Evaluating the visual scanning efficiency of geovisualisation displays

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Problem

• limited display area vs. large amount of geospatial data

Challenge

• to visualise as less as possible and as much as needed
• separate relevant from irrelevant geospatial information (filter)
• guide visual attention of users to relevant geospatial information
• effectively encode classes of relevant information

Objective

• fast localisation of relevant geospatial information
• efficient decoding of relevance classes
• economically exploit cognitive resources and support decision making
Visual scanning

users visually scan displays for relevant information

detected visual scanning involves
- shifting of attention (through sequences of gaze shifts)
- visual information is processed (during gaze fixations)

sequences of gaze shifts and fixations form the scan path

visual scanning requires a coarse representation of the spatial properties of the actual scene (global view) for guiding attention shifts, and finding fixation locations optimal for processing of the relevant information

detecting and analysing relevant information is controlled by working memory and and highly dependent on its limited capacity

cognitive workload can be reduced by activating visual brain areas that are involved in visual scanning, and are modulated by attention

scanning efficiency is the ratio of performance and cognitive workload
The concept of cognitive relevance

geovisualisation displays: complex external visual stimuli

geographic information is only assembled through internal cognitive processes

geovisualisation stimulate inference and decision making through
- coupling and interacting with existing knowledge.
- activating functions of visual brain areas in order to tight existing knowledge to a current intention.

**visual information** is more **relevant** if it has a **high contextual effect** (e.g. changes state of knowledge) and can be processed with **small effort**
Design principles & methodology

- **Attention-guiding hierarchy**
- **Bottom-up hierarchy**
- **Top-down hierarchy**
- **Spatial reference information (context)**
- **Detected information**

Classic design principles for thematic maps:

- **Simplicity**: reduction of visual complexity
- **Visual hierarchy**: structuring of information in visual hierarchies
- **Conciseness**: salient visualisation of relevant information
Potential visual variables for encoding relevance classes

- hue (1,2)
  - blue
  - red

- value (1,2)
  - white
  - gray

- saturation (1,2)
  - light blue
  - dark blue

- size (1,2)
  - black
  - gray

- orientation (1,2)
  - square
  - diamond

- form (1,2)
  - circle
  - star

- pattern (1)
  - circles
  - grid

- clarity crispness (1)
  - blank
  - filled

- clarity resolution (1)
  - light gray
  - dark gray

- clarity transparency (1)
  - black
  - transparent

- flicker (2)
  - circle
  - circle moving

- lightening (2)
  - circle
  - circle lightening

- darkening (2)
  - circle
  - circle darkening

- motion contraction
  - circle
  - circle shrinking

- motion rotation
  - circle
  - circle rotating

- motion speed
  - circle
  - circle moving faster

- motion acceleration
  - circle
  - circle moving faster

- motion direction (2)
  - circle
  - circle moving in a direction

- motion radial
  - circle
  - circle moving radially

- surprise
  - explosion

References:
(1) Bertin (1976), MacEachren (1995)
(2) Wolfe and Horowitz (2005)
Evaluation (methodology)

1. **pre-test**: computational vision model (Itti et al., 1998)
2. **pen & paper test** (N=42): task difficulty

3. **eye movement recording**

   - untrained test subjects: N=15 (5 m, 10 w)
   - average age: 28 years [22-38]
   - system: IVIEW-SMI system
   - recorded fixations: 1° (attention focus), 100 ms (duration)
   - subject exclusion criteria: visual acuity & colour blindness test

   displays
   - three design cases (randomised order of presentation)
     - case 1: unfiltered, but cognitively adequate visualised
     - case 2: filtered, but cognitively inadequate visualised
     - case 3: filtered and cognitively adequate visualised

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Benefits from eye movement studies

qualitative, visual analysis of static scan paths (patterns) and replay of visual scanning

quantitative analysis -> measurable behaviour (objective results):
first fixation
fixation frequencies and duration
number of re-fixations
link to time axis (events, e.g. mouse clicks)
statistical analysis for pre-defined areas of interest
sequence analysis

knowledge about where users have looked at and for how long
not task completion time only, but indication of how task has been solved, difficulties etc.
correlation with visual attention (Goldberg and Kotval, 1999)
hints on cognitive processes

allows for evaluating designs
clear additional insights into behaviour

main benefit: attentional processing is directly observed
Hue

<table>
<thead>
<tr>
<th>Variable</th>
<th>case 1</th>
<th>case 2</th>
<th>case 3</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>time (SD)</td>
<td>16.04 (11.53)</td>
<td>3.67 (1.13)</td>
<td>2.55 (1.18)</td>
<td>.001</td>
</tr>
<tr>
<td>length of scan path (SD)</td>
<td>204.09 (184.67)</td>
<td>48.61 (27.25)</td>
<td>37.06 (26.26)</td>
<td>.004</td>
</tr>
<tr>
<td>number of fixations (SD)</td>
<td>27.21 (21.99)</td>
<td>7.21 (1.67)</td>
<td>5.21 (2.86)</td>
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<td>7.29 (8.57)</td>
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<td>0.21 (0.58)</td>
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<tr>
<td>duration of fixations (SD)</td>
<td>0.20 (0.04)</td>
<td>0.21 (0.03)</td>
<td>0.19 (0.03)</td>
<td>n.s.</td>
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</tbody>
</table>

(SD): standard deviation
<table>
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</tr>
</thead>
<tbody>
<tr>
<td>time (SD)</td>
<td>11.07 (5.08)</td>
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<td>1.85 (0.55)</td>
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<tr>
<td>length of scan path (SD)</td>
<td>172.29 (114.09)</td>
<td>34.36 (12.52)</td>
<td>23.12 (9.47)</td>
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<tr>
<td>number of fixations (SD)</td>
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<td>5.86 (2.32)</td>
<td>3.79 (1.58)</td>
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<td>repetition of fixations (SD)</td>
<td>4.71 (5.15)</td>
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<tr>
<td>duration of fixations (SD)</td>
<td>0.19 (0.03)</td>
<td>0.19 (0.02)</td>
<td>0.19 (0.02)</td>
<td>n.s.</td>
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## Saturation

<table>
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<tbody>
<tr>
<td>time (SD)</td>
<td>5.39 (3.10)</td>
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<tr>
<td>length of scan path (SD)</td>
<td>87.78 (74.12)</td>
<td>37.94 (15.84)</td>
<td>42.69 (25.52)</td>
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<tr>
<td>number of fixations (SD)</td>
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<td>0.19 (0.03)</td>
<td>n.s.</td>
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### Size

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<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>time (SD)</td>
<td>2.61 (1.20)</td>
<td>2.20 (0.61)</td>
<td>2.21 (1.08)</td>
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<td>4.60 (2.82)</td>
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<td>0.19 (0.02)</td>
<td>0.19 (0.03)</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

[Images: 1, 2, 3]
### Contour

<table>
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<tr>
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<th>case 2</th>
<th>case 3</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>time (SD)</td>
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<td>1.95 (0.75)</td>
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<tr>
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<td>21.51 (9.12)</td>
<td>&lt;.001</td>
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<tr>
<td>number of fixations (SD)</td>
<td>10.33 (5.50)</td>
<td>5.33 (2.89)</td>
<td>3.33 (1.40)</td>
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<tr>
<td>repetition of fixations (SD)</td>
<td>1.33 (1.84)</td>
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<td>0.20 (0.04)</td>
<td>0.18 (0.02)</td>
<td>.031</td>
</tr>
</tbody>
</table>
analysis of eye-tracking measures confirm efficiency of design approach:

- all tested variables shift attention to the first relevance class for case 3

- case 1 --> case 2: visual complexity reduction
  visualisation of unfiltered information affects processing more than salient
  visualisation of spatial reference information

- case 2 --> case 3: salient visualisation of relevant information
  measurable effect on processing capabilities

- variable \textit{size} shows no significant differences in performance among the three
  rest cases; however \textit{size} may not be the variable of choice for small displays!

- test subjects visually scanned relevance classes in decreasing order
  (although this was not explicitly asked for)
  --> seems to confirm the underlying design theory of the approach
applying attention-guiding visualisation has a **measurable** effect

eye-tracking is a complementary evaluation technique providing additional insights into efficiency of design alternatives

further research planned:

• testing more visual variables and multiple encodings
• include semantic decoding of information into tests
• intensify interdisciplinary collaboration