Evaluating the visual scanning efficiency of geovisualisation displays

Olivier Swienty, **Tumasch Reichenbacher**
Technical University Munich, **University of Zurich**

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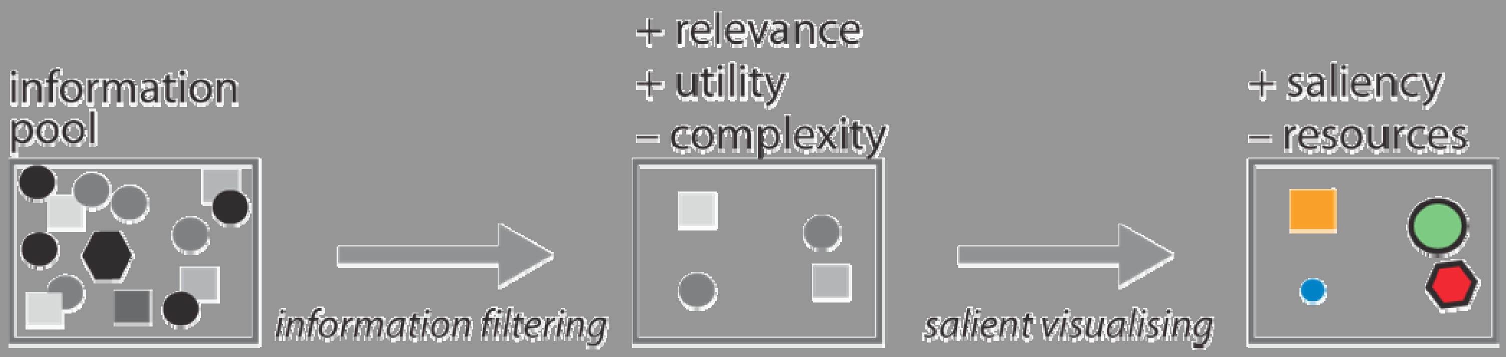
Context of visual information processing



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

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

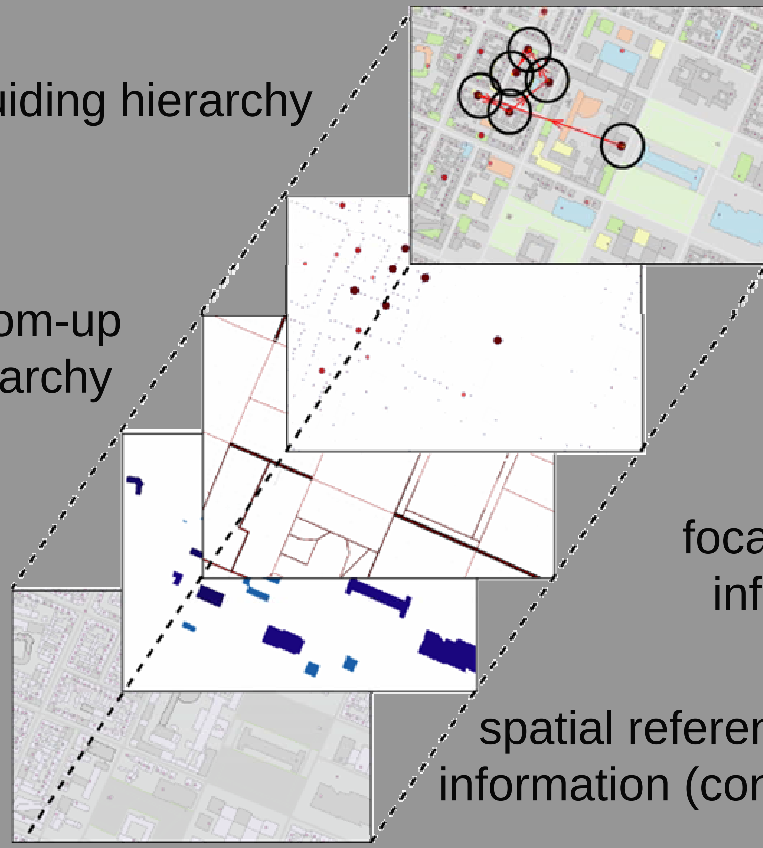
geovisualisation displays: complex external visual stimuli

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



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)

value (1,2)

saturation (1,2)

size (1,2)

orientation (1,2)

form (1,2)

pattern (1)

clarity *crispness* (1)

clarity *resolution* (1)

clarity *transparency* (1)

flicker (2)

lightening (2)

darkening (2)

motion *direction* (2)

motion *radial*

motion *contraction*

motion *rotation*

motion *speed*

motion *acceleration*

semantic motion

surprise

(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

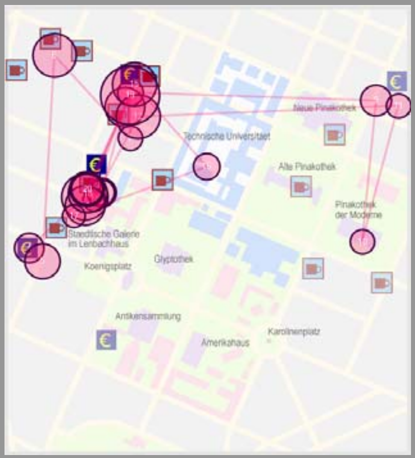
3. **eye movement recording**

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 cognitevly adequate visualised
	case 2: filterd, but cognitively inadequate visualised
	case 3: filtered and cognitively adequate visualised

Swienty, Olivier: Attention-Guiding Geovisualisation. A cognitive approach of designing relevant geographic information. PhD Thesis. Technical University of Munich. 2008

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

	case 1	case 2	case 3	p
time (SD)	16.04 (11.53)	3.67 (1.13)	2.55 (1.18)	.001
length of scan path (SD)	204.09 (184.67)	48.61 (27.25)	37.06 (26.26)	.004
number of fixations (SD)	27.21 (21.99)	7.21 (1.67)	5.21 (2.86)	.003
repetition of fixations (SD)	7.29 (8.57)	0.43 (0.65)	0.21 (0.58)	.009
duration of fixations (SD)	0.20 (0.04)	0.21 (0.03)	0.19 (0.03)	n.s.

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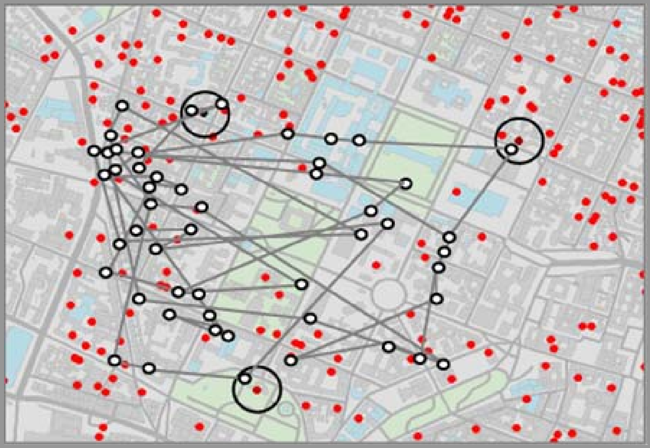
(SD): standard deviation

Value

	case 1	case 2	case 3	p
time (SD)	11.07 (5.08)	2.55 (0.98)	1.85 (0.55)	<.001
length of scan path (SD)	172.29 (114.09)	34.36 (12.52)	23.12 (9.47)	<.001
number of fixations (SD)	20.07 (13.27)	5.86 (2.32)	3.79 (1.58)	.001
repetition of fixations (SD)	4.71 (5.15)	0.36 (0.50)	0.14 (0.36)	.007
duration of fixations (SD)	0.19 (0.03)	0.19 (0.02)	0.19 (0.02)	n.s.



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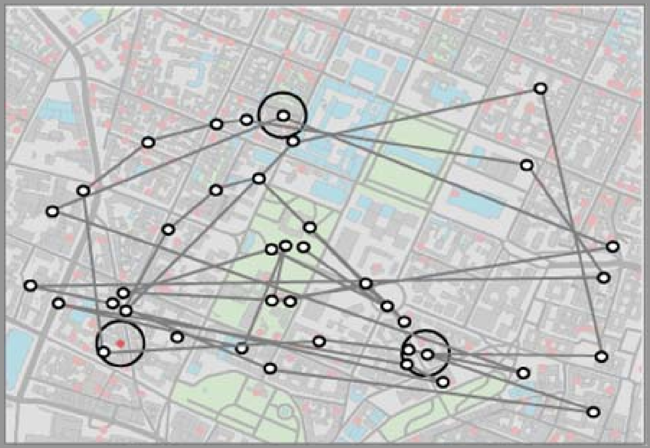
Saturation

	case 1	case 2	case 3	p
time (SD)	5.39 (3.10)	2.89 (0.72)	3.21 (1.92)	.004
length of scan path (SD)	87.78 (74.12)	37.94 (15.84)	42.69 (25.52)	.018
number of fixations (SD)	10.20 (7.02)	5.45 (1.36)	5.67 (2.82)	.025
repetition of fixations (SD)	1.93 (1.71)	0.00 (0.00)	0.40 (0.73)	.001
duration of fixations (SD)	0.19 (0.03)	0.19 (0.02)	0.19 (0.03)	n.s.



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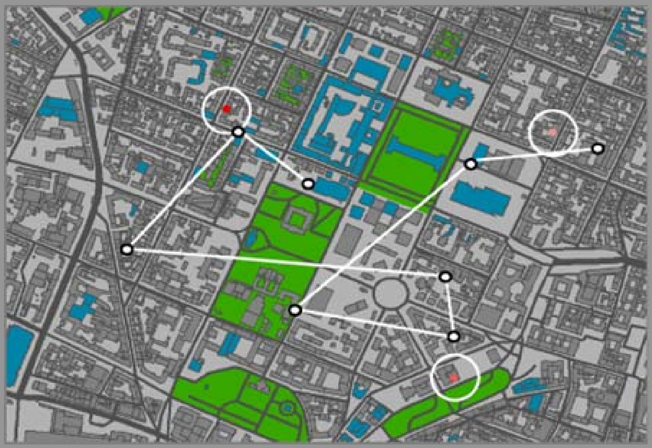

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Size

	case 1	case 2	case 3	p
time (SD)	2.61 (1.20)	2.20 (0.61)	2.21 (1.08)	n.s.
length of scan path (SD)	29.20 (12.90)	28.47 (12.14)	24.51 (11.18)	n.s.
number of fixations (SD)	5.07 (2.74)	4.07 (1.10)	4.60 (2.82)	n.s.
repetition of fixations (SD)	0.40 (0.83)	0.00 (0.00)	0.20 (0.41)	n.s.
duration of fixations (SD)	0.19 (0.02)	0.19 (0.02)	0.19 (0.03)	n.s.

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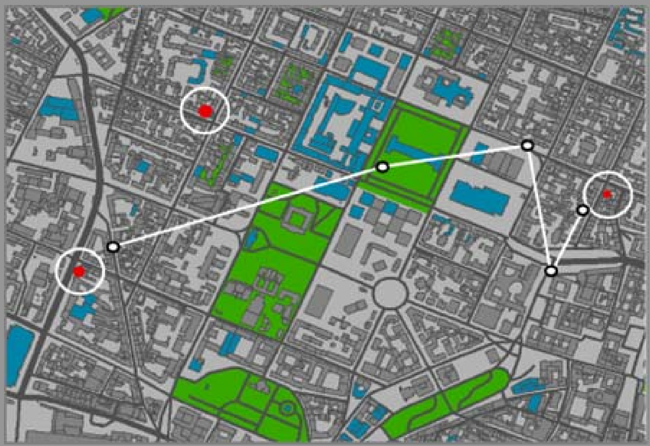

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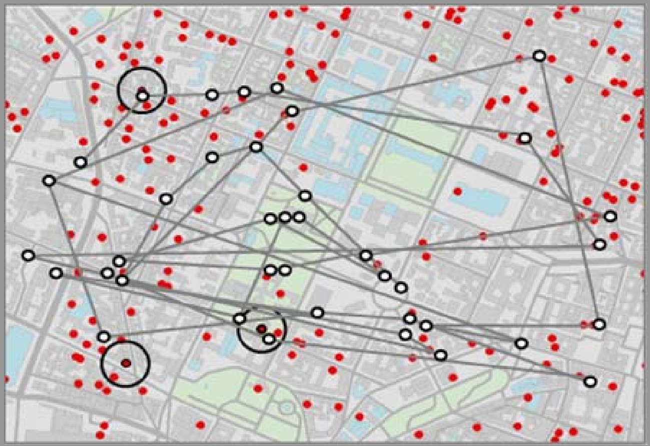
Contour

	case 1	case 2	case 3	p
time (SD)	5.49 (1.90)	3.01 (1.88)	1.95 (0.75)	<.001
length of scan path (SD)	77.75 (35.28)	32.77 (15.42)	21.51 (9.12)	<.001
number of fixations (SD)	10.33 (5.50)	5.33 (2.89)	3.33 (1.40)	<.001
repetition of fixations (SD)	1.33 (1.84)	0.33 (0.62)	0.00 (0.00)	.019
duration of fixations (SD)	0.21 (0.04)	0.20 (0.04)	0.18 (0.02)	.031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Conclusions

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 ***size*** shows no significant differences in performance among the three rest cases; however *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

Summary & Outlook

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