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Visual Semiotics & Uncertainty Visualization: An Empirical Study

TVCG, 2012

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General Information

Why Choose This Paper?

1. Multi-variable control in experiment design
2. Related to **iconicity design** in visualization
3. How to represent uncertain information in visualization

Audience

Target community: Visualization

Target users: Ordinary people

Type

Experimental research paper

Overview

This paper presents two linked empirical studies focused on **uncertainty visualization**

1. Delineate kinds of uncertainty matched with space, time, and attribute components of data
2. Characterize the kind of visual signification for representing different categories of uncertainty

Research Problems

1. **When** and **why** one uncertainty visualization strategy should be used over others?
2. **How** to signify different categories of uncertainty?
3. **What** is the relative effectiveness of a set of uncertainty representation solutions when used to represent three types of uncertainty (due to accuracy, precision, and trustworthiness) matched to three components of information (space, time, and attribute)?

Theoretical Foundation

1. Conceptualizations/taxonomies of uncertainty
2. Visual semiotic frameworks
    1). Review basic building blocks of a graphic representation (the visual variables)
    2). Summarize extant visual variable typologies
3. Iconic and abstract symbols

Conceptualizing Uncertainty

Category	Space	Time	Attributes
Accuracy/ error	coordinates., buildings	+/- 1 day	counts, magnitudes
Precision	1 degree	once per day	nearest 1000
Completeness	20% cloud cover	5 samples for 100	75% reporting
Consistency	from / for a place	5 say M; 2 say T	multiple classifiers
Lineage	# of input sources	# of steps	transforma-tions
Currency/ timing	age of maps	C = Tpresent - Tinfo	census data
Credibility	knowledge of place	reliability of model	U.S. analyst vs. informant
Subjectivity	local ←→ outsider	expert ←→ trainee	fact ←→ guess
Interrelatedness	source proximity	time proximity	same author

Table 1: Conditions of Information Uncertainty. 3 components of information paired with 9 uncertainty types. Table updated from MacEachren et al.

Visual Semiotics

Semiotics

1. **Definition**: the study of sign systems
2. **Goal**: to understand a symbol (the sign-vehicle) becomes imbued with meaning (the interpretant) to represent a thing or concept (the referent)

Visual variables

- Bertin, 1967 (7): 1). location, 2). size, 3). color hue, 4). color value, 5). grain, 6). orientation, 7). shape;
- Morrison, 1974 (2): 8). color saturation, 9). arrangement;
- MacEachren, 1992 (3): 10). clarity (fuzziness) of sign vehicle components, 11). resolution (of boundaries and images), 12). transparency (each is potentially relevant for signification of uncertainty).

N.B.: The experiments reported here focus on point symbols only, so “resolution” is omitted.

Syntactic Relations of Visual Variables

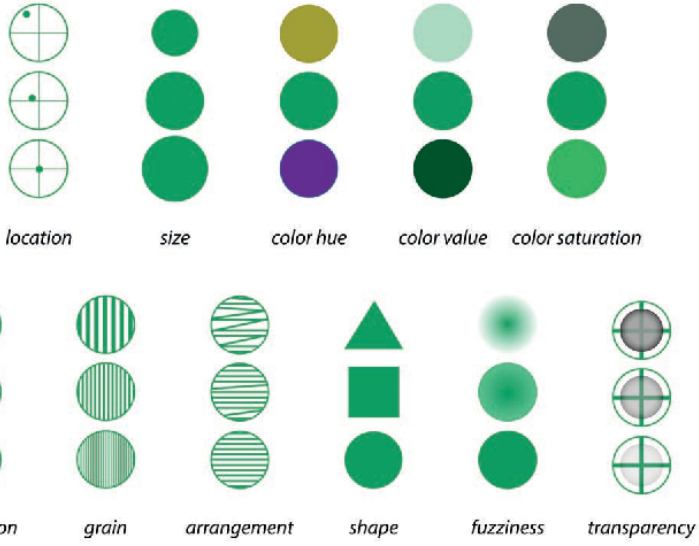


Fig 1. Visual variables applied to point symbol sets.

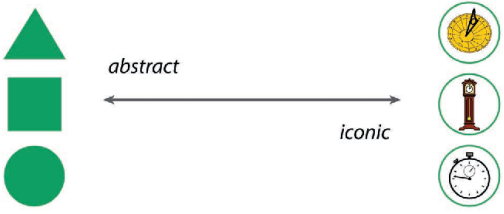
Symbolic Iconicity

Abstract symbols

1. Geometric, having an arbitrary link with referent and varying only a single visual variable
2. Good for tasks that take advantage of pre-attentive processing

Iconic symbols

1. Associative or pictorial, prompting metaphors, resembling or having similarity with the referent
2. Potentially easier to match correctly with qualitatively different aspects of data, such as uncertainty conditions



Symbol Set Design

1. Each symbol set contained three symbols matched to a range from high to low certainty
2. The individual symbol sets were grouped into 10 series
   1). Series #1: One for the general representation of uncertainty
      (1). Abstract symbol set
      (2). 22 total: 11 symbol sets $\times$ 2 directions
      (3). Symbolization of uncertainty, redundant and multivariate signification
   2). Series #2-10: Nine categories of uncertainty with (space, time, attribute) $\times$ (accuracy, precision, trustworthiness)
      (1). Abstract $+$ iconic symbol sets
      (2). 54 total: 6 symbol sets (3 abstract $+$ 3 iconic) $\times$ 9 conditions
      (3). An appropriate metaphor for each of the nine uncertainty category
3. Controlled factors: Color (hue $+$ value $+$ saturation $+$ transparency) $+$ Shape (circular outline) $+$ Size

Methodology

DVAS: Discrete Visual Analog Scale

- Presented as a **sequential scheme** with **no neutral middle-point**, requiring the labeling of **only the poles** of the continuum;
- Presented in a half circle, so that all buttons are an **equal distance** from this repositioned cursor location.

cf. Likert Scale

- Presented as a **diverging scheme** with a central middle point representing the **neutral state**, with each step in **either direction** explicitly labeled.

Experiment #1: Assessing Intuitiveness

1. Addresses representation intuitiveness (i.e., directly apprehended or readily understood), considering both visual variables and iconicity of representation.
2. Task: Experiment #1 required participants to judge suitability of symbol sets for representing variation in a given category of uncertainty.
3. IV (three high-level types, cover seven out of nine-part uncertainty typology):
   1). **Accuracy**: **correctness** or freedom from mistakes, **conformity** to truth or to a standard or model
   2). **Precision**: **exactness** or **degree of refinement** with which a measurement is stated or an operation is performed
   3). **Trustworthiness**: **source dependability** or the **confidence** the user has in the information
4. DV: intuitiveness rankings, response time
5. Participants: 72 graduate students from GIScience major

6. Interface

1). A symbol set

2). A set of intuitiveness ranking responses

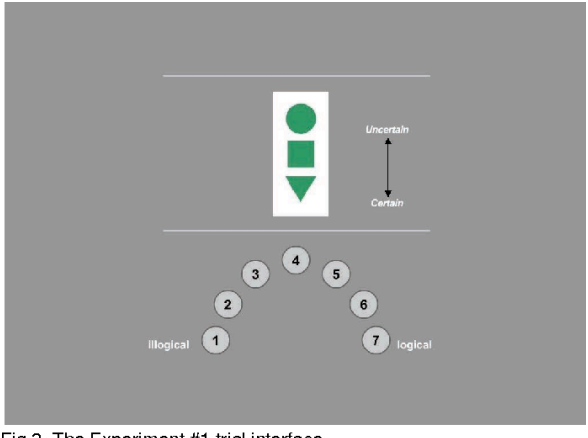


Fig 3. The Experiment #1 trial interface.

Experiment #2: Symbol Sets in Map Displays

1. Addresses relative performance of the most intuitive abstract and iconic representations of uncertainty appear on a display.
2. Task: Experiment #2 ask participants to select the region of the pair for which information is least certain overall.

   240 trials $=$ [Two abstract symbol sets (**fuzziness** and **color value**) from Series #1 $+$ 2nd highest symbol sets (**abstract** $+$ **iconic**) from Series #2-10] $\times$ 12 different maps
3. IV: Four degrees of aggregate uncertainty (H = most uncertain symbol, M = middle symbol, and C = most certain symbol in symbol set)
   1). Highly uncertain: 7-H + 1-M + 1-C
   2). Moderately uncertain: 4-H + 3-M + 2-C
   3). Moderately certain: 2-H + 3-M + 4-C
   4). Highly certain: 1-H + 1-M + 7-C
4. DV: suitability rankings, response time
5. Participants: 30 GIScience background professionals

6. Interface

1). A legend showing the three symbols with an indication of their uncertainty order
2). A map region trial

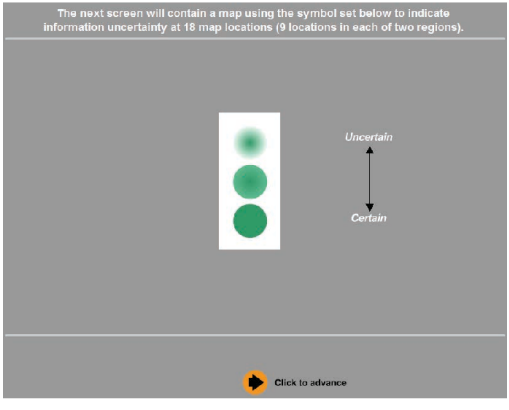


Fig.5: Screen #1

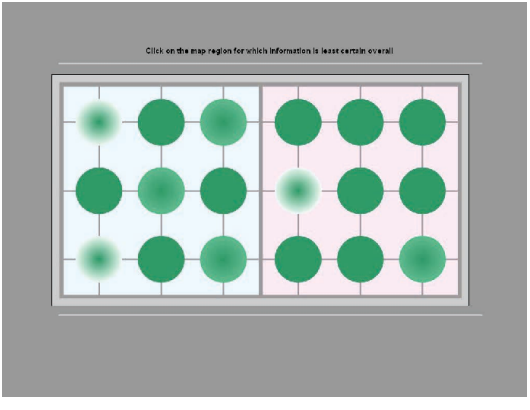


Fig.6: Screen #2

Experiment #1

Goals

1. Stage #1: Identify the most intuitive symbol set for each **condition of uncertainty** (this was done for abstract symbols, iconic symbols, and symbols overall)
2. Stage #2: Examine the **differences** and determine the **relative merits** between the abstract and iconic symbol sets within and across series

Methods

1. Stage #1: examining statistical difference across **three or more groupings**
   1). The Kruskal-Wallis test (i.e., one-way ANOVA on ranks, nonparametric) to the intuitiveness rankings
   2). The ANOVA test (parametric) to the RTs
2. Stage #2: examining statistical difference between two **unmatched groups**
   1). The Mann-Whitney test (nonparametric) to the intuitiveness rankings
   2). The independent two-group t-test with Welsh df modification (parametric) to the RTs

Experiment #2

Goals

1. Stage #1: get insight into the nature of geospatial uncertainty and the relative difficulties exhibited when performing map reading tasks under different uncertainty conditions
2. Stage #2: determine the relative merits of abstract versus iconic symbolization for visualizing uncertainty

Methods

1. Stage #1: examining the differences in accuracy and RT across Series#2-10
   1). The Pearson's chi-square test with Yates' continuity correction (nonparametric) to the accuracy recordings
   2). The ANOVA test (parametric) to the RTs
2. Stage #2: examining the differences between the abstract and iconic symbol sets within and across series
   1). The Pearson's chi-square test with Yates' continuity correction (non-parametric) to the accuracy recordings
   2). The independent two-group t-test with Welsh df modification (parametric) to the RTs

Results of Experiment #1

Series #1

1. Significant differences found in intuitiveness ranking: Not all visual variables are intuitive for visualizing ordinal uncertainty information
2. No significant difference in RT: The task of judging intuitiveness to be similarly easy/difficult
3. For visualizing discrete entity uncertainty reported at the ordinal level

Good	**Fuzziness**, **location**, and **value**
Acceptable	**Arrangement**, **size**, and **transparency**
Unacceptable	**Saturation**, **hue**, **orientation**, and **shape**

Series #2-10

1. All **space** conditions and all **trustworthiness** conditions exhibit differences in symbol set intuitiveness ratings
2. No significant difference in RT

N.B.: Click here for detail.

Results of Experiment #2

Significance was found when examining abstract or iconic symbol sets in isolation or when pooling all symbol sets together.

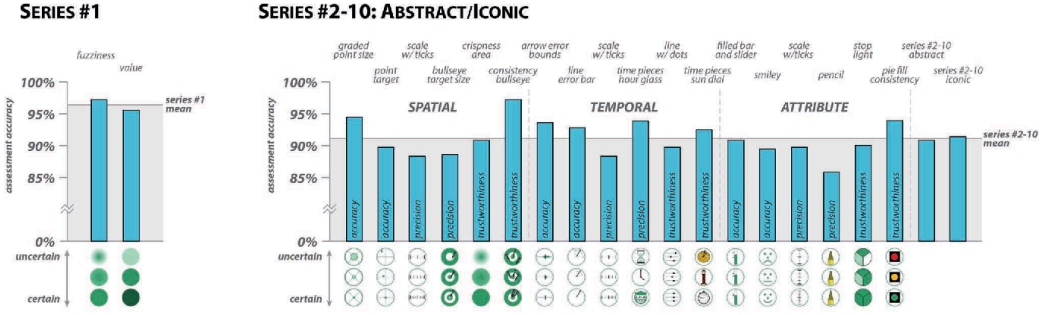


Fig 8. Experiment #2 descriptive statistics by series and symbol set.

Fig. 7: Experiment #2 descriptive statistics by series and symbol set.

Conclusions

Experiment #1

1. Abstract symbol sets
   Fast to judge since the process of interpreting order and directionality
2. Iconic symbol sets
   Require more cognitive processing to identify the intended metaphorical relationship with the uncertainty condition signified

Experiment #2

1. Participants were not equally comfortable making assessments of aggregate uncertainty for all uncertainty conditions
2. The level of iconicity did not have a consistent influence on accuracy of aggregate uncertainty assessment

Take-Home Message

1. Not possible to state that the iconic symbolization is consistently more intuitive regardless of uncertainty condition.
2. The methods of conducting controlled experiments.
3. Iconic sign-vehicles can be more intuitive and more accurately judged when aggregated (than are abstract sign-vehicles), the abstract sign-vehicles can lead to quicker judgments.
4. One question: how the visualization of uncertainty influences reasoning and decision making in problem context for which uncertainty matters?

References

Alan M. MacEachren, Robert E. Roth, James O'Brien, Bonan Li, Derek Swingley, and Mark Gahegan. Visual semiotics & uncertainty visualization: An empirical study. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2496–2505, December 2012.