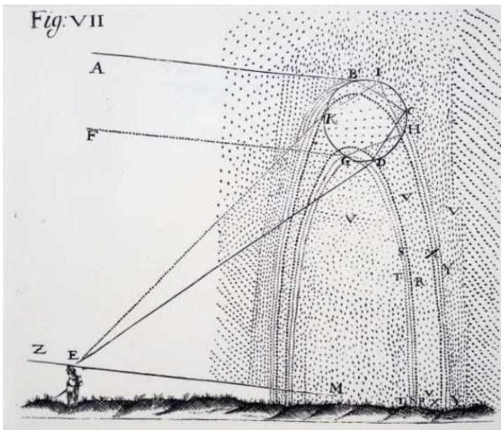
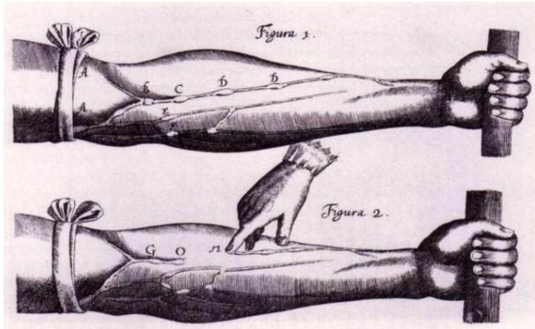
Cognitive Foundations of Visualisation

History

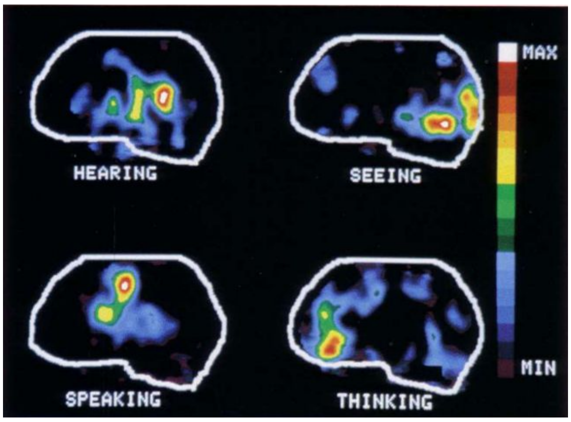
- **dispute over pictures:**
    - pagan antiquity: pictorial representations are self-evident
    - Judeo-Christian tradition: prohibition of images, images are associated with idolatry (applies to all book religions)
    - until time of state recognition of Christianity, church has fundamentally opposed use of images
    - 6th century: Pope Gregory the Great praises the preference of images as a means of understanding for the illiterate and the “heathens”
    - Byzantium: the worship of images is forbidden
    - Reformation: forbids praying in front of Christian images and sculptures
- **techniques of image representation:**
    - **Papyrus**: easy integration of text and image; drawing pictures is difficult
    - **Manuscript**: integration of image and text relatively easy
    - **Book**: integration of image and text difficult because of various printing techniques (printing press, woodcut, copperplate engraving)
    - **electronic text**, hypertext: integration of image and text simple (pixels)
- **central perspective:**
    - supposed to evoke the **illusion of 3D space**
    - assumes that **time stands still during** the gathering of information and the **viewers do not move**
    - originated at the beginning of the **15th century** in Florence
    - **Renaissance's** enthusiasm for the perspective arose
        - from the **desire to imitate nature**
        - at a time when **painting** developed from craftsmanship in the Middle Ages to an **art**
    - **construction**:
        - **baseline** of an image is divided into equal sections
        - **vanishing point** is set, which is at eye level of the artist
        - **checkerboard pattern** is constructed on the "floor" in which the foreshortening is considered
- **pictures in historiography:**
    - **society:** role of the image is the **exchange of information**
    - **science**: **mistrust** of learned men against the sensuality of images ruled for a very long time
    - **modern times:**
        - analysis of images did not play a particularly important role
        - disciplines were mainly based on the interpretation of written text
        - changed in the last few years **images are increasingly being used in historic research** (e.g., research into the use of everyday objects such as glasses, underwear, etc.)
- **scientific illustration:**
    1. **Observation:**
        - **drawing**: simplest and oldest form of scientific illustration
        - **scientists report what they have seen, pictures are pure descriptions**
        - **example: thistle of Pedanios Dioscorides** (Greek doctor who described plants etc., manuscript was later illustrated, became very important in the antiquity)



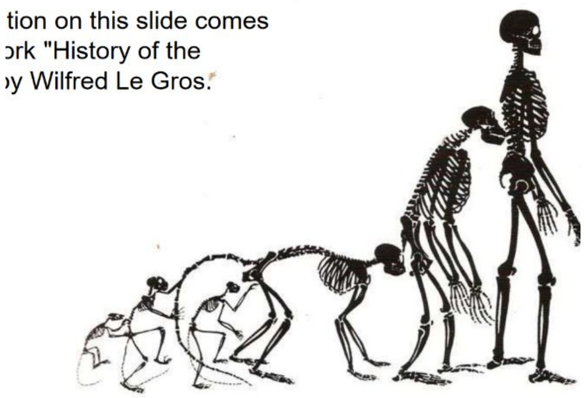
2. **Induction:**
    - answers questions such as **"why" and "how"**
    - **represent and clarify explanations of specific phenomena**
    - **example: emergence of a rainbow by René Descartes**
3. **Methodology:**
    - essential feature of scientific research is the **systematic approach**, scientific methods play an important role
    - **methodological illustrations show how such procedures can work**
    - **example: circulation of the blood** by William Harvey (discovered circulatory system)



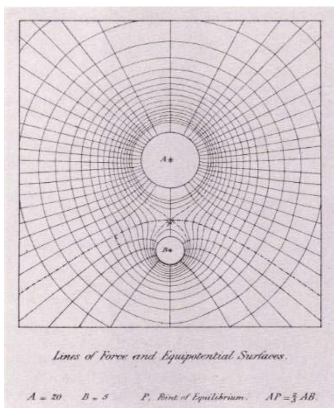
4. **Self-illustration:**
    - **when scientists observe a repetitive process, they want to find out its cause**
    - nature itself provides an important picture that can be deciphered
    - **scientists have found ways in which phenomena can illustrate themselves**
    - example: Positron Emission Tomography **(PET scan)**



5. **Classification:**
    - attempt to **recognise something like order in nature**
    - knowledge must be encrypted and stored so that subsequent observations can be compared
    - **differences can be studied and explained**
    - ordering systems are the **basis for further investigation and evaluation** of research results
    - **example: evolution of Homo sapiens**

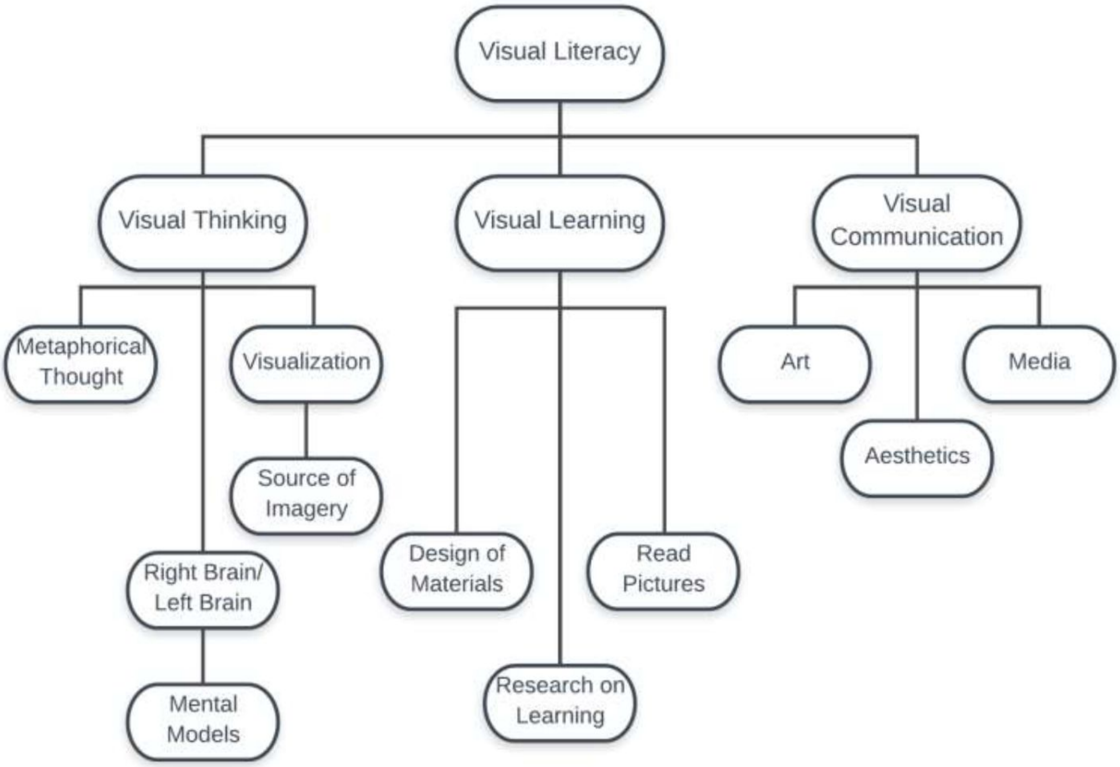


6. **Conceptualization:**
    - concepts allow us to **reflect on our observations** and experiences in the objective world
    - **example: electromagnetic fields**



- **differences between verbal and pictorial representation:**
    - **language:**
        - discrete symbols
        - explicit, requires symbols to express relationships
        - grammatical; clear rules for combining different types of symbols
        - abstract
    - **pictograms:**
        - no discrete symbols
        - implicit; no own symbols to express relationships
        - no clear rules for combination of different symbol types
        - concrete
    - do visual and verbal representations reflect reality in a similar way?
        1. **images are based (like language) on conventions**
            - understanding images **needs to be learned**
            - conventions for how images should be interpreted

        - **images also have their own "grammar"** that is artificially defined
    2. **images can be understood spontaneously**
        - realistic (perspective) painting and photography **correspond to reality** and reflect it "as it is"
        - **ability to understand images is largely innate**
- **forms of pictorial representations:**
    - **analogous pictures:**
        - **show similarity to the things or concepts for which they stand**
        - **drawings or photographs** that show how things look like
    - **logical pictures:**
        - **e.g., line or bar charts**, flow charts
        - do not resemble the depicted facts and can (like tables or texts) **represent things that cannot be perceived**
        - **interpretation must be learned**
- **visual literacy:**
    - **literacy:**
        - several definitions
        - **ability to read and write (narrow)**
        - understanding written material, **education (wide)**
    - **digital literacy:**
        - **ability to understand and use information in multiple formats**
        - from a **wide range of sources** when it is **presented via computers**
    - **visual literacy:**
        - **ability to understand (read) and use (write) images and to think and learn in terms of images**
        - research on visual literacy is based on several disciplines: Art, Psychology, Linguistics, Philosophy, ...
        - definitions rather based on the idea that **dealing with pictorial material is learned**
        - **ability to understand visual media**
        - **enhancement of cognitive abilities** through increase visual literacy
        - raising the awareness of manipulation through increased visual literacy
        - aesthetic appreciation
        - **visual thinking:**
            - **based on Rudolf Arnheim** who opposes the separation of perception and thinking
            - **thinking depends on perception and happens in pictures**
            - **examples: active selectivity as a basic trait of vision**, concept formation
        - **visual learning:**
            - **learning from and through images**
            - science that deals with the design of visual educational material
        - **visual communication:**
            - attempt to **express oneself with pictorial and graphic symbols**
            - especially important: critical reflection of mass media
            - messages are communicated by visual material
            - e.g., **perspective implies relationship between the viewer and what is depicted** (frontal vs. oblique)



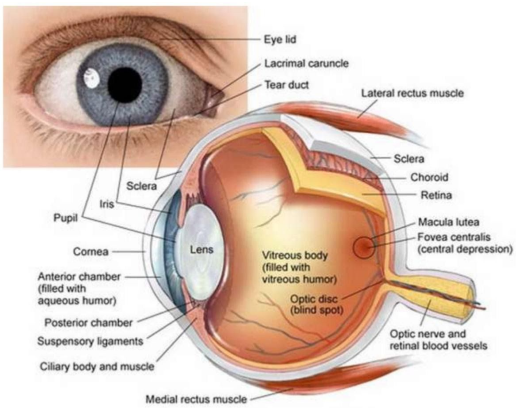
Perception

Low-Level Vision

- **direct perception vs. conventional representation:**
  - **direct sensory perception:**
    - usually very **effective and stable**
    - largely **innate**, so it is usually **culture-invariant**
    - however, there are **some acquired differentiations of the brain** (e.g., new born cats reared in an exclusively striped environment develop a greater number of neurons in the brain responding to bar-like stimuli)
  - **conventional representations:**
    - usually hard to learn
    - phenomena of immediate perception: **perception of colours and patterns**
    - **can be generalised to all humanity**
    - **perceptual performance is based on combination of innate and acquired mechanisms**
- **properties of direct sensory perception:**
  - **understanding without learning**
  - behaviour **cannot be unlearned**
    - **optical illusions** are still perceived even when they are known to be deceptions
  - **sensual immediacy**
    - certain phenomena are perceived very quickly because they are not learned but "hardwired" in the brain
  - study through neuroscience
- **properties of conventional representations:**
  - **hard to learn** (e.g., writing)
  - **easy to forget**
    - however, there are visual representations that have been overlearned (such as numbers) that can almost not be forgotten

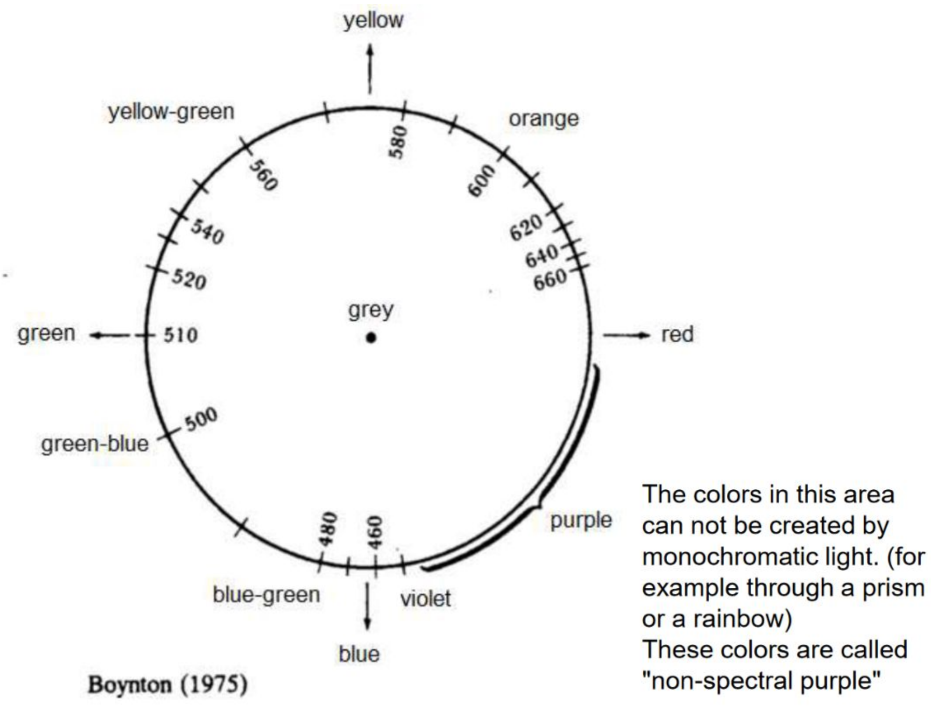
- **embedded in the cultural context**
  - in addition, there are artificial symbols that are very common (Arabic numerals)
  - existing artificial/conventional representations can sometimes be difficult to replace with newer ones
- **powerful form of representation**
  - e.g., mathematical representations: example that not all visual representations can be easily learned
- **rapid changeability**
  - immediate perception changes during evolution, while conventional representations change in the course of historical development
- investigation of conventional forms of representation
  - e.g., through psychology, sociology, HCI

- **human eye:**
  - **Retina:**
    - innermost, light-sensitive layer of tissue
    - **contains specialised cells called photoreceptors (rods and cones)**
  - **Pupil, Lens:**
    - **pupil controls the amount of incident light**
    - **lens controls the refraction of light**
  - **Rods and Cones:**
    - light-sensitive receivers are in the outermost layer of the retina
    - **ca. 3 - 6 million cone cells serve for colour vision**
    - **black and white sensations are mediated by 75 to 125 million rod cells**
  - **Fovea centralis:**
    - **highest acuity of vision**
    - **only cones**
    - visual axis
  - **image on the retina is reversed and inverted** perception still corresponds to the state of things in the environment
  - visual acuity (resolution) is greatest in the fovea centralis and much lower outside, **foveal cones are very close to each other** and each has its own ganglion cell, while outside the fovea the cones are further apart and mixed in with rods
  - visual field is irregular due to the shape of the face
  - **seeing with two eyes allows depth perception** for nearby stimuli, the brain infers from the position of the eyes how close or how far away an object is
  - depth perception in the distance is derived from learned cues (occlusion, colour, texture)
  - **retina produces a 2D picture, the brain infers a 3D image from consecutive pictures** according to certain rules



- **lateral inhibition:**
  - **mechanism in the retina**
  - **ensures that in areas of change in light intensity, contrasts are emphasised**
  - **ensures that in areas of constant light intensity, activity of the nerve cell remains low**
  - causes the world to be seen as consisting of highly contoured objects, to a much greater extent than in “reality”
  - nerve cells are not only connected upwards, but also connected to their lateral neighbours, assumption is that **adjacent nerve cells inhibit each other creates contrast phenomena in areas of strong change in light intensity**
  - **neurons subject to low light intensity → little neural response, inhibit neighbours little**
  - **neurons subject to high light intensity→ high neural response, strongly inhibit neighbours**

- **colour perception:**
  - **white sunlight is composed of all spectral colours**
  - each spectral colour has a specific wavelength and cannot be further decomposed into other colours
  - **monochromatic colours: light of only one wavelength**
  - **polychromatic colours: light of several wavelengths**
  - wavelength measured in nanometres: ca. **400nm violet/blue**, ca. **700nm red/purple**
  - for the same objective light intensity: **colours in the middle of the spectrum (green, yellow, orange) are brighter than colours at the edge of the spectrum**
  - colour perception can greatly **facilitate the differentiation of objects**, enables objects to be identified in front of a highly structured background (e.g., colour-blind have great difficulty picking berries)



  - **colour shade:** wavelength function
  - **saturation:** expression for the **number of different wavelengths** (**more mixed less saturated, more saturated brighter colour**)
  - **brightness: light intensity**, depends on the **adaptation of the eye** and the illumination intensity of the environmental cues

- **colour theory:**
  - 2 theories, different components of a unified process
  - **Trichromatic theory:**
    - assumes that **each hue can be mixed by the light of three different wavelengths (additive colour mixing)**
    - requirements: **3 different receptor mechanisms with different spectral sensitivity**
    - ca. 1960: 3 different pigments were detected in the cones
  - **Opponent process theory of colour vision:**
    - **trichromatic theory cannot explain various effects of colour vision: simultaneous and successive contrasts, afterimages, red-green blindness**
    - assumes that there are **mechanisms of perception that produce opposite responses** (e.g., intense viewing of a red field green (negative) afterimage)
    - **3 pairs: red-green, blue-yellow, black-white**
- **physiological reports:**
  - measurements of the responses of neurons in the retina and in the corpus geniculatum laterale could confirm that there are **opposing neurons that react with an excitatory response to light at one end of the spectrum and with an inhibitory response at the other end of the spectrum**
  - why have mechanisms of opposing neurons in addition to colour perception in the cones?
    - additional mechanism allows a **more precise perception**
    - phenomena described by Hering are bound to neurons in the retina and in the corpus geniculatum laterale, therefore at **later stages of perception**
    - mechanism of colour perception described by the trichromatic theory is only bound to the cones
- **colour constancy:**
  - colour perception depends not only on the **wavelength of the observed light**, but also on the **brightness and the type of lighting**
  - in sunlight, light of all wavelengths is combined in ca. the same ratio
  - in a light bulb, the proportion of long-wave light is higher → light looks slightly yellowish
  - nevertheless, the **colours are perceived largely similarly** in both lighting conditions
  - the reason for this is that the **colour pigments of the cones fade when they are exposed to the light of a certain wavelength for a longer period of time** (**chromatic adaptation**)

High-Level Vision

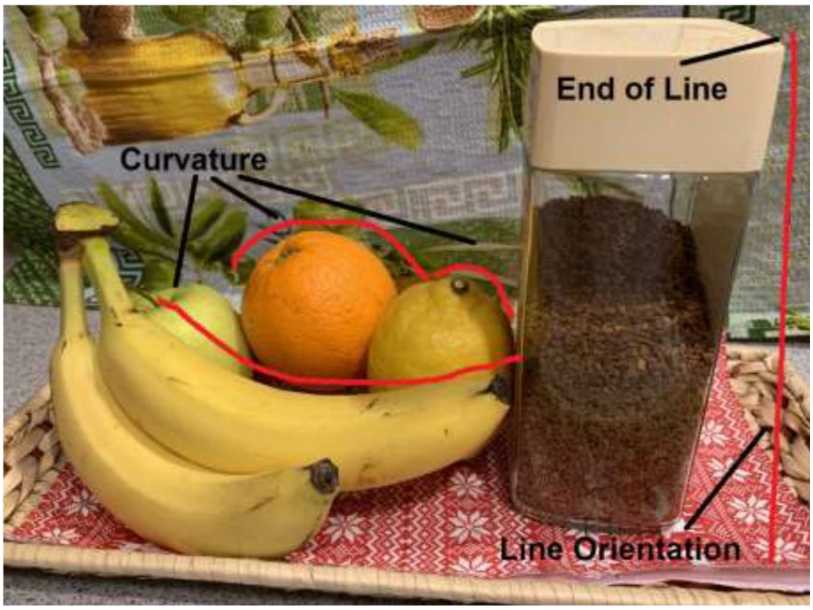
- general:
  - distinction between conscious/unconscious perception
    - **much of our perception is unconscious** (e.g., our body perception)
  - **perception is an active process**
    - development together **with the musculoskeletal system**
    - **Saccades: eyes move frequently, successively examining different parts of the environment** (ca. 5 to 6 times/second)
    - visual perception ≠ photo
  - **orientation**
    - we need to be able to control our movement on Earth to ensure our survival we have to make **constant movements with our head and eyes**
    - we also need to be able to **predict events**
    - perception supports both **goal-directed and exploratory movement**
  - **strengths of human perception:**
    - **good at perceiving changes**
    - **eyes can detect movement very efficiently**

- **good at recognizing visual patterns** and distinguishing between different types of patterns
- **weaknesses of human perception:**
  - **consistent information is less well perceived** (similar to animals) not necessarily a disadvantage **we only deal with new information**
  - **cannot recognise a range of environmental information** (radio waves, radioactive rays, magnetic forces, ultraviolet rays, ...)

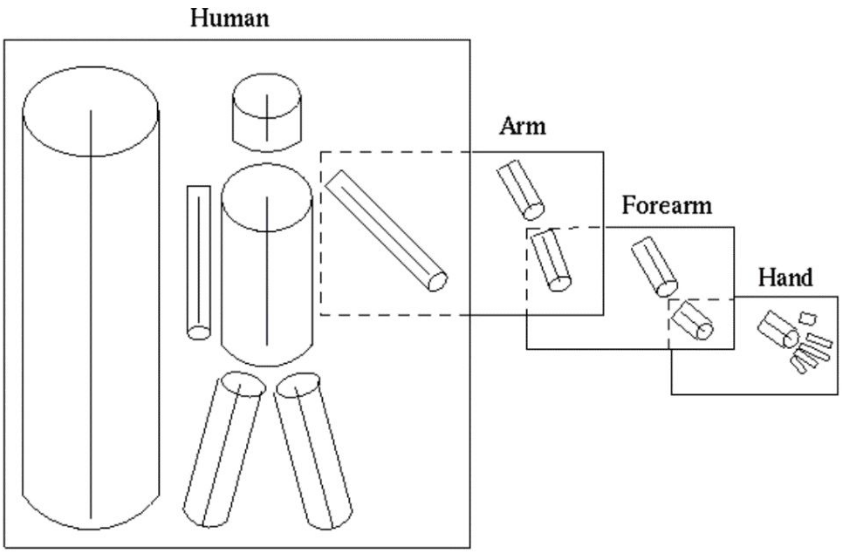
Object Perception

- usually seen as something that **takes place at a higher level than pattern recognition or colour perception (high-level vision)**
- does not necessarily have to take place later in time than the simpler forms of perception (low-level vision)
- **often does not focus on the entire field of view, but only on certain parts that seem particularly important in a particular situation**
- object perception is thus also about (situation-dependent) interpretation of objects
- **objects can be recognised by their shape, but also by their colour or texture (e.g., a tree crown) or by their location (e.g., doorknob)**
- **previous knowledge, expectations and context play a major role**

- **theories of object perception:**
  - **shape usually dominates all other factors**
  - relationship to classification
  - simple theory: if we had stored a lot of views of different objects in the brain whenever we see an object, we compare it to the stored images in the brain 3 reasons why this theory is unlikely:
    1. number of possible views of an object is very large
    2. views are probably not similar enough to recognise an object (different angles, different lighting, different context)
    3. changing shape (movement of human body)
  - **Feature Integration Theory:**
    - **pre-attentive phase: basic 2D properties are determined**
    - **focused attention phase: properties are combined**
    - on this basis, an object is recognised
    - basic properties are e.g., **curvature, end of a line, orientation of a line** etc.
    - **recognising the object by comparing the perceived object with information stored in the memory**



- **Recognition-by-Components Approach:**
  - also relies on the **recognition of basic properties, but in 3D**
  - however, these are **volumetric primitives** (cylinder, sphere, etc.) and called “geons”
  - we are able to **recognise objects by separating them into geons** (the object’s main component parts)
  - **36 different geons**
  - **properties:**
    - **view invariance**
      - invariance with regard to the **angle of view**
      - geons can be easily identified even if they are seen from different angles
    - **discriminability**
      - **geons can be easily distinguished from each other**
    - **resistance to visual noise**
      - geons can also be recognised well when seen in **poor visibility conditions**
    - **criticism:** mechanisms allow us to **distinguish between classes of objects**, but **not between similar objects (e.g., one bird from another)**



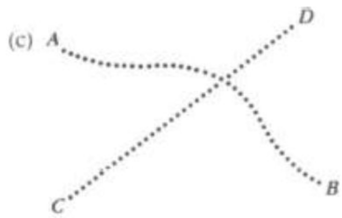
- **Alignment Method:**
  - **compensate for the transformations separating the viewed object and the corresponding stored model**, and then compare them
  - example: difference in size
  - we **search for a maximum fit of object model, transformations and viewed object**
  - possible transformations: **size, position, orientation**
  - example of **object-specific transformations: distortions of the face due to facial expressions**
  - orientation changes are difficult: orientation can be determined either based upon horizontal or vertical line segments or symmetry
  - after the compensation stage, comparison with stored models should be straightforward
  - **problem: alignment for more complex features than size, position or orientation** (e.g., faces – facial expression)

Perception Theories

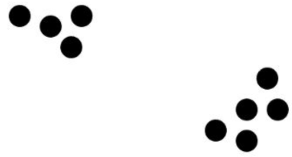
- **Gestalt Psychology:**

- important for screen design
- **law: distinction between figure and ground**
  1. figure is more "thing-like" than the ground
  2. figure is in front of the ground
  3. the ground is seen as unshaped material
  4. contour of the figure is seen as part of the figure
  - under otherwise identical circumstances, **smaller, lighter and better structured stimuli are seen as figures in front of a background** – in contrast to that, larger, darker and less textured fields as background of a figure
  - **symmetrical objects are rather seen as a figure**
  - vertically and horizontally oriented areas are seen as figures rather than areas with different orientations
  - areas that allow a meaningful interpretation are seen more as a figure

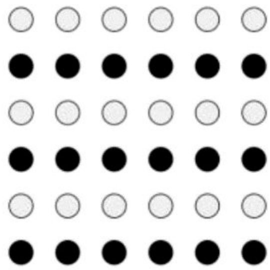
- **law: good continuation**
  - **points that, when connected,** are either straight or form a well-formed curve and **are considered as belonging together**



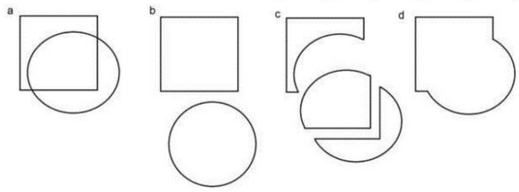
- **law: proximity**
  - **elements are organised as a related shape when they are close to each other**



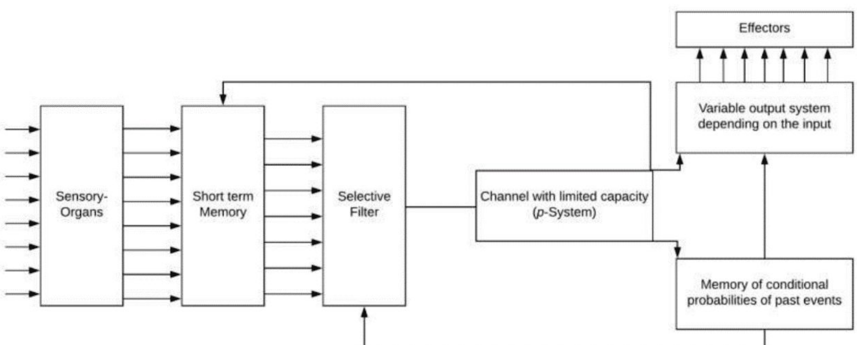
- **law: similarity**
  - under the same circumstances, **elements that are similar to each other are organised into a single entity**



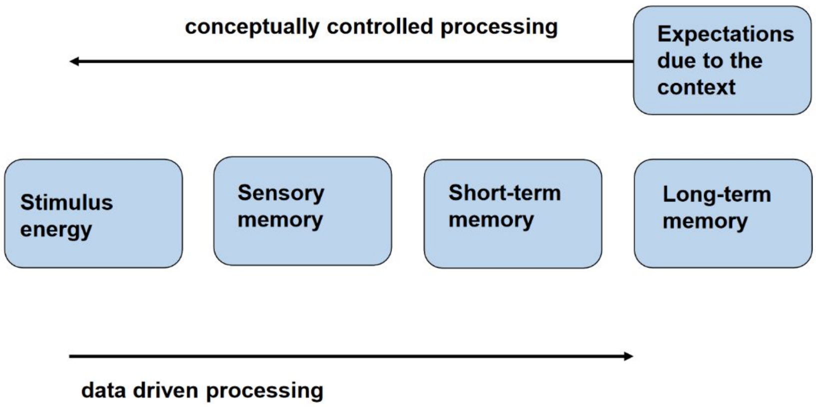
- **law: "good form"**
  - **each configuration is supposed to provide the simplest possible structure**



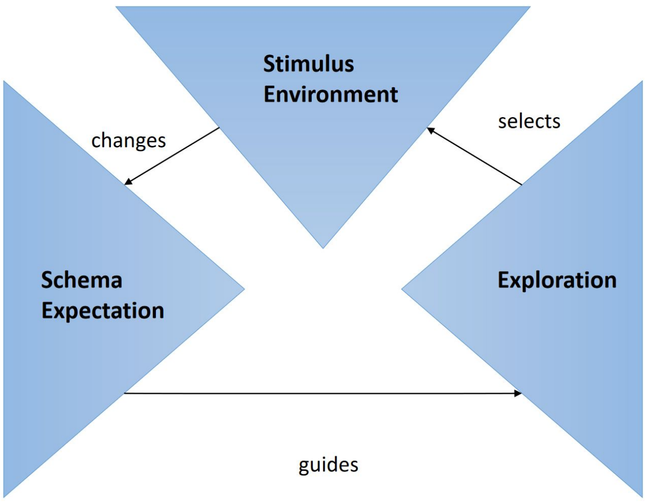
- **Information processing approach:**
  - relies to a large extent on the analogy with the computer
  - **human and machine information processing are essentially considered identical**
  - problem: computer technology has developed rapidly in recent decades → the information processing approach has changed dramatically
  - initial approach assumed that information would be processed sequentially
  - **information meets the sensory organs moves into the short-term memory stored in the long-term memory**
  - **this model is too simplistic**: empirical studies show that **information is always interpreted in the light of previous experience** and that there are **many feedback loops** in this process more complex models of information processing were developed
  - **Model of Broadbent:** humans process information with limited capacity and select information to be processed early:



- **Model of Selfridge:**
  - **most commonly used patterns of our culture** (for example, letters) are **composed of a few elements**, e.g., from vertical bars, right corners, left corners, right arcs, left arcs, etc.
  - these elements also retain their meaning when the character size is changed, and to a certain extent they are also **insensitive to transformations** (e.g., fonts, rotation)
  - for these elements, our **brain has developed feature detectors that can work in parallel**
  - in addition, **neural structures are assumed** where the information coming from the feature detectors converges and the **detected patterns are integrated** again
  - at the same time, **checks are run as to whether the composite pattern corresponds to a previously learned character**
  - if it corresponds to a plurality of characters, then it is decided on the basis of the **context information which character corresponds to the neural structure**
- **„Pandemonium system“** (Lindsay & Norman): pattern is first perceived in its parts before the "whole"
- **Data driven vs. conceptually controlled processing:**



- **Perceptual cycle (Neisser):**
  - **expectation of perceivers guides the exploration of the available information**
  - **object features found in reality change the expectations**



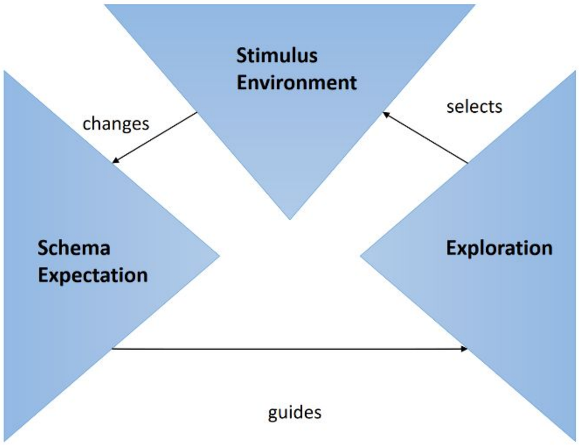
- **Ecological approach (Gibson):**
  - **Gibson criticised classical perceptual psychology because it tests only unrealistic situations (immobile observers, very limited stimulus configurations)**

- he assumes that human visual perception has developed in a human body with an upright posture standing on solid ground
- solid ground has essential properties that provide a frame of reference for perception (e.g., texture)
- **movement plays an important role**
  - **different angle when we move**
  - we always experience these things as the **same objects** (**invariance**)
  - **creates an optical flow field** (**ambient optic array**)
- **perception is immediate and results from the optical arrangement itself** (as opposed to the information processing approach or constructivism)
- **ambient optic array:**
  - Gibson assumes that the **environment is heterogeneous and differentiated**, not empty, but **filled with shaped objects**
  - structured **environment completely encloses the observers**
  - observers always take a **concrete point of observation in space** point is not fixed and static, but **constantly changes** with their movement
  - from the respective point of view, there is always a **certain angle to the objects**
  - essential aspect of perception is that **objects are covered by other objects** over and over again (**occlusion**)
- **texture:**
  - natural substances are rarely homogeneous but **aggregates of natural substances**
  - in addition, they are not amorphous, but **consist of bits of different materials**
  - **→ natural substances are heterogeneous and polymorphous**
  - surface is rough and irregular (exception, e.g., glass) creates a specific texture (usually regular)
  - same "amount" of texture is an indication of an equal area of ground
- **affordance:**
  - **function can be derived directly from the shape of an object** (e.g., hammer: to drive in a nail but not cutting a sheet of paper)
  - however, the **motivational nature of an object also depends on the needs of the perceiving person** (e.g., an orange = for hungry person food, for angry person missile)
  - **meaning of objects can be perceived directly** in this way, since the **motivational nature of an object is immediately visible**
  - no complex information processing activities
  - recourse to long-term memory not necessary, no top-down processes
- **invariance:**
  - **perceptible properties of objects/events that remain constant despite transformations:**
    - lightness, colour constancy
    - size constancy
    - structural invariance (size, texture)
    - transformation invariance (time – movement)
    - shape constancy
  - phenomenon is not based on memory performance, but can be immediately perceived

- Perception: constructed or direct?
  - **= is perception a bottom-up process or a top-down process?**
  - **both play a role**: 2 theories:
    - **constructivist theories (top-down)**: Information processing approach
    - **direct perception (bottom-up)**: Gibson

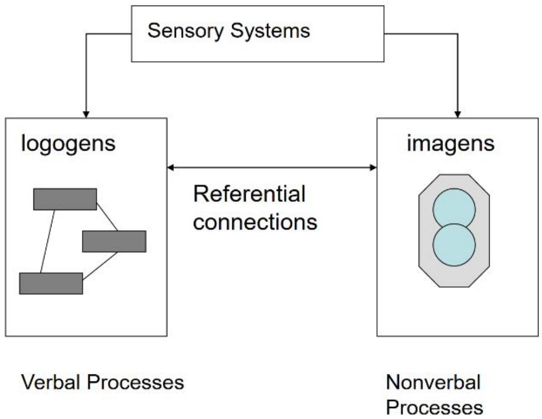
- **Constructivist Theories:**
  - top-down theory
  - assumptions:
    1. **perception is an active and constructive process**
    2. perception is not directly determined by the stimuli that affect the sensory organs, but is the **end product of the interaction between the stimuli and internal hypotheses, expectations, and knowledge sensory information forms the basis for conclusions about the objects**
    3. **since perception is characterised by hypotheses and conclusions, it can be flawed**
    4. **contextual information is very important**
  - empirical investigations:
    - Importance of Contextual Information – Palmer 1975
    - Incorrect Perception Through Hypotheses – Bruner & Postman 1949
    - **used to explain perceptual illusions**
  - **discussion:**
    - **big problem: perception is usually correct**, although based on these theories one would have to conclude that perception is often wrong not plausible to assume that our hypotheses and assumptions are so often correct
    - **high explanatory value for perceptual illusions** many predictions resulting from these theories have been empirically proven, can also justify the influence of the context on the perception very well
    - **very valuable when stimuli are presented only briefly or when the stimuli are poorly recognisable**
- **Direct Perception (Gibson):**
  - **bottom-up theory**
  - light that strikes the eye can be considered as an **optical flow field containing all visual information from environment**
  - optical flow field **contains unambiguous or invariant information about the objects** in space
  - perception means that this “rich” information is received in a direct way **no process of information processing**
  - **meaning arises directly through the prompting character of the objects** and not through the memory, which assigns meaning to patterns of perception in a feedback loop
  - **discussion:**
    - **theory showed how differentiated and comprehensive the contents of visual perception are**
    - Gibson was the first to describe **optical flow fields and texture gradients**, however, until now there are **no conclusive empirical findings** that these are actually used in perception
    - **Gibson cannot explain optical illusions**: some optical illusions arise only through artificial laboratory situation but there are illusions that also occur in real life (vertical/horizontal illusion)
    - Gibson cannot explain the meaning of objects **affordance often not sufficient to explain the meaning of objects** (e.g., sofa as spaceship in children’s games)
- **comparison: constructivist vs. direct**
  - **bottom-up or top-down: depends on context (e.g., time and perceptual conditions)**
  - **Neisser: formulates synthesis of both processes**

- based on a **perceptual cycle** containing both **object perception and conclusions based on existing schemata in memory**
- **schemata initiate exploration processes**
- **schemata can be changed if required by new information**



Mental Images

- **recognition of images works very well with humans**, reasons:
  1. **images differ in many features within a wide range of dimensions**, even if only a fraction of these features is stored, images can be recognised
  2. it's possible that **subjects use verbal descriptions to supplement their visual memory**
     - memory performance is even very high for images of poorly textured, difficult to verbalise objects (inkblots, snow crystals)
- **Dual Coding Theory:**
  - there are **two types of memory for memory content:**
    1. **one for verbal material**
    2. **one for "images"** (including auditory, haptic, etc. memories)
  - it's well known that **concrete objects** (dog, house, sun, ...) **are easier to keep in mind than abstract ones** (truth, philosophy, theory of relativity, ...)
  - Dual Coding Theory: this is because **concrete objects are stored both verbally and as images**



- **Imagery Debate: Pylyshyn vs. Kosslyn**
  - debate about the **importance of images, hard to decide empirically**
  - images convey no essential information converted into linguistic material in the brain
  - **Pylyshyn: against mental images in the brain**
  - **Kosslyn: pro mental images in the brain**; studies of brain activity suggest exactly that
  - arguments for **Pylyshyn**:
    - **mental images work like photographs in the brain wrong!**
    - contradicts the fact that our mental images are pre-organised (e.g., if we have an image of a room, we do not forget half a sofa, but the whole sofa)
    - suggests that images are stored in the brain in the form of **propositions**
      - **abstract structures that specify exact relationships between entities**
      - **not linguistic structures**: may contain terms that have no linguistic connotation
      - often can be approximated by simple sentences
      - **either true or false**

- arguments for **Kosslyn**:
    - **perception is a process of information reduction**, with a vast wealth of sensations traced back to simpler and more organised forms
    - these **larger units are stored and later linked into mental images** and **experienced as pictorial spatial entities** finding and storing pictorial associations is easy
    - **propositions are not well suited to the representation of images** they require an explicit designation of the elements and their relations propositional and pictorial representations are not equivalent
    - **Kosslyn thinks that these images are already processed and not like photos**
    - **we only store important aspects of the environment and forget the rest**
    - Kosslyn could show through neurophysiological studies that there are specific pictorial representations in the brain
- **empirical research:**
    - **research indicates that we do store some kind of images in our mind**
    - **mental rotation:**
        - if the angle between two objects plays a role when we have to decide whether they are the same or different then we store images as images and not as propositions
    - **islands experiment:**
        - participants study a map and then draw a black dot from one specific point to another on the imagined map
        - distance between the two locations on the map plays major role
        - takes longer to draw the imagined point between two locations that are more distant
    - **critique: these experiments are very artificial and nudge** the study participants to behave in the way they do

(Pre-)Attentive Processes

- **pre-attentive processes:**
    - short summary:
        - **executed automatically**
        - **without the influence of consciousness**
        - **very short-term**
        - **immediate image interpretation**
    - **parallel processes** of perceptual organisation, pattern recognition or object identification
    - perception mechanism is organised to **rapidly grasp global significance**, details processed at second glance
    - **schemata reduce** the basically infinite possibilities of interpreting pictorial signs
    - **not just bottom-up recording processes**, but activities that are influenced by higher centers and are constructive in nature
    - bottom-up pre-attentive processes: **colour, orientation, size, shape, blinking, direction of movement, sharpness of the image → control attention**
- **attentive processes:**
    - short summary:
        - **controlled search**
        - **explicit processing**
        - **greater mental effort**
    - **intentional, task-oriented processing of an image**
    - individually and selectively analysing and interpreting image elements

- **can be improved by appropriate instructions**
- observers extract task-relevant information from the picture, compare it, draw conclusions, and combine pictorial and verbal information

- **Combination of the Senses and Primacy of Seeing:**
  - **perception and social/emotional influences**:
    - experiment: children from poorer families overestimate size of coins more than children from richer families
    - **emotional assessments can also influence the discoverability of words and objects**
  - **combination of the senses:**
    - perception in everyday life is based on combination of sensory experiences
    - integration of multiple sensory channels in computer programs is difficult → unclear how the different sensory channels work together
    - often assumed that visual sense is most important → wrong!
  - **theoretical positions:**
    1. **doctrine of equivalent information**
       - **different senses inform about the same characteristics** of the outside world
       - doubtful whether the information of different senses actually has the **same information content**
    2. **doctrine of analogous qualities**
       - **various sensory modalities extract very specific information** from the environment
       - → they also convey some **common nonspecific information (e.g., intensity)**
    3. **doctrine of corresponding psychophysical properties**
       - **the way in which perceptual systems work is comparable**
       - the laws established in the context of physical environmental characteristics and perception systems prevail in all sensory systems
    4. **doctrine of corresponding information**
       - objects and events of our world contain **parallel information on very different channels**
       - channels can also be **recorded in parallel** by our different perceptual subsystems
       - information that we can pick up through the subsystems is **rarely equivalent** → it is at best analogous and, in fact, corresponding
    5. **doctrine of mutual influence of different perception systems:**
       - example of intermodal interaction: **frequent change in leadership between visual and auditory systems**
  - **primacy of visual perception:**
    - visual perception is more important than auditory because people can visually process more information than auditorily
    - **auditory system is more directed to the visual information than vice versa**
    - **seeing is always towards objects and space**, whereas **hearing conveys a more planar impression without spatial depth**
    - **not possible to argue that you can process more information visually than in an auditory manner → presupposes that information recorded is identical or at least equivalent**
    - basic function of the **auditory system: direct the visual attention to objects and events that are acoustically noticeable** and are not in the current field of vision

            - also possible in other direction
            - visual perception has a more spatial and object-oriented character than auditory
            - in **action control, the perceptual subsystems support each other**, and the overall information received is integrated (**holistic perception**)

Integration of Image and Text

- make text-image combinations redundant or complementary?
- redundant presentation of information:
    - evidence from cognitive psychology (e.g., Paivio's dual coding)
- empirical studies do not allow a recommendation in one direction or the other
- **if image and text belong together, they should also be located close to each other**

1. **redundancy:**
    - **content is the same**; most essential ideas are repeated
    - beneficial for presentations with **complex content**
    - annoying for simple information
2. **complementarity:**
    - both text and image have **different content**
    - **contents should complement each other**
    - display modes only work together
3. **supplementarity:**
    - **one mode plays the more important role**, other mode has a supporting effect
    - used to **emphasise certain points** → helpful for learning
    - facilitates information processing/learning
4. **juxtaposition:**
    - **attention should be attracted** by the juxtaposition of actually contradictory elements
    - this remedy is often used in **advertising**
5. **stage-setting:**
    - used to attune people to a specific topic and **create a specific context**

Information Visualisation

Benefits of Visualisations

1. **Larger cognitive resources:**
    - **short-term memory** can be increased
    - **large amounts of data** can be easily represented with appropriate visualisations
    - some attributes of visualisations can be **processed in parallel** while text is always serial
2. **Faster search processes:**
    - **grouping** of information
    - **high data density**
3. **Improved pattern recognition:**
    - **recognition** instead of remembering
    - **abstraction and aggregation**
    - visual **organisation** of data (e.g., on a timeline)
4. **Perceptual inference:**
    - **simultaneity** of phenomena when comparing two timelines
5. **Perceptual monitoring:**
    - **large amounts of data** can be surveyed if the visualisation is organised properly

6. **Interactivity:**
    - thinking "with" artifacts from the environment
    - humans want to interact with their environment
    - perception is adapted to motion
    - example: Gravi++ (tool)
    - **selection of data to be represented**
    - **selection of methods of representation**
    - **selection of level of detail**
    - helpful → **perception is highly selective**
    - **disadvantage: users may not use appropriate methods of representation**
    - theoretical basis for this approach is Gibson's theory of perception

Change / Inattentional Blindness

- **attention is limited** → humans sometimes are not able to detect changes in their environment
- **change blindness:**
    - people usually focus on certain aspects of the environment and ignore everything else
    - people do not notice (gradually) changing information
    - **= failure to notice an obvious change**
    - e.g., from image flickering, saccades, blinking or occlusion by passing objects
- **inattentional blindness:**
    - area of high visual acuity is very small
    - **= failure to notice an unexpected item**
    - when attention is focused on a certain task or object → other objects are not noticed
    - e.g., when driving a car
- **consciousness illusion:**
    - subjective impression that we can perceive the environment in detail
    - research: **we can absorb and process very little information at a specific time**
    - illusion arises from the fact that we always have the opportunity to focus our attention on interesting objects
    - **→ we use the environment as an external memory**
- **design guidelines by R. Rensink:**
    1. items on the screen should be **manageable and easy to identify**
    2. visual **events should be minimised**
    3. screen should be designed to **highlight the right object at the right time**

Evaluation

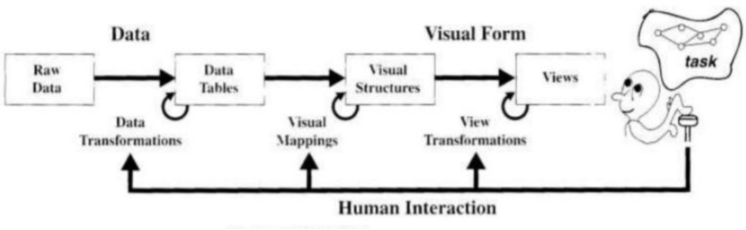
- **quantitative:**
    - **experiment:**
        - effect of independent variables on dependent variables studied
        - many intervening variables possible
    - **questionnaire:**
        - exact definition of research question necessary
        - define target group
        - should be short and worded unambiguously
        - advantage: large samples possible, good overview
        - problem: misunderstandings cannot be clarified
        - problem: acquiescence bias, no extremes ticked
    - **logfile - analysis:**
        - user activities are logged and analysed

        - advantage: unobtrusive, accurate
        - problem: interpretation of the data often difficult
    - **eye-tracking:**
        - perception is active, eyes move constantly
        - measures saccades, fixations
        - advantage: exact study of the elements that attract the attention
        - problems:
            - interpretation often difficult
            - generalisation difficult because it is not easy to compare different visual paths
            - one can only study short and well-defined tasks
            - rather unnatural procedure
- **qualitative:**
    - **interviews:**
        - structured, semi-structured or completely open interviews
        - in structured interviews: guideline important
        - possible to react to interviewees
        - evaluation by category systems
        - advantage: very detailed information about how to use an IT system
        - advantage: possibility to dispel misunderstandings
        - problem: subjective view of the study participants
        - problem: lots of data, sometimes not comparable
    - **focus groups:**
        - similar to interview, but in a group
        - group size about 7 people
        - guidelines necessary
        - important: all participants should participate in the discussion
        - advantage: with suitable facilitation → detailed discussion of contradictory opinions
        - advantage: quick and easy execution, still detailed data
        - problem: sometimes not all participants participate
        - problem: sometimes individuals dominate the discussion
    - **observation:**
        - often not as easy as it may seem
            - you often do not see everything you want to see
            - Hawthorne effect (participants change their behaviour because they are observed)
        - categorisation important
        - video recording: not as disturbing as direct observation
        - problem: large amount of data that is difficult to interpret
    - **thinking aloud (protocol analysis):**
        - aim: capture the immediate thoughts of subjects as they work on tasks or solve problems
        - avoids interpretation of own activities in retrospect
        - advantage: very detailed information, reasons
        - problem: intrusive procedure, rather unnatural
- **beyond time and error - novel evaluation methods:**
    - interaction with up-to-date InfoVis tools is an exploratory process
    - possible results often cannot be clearly defined
    - **traditional variables for evaluation: time, error**
        - variables do not make sense in the context of exploratory interaction with InfoVis tools

        - **time: results are often more valid when users take more time**; the interaction process is often iterative
        - **errors: it is often difficult to define what constitutes an error** (ill structured domains)
    - **alternative variables: complexity of results**, support for creativity and divergent thinking, cognitive strategies

Definition Information Visualisation

- Robert Spence:
    - *"important to distinguish information visualization from scientific visualization"*
    - scientific visualisation: what is seen primarily relates to something physical
    - information visualisation: deals with abstract quantities
- Ward et al.
    - *"information visualisation: risk of being overwhelmed by attractive pictures"*
- **scientific visualisation: based on physical data**
- **information visualisation:**
    - **abstract phenomena**
    - no obvious analogy to phenomena of physical world
    - problem: what kind of spatial representation to choose to represent a set of abstract data
- Card et al.
    - ***"use of computer-supported, interactive, visual representations of abstract data to amplify cognition"***
- goal: gain insights
- **images serve the discovery of new knowledge, decision-making and explanation**
- **external cognition:**
    - multiplications are easier with pen and paper
    - difficulty: intermediate results
    - pen and paper **relieves short-term memory**
    - **cognition achieved by using external artefact**
- **visual analytics:**
    - **problem: growing amount of data, interpretation of big data**
    - solution: organisation of data, visualisation
    - **visual analytics: turn information overload into opportunity**
    - definition: science of analytical reasoning facilitated by interactive visual interfaces
    - difference VA and InfoVis: InfoVis only consists of visualisations, **VA always includes an analytical component (e.g., machine learning)**
    - **VA combines strengths of humans and machines**
    - users are the ultimate authority who determine the direction of the analysis
    - **challenges:**
        - **exploratory approach**
        - open solution space, formalisation difficult
        - problem solving as generation of insights
- **rearrangement of data:**
    - **can lead to valuable insights**
    - **interactivity can increase effectiveness** of the tool
    - graphical representations are reconstructed many times
    - encourages users to formulate hypotheses and to engage more closely with the visualisation
- **mapping:**
    - **raw data → data tables → visual analogy/structure → add interactive elements**
    - users can influence transformations



- ○ data types: nominal, ordinal, quantitative
- ○ quality of mappings:
  - ■ data should be preserved through visual structure, not all are good → difficult as visualisations sometimes support unwanted interpretations (**expressive mapping**)
  - ■ visualisations must be well understood by humans (**effective mapping**)
  - ■ individual patterns are not in a natural sequence (**un/natural mapping**)

Interaction Methods

- **scrolling**
- **filtering**
- **data reordering**
- **overview & detail:**
  - tackles the problem that it is **often not possible to display all the data** on the screen
  - overview tries to **preserve the context**
  - also: **zoom**
- **focus & context:**
  - problem of focus and context arises when **details should be represented in a wider context**
  - size of computer screens is limited → can lead to difficulties
  - several ways to deal with this problem: e.g., **distortion techniques**
    - allow fine details to be displayed locally, but the rest of the visualization is much coarser
    - allows focus and context to be displayed simultaneously on a small screen
    - example: hyperbolic tree
- **dynamic queries:**
  - **incremental search**, criteria are gradually changed, alternative to SQL and the like
  - more precise search and **faster feedback**
  - uses "**sliders**", search result can be changed step by step
- **multiple views:**
  - show **same data in different visualisations**
  - multiple visualisations, taking advantage of the strength of each → create an even more **powerful information exploration environment**
  - example: **Windows Explorer** employs three visualisations
    - outliner visualisation of folders
    - tabular visualisations of files
    - textual visualisation of details
  - **brushing and linking:**
    - exploratory data analysis technique used when displaying a set of data items in multiple visualisations
    - **users select items in one visualisation → same items are automatically highlighted in all the visualisations**
  - **overview and detail view:**
    - **selecting an item in the overview → navigates the detail view to the corresponding details**

        - items are represented visually smaller in the overview
        - → provides context and allows direct access to details
    - **drill down:**
        - allows users to navigate down successive layers of a hierarchical database
        - selecting a parent item on one visualisation loads children items into another visualisation
        - enables exploring very large-scale data
    - **synchronised scrolling:**
        - users can conventionally scroll through multiple corresponding data sets

Examples of Visualisations

1. **geometric techniques:**
    - mapping of attributes to the **geometric space**
    - **scatterplots**
        - only two dimensions
    - **parallel coordinates**
        - multidimensional, high amount of data
        - do not scale well, occlusion will happen
2. **icon techniques:**
    - **mapping of attributes to features of pictorial representation** (colour, shape, size, orientation)
    - e.g., Starglyph, Chernoff Faces
    - advantage: **compact** presentation, often high clarity
    - problem: clarity sometimes misleading, high amount of data
    - **Chernoff Faces:**
        - people perceive faces in great detail → faces used for visualisation
        - individual features of the face are used as expressions of different variables
    - **Stardinates/Starglyphs:**
        - represent **multidimensional** data
        - axes arranged in parallel coordinates are arranged in star shape
        - **compact** presentation
        - correspond more to **Gestalt law of good form**
        - **interactive exploration**
        - advantages:
            - **differences and similarities** in the data are easily recognisable
            - data with **high complexity** can be visualised
            - **interactivity** motivates users to hypothesise
        - disadvantages:
            - data lines with the same values **overlap**
            - **number of axes are limited**
            - number of stardinates that can be viewed simultaneously is limited
3. **pixel-oriented techniques:**
    - solving the problem of displaying **large amounts of data**, not really used though
    - **mapping of attributes to pixels**, maximum density of possible information can be displayed
    - questions:
        - What do the pixels represent? How are the pixels arranged? Which colors should be used?
    - example: Market Radar, analysis of stock price development, very confusing
4. **networks/graphs:**
    - illustration of networked structures in the data (**relationships**), uses nodes and edges

- structure must be made transparent by the representation
- also **social networks** (e.g., company structure)
- questions:
  - positioning of the nodes
  - representation of the edges
  - interaction
- advantages:
  - **intuitive**
  - **2nd degree neighbours** clearly visible
  - **paths** clearly visible
- problems:
  - **does not scale well**
  - get big and **confusing** quickly
  - **overlapping** of links
  - **representation of links** (direction, curved/straight)
  - representation of temporal evolution
- **matrix representation**: represent dense networks as matrices → prevent overlapping
  - advantage: good for big networks
  - advantage: **temporal development is represented better**
  - problem: not very intuitive

5. **hierarchical data:**
   - special case of network/tree structure, example: file system on a computer
   - similar problems as with network structure
   - space-filling technique: screen space is divided into rectangles starting from the root node, then each rectangle is further divided for each level of the hierarchy
   - size according to one fixed numerical value
   - values of the end nodes added up
6. **dynamic representations (animations):**
   - can be very **confusing**
   - discussed controversially
   - depends on context if useful or not
   - most relevant for the **presentation of time-dependent data**
   - interactivity useful
   - speed important
   - useful to **observe change**
7. **3D representations:**
   - we do not perceive 3D → images on retina are 2D
   - abstract non-spatial data has not been successfully visualised in 3D
   - **3D often obscures important information** → needs movement → very difficult
8. **incomplete/corrupt data:**
   - sometimes data is just wrong
   - incomplete:
     - remediate through **interpolation**
   - corrupt:
     - e.g., faulty sensor data, erroneous human inputs
     - remediate through **data cleansing**
     - very time consuming