Cognitive and Visual Principles
Part 2: Cognitive Principles

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Theories of Cognition and Perception

- From the domain of Psychology
- Help us understand principles that can be used in design
- These are principles that you should be able to apply in creating visualizations
  - Also apply to a lot of User Interface design, as well

Cognitive Principles

- Cognition == “Thinking”
- Understanding how mental processes work can also influence design

- Information in this presentation primarily taken from Maria dos Santos Lonsdale, *Information Visualisation: From Theory, to Research, to Practice… and Back*. Sage Publishing, 2023. Section 1.1

Levels of Memory in Computing Tasks

- Iconic Memory
- Working Memory
- External Memory
- Long-Term Memory

Levels of Memory in Computing Tasks

- Iconic Memory
  - Memory used for visual processing
  - Less than 1 second
  - Sometimes called “pre-attentive”
  - Notice some basic information:
    - Color
    - Form
    - Location
  - Things that should stand out need to target this
- Working Memory
- External Memory
- Long-Term Memory

Levels of Memory in Computing Tasks

- Iconic Memory
- Working Memory
  - Temporary memory – what is "in your head" as you work
    - Some indication that visual is separate from words
  - Limited in capacity: can comprehend "chunks" of related information
    - But, limited to 3-5 chunks at a time (some have said more, but 3-5 is best current estimate)
  - Therefore, important to reduce cognitive load, and support chunking of data
- External Memory
- Long-Term Memory

Levels of Memory in Computing Tasks

- Iconic Memory
- Working Memory
- External Memory
  - Affordances facilitate users' access to information
  - Provided by the computer/tools/UI (or even just plain pen and paper)
  - Help a user hold more information than can be kept in working memory, and access it later
- Long-Term Memory

Levels of Memory in Computing Tasks

- Iconic Memory
- Working Memory
- External Memory
- Long-Term Memory
  - Things you will comprehend, remember longer term
    - After processing in working memory
  - Key to recognizing visuals
  - Key for understanding, insight, etc.

Cognitive Load

- Our capacity to think is limited:
  - Working memory
  - Too much information to process, too much relation between elements, too complex of thought to understand
  - Overload leads to inability to comprehend
- Want to help ensure our visualizations take into account cognitive load
- Want to ensure we focus on “good” cognitive load

Cognitive Load Types

- Intrinsic Cognitive Load
  - Information relevant to the task and the information itself
    - Visual complexity, interaction, etc.
- Extrinsic Cognitive Load
  - Information to think about but irrelevant to the task at hand
    - Excess color, lines, symbols, shadows, etc.
- Germane Cognitive Load
  - Information relative to thinking/learning

Controlling Cognitive Load

- Idea is to reduce intrinsic and extrinsic load, to allow more germane load
- Reduce intrinsic:
  - Split information into smaller steps
  - Replace text by icons/illustrations
- Reduce extrinsic:
  - Limit colors, fonts, shapes, lines, etc.
  - Organize text

Cognitive Load Effects

- Split Attention
  - Needing to gather information from multiple places to integrate causes more load
  - Put information near where it is needed
    - e.g. next to chart, rather than in legend
- Modality
  - Can sometimes process more overall, if from different modalities
  - Can use more than one “channel” – typically audio and visual, to convey more overall info
- Redundancy
  - Multiple sources of the same info adds load to distinguish what is/isn’t useful
  - Avoid presenting same info more than once

15 Cognitive Principles in Visualization

1. Chunking
   - Elements should be grouped together in a meaningful way
   - e.g. Subtopics in an infographic

15 Cognitive Principles in Visualization

2. Consistency

- Common information placed in same way across multiple graphics/pages
- e.g. heading, legend, etc. in same location

15 Cognitive Principles in Visualization

3. Continued Engagement
   - Keep engaged longer
   - e.g. Illustrations and icons to enable quicker understanding
   - e.g. graphics to left of text

15 Cognitive Principles in Visualization

4. Continuity and Proximity

- Keep things that relate to each other close together
- e.g. Keep images close to related text

15 Cognitive Principles in Visualization

5. Element Interactivity
   - Elements of presentation that relate should be easy to match
   - e.g. Use same color for icon and relevant text
   - e.g. Don’t add elements not intrinsic to content

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6. Emphasis and Salience
   - Emphasis to facilitate finding key information
   - e.g. Color, bold font or font size to highlight

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7. Familiarity and Connection

- Build on what users already know or help them learn if it's something new
- e.g. Use well-known colors/icons for standard things
- e.g. Apply a label/marker if something will be new to a user

15 Cognitive Principles in Visualization

8. Focus
   - Avoid distractions, guide user to key info
   - e.g. Arrows or boxes to highlight key points

15 Cognitive Principles in Visualization

9. Hierarchy and Organization

- Hierarchy helps understand importance, relevance, order, priority. Present data in a way compatible with this
- e.g. Presenting action in broader to more specific detail

15 Cognitive Principles in Visualization

10. Number of visuals
    - Too many visuals cause too much load, so limit to most relevant
    - e.g. remove decorative elements, grid lines

15 Cognitive Principles in Visualization

11. Order
    - Information should be ordered so most relevant info is first (it sets an expectation)
    - e.g. Title in an infographic should convey more than subheadings

15 Cognitive Principles in Visualization

12. Range of Choices

- Too many choices increase load, so limit number of choices given
- e.g. don’t necessarily allow filtering of every possiblility

15 Cognitive Principles in Visualization

13. Reasoning
   - Tie ordering and valuation to known, standard systems
   - e.g. using red-yellow-green of traffic lights for presenting danger/caution/OK in visualization

15 Cognitive Principles in Visualization

14. Simplicity
    - Make it as easy to understand key concepts as possible
    - e.g. use icons for alert – danger/problem/etc.

15 Cognitive Principles in Visualization

15. Visual cues
  - Direct attention toward and remind users of key information
  - e.g. labels, text to mark/remind users of important related info

Summary

- Well-designed information should:
  - Engage and promote high-level cognitive functioning, i.e. to gain insight, reasoning, and understanding
  - Attract users to relevant information (instead of ignoring it)
  - Promote chunking that provides strong retrieval cues that will then be passed on to long-term memory and support reasoning, thinking, and decision making