatterplot points associated with the same data point
P_4	width of the rectangle in a survey plot
P_5	length of the parallel coordinate lines
P_6	blocking factor for the parallel coordinate lines
P_7	size of the RadViz plot point
P_8	length of the spring lines extending from individual anchor points of a RadViz plot
P_9	the zoom factor for the spring K constant

ɔle 4.10. Hoffman's dimensional anchor graphical parameters.

2.5. Visualization Taxonomies

A taxonomy is a means to convey a classification. Often hierarchical in nature, a taxonomy can be used to group similar objects and define relationships.

In visualization, we are interested in many forms of taxonomies, including data, visualization techniques, tasks, and methods for interaction.

1. Keller and Keller (1994) Taxonomy of Visualization Goals

Keller and Keller, in their book Visual Cues , classify visualization techniques based on the type of data being analyzed and the user's task(s). Similar to those identified earlier in this book, the data types they consider are:

• scalar (or scalar fields) •nominal; • direction (or direction field); • shape; • position; • spatially extended region or object (SERO).

The authors also define a number of tasks that a visualization user might be interested in performing. While some of the tasks seem interrelated, their list is a useful starting position for someone setting out to design a visualization for a particular application.

2.Shneiderman (1996) Data Type by Task Taxonomy

His list of data types consisted of: • one-dimensional linear; • two-dimensional map; • three-dimensional world; • temporal; • multidimensional; • tree; • network.

For his tasks, Shneiderman looked more at the behavior of analysts as they attempt to extract knowledge from the data.

3.Keim (2002) Information Visualization Classification

Keim designed a classification scheme for visualization systems based on three dimensions: data types, visualization techniques, and interaction/distortion methods .

Classification of Data Types.

6 types of data exist:

1. One-dimensional data—e.g., temporal data, news data, stock prices, text documents 2. Two-dimensional data—e.g., maps, charts, floor plans, newspaper layouts 3. Multidimensional data—e.g., spreadsheets, relational tables 4. Text and hypertext—e.g., new articles, web documents5. Hierarchies and graphs—e.g., telephone/network traffic, system dynamics models 6. Algorithm and software—e.g., software, execution traces, memory dumps

Classification of Visualization Techniques.

5 classes of visualization techniques exist:

1. Standard 2D/3D displays—e.g., x, y- or x, y, z-plots, bar charts, line graphs; 2. Geometrically transformed displays—e.g., landscapes, scatterplot matrices, projection pursuit techniques, prosection views, hyperslice, parallel coordinates; 3. Iconic displays—e.g., Chernoff faces, needle icons, star icons, stick figure icons, color icons, tilebars; 4. Dense pixel displays—e.g., recursive pattern, circle segments, graph sketches; 5. Stacked displays—e.g., dimensional stacking, hierarchical axes, worlds-within-worlds, treemaps, cone trees.

Classification of Interaction and Distortion Techniques.

5 classes of interaction exist

1. Dynamic projection—e.g., grand tour system, XGobi, XLispStat, ExplorN; 2. Interactive filtering—e.g., Magic Lenses, InfoCrystal, dynamic queries, Polaris; 3. Interactive zooming—e.g., TableLens, PAD++, IVEE/Spotfire, DataSpace, MGV and scalable framework; 4. Interactive distortion—e.g., hyperbolic and spherical distortions, bifocal displays, perspective wall, graphical fisheye views, hyperbolic visualization, hyperbox; 5. Interactive linking and brushing—e.g., multiple scatterplots, bar charts, parallel coordinates, pixel displays and maps, Polaris, scalable framework, S-Plus, XGobi, XmdvTool, DataDesk.

2.6 Experimental Semiotics Based on Perception:

In essence, argument is that visualization is about diagrams and how they can convey meaning. Generally, diagrams are held to be made up of symbols, and symbols are based on social interaction. The meaning of a symbol is normally understood to be created by convention, which is established in the course of person-to-person communication.

Diagrams are arbitrary and are effective in much the same way as the written words on this page are effective-we must learn the conventions of the language, and the better we learn them, the clearer that language will be. Thus, one diagram may ultimately be as good as another; it is just a matter of learning the code, and the laws of perception are largely irrelevant. This view has strong philosophical proponents from the field of semiotics.

1.Semiotics of Graphics

The study of symbols 'and how they convey meaning is called semiotics. This discipline was originated in the United States by C.S. Peirce and later developed in Europe by the French philosopher and linguist Ferdinand de Saussure (1959).

Semiotics has been dominated mostly by philosophers and by those who construct arguments based on example rather than on formal experiment.

In his great masterwork, Semiology of Graphics, Jacques Bertin (1983) attempted to classify all graphic marks in terms of how they could express data. For the most part, this work is based on his own judgment, although it is a highly trained and sensitive judgment. There are few, if any, references to theories of perception or scientific studies

It is often claimed that visual languages are easy to learn and use. But what do we mean by the term visual language-clearly not the writing on this page. Reading and writing take years of education to master, and it can take almost as long to master some diagrams.

Because it seems entirely reasonable to consider visualizations as communications, their argument strikes at the root of the idea that there can be a natural science of visualization with the goal of establishing specific guidelines for better representations.

2.Pictures as Sensory Languages

The question of whether pictures and diagrams are purely conventional, or are perceptual symbols with special properties, has been the subject of considerable scientific investigation. A good place to begin reviewing the evidence is the perception of pictures. There has been a debate over the last century between those who claim that pictures are every bit as arbitrary as words and those who believe that there may be a measure of similarity between pictures and the things that they represent. This debate is crucial to the theory presented here; if even "realistic" pictures do not embody a sensory language, it will be impossible to make claims that certain diagrams and other visualizations are better designed perceptually.

3.Sensory versus Arbitrary Symbols

the word sensory is used to refer to symbols and aspects of visualizations that derive their expressive power from their ability to use the perceptual processing power of the brain without learning. The word arbitrary is used to define aspects of representation that must be learned, because the representations have no perceptual basis. For example, the written word dog bears no perceptual relationship to any actual animal. Probably very few graphical languages consist of entirely arbitrary conventions, and probably none is entirely sensory. However, the sensory-versus-arbitrary distinction is important. Sensory representations are effective (or misleading) because they are well matched to the early stages of neural processing. They tend to be stable across individuals, cultures, and time. A cave drawing of a hunt still conveys much of its meaning across several millennia. Conversely, arbitrary conventions derive their power from culture and are therefore dependent on the particular cultural milieu of an individual.

2.7 Gibson's Affordance theory :

The great perception theorist J.J. Gibson brought about radical changes in how we think about perception with his theories of ecological optics, affordances, and direct perception.

Gibson assumed that we perceive in order to operate on the environment. Perception is designed for action. Gibson called the perceivable possibilities for action affordances; he claimed that we perceive these properties of the environment in a direct and immediate way. This theory is clearly attractive from the perspective of visualization, because the goal of most visualization is decision making. Thinking about perception in terms of action is likely to be much more useful than thinking about how two adjacent spots of light influence each other's appearance (which is the typical approach of classical psychophysicists).

Much of Gibson's work was in direct opposition to the approach of theorists who reasoned that we must deal with perception from the bottom up, as with geometry. The pre-Gibsonian theorists tended to have an atomistic view of the world. They thought we should first understand how single points of light were perceived, and then we could work on understanding how pairs of lights interacted and gradually build up to understanding the vibrant, dynamic visual world in which we live. Gibson took a radically different, top-down approach. He claimed that we do not perceive Points of light; rather, we perceive possibilities for action. We perceive surfaces for walking, handles for pulling, space for navigating, tools for manipulating, and so on. In general, our whole evolution has been geared toward perceiving useful possibilities for action. In an experiment that supports this view, Warren (1984) showed that subjects were capable of accurate judgments of the "climbability" of staircases. These judgments depended on their own leg lengths. Gibson's affordance theory is tied to a theory of direct perception. He claimed

that we perceive affordances of the environment directly, not indirectly by piecing together evidence from our senses.
Translating the affordance concept into the interface domain, we might construct the following principle: to create a good interface, we must create it with the appropriate affordances to make the user's task easy. Thus, if we have a task of moving an object in 3D space, it should have clear handles to use in rotating and lifting the object. Figure 1.10 shows a design for a 3D object-manipulation interface from Houde (1992). When an object is selected, "handles" appear that allow the object to be lifted or rotated. The function of these handles is made more explicit by illustrations of gripping hands that show the affordances.

However, Gibson's theory presents problems if it is taken literally. According to Gibson, affordances are physical properties of the environment that we directly perceive. Many theorists, unlike Gibson, think of perception as a very active process: the brain deduces certain things about the environment based on the available sensory evidence. Gibson rejected this view in favor of the idea that our visual system is tuned to perceiving the visual world and that we perceive it accurately except under extraordinary circumstances. He preferred to concentrate on the visual system as a whole and not to break perceptual processing down into components and operations. He used the term resonating to describe the way the visual system responds to properties of the environment. This view has been remarkably influential and has radically changed the way vision researchers think about perception.

There are three problems with Gibson's direct perception in developing a theory of visualization. The first problem is that even if perception of the environment is direct, it is clear that visualization of data through computer graphics is very indirect. Typically, there are many layers of processing between the data and its representation. In some cases, the source of the data may be microscopic or otherwise invisible. The source of the data may be quite abstract, such as company statistics in a stock-market database. Direct perception is not a meaningful concept in these cases.
Second, there are no clear physical affordances in any graphical user interface. To say that a screen button "affords" pressing in the same way

as a flat surface affords walking is to stretch the theory beyond reasonable limits. In the first place, it is not even clear that a real-world button affords pressing. In another culture, these little bumps might be perceived as rather dull architectural decorations. Clearly, the use of buttons is arbitrary; we must learn that buttons, when pressed, do interesting things in the real world. Things are even more indirect in the computer world; we must learn that a picture of a button can be "pressed" using a mouse, a cursor, or yet another button. This is hardly a direct interaction with the physical world.
Third, Gibson's rejection of visual mechanisms is a problem. To take but one example, much that we know about color is based on years of experimentation, analysis, and modeling of the perceptual mechanisms. Color television and many other display technologies are based on an understanding of these mechanisms. To reject the importance of understanding visual mechanisms would be to reject a tremendous proportion of vision research as irrelevant. This entire book is based on the premise that an understanding of perceptual mechanisms is basic to a science of visualization.

2.8 A Model of Perceptual Processing

Figure gives a broad schematic overview of a three stage model of perception. In Stage 1, information is processed in parallel to extract basic features of the environment. In Stage 2, active processes of pattern perception pull out structures and segment the visual scene into regions of different color, texture, and motion patterns. In Stage 3, the information is reduced to only a few objects held in visual working memory by active mechanisms of attention to form the basis of visual thinking.

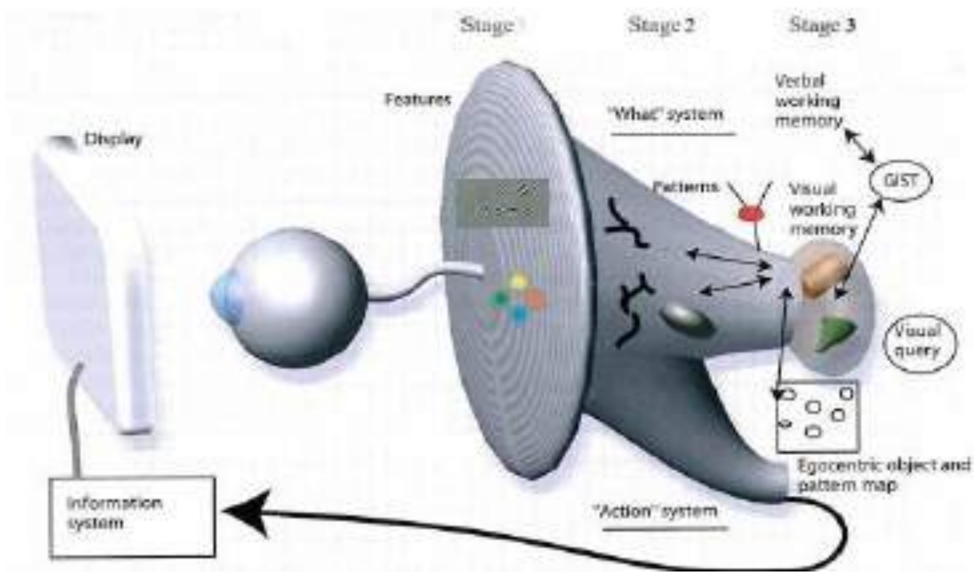


Fig: A 3 Stage model of perception

Stage 1: Parallel Processing to Extract Low-Level Properties of the Visual Scene Visual information is first processed by large arrays of neurons in the eye and in the primary visual cortex at the back of the brain. Individual neurons are selectively tuned to certain kinds of information, such as the orientation of edges or the color of a patch of light. In Stage 1 processing, billions of neurons work in parallel, extracting features from every part of the visua field simultaneously. This parallel processing proceeds whether we like it or not, and it is largely independent of what we choose to attend to (although not of where we look). It is also rapid. If we want people to understand information quickly, we should present it in such a way that it could easily be detected by these large, fast computational systems in the brain.

Important characteristics of Stage 1 processing include:

* Rapid parallel processing

*Extraction of features, orientation, color, texture, and movement patterns

*Transitory nature of information, which is briefly held in an iconic store

*Bottom-up, data-driven model of processing

Stage 2: Pattern Perception

At the second stage, rapid active processes divide the visual field into regions and simple patterns, such as continuous contours, regions of the same color, and regions of the same texture.

Important characteristics of Stage 2 processing include:

*Slow serial process

* Involvement of both working memory and long-term memory

*More emphasis on arbitrary aspects of symbols

*In a state of flux, a combination of bottom-up feature processing and top-down attentional mechanisms

* Different pathways for object recognition and visually guided motion

Stage 3: Sequential Goal-Directed Processing

At the highest level of perception are the objects held in visual working memory by the demands of active attention. In order to use an external visualization, we construct a sequence of visual queries that are answered through visual search strategies. At this level, only a few objects can be held at a time; they are constructed from the available patterns providing answers to the visual queries. For example, if we use a road map to look for a route, the visual query will trigger a search for connected red contours (representing major highways) between two visual symbols (representing cities).