Visual attention and things that pop out

Week 5
IAT 814
Lyn Bartram

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The visualization process

- Finding patterns is key to information visualization.
- Example Tasks:
  - Patterns showing groups?
  - Patterns showing structure?
  - What patterns are similar?
- How should we organize information on the screen?

Visual attention

- Attention is the cognitive process of selectively concentrating on one aspect of the environment while ignoring other things
- Comprises a range of cognitive and perceptual processes
- One convenient (if perhaps simplistic) way to frame these is as **top-down** or **bottom-up** attention
  - Top down ➔ "cognitive",voluntary
  - Bottom-up ➔ "perceptual", involuntary
- These processes interact, but there are distinct models for each that are relevant to visualization design

Bottom-up vs. Top-Down Processing

- "My wife and mother-in-law"
  - http://psylux.psych.tu-dresden.de/i1/kaw/diverses%20Material/www.illusionworks.com/html/perceptual_ambiguity.html
- Do you see the "wife" (young woman) or "mother-in-law" (older woman)?
- Interpretation of Ambiguous stimuli can change depending on context

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Top down vs bottom up processing

- Top-down
  - Conceptually-driven, perception based on information (concepts) coming from previous experience, stored in memory
- Bottom-up
  - “data-driven”, perception guided by information (data) currently coming in through the senses

- All perception is based on some combination of these two factors
- Perceptual Priming

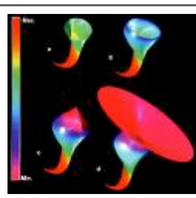
Visual search and visual attention

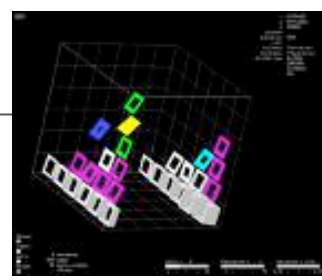
- The eye as information-gathering searchlight, sweeping the visual world
  - We can “parse” between 4-12 items in each fixation
- Visual search is a very powerful tool but depends on efficient use of early vision -that is, on understanding what features are most accessible to low-level vision
  - Parallel processing
- Attention is both a high-level and a low-level property of vision
  - Most of the time we are not “paying attention”
- Low-level mechanisms help us understand what is readily available to attention
  - How to make information visually distinct - to stand out
- But wait! We’ll get to the top down issues soon

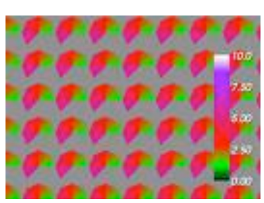
Primitives of perception

- The whole visual field is processed in parallel
- This machinery tells us what kinds of information are easily distinguished
- *Popout* effects (prior to conscious, top-down attention)
- *Segmentation* effects (dividing up the visual field)
- Contribution to glyph design
  - A glyph is a graphical object that shows multiple data values
- Contribution to maps and fields
  - Combinations of multiple glyphs and multidimensional data maps
  - Visual regions and pattern identification

Glyphs







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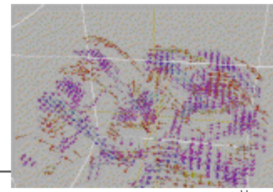
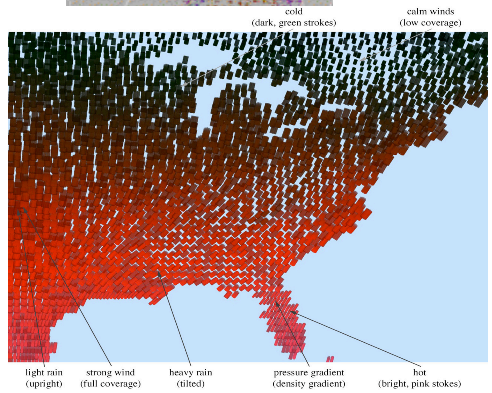
Glyphs in context



- Color represents temperature
- Coverage represents wind speed
- Density represents pressure
- Orientation represents precipitation



Visual attention

- The attention process is concentrated around the fovea, where vision is most detailed.
- However, we can redirect attention to objects within a single fixation, and the region of visual space we attend to expands and contracts based on task, the information in the display, and the level of stress in the observer.

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Useful field of view

- A concept called the useful field of view (UFOV) has been developed to define the size of the region from which we can rapidly take in information.
- The UFOV varies greatly, depending on the task and the information being displayed.

Useful field of view

- Experiments using displays densely populated with targets reveal small UFOVs, from 1 to 4 degrees of visual angle
- For low character densities (less than one per degree of visual angle), the useful visual field can be as large as 15 degrees.
- With greater target density, the UFOV becomes smaller and attention is more narrowly focused; with a low target density, a larger area can be attended.

Tunnel vision and UFOV

- A phenomenon known as tunnel vision has been associated with operators working under extreme stress.
- In tunnel vision, the UFOV is narrowed so that only the most important information, normally at the center of the field of view, is processed.

Tunnel Vision and UFOV

- This phenomenon has been specifically associated with various kinds of nonfunctional behaviors that occur during problem handling in disaster situations.
  - L.J. Williams. Tunnel Vision or General Interference? Cognitive Load and Attentional Bias Are Both Important. The American Journal of Psychology, Vol. 101, No. 2 (Summer, 1988), pp. 171-191
- The Williams data shows that we should not think of tunnel vision strictly as a response to disaster.
- It may generally be the case that as cognitive load goes up, the UFOV shrinks.

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UFOV and motion

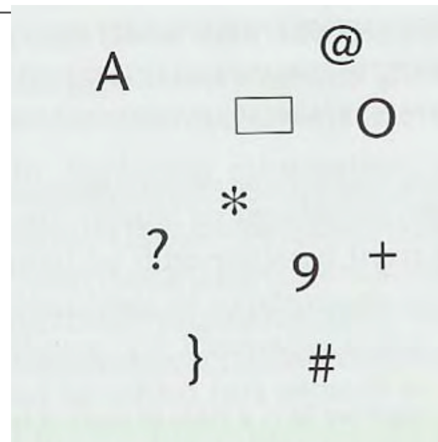
- The UFOV function can be far larger for detection of moving targets than for detection of static targets.
- Subjects can respond in less than 1 second to targets 20 degrees from the line of sight, if the targets are moving.
- If static targets are used, performance falls off rapidly beyond about 4 degrees from fixation.

UFOV and motion

- There is every reason to suppose that the useful visual field for moving targets is even larger; it may well encompass the entire visual field.
- Thus, motion of icons in user interfaces can be useful for attracting attention to the periphery of the screen.
- Bartram, Ware and Calvert: Moving Icons: Detection, Distraction and Task, IJHCCS, 2003.

The iconic buffer

- Figure 5.2. How many of these symbols can you remember after a glimpse 1/10 second long?



- Ware, C. Information Visualization: Perception for Design. Elsevier, 2004. P 149.

The iconic buffer

- Figure 5.2 shows a collection of miscellaneous symbols. If we briefly flash such a collection of symbols on a screen— say, for one-tenth of a second —and then ask people to name as many of the symbols as they can, they typically produce a list of **three** to **seven** items.

- Several factors limit the number of items listed.

The iconic buffer

- The first is the short-lived visual buffer that allows us to hold the image for about one to two tenths of a second while we read the symbols into our short-term memory.

- This visual buffer is called *iconic memory*.

    - Highly transient store

- Any information that is retained longer than three-tenths of a second has been read into *visual* or *verbal working memory*.

Working from the iconic buffer

- In each fixation between saccadic eye movements, an image of the world is captured in iconic memory
- from this transient store higher-level processes must identify objects, match them with objects previously perceived, and take information into working memory for symbolic analysis.

- Can we tune the information display to optimise this visual detection and identification?

Pre-attentive processing: Yes, we can

- We can do certain things to symbols to make it much more likely that they will be visually identified even after very brief exposure.
- Certain simple shapes or colors “pop-out” from their surroundings.
- The theoretical mechanism underlying pop-out is called *pre-attentive processing* because logically it must occur prior to conscious attention.
  - Treisman
- The model of preattention has been evolved into a gamut rather than a threshold

Preattentive processing

- The features that are pre-attentively processed can be organized into a number of categories based on form, color, motion, and spatial position.
- Understanding of what is processed preattentively is probably the most important contribution that vision science can make to data visualization.

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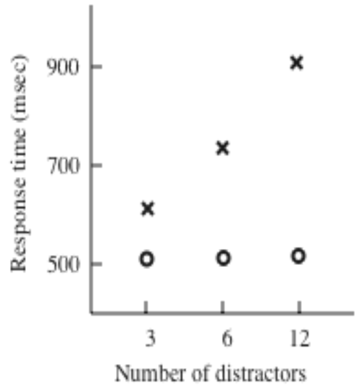
example

19207509817375983288056709824765875247745271908590138659821
73650919098726473572298978650976495761292047569000275983048
56986759450375057957362037664039798686204865639220967594303
8673076695047221086543998865O9876

Colour is pre-attentive - pops out

19207509817375983288056709824765875247745271908590138659821
73650919098726473572298978650976495761292047569000275983048
56986759450275057957462097664039798686204865639220967594303
8673076695047221086543998865O9876

What do we mean by preattentive?



- Time taken to find a target is independent of number of distractors
- Preattentive ~= 10 msec per item or better.

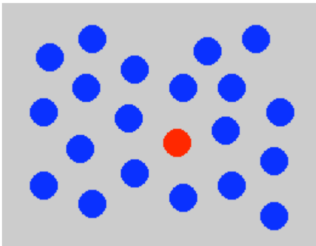
Ware, C. Information Visualization: Perception for Design. Elsevier, 2004..

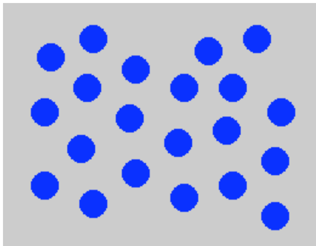
Preattentive processing

- A limited set of visual properties are processed preattentively (without need for focusing attention).
  - **Visual features**
- This is important for the design of visualizations
  - what can be perceived immediately
  - what properties are good discriminators
  - what can mislead viewers
  - Differentiate items “at a glance”

Some examples from Chris Healey:
http://www.csc.ncsu.edu/faculty/healey/PP/PP.html

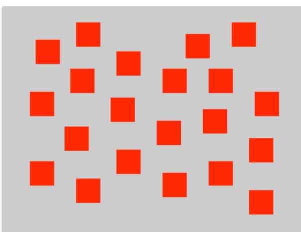
Example: Colour selection

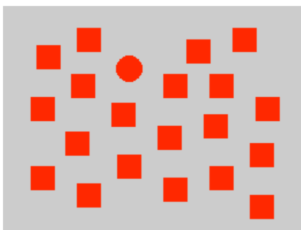




Viewer can rapidly and accurately determine whether the target (red circle) is present or absent. Difference detected in color.

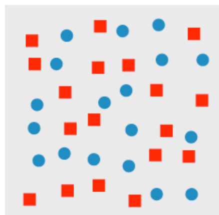
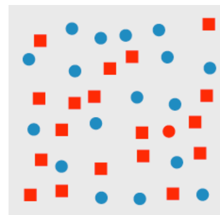
Example: shape selection





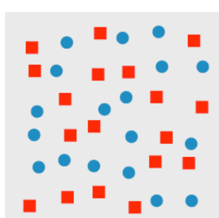
Viewer can rapidly and accurately determine whether the target (red circle) is present or absent. Difference detected in form (curvature)

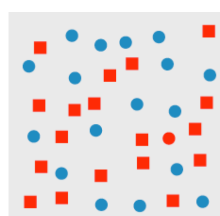
Conjunction

- A target made up of a combination of non-unique features (a conjunction target) normally cannot be detected preattentively - find the red circle.

Conjunction


absent

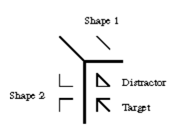

present

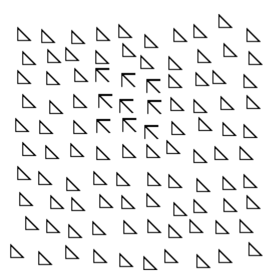
- A target made up of a combination of non-unique features (a conjunction target) normally cannot be detected preattentively - find the red circle.

Try for yourself

- Healey's applet

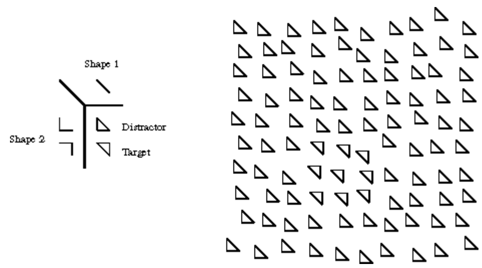
Example: emergent features





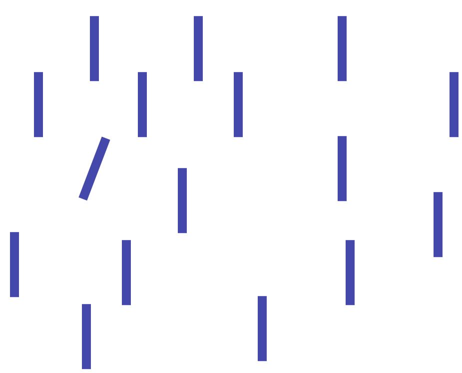
Target has a unique feature with respect to distractors (open sides) and so the group can be detected preattentively.

Example: emergent features



Target does not have a unique feature with respect to distractors and so the group cannot be detected preattentively.

Example: orientation



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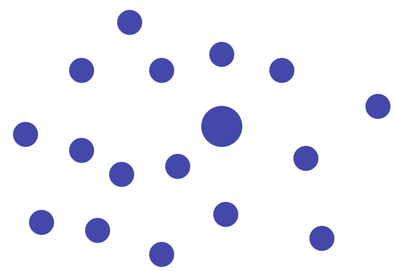
Example: size



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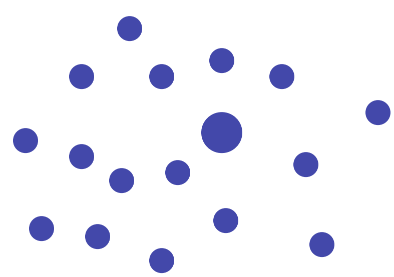
Example: motion



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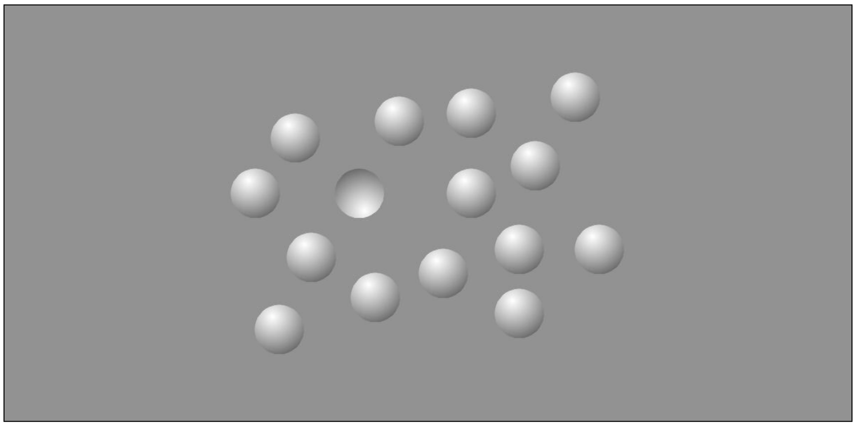
Example: simple shading



Preattentive channels

- Form (orientation/size)
- Colour
- Simple motion/blinking
- Addition/numerosity (up to 3)
- Spatial, stereo depth, shading, position

Preattentive processing features

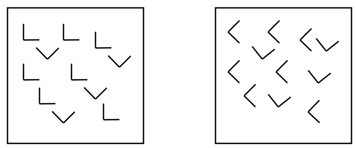
- Form
  - Line orientation
  - Line length
  - line width
  - Size
  - Curvature
  - Spatial grouping
  - Blur
  - numerosity
- Colour
  - Hue
  - Intensity
- Motion
  - Flicker
  - Direction of motion
- Spatial position
  - 2D position
  - Stereo depth
  - Concavity/convexity shape from shading

For more examples, check

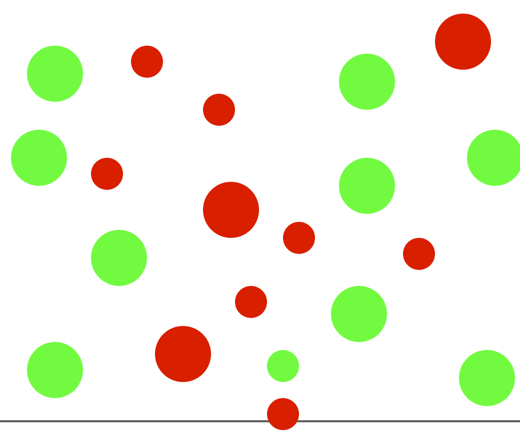
- Chris Healey's table of visual features shown to be preattentively processed

Asymmetric and graded preattentive properties

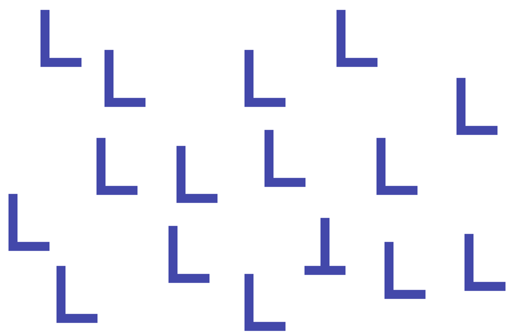
- Some properties are asymmetric
  - a sloped line among vertical lines is preattentive
  - a vertical line among sloped ones is not
- Some properties have a gradation
  - some more easily discriminated among than others



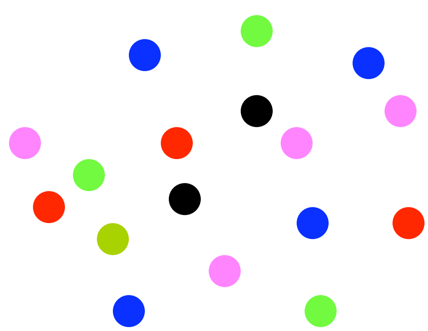
Conjunction does not pop out



Compound features do not pop out



Surrounded colours do not pop out



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Preattentive processing

- One thing that is clear is that pre-attentive symbols become less distinctive as the variety of distractors increases.
- Studies have shown that two factors are important in determining whether something stands out preattentively:
  - the **degree of difference** of the **target** from the **non-targets** (distractors), and
  - the **degree of difference** of the **non-targets** from **each other**.

Preattentive processing

- For example, yellow highlighting of text works well if yellow is the only color in the display besides black and white, but if there are many colors the highlighting will be less effective.
- So which visual dimensions are pre-attentively stronger and therefore more **salient** (get attention better)?

Coding with combinations of features

- A critical issue for information display is whether more complex patterns can be preattentively processed.
- What happens if we wish to search for a gray square, not just something that is gray or something that is square?
- It turns out that this kind of search is slow if the surrounding objects are squares (but not gray ones) and other gray shapes.

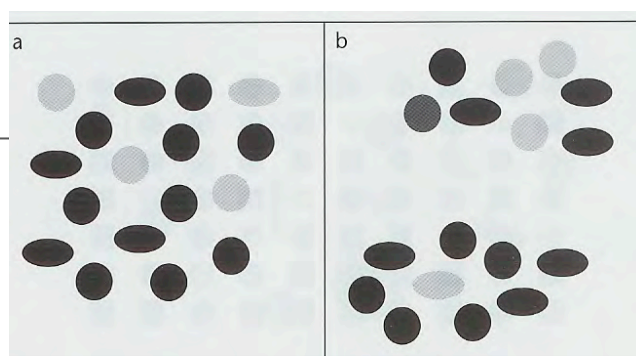
Coding with combinations of features

- We are forced to do a serial search of either the gray shapes or the square objects.
- This is called a *conjunction search*, because it involves searching for the specific conjunction of gray-level and shape attributes.
- Conjunction searches are generally not pre-attentive, although there are a few very interesting exceptions.

Conjunctions with spatial dimensions

- There are a number of preattentive dimension pairs that do appear to allow conjunctive search
- Spatial grouping on the XY plane

Ware, C. Information Visualization: Perception for Design. Elsevier, 2004..



- Figure 5.8 Spatial conjunction. The pattern on the left is a classic example of a pre-attentive conjunction search. To find the gray ellipses, either the gray things or the elliptical things must be searched. However, the example on the right shows that the search can be speeded up by spatial grouping. If attention is directed to the lower cluster, perceiving the gray ellipse is pre-attentive. This is a pre-attentive conjunction of spatial location and gray value.

Conjunction with spatial dimensions

- Stereoscopic depth
  - Depth and colour
  - Depth and movement
  - Useful for highlighting techniques allowing for preattentive search within the set of highlighted items
  - Decreses as depth layers increase
- Convexity, concavity and colour
- Motion and shape, motion and colour
  - Can find a red circle in a set of moving targets

Example application

- An application in which pre-attentive spatial conjunction may be useful is found in geographic information systems (GISs).
- In these systems, data is often characterized as a set of layers; for example, a layer representing the surface topography, a layer representing minerals, and a layer representing ownership patterns.
- Such layers may be differentiated by means of motion or stereoscopic-depth cues.

HIghlighting

- The purpose of highlighting is to make some information stand out from other information.
- This is the most straightforward application of pre-attentive processing results.

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Basic guidelines for highlighting

- Adding marks to highlight is better than taking a mark away
- Simple numerosity is strong (how many elements are there?)
- Coding must stand out on some simple dimension
  - color,
  - simple shape = orientation, size
  - motion,
  - Depth
- Use whatever graphical dimension is **least used** elsewhere

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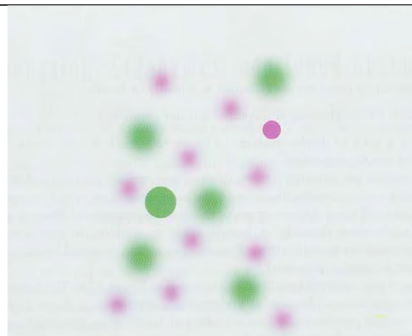
Blur : a new technique for highlighting

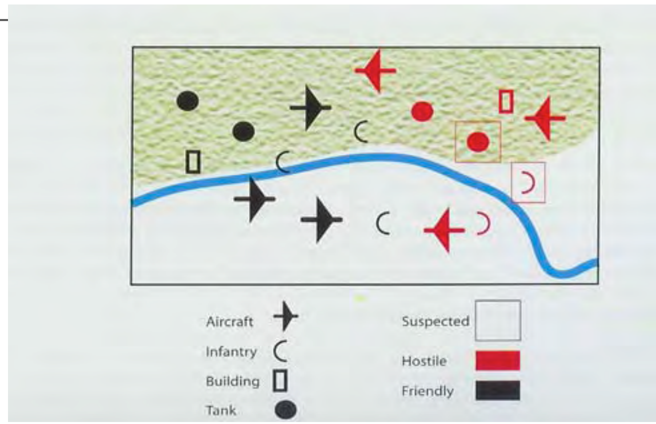


- Kosara et al. (2002) suggested blurring everything else in the display to make certain information stand out.
- *semantic depth of field*, applies the depth of focus effects that can be found in photography to the display of data according to semantic content.

Ware, C. Information Visualization: Perception for Design. Elsevier, 2004..

Designing symbol sets

- One way to think about pre-attentive processing is to understand that we can easily and rapidly perceive the “odd man out” in visual feature space.
- If a set of symbols is to be designed to represent different classes of objects on a map display, then these symbols should be as distinct as possible.
- Military operational maps are an obvious example in which symbols can be used to represent many different classes of targets
- Consider example:
  - Aircraft, tanks, building, troop position
  - Friendly vs hostile
  - Known vs suspected



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Neural Processing, Tuned receptors and graphemes

- It is useful to think of the things that are extracted by the early neural mechanisms as the “phonemes” of perception.
- Phonemes are the smallest elements in speech recognition, the atomic components from which meaningful words are made.
- In a similar way, we can think of orientation detectors, color detectors, and so on as “visual phonemes,” the elements from which meaningful perceptual objects are constructed.

Graphemes

- *grapheme* describes a graphical element that is primitive in visual terms, the visual equivalent of a phoneme.
- the pattern that most efficiently excites a neuron in the visual system is exactly the pattern that the neuron is tuned to detect.
- Once we understand the kinds of patterns the tuned cells of the visual cortex respond to best, we can apply this information to create efficient visual patterns.

- Large number of neurons have spatial (size) and orientation tuning
- The Gabor function decsribes the receptive field properties of these neurons
- Models how visual system segments visual world into regions of distinct visual texture

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Perceptual texture coding

- Critical features are 3:
  - Orientation
  - Size (=1/spatial frequency component)
  - Contrast
- Can map a 4th dimension to hue

Coding with texture

- For textured regions to be visually distinct:
  - the dominant spatial frequencies should differ by at least a factor of 3 or 4
  - the dominant orientations should differ by more than 30 degrees,
  - all other factors (such as color) being equal.
- In general, the more displayed information differs in spatial frequency and in orientation, the more distinct that information will be.

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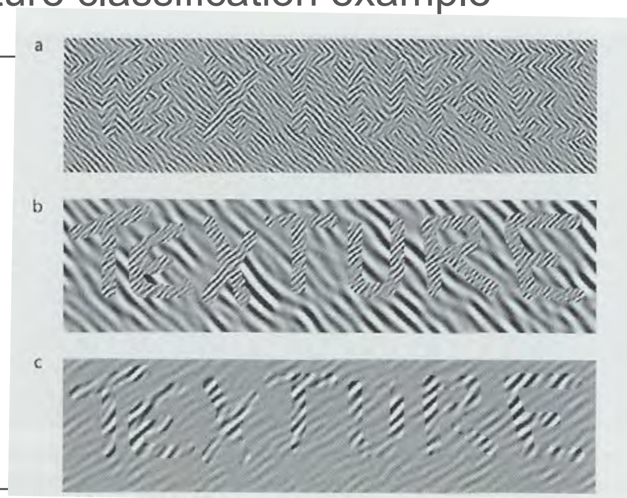
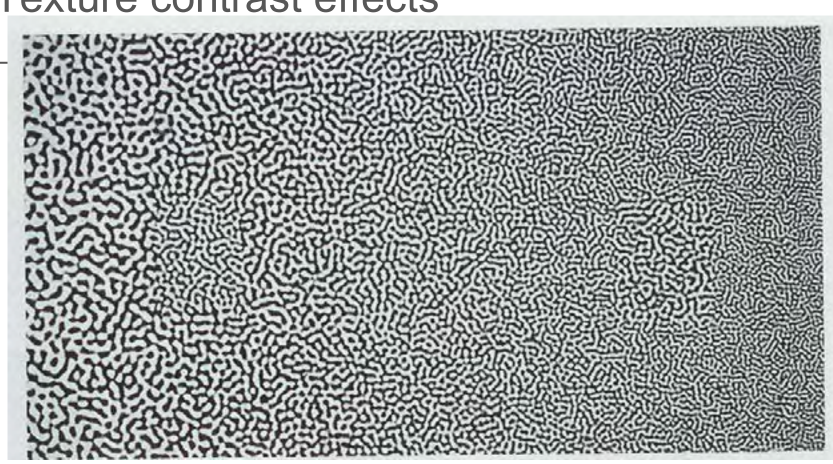
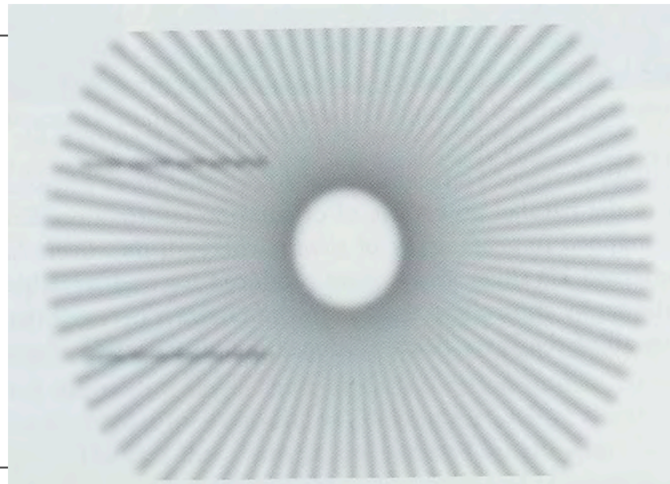
Texture classification example



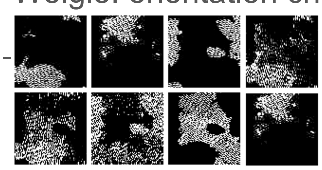
Texture contrast effects

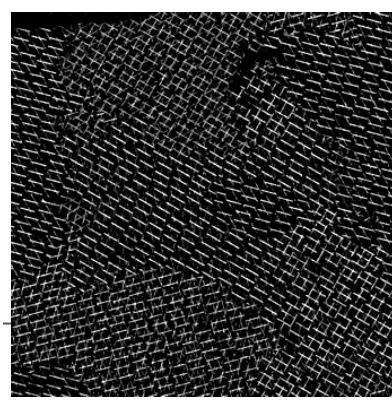


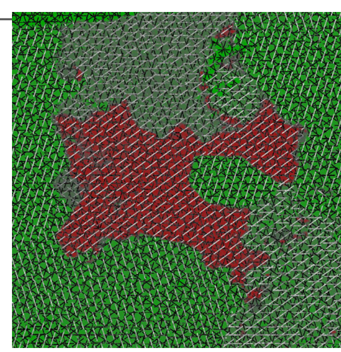
Orientation contrast effects



Weigle: orientation channels for information display







3 sliver orientations – also hue

Oriented sliver fields – 8 orientations at 15 degrees

Mapping multivariate data

- Tradeoffs in trying to display high-dimensional data
- Luminance variation is our only real way of showing much detail
- Every time we use texture, or any kind of glyph field, we sacrifice detail
- Large glyphs == less detail
- Clear orientation discrimination needs wider glyph spacing
- Colours must be chosen for dissimilarity

Glyphs and multivariate data

- Glyphs are frequently used for discrete multivariate data
- How do the coding schemes (features used) work together?
- *Integral* vs. *separable* visual dimensions

Integral and separable visual dimensions

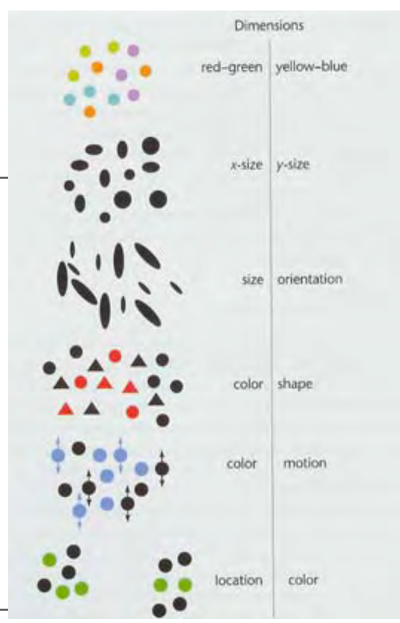
- Integral:
  - 2 or more features are processed holistically
  - Example: rectangle shape = width, height
- Separable:
  - People make separate judgments about each dimension
  - Example: Big red ball, size and colour are distinct
- Speeded classification task. Sort into two piles on one dimension or another

Integral and separable visual dimensions

- Redundant coding: using separable dimensions to encode the same thing
- Interference: one visual attribute affects performance on the other

Integral and separable visual dimensions

- Not hard and fast distinction, a continuum
- In practice there is always some interference
- However, well established list of display dimension pairs
- No research done on effects of more than 2
- Not theoretically perfect - simplistic
- Extremely useful design guideline



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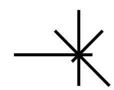
Multivariate discrete data

- Limited set of visual atttributes for coding
- Many of these are not independent
- Small resolvable steps in each dimension
- Conjunctions are effortful
- Stars and whiskers glphs are promising
- Large numbers of glyphs --> texture field



Conclusions

- in the early stages of vision, literally billions of neurons act in parallel to extract elementary aspects of form, color, texture, motion, and stereoscopic depth.
- The fact that this processing is done for each point of the visual field means that objects differentiated in terms of these simple low-level features **pop out** and can be noticed easily.
- Understanding such pre-attentive processes is the key to designing elements of displays that must be efficiently understood and processed.
- Making an icon or a symbol **significantly different** from its surroundings on one of the pre-attentive dimensions ensures that it can be detected by a viewer without effort and at high speed.

Lessons for information display

- Fundamental tradeoffs in design choices for coding
- We can usefully consider color, elements of form (orientation, size), position, simple motion, and stereoscopic depth as separate channels.
- For glyphs to be seen rapidly, they must stand out clearly from all other objects in their near vicinity on at least one coding dimension.
- In a display of large symbols, a small symbol will stand out.
- In a display of blue, green and gray symbols or a red symbol will stand out.

Lessons for information display

- There is more visual interference within channels.
- The basic rule is that, in terms of low-level properties, like interferes with like.
- If we have a set of small symbols on a textured background, a texture with a grain size similar to that of the symbols will make them hard to see.

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Lessons for information display

- There is more separability between channels.
- If we wish to be able to read data values from different data dimensions, each of these values should be mapped to a different data dimension.
- Mapping one variable to color and another to glyph orientation will make them independently readable.
- If we map one variable to X-direction size and another to Y-direction size, they will be read more holistically.
- If we have a set of symbols that are hard to see because they are on a textured background, they can be made to stand out by using another coding channel;
  - having the symbols oscillate will also make them distinct.

Lessons for information display

- Orthogonality - use a different channel for a different type of information
- If you need this use separable channels
- If you need to highlight by two properties use conjunctions (also separable dimensions)

“The programmable filter”

- We can only search for patterns of simple features
- Conjunctions of shape, colour cannot be programmed for parallel search of field
- Conjunctions of depth/motion and colour/shape can be
- Integral dimensions tend to be seen holistically cannot be separated
- Separable dimensions tend to be seen separately