Perspectives on Uncertainty, Geovisualization, and Geographical Reasoning / Decision-making

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Outline

- *What is uncertainty* (in the context of geographical information)?
- *How can we depict uncertainty visually* (in static and interactive displays)?
- *How should we depict uncertainty visually*? What do we know about which methods work?
- *What happens when we depict uncertainty visually*; what are the implications for reasoning and decisions?

Outline

- What is uncertainty (in the context of geographical information)?

Categorizing Uncertainty: GIScience emphasis on data quality

Data Quality \ Data Type	Positional Accuracy	Attribute Accuracy	Logical Consistency	Completeness	Lineage
Discrete Points and Lines	Size Shape (Error ellipses) (Epsilon bands)	Value Color Saturation (Feature code checks)	Color mixing Redundancy by overprinting Slivers by solid fills (Topological cleaning)	Mapping Technique Density traces Marginalia Generalization algorithm Mapping tolerance Buffer size	Mapping Technique Minimum Bounding Rectangles
Categorical Aggregation & Overlay (Tesselation, tiling, Areal coverages)	Texture Value (Certainty of boundary location)	Color mixing (Attribute code checks) (Topographic classifier)	lack error models	Mapping Technique Missing values Logical adjacency surface Marginalia Discrete model weights	
Partitioning & Enumeration (Metric class breaks)	not meaningful	Size = height (Blanket of error)	Size = height (Maximum likelihood prism maps)	Mapping Technique Missing values Missclassification matrix Classing scheme OAL/TAI	Marginalia Source of data Scale/Resolution Date Geometry
Continuous Interpolation (Surfaces and volumes)	no clear distinction b/w the two Value Color Saturation (Continuous tone vignettes) (Continuous tone isopleths)		Size = line wt Color Shape = compactness (TIN links)	not possible by definition Mapping Technique Surface of search attenuation Marginalia Interpolation algorithm	

Graphical Syntax ←→ (Positional Accuracy, Attribute Accuracy, Logical Consistency)

Graphical/Lexical Syntax ←→ (Completeness, Lineage)

after: Buttenfield, B.P. and Weibel., R. 1988: Visualizing the Quality of Cartographic Data., Presented at Third International Geographic Information Systems Symposium (GIS/LIS 88), San Antonio, Texas..

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Categorizing Uncertainty: Cartography – emphasis on attributes of phenomena & measurement

	Accuracy	Precision
Location	***position*** of vegetation boundaries	***state*** birth rate
Attributes	***total*** HIV positive caes/county	soil ***order***
Time	***date*** of the last glacier	mean ***monthly*** rainfull

after: MacEachren, Alan M. (1992) Visualizing uncertain information, *Cartographic Perspectives*, 13:10-19.

Categorizing Uncertainty: integration

Category	Components		
	Space	**Time**	**Attributes**
Accuracy/ error	coordinates., buildings	+/- 1 day	counts, magnitudes
Precision	1 degree	once per day	nearest 1000
Lineage	geographic sources/transforms	time sources/transforms	attribute sources/transforms
Consistency	from / for a place	5 say Mon; 2 say Tues	multiple classifiers
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 independence	source independence	source independence

after: MacEachren, A.M., Robinson, A., Hopper, S., Gardner, S., Murray, R., Gahegan, M. and Hetzler, E. 2005: Visualizing Geospatial Information Uncertainty: What we know and what we need to know. *Cartography & Geographic Info. Science* 32, 139-160.

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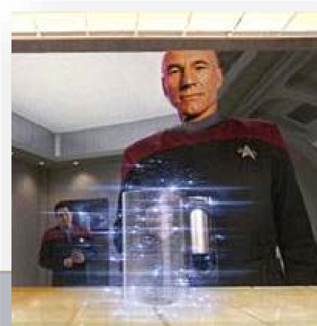
Kinds of uncertainty about decisions:

categories from: Courtney, H. 2003: Decision-driven scenarios for assessing four levels of uncertainty. Strategy & Leadership 31, 14-22

- **Clear enough future**: point forecasts 'close enough' for decision at hand (e.g., location decision certainty: will a Segafredo Café opened at Kärntner Str and Philharmoniker Str will make a profit?)
- **Choice among alternate futures**: limited set of possible outcomes can be defined (e.g., given a choice of 2 intersections vs. a location inside the train station for a Segafredo Café, which will be the most successful?)
- **Range of futures**: possible range is definable within some bounds (e.g., given an estimate that 35-55% of Starbucks patrons will switch allegiance, will a Segafredo Café be successful across the street?)
- **True ambiguity**: not possible to even define the range of possible outcomes – uncertainties both unknown and unknowable (e.g., how will Star Trek like food replicators that bring a cup of 'real' Segafredo espresso and pastry to you impact the success of physical Segafredo Café locations?)



http://guardianlv.com/2014/06/nestle-trying-to-create-star-trek-like-food-replicator/

Info-processing Decision Impediments

from Zack, 2007, adapted for crisis mgt. decisions by Muhren & van de Walle, 2010

4 reasons for uncertainty about which decision is best

what is processed / processing problem	Information	Frame(s) of Reference
Lack of …	uncertainty	ambiguity
Diversity of …	complexity	equivocation

- **uncertainty**: not enough info to process task – requires tools for *information foraging*
- **complexity**: more info than can be processed – requires tools for *information filtering, fusion, synthesis*
- **ambiguity**: lack of framework to interpret – requires tools to *build context*
- **equivocation (confusion)**: competing/contradictory frameworks – requires tools for *re-framing, analysis of competing hypotheses, deliberation, negotiation, etc.*

Zack, M.H. 2007: The role of decision support systems in an indeterminate world. Decision Support Systems 43, 1664-1674.

Muhren, W. and Van de Walle, B. 2010: A Call for Sensemaking Support Systems in Crisis Management. *Interactive Collaborative Information Systems, Berlin: Springer, 425-452.*

Outline

- What is uncertainty (in the context of geographical information)?
- How *can* we depict uncertainty visually (in static and interactive displays)?
  - adjacent vs. coincident display
  - visually integral vs visually separable signification
  - static versus dynamic display

categories from: Kinkeldey, C., MacEachren, A.M. and Schiewe, J. 2014: How to Assess Visual Communication of Uncertainty? A Systematic Review of Geospatial Uncertainty Visualization User Studies. *Cartographic Journal* (advance PDF available on publisher site).

Visualizing uncertainty & ensemble data: adjacent versus coincident

adjacent display

coincident visually separable display: overlay

coincident display: visual variables

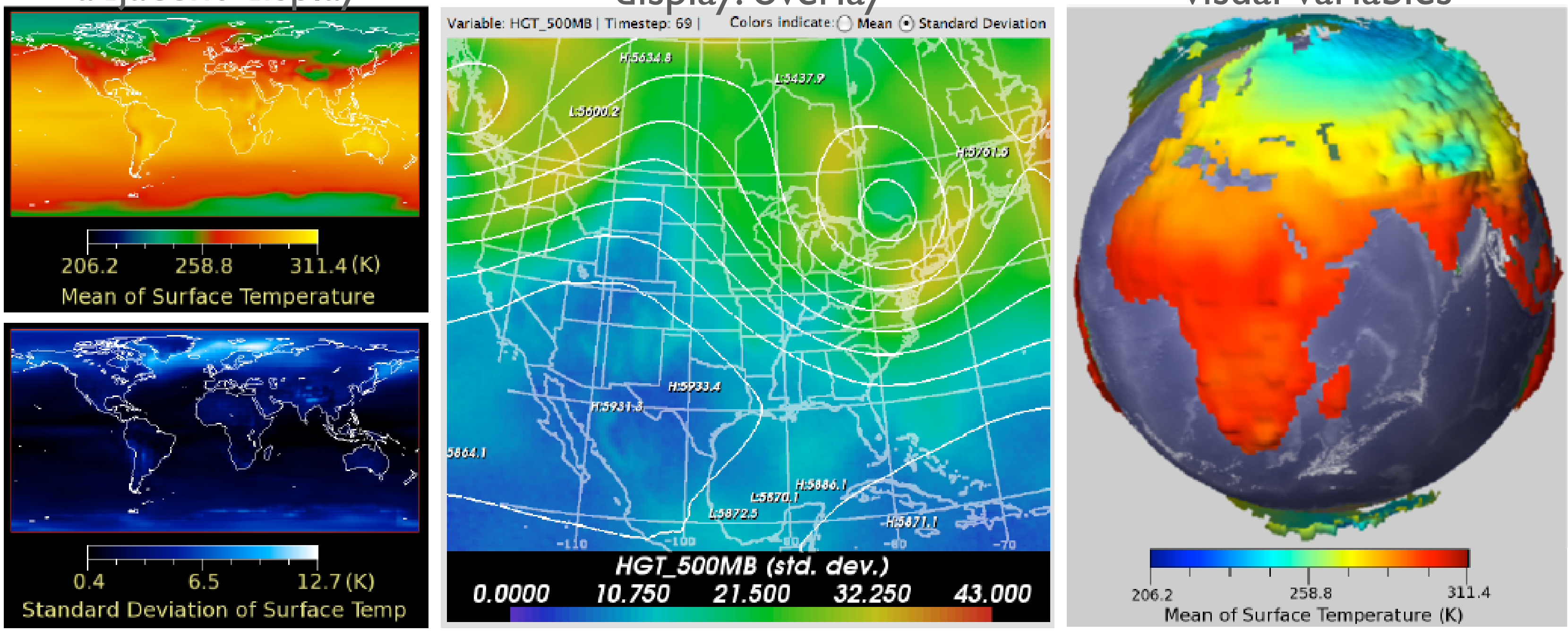
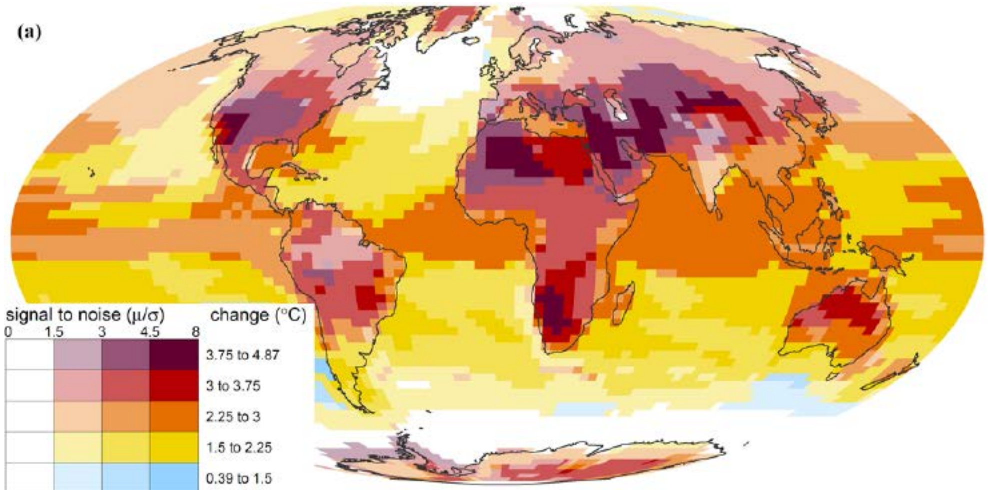


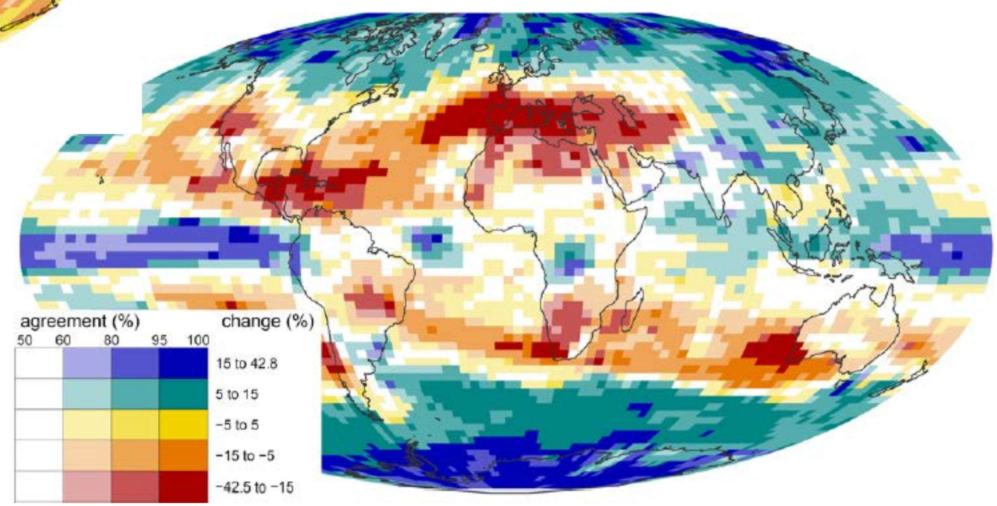
Figure 3. Visualizations of mean and standard deviation. (Left) Mean and standard deviation are visualized independently using color maps. (Center) Mean is presented through a color map, and standard deviation is shown as an overlaid contour. (Right) Standard deviation is mapped to a height field and mean is color mapped.

Potter, K., Wilson, A., Bremer, P.-T., Williams, D., Doutriaux, C., Pascucci, V. and Johhson, C. 2009: Visualization of uncertainty and ensemble data: Exploration of climate modeling and weather forecast data with integrated ViSUS-CDAT systems. *Journal of Physics: Conference Series 180, 012089.*

Uncertainty via visual variables: coincident integral display: visual variables



Estiamted temperature change between 1961–1990 and 2070–2099 for the mean of the IPCC AR4 ensemble based on the SRES A1B scenario



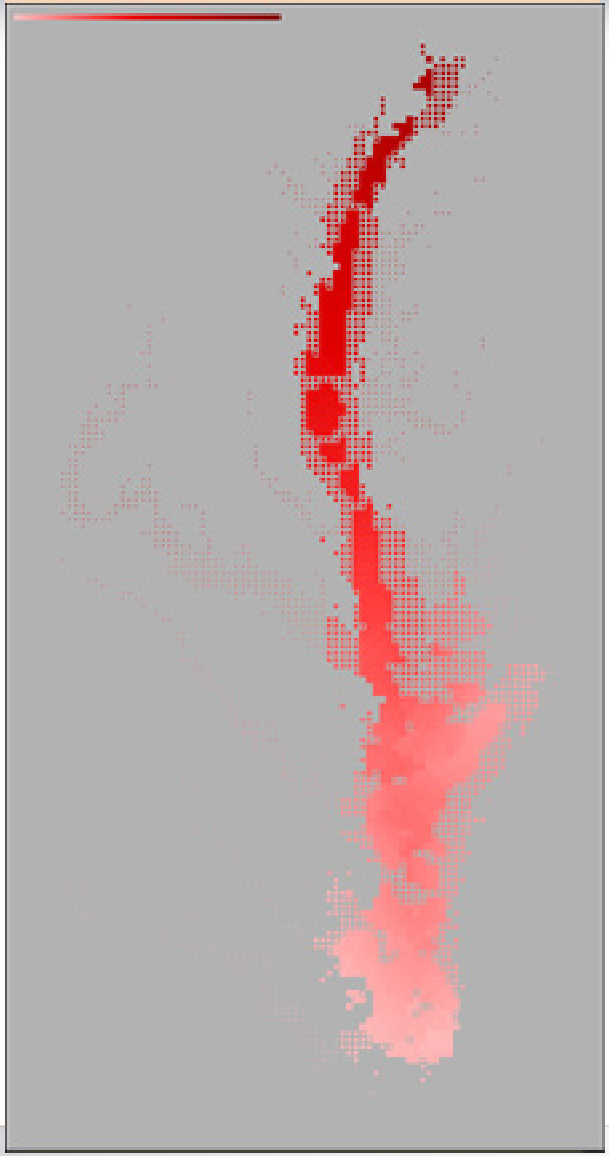
Estiamted precipitation change between 1961–1990 and 2070–2099 for the mean of the IPCC AR4 ensemble based on the SRES A1B scenario

Kaye, N., Hartley, A. and Hemming, D. 2011: Mapping the climate: guidance on appropriate techniques to map climate variables and their uncertainty. Geoscientific Model Development Discussions 4, 1875-1906.

Uncertainty via visual variables: coincident separable, interactive size (of grid square)

- dynamic depiction of data (dissolved inorganic nitrogen) and data uncertainty

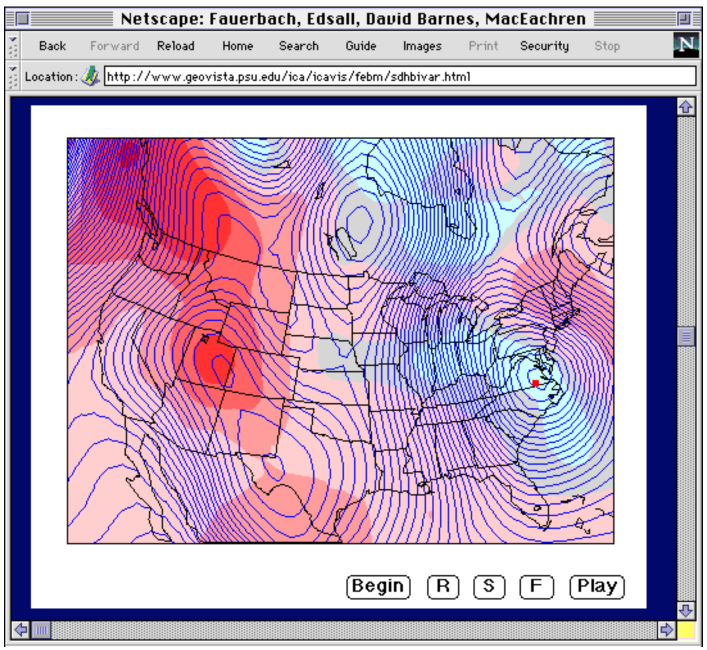
data + uncertainty

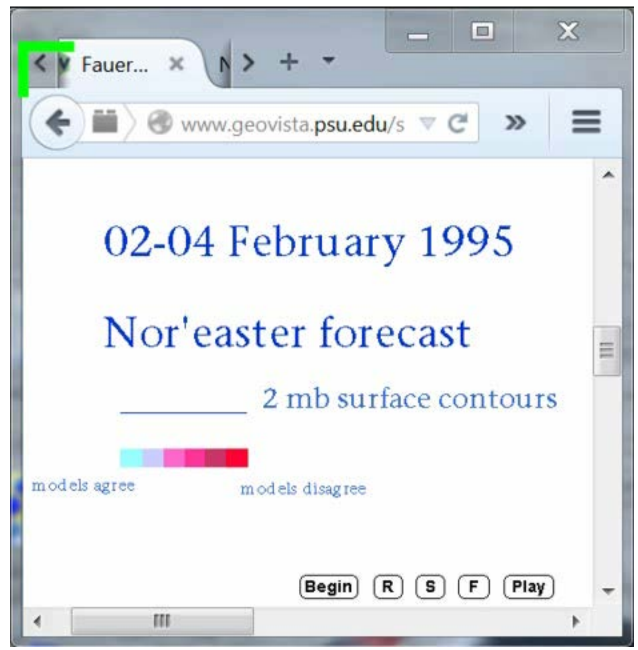


Howard, D. and MacEachren, A.M. 1996: Interface design for geographic visualization: Tools for representing reliability. *Cartography and Geographic Information Systems 23, 59-77.*

Coincident separable dynamic: Uncertainty as a data layer – Meteo. forecast uncertainty

Fauerbach, E., Edsall, R., Barnes, D. and MacEachren, A. 1996: Visualization of uncertainty in meteorological forecast models. In Kraak, M.J. and Molenaar, M., editors, *Proceedings of the International Symposium on Spatial Data Handling, Delft, The Netherlands, August 12-16: Taylor & Francis, 465-476.*



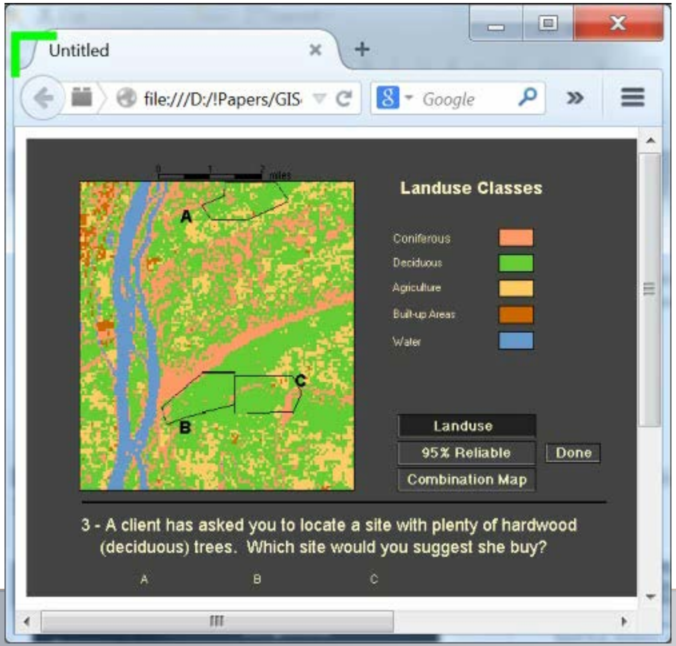


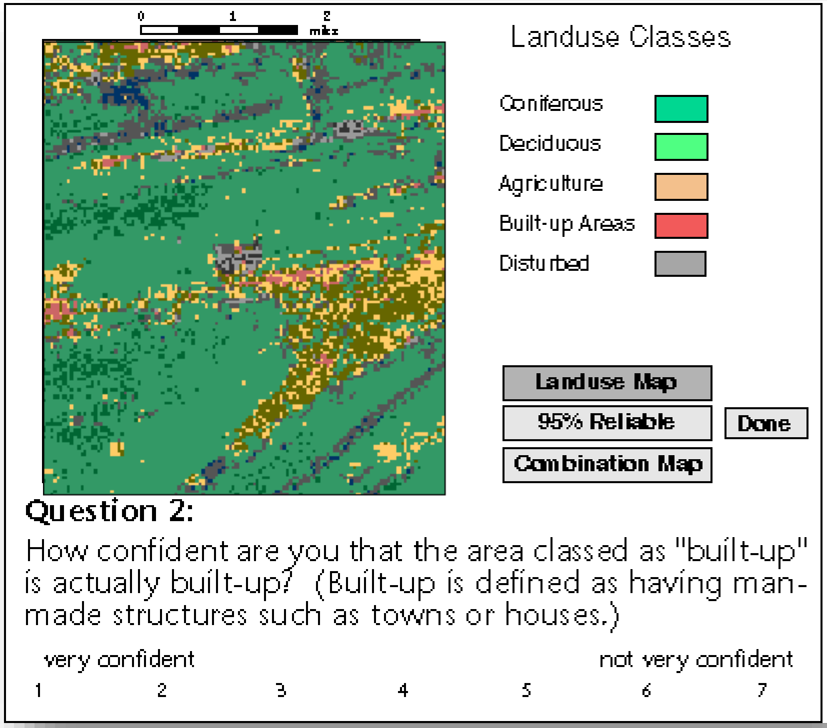
Blue = models agree; Red = models disagree

http://www.geovista.psu.edu/sites/icavis/icavis/febm/sdhbivar.html

Uncertainty via visual and dynamic variables: Landcover classification

- Evans, B.J. 1997: Dynamic display of spatial data-reliability: does it benefit the user? *Computers & Geosciences, special issue on Exploratory Cartographic Visualization 23, 409-422.*

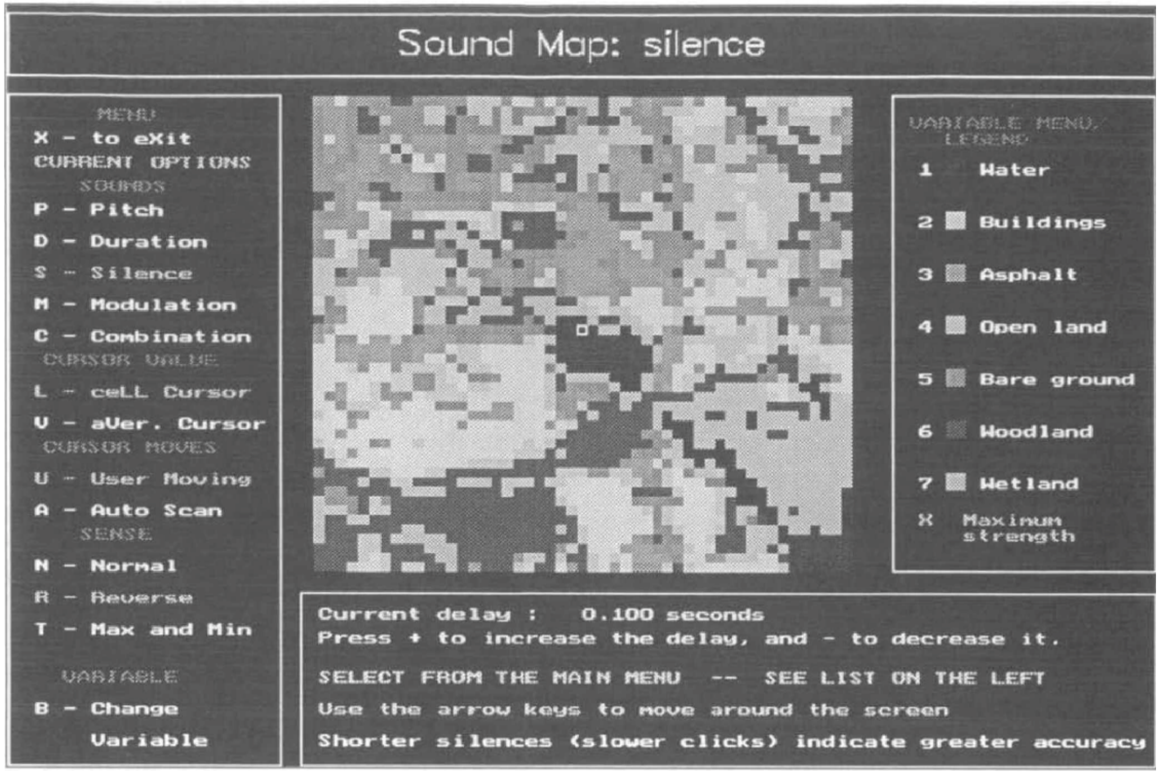




coincident, integral static compared to coincident separable dynamic

Uncertainty via sonic variables: coincident, separable, dynamic Landcover classification

- Fisher, P. (1994). "Hearing the reliability in classified remotely sensed images." Cart. and Geog. Info. Sys. 21(1): 31-36.



Outline

- What is uncertainty (in the context of geographical information)?
- How *can* we depict uncertainty visually (in static and interactive displays)?
- How *should* we depict uncertainty? What do we know about which methods work?

for more background, see new review paper:

- Kinkeldey, C., MacEachren, A.M. and Schiewe, J. 2014: How to Assess Visual Communication of Uncertainty? A Systematic Review of Geospatial Uncertainty Visualization User Studies. *Cartographic Journal* (advance PDF available on publisher site).

NCHS atlas color/reliability schemes

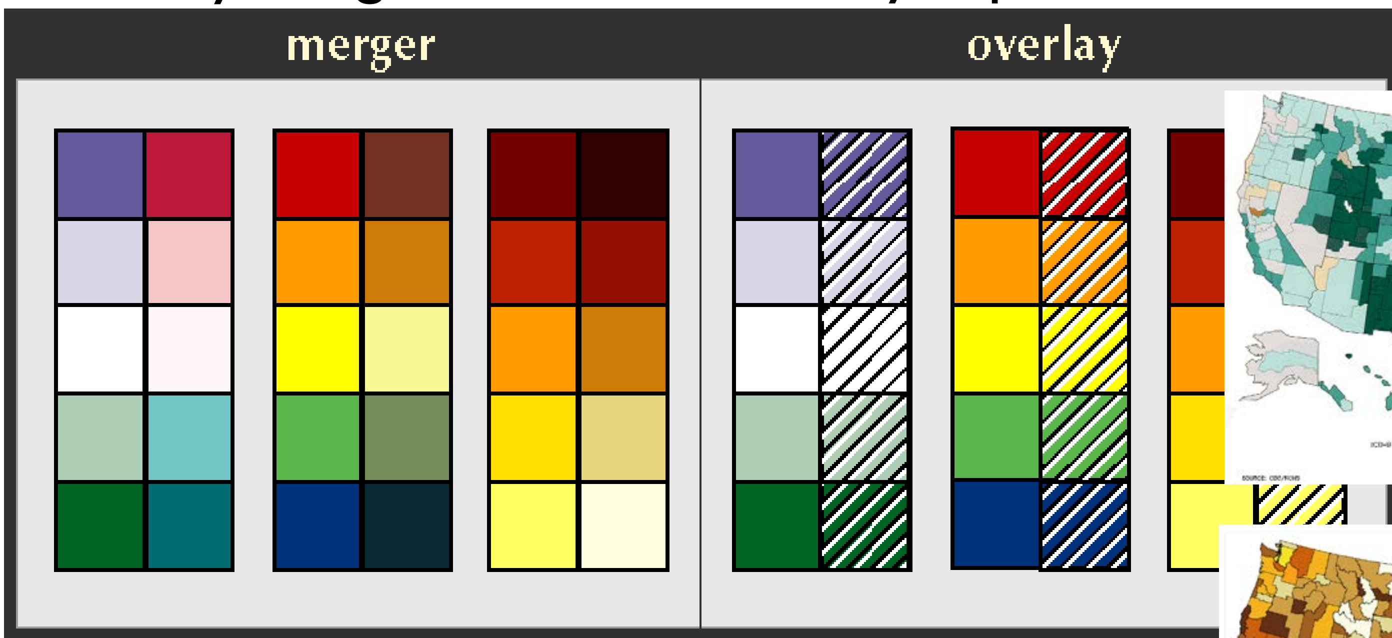
Cindy Brewer and **Alan MacEachren** researched the color and reliability map symbols for the *Atlas of United States Mortality* by the National Center for Health Statistics (CDC).

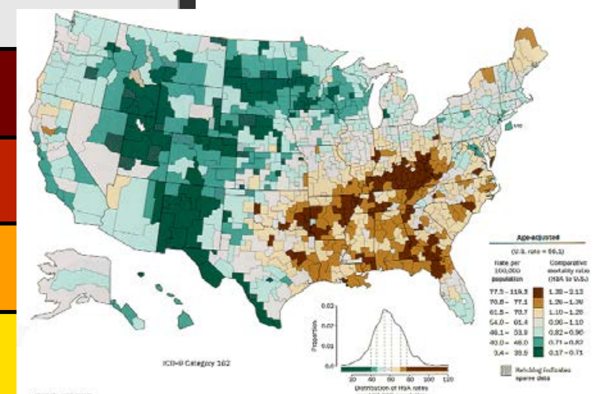
www.cdc.gov/nchswww/products/pubs/pubd/other/atlas/atlas.htm

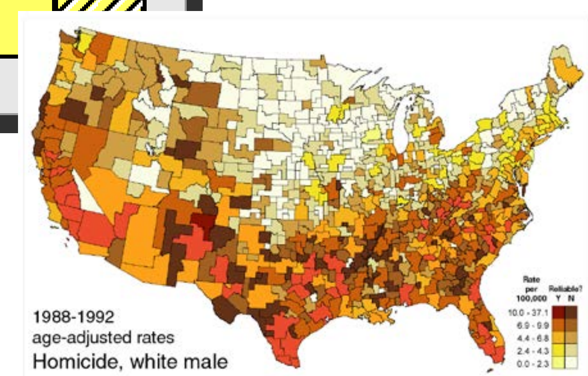
atlas author: Linda Pickle

colors/textures to represent reliability

visually integral | visually separable

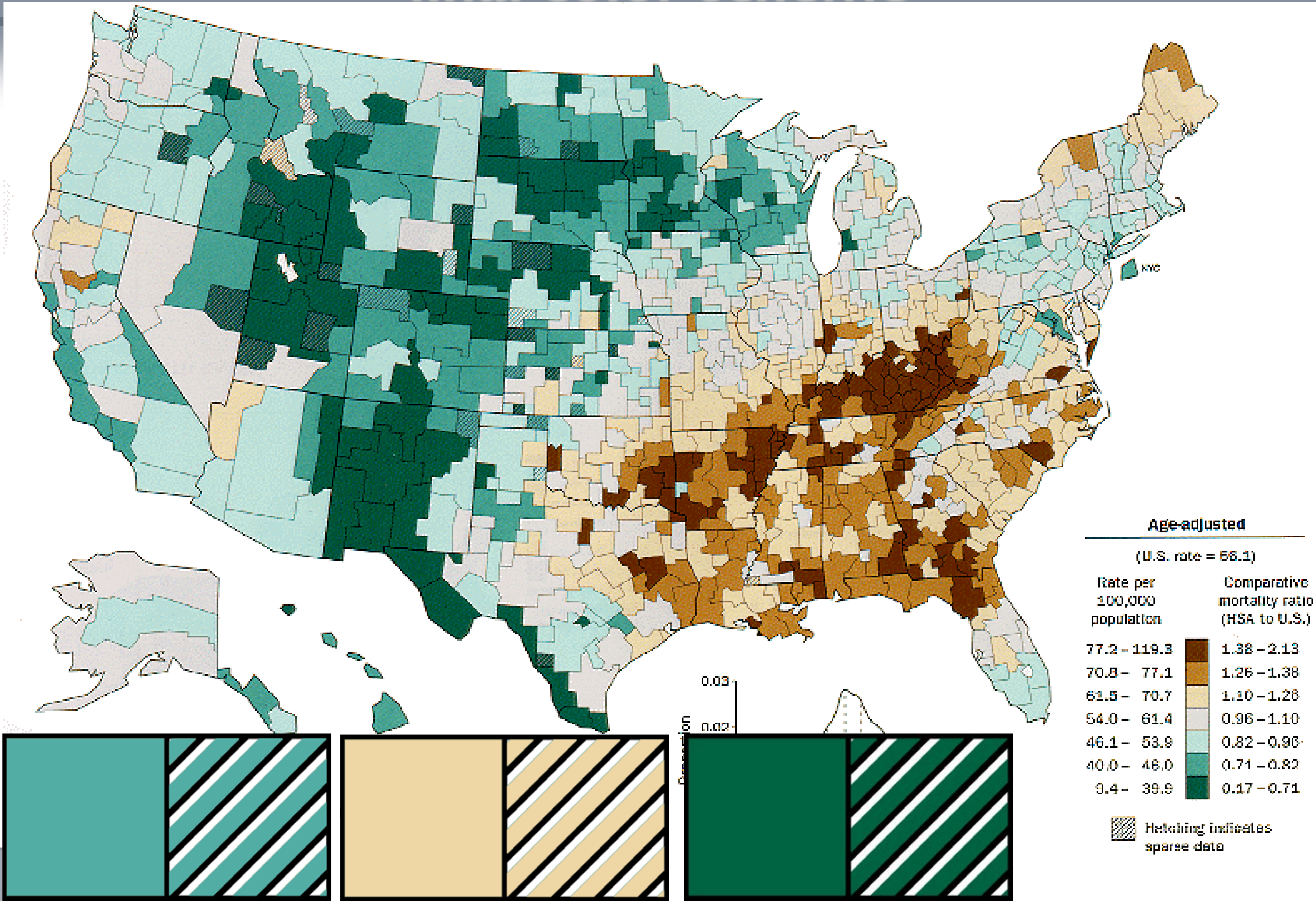






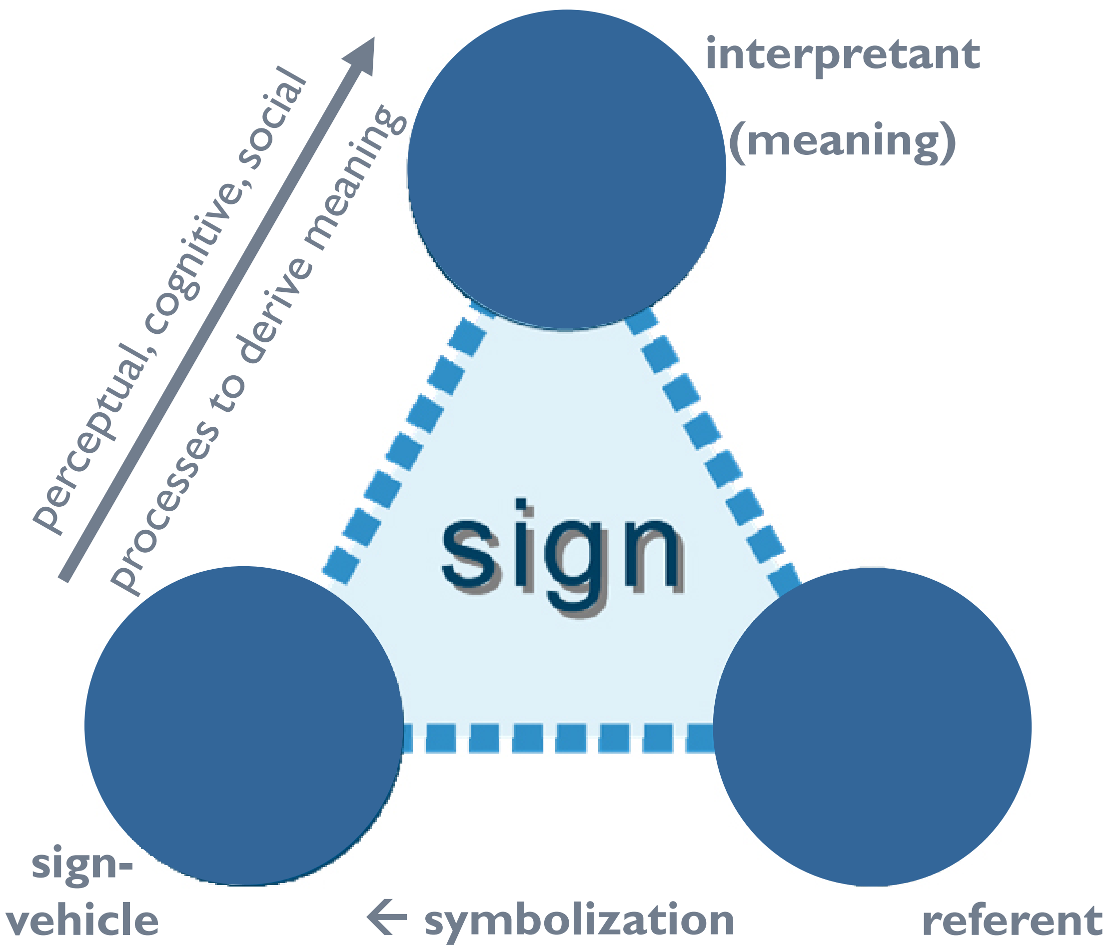
MacEachren, A.M., Brewer, C.A. and Pickle, L.W. 1998: Visualizing Georeferenced data: Representing reliability of health statistics. *Environment and Planning: A 30, 1547-1561.*

final color scheme



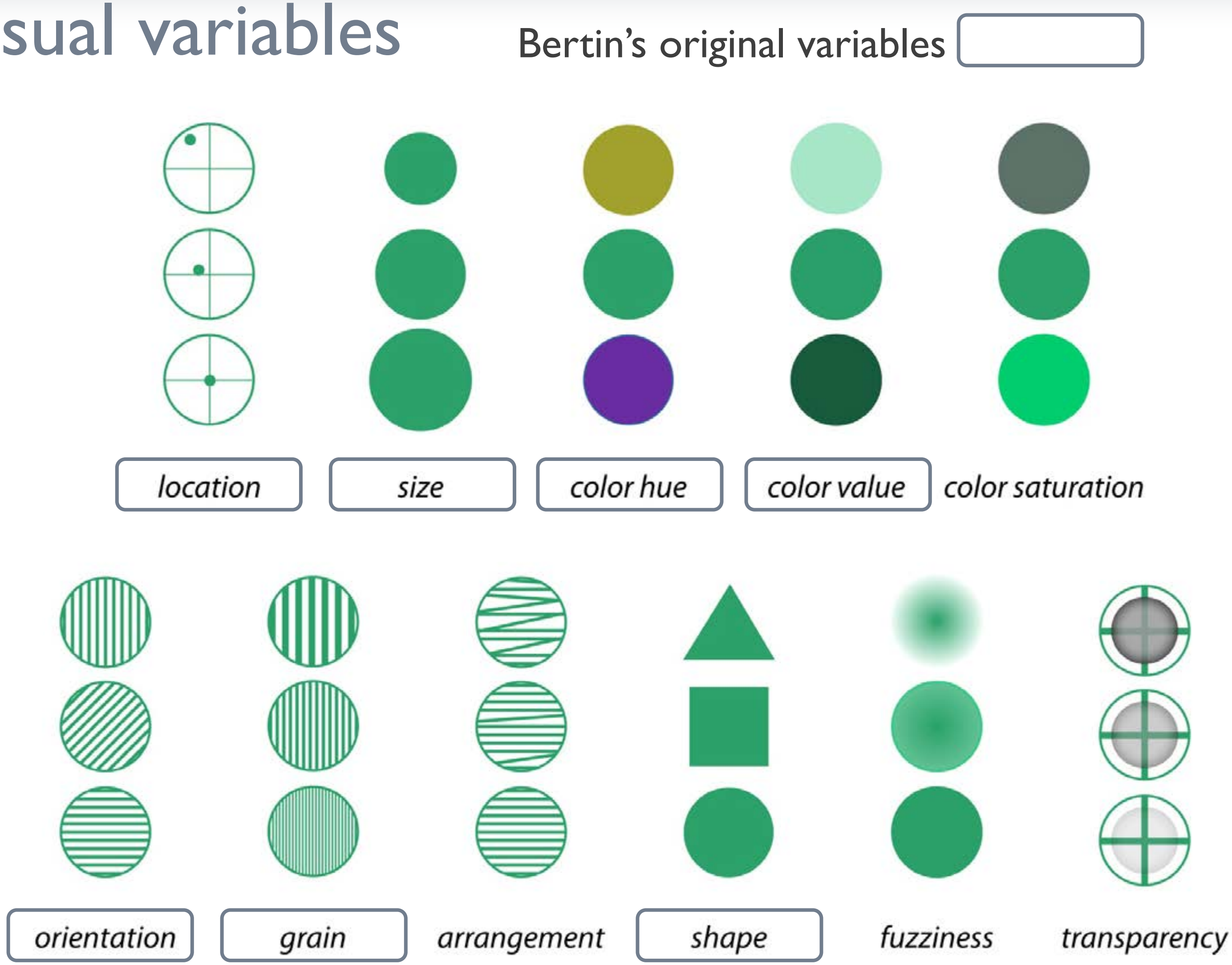
Semiotics: the science of "signs" and sign systems

triadic model of signs as relations



Visual Semiotics: which visual variables imply uncertainty?

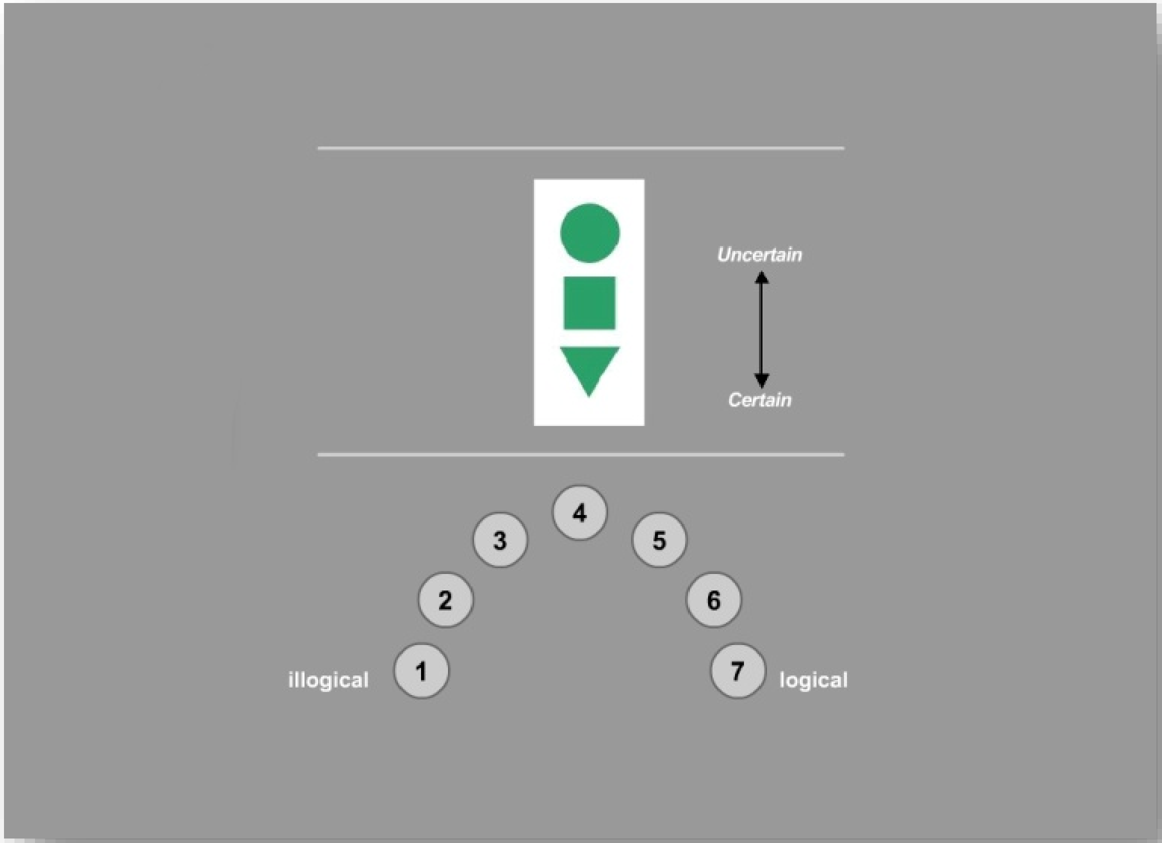
- Visual variables



MacEachren, A.M., Roth, R.E., O'Brien, J., Li, B., Swingley, D. and Gahegan, M. 2012: Visual Semiotics & Uncertainty Visualization: An Empirical Study. IEEE Transactions on Visualization & Computer Graphics 18, 2496-2505.

Experiment 1: Assessing intuitiveness

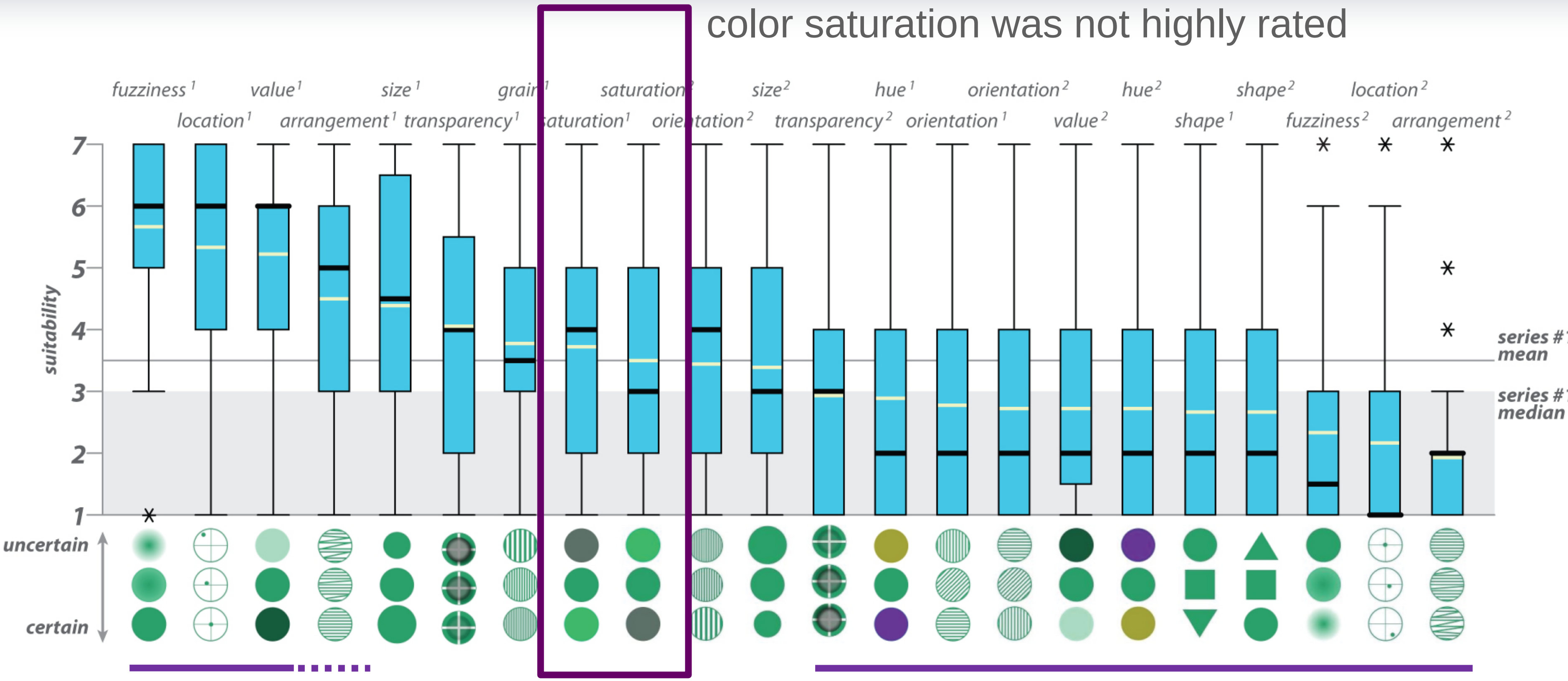
- Participants (31 in pilot + 72 in main study) rate the logic (intuitiveness) of the symbol set



MacEachren, A.M., Roth, R.E., O'Brien, J., Li, B., Swingley, D. and Gahegan, M. 2012: Visual Semiotics & Uncertainty Visualization: An Empirical Study. IEEE Transactions on Visualization & Computer Graphics 18, 2496-2505.

Series 1: Results

color saturation was not highly rated



fuzziness, location, and ***value*** rate high; ***arrangement*** is marginally successful

color *hue* and ***shape*** rate low (as expected), as do orientation, ***inverted transparency, fuzziness, location, value, arrangement***

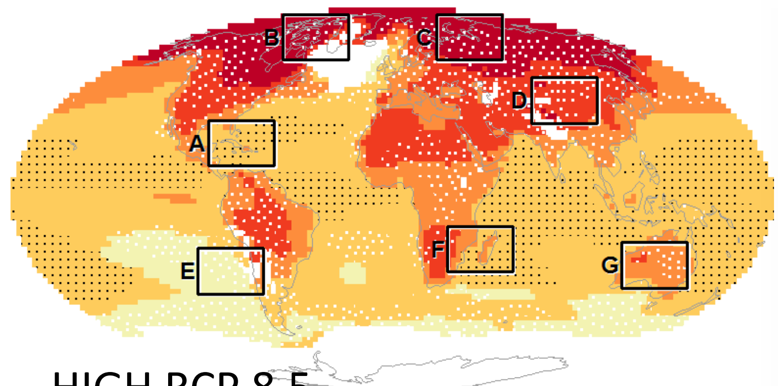
MacEachren, A.M., Roth, R.E., O'Brien, J., Li, B., Swingley, D. and Gahegan, M. 2012: Visual Semiotics & Uncertainty Visualization: An Empirical Study. IEEE Transactions on Visualization & Computer Graphics 18, 2496-2505.

Mapping Climate Change Uncertainty:

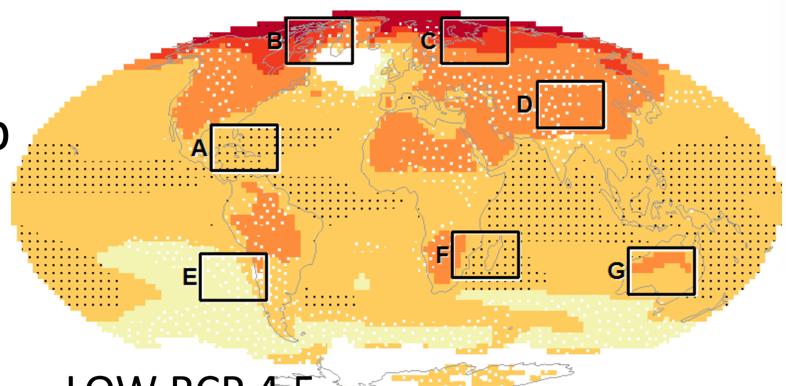
A pilot study of effects on risk perceptions and decision making

David Retchless, PhD candidate; dpr173@psu.edu

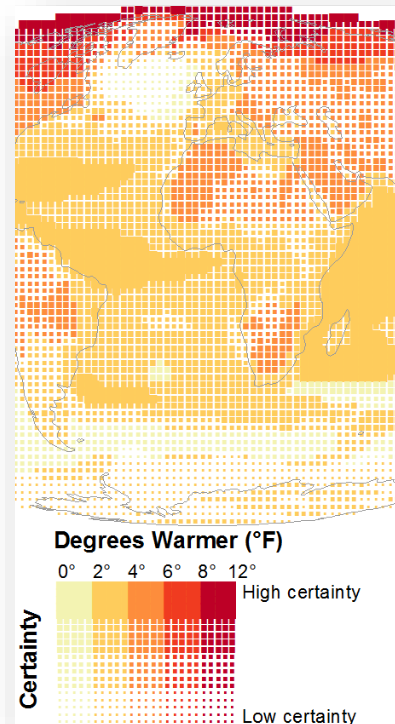
- Methods: 274 respondents, randomly assigned 1 of 20 maps:
  - 10 types of maps
  - 2 emissions scenarios (high & low)
  - ~14 respondents/map
  - Data from CMIP5



HIGH RCP 8.5



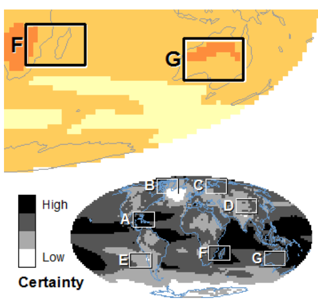
LOW RCP 4.5



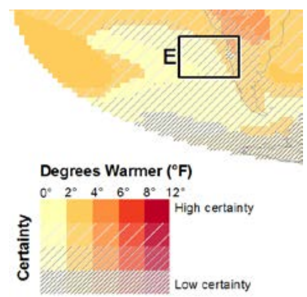
for details, see: Retchless, D. 2012: Mapping Climate Change Uncertainty: Effects on Risk Perceptions and Decision Making, Paper #GC43B-1024. *AGU Fall Meeting, San Francisco, CA. fallmeeting.agu.org/2012/eposters/eposter/gc43b-1024*

Conclusions: Understanding Magnitude & Certainty

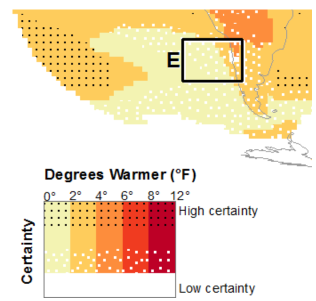
- Temperature ranking was easy, uncertainty ranking was hard.
- Consistent with MacEachren et al. (1998), texture outperformed color for uncertainty ranking.
- Best maps for uncertainty ranking:



Control with small map



Texture – Lines



Texture – Spots

for details, see: Retchless, D. 2012: Mapping Climate Change Uncertainty: Effects on Risk Perceptions and Decision Making, Paper #GC43B-1024. *AGU Fall Meeting, San Francisco, CA. fallmeeting.agu.org/2012/eposters/eposter/gc43b-1024*

Just published review of existing empirical studies of uncertainty communication

- Kinkeldey, C., MacEachren, A.M. and Schiewe, J. 2014: How to Assess Visual Communication of Uncertainty? A Systematic Review of Geospatial Uncertainty Visualization User Studies. *Cartographic Journal* (advance PDF available on publisher site).
- Lessons learned:
  - 2 study types typical: improve uncertainty display, understand cognitive process in using displays
  - choice of techniques to compare is fundamental: consider both informational and computational equivalence
  - particular care is needed in empirical research to enlist representative users and consider the multiple kinds of expertise possible
  - categorization of uncertainty difficult to apply in practice
  - distinction between classed and unclassed uncertainty signification is under-researched
  - uncertainty is not "just another variable"
- Conclusions (related to studies of uncertainty communication):
  - "… most important outcome is that we need to systematize future empirical studies on uncertainty visualisation to better enable comparison and generalization of the findings."
  - future studies should be more explicit in specifying kinds of task, as: communication, analysis, or exploration

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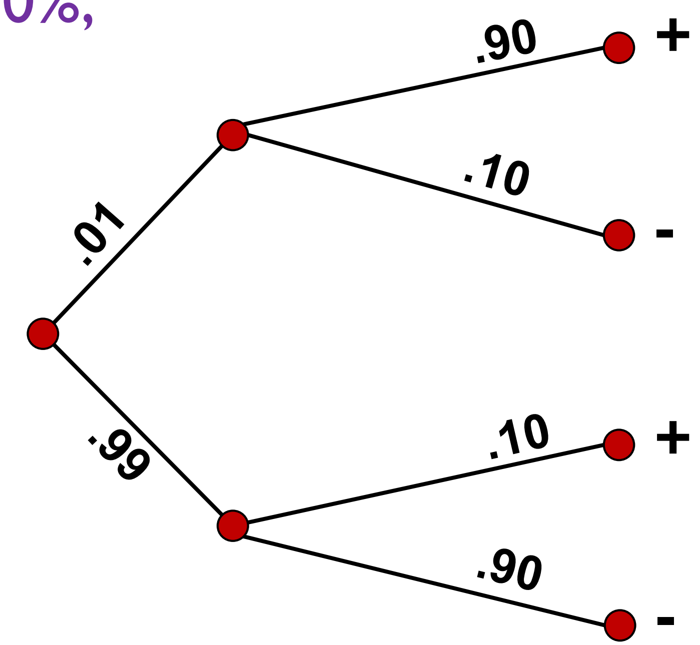
- How should we depict uncertainty? What do we know about which methods work?
- What happens when we depict uncertainty; what are the implications for reasoning and decisions? short answer: *we do not yet know*

Non-geographical Bayesian reasoning example

- approximately 1% of women aged 40-50 have breast cancer. A woman with breast cancer has a 90% chance of a positive test from a mammogram, while a woman without has a 10% chance of a false positive result.
- What is the probability that a woman has breast cancer given that she just had a positive test?

  (a) >50%; 31-50%; 10-30%; <10%;



P(cancer | +) =
P(+ | cancer) * P(cancer) / P(+)

P(cancer | +) =
= (.90)(.01) / (.01)(.90)+(.99)(.10)
= .009 / (.009 + .099)
= 9 / 108
= **8.3%**

Non-geographical Bayesian reasoning example

- **visual support**: Micallef, L., Dragicevic, P. and Fekete, J. 2012: Assessing the Effect of Visualizations on Bayesian Reasoning through Crowdsourcing. *Visualization and Computer Graphics, IEEE Transactions on 18, 2536-2545.*

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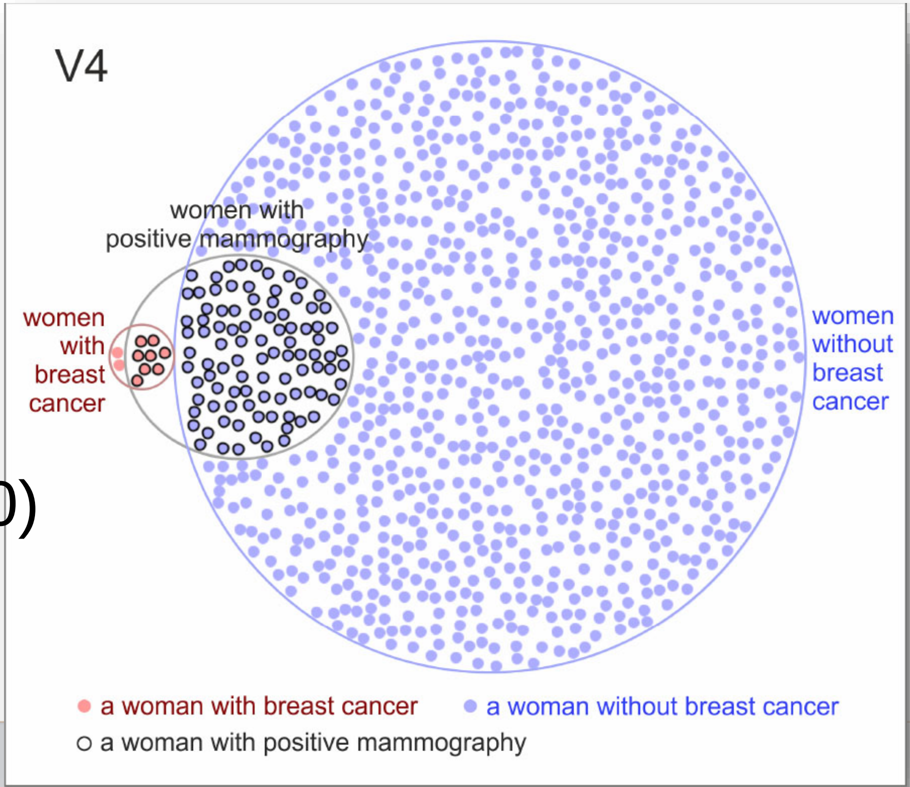

Kinds of uncertainty vis effects on geographic reasoning/decision-making that have been studied

- understanding of visually-communicated probabilities
- decision accuracy
- decision speed
- decision confidence
- perceived info sufficiency for decisions
- understanding the decision context (uncertainty characteristics leading to poor decisions)
- impact of uncertainty depiction on risk beliefs/perception, perceived ambiguity, and perceived assessment/decision difficulty

ideas on this slide are derived from a collaboration with Christoph Kinkeldey and Maria Riveiro on a review paper about the "effect" of uncertainty visualization (Christoph is leading the effort)

Decision-making

- The impacts of uncertainty on analytical reasoning and decision-making are not well understood. Only a few studies have been carried out, e.g.
  - Leitner and Buttenfield (2000) found that uncertainty representation for facility location can clarify the map and lead to more accurate decisions.
  - Cliburn, et al (2002) "Decisions cannot be made from uncertain data; it only leads decision-makers to discount the results. Unfortunately, not considering uncertainty may lead to inappropriate decisions. A potential collaborator, who viewed the application in its later stages, suggested incorporating a reasoning network of potential actions to problems presented by the visualizations."
  - Aerts, et al (2003) report (for urban planning) that uncertainty information can improve decision-making efficiency.
  - Deitrick and Edsall (2006) present evidence that uncertainty information has an influence on decision making.
  - Hope and Hunter (2007) found evidence for "ambiguity aversion" and associated irrational decisions when uncertainty was depicted on maps. In complementary research, different methods for depicting positional uncertainty resulted in very different decision behaviors related to travel risks (Hope and Hunter, 2007).
  - Severtson and Meyers (2012), found that geo-uncertainty representation factors ("focus" / crispness of map contours and verbal-relative versus numeric risk expression) and personal characteristics (prior beliefs and numeracy) interacted to influence risk beliefs related to modeled cancer risk from air pollution.

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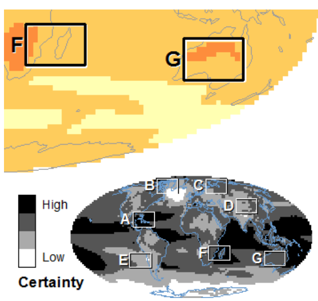
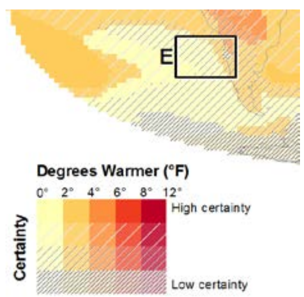
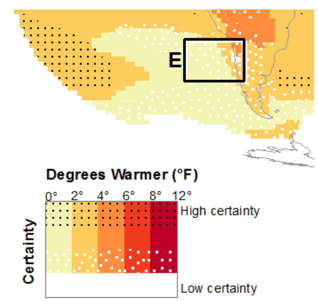


Control with small map



Texture – Lines



Texture – Spots

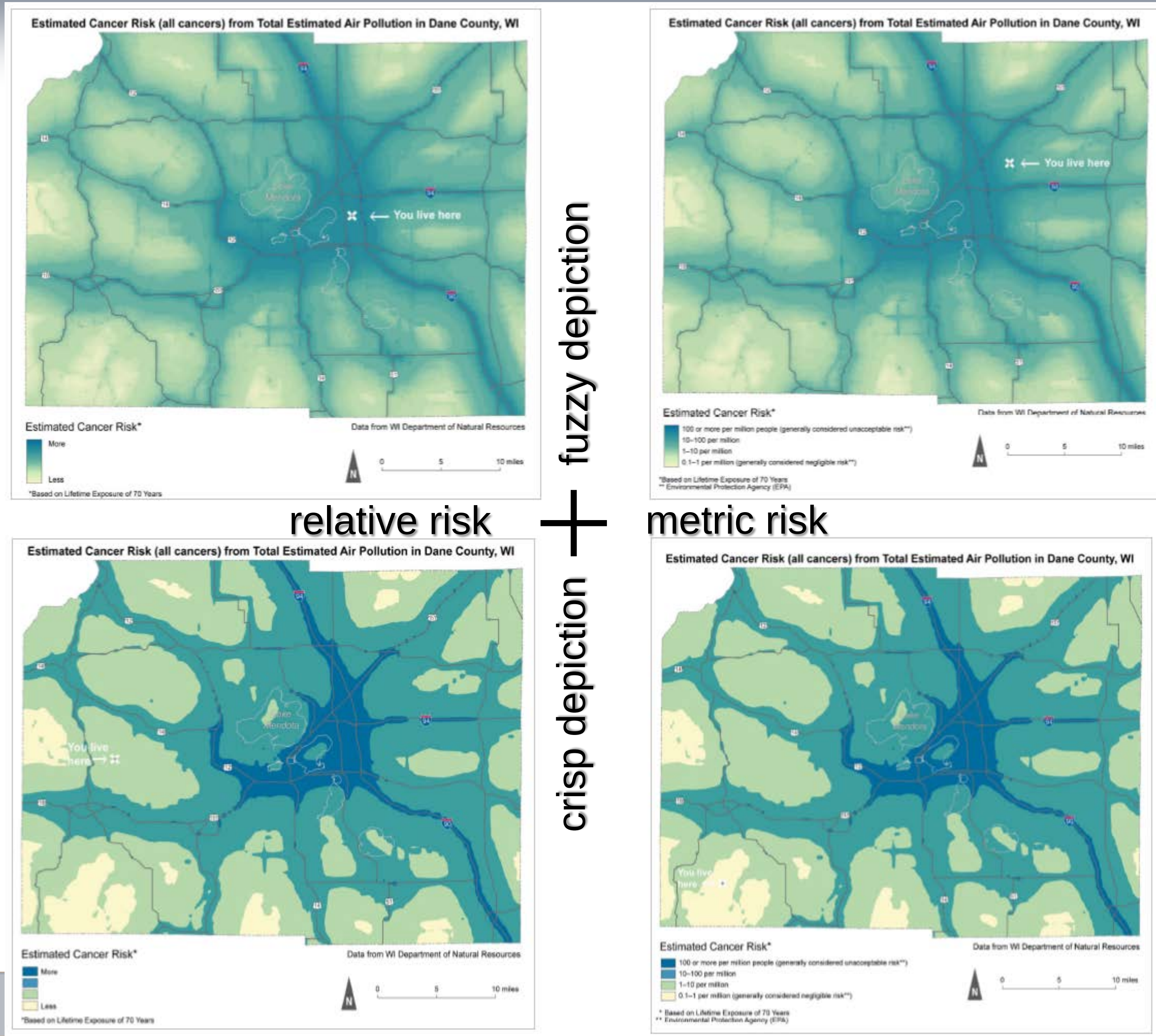
- **Magnitude was primary driver of risk assessment and decisions.**

for details, see: Retchless, D. 2012: Mapping Climate Change Uncertainty: Effects on Risk Perceptions and Decision Making, Paper #GC43B-1024. *AGU Fall Meeting, San Francisco, CA. fallmeeting.agu.org/2012/eposters/eposter/gc43b-1024*

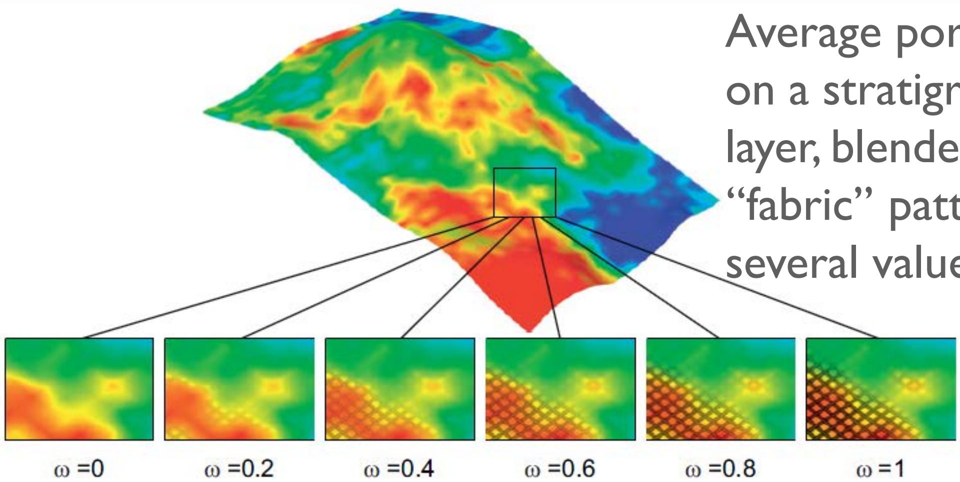
Communicating ambiguity in risk

Severtson, D.J. and Myers, J.D. 2012: The Influence of Uncertain Map Features on Risk Beliefs and Perceived Ambiguity for Maps of Modeled Cancer Risk from Air Pollution. Risk Analysis, online pre-print. in a study with over 800 student participants found:

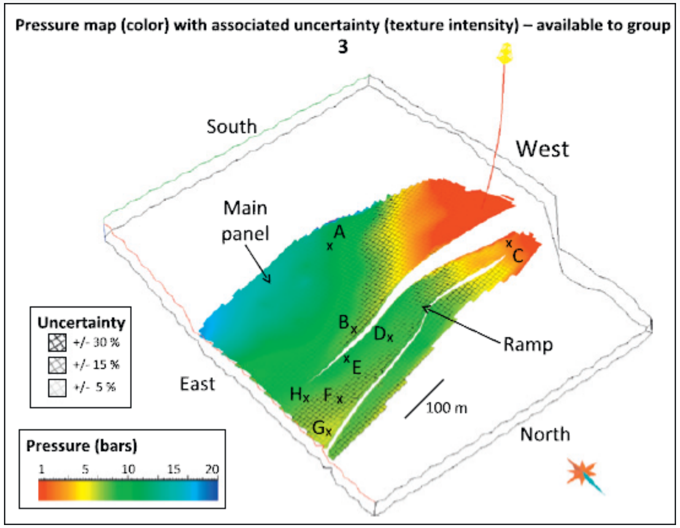
"Overall, results indicate incremental shading effectively conveys a dose-response message, and **contour focus and risk expression (more-less vs. numerical ranges) show promise for conveying information uncertainty**."



Coincident versus Adjacent display & Decision-making



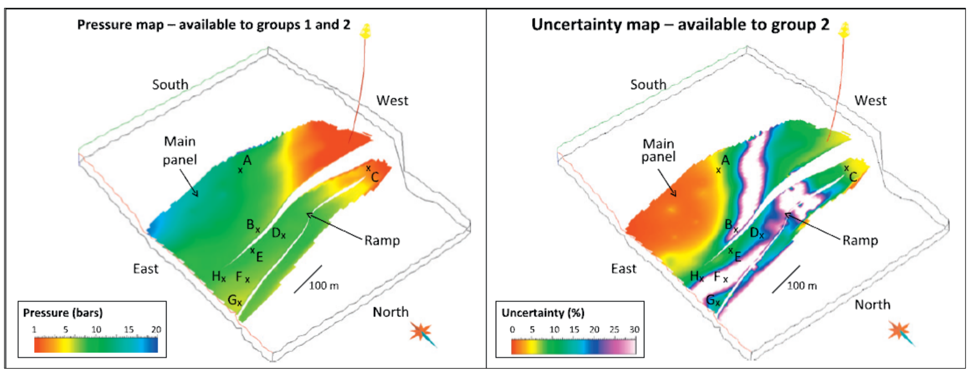
Average porosity map on a stratigraphic layer, blended with “fabric” pattern with several values of ω.



Coincident map used in experiment

Findings:

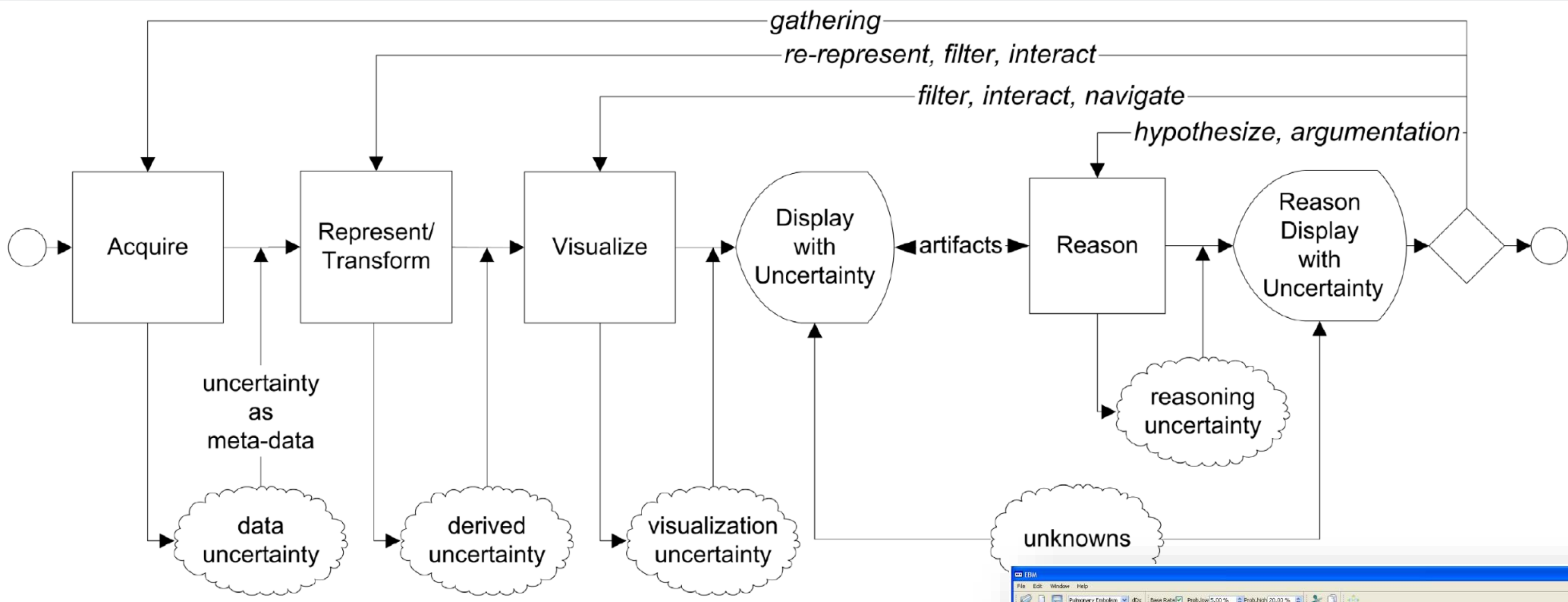
- uncertainty influences decision-making
- **coincident display better for complex decision tasks**
- uncertainty via coincident depiction does not decrease data interpretation accuracy
- no performance difference for 2.5D vs 2D data-uncertainty depictions

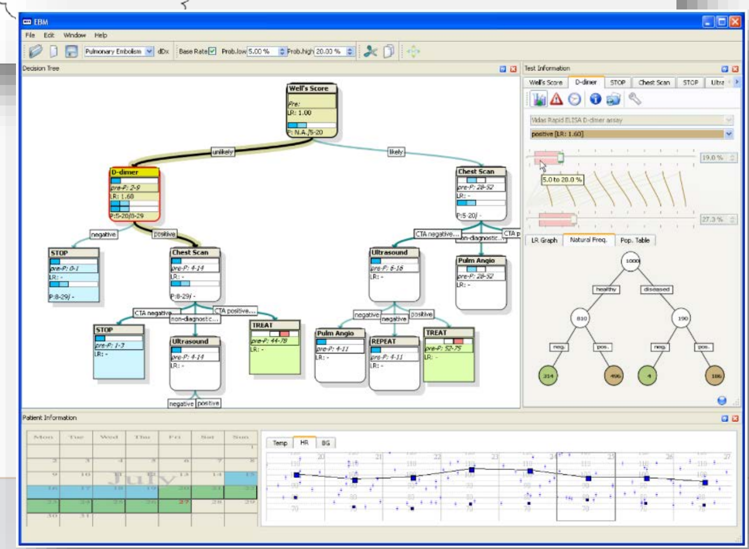


Adjacent maps used in experiment

Viard, T., Caumon, G. and Lévy, B. 2011: Adjacent versus coincident representations of geospatial uncertainty: Which promote better decisions? Computers & Geosciences 37, 511-520.

Zuk's reasoning extensions to Pang's Viz pipeline in a sensemaking framework





source: Zuk, T. and Carpendale, S. 2007: Visualization of Uncertainty and Reasoning. In Butz, A.e.a., editor, *Smart Graphics, LNCS 4569, Berlin: Springer-Verlag, 164-177. – citation 31: Pang, A.T., Wittenbrink, C.M., Lodha, S.K.: Approaches to uncertainty visualization. The. Visual Computer 13(8), 370–390 (1997)*

Challenges: related to uncertainty visualization for geographic data/reasoning/decisions

- understand components of uncertainty and their relationships to use domains, expertise (of multiple kinds), information needs, other user characteristics, and kinds of reasoning
- understand how knowledge of uncertainty influences reasoning, decision making, and outcomes
- understand how (or whether) uncertainty visualization aids / hinders exploratory analysis, reasoning, and decisions
- leverage understanding to develop useful/usable methods/tools:
  - to signify multiple kinds of uncertainty
  - for interacting with uncertainty depictions
  - to support reasoning/decisions under uncertainty
  - to capture and encode analysts' or decision makers' uncertainty
- assess usability and utility of the methods/tools – design studies for reproducibility and comparability.

That's all: Thanks

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