Visual Analytical Approaches to Evaluate Uncertainty and Bias in Crowdsourced Crisis Information

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Abstract

Increasing numbers of people are using social media to exchange information during crisis and conflict events. On the one hand, the humanitarian community is reluctant to use this information in the response effort as it fears the cost of untrustworthy and inaccurate information. On the other, the volunteer and technical communities have attempted to resolve this impasse by crowdsourcing crisis information; for example, by asking volunteers to ascertain whether a crisis report is trustworthy and accurate.

Trust and accuracy are two characteristics of uncertainty: The fact that each is likely to have spatial, temporal and thematic aspects is supported by research, which suggests that geography characterises crisis information. Consequently, a research programme grounded in geographic information science, (geo)visualization and (geo)visual analytics is presented that seeks to evaluate the degree to which uncertainty and bias (systematic variation) are found in crowdsourced crisis information; and seeks to provide heuristics to help manage these factors. This programme consists of a methodology for undertaking interactive, analysis-guided software development that is informed by action research, scenario-based design and Munzner's model of visualization validation; and a prototype software application that combines interactive visual representations with spatial statistical functions to explore two datasets of crowdsourced crisis information.

Following a review of the literature and a description of the data, the

methodology and its implementation are placed within an appropriate work plan. Three supporting publications are included, as well as supporting statements regarding the author's skills and engagement with the academic community.

1 Introduction

People affected by crisis events are turning to new communications technologies to exchange information (Coyle & Meier 2009). However, whilst the humanitarian community tend to see the risks associated with these technologies (Tapia et al. 2011), the volunteer and technical communities focus on the rewards (Liu & Palen 2010).[1] Nevertheless, organisations such as Ushahidi (Ushahidi 2011*c*) are seeking to reconcile the costs of using untrustworthy and inaccurate information with the benefits of engaging a large number of motivated and able individuals. They are doing so by developing software to support the gathering (Ushahidi 2011*b*), augmenting (Ushahidi 2011*a*) and verifying (Ushahidi 2011*d*) of crisis information, where these tasks are *crowdsourced*, or completed by a heterogeneous group in response to an open call (Howe 2006, 2009).

Trust and accuracy, however, are not the only characteristics of uncertainty (MacEachren et al. 2005, Thomson et al. 2005). Furthermore, each characteristic of uncertainty has spatial, temporal and thematic aspects (Veregin 1999). Analysis is as important as situational information to humanitarian response (King 2005) but analysis that ignores uncertainty (in all its forms) is of limited use (Fisher 1999). Geographic information science has made considerable progress in evaluating and communicating the uncertainty associated with geographic information (Devillers et al. 2010) and uncertainty is a familiar topic in the visualization (Pang et al. 1997) and the geovisualization literature (MacEachren et al. 2005, Thomson et al. 2005). Consequently, geographic information science, visualization and geovisualization are well placed to help evaluate uncertainty and bias in crowdsourced crisis information.

[1] The term 'volunteer and technical communities' is from Harvard Humanitarian Initiative (2011). Following Goodchild (2009), the term 'NeoGeographer' is more common in the geographic information science literature.

2 Research questions, aims and objectives

- To what degree are uncertainty and bias found in crowdsourced crisis information?
  - What characteristics of uncertainty can be identified in crowdsourced crisis information?
  - To what degree do these characteristics vary over space?
  - To what degree do these characteristics vary over time?
  - To what degree do these characteristics vary with theme?
  - Are any of these characteristics subject to *bias*, or systematic variation?
- What heuristics help manage uncertainty and bias in crowdsourced crisis information?

3 Literature

3.1 Characterising uncertainty

MacEachren et al. (2005), building on Thomson et al. (2005), make two fundamental points about uncertainty: It is a complex concept that has domain-specific interpretations; and effective characterisation of uncertainty is central to effective visual representation of uncertainty. With these points in mind, they identify nine characteristics of uncertainty relevant to the geographic information science and geovisualization domains (see Table 1). Veregin (1999) argues that four of these characteristics (accuracy, precision, completeness and consistency) have spatial, temporal and thematic aspects to match the spatial, temporal and thematic components of geographic information. Consequently, it is reasonable to conclude that the nine characteristics of uncertainty identified by MacEachren et al. (2005) have spatial, temporal and thematic aspects.

There are, however, alternative perspectives on uncertainty. For example, Fisher (1999) characterises uncertainty according to the 'definition' of geographic objects or classes of geographic objects. In this way, uncertainty associated with well defined geographic objects may be caused by accuracy and uncertainty associated with poorly defined geographic objects may be

Characteristic	Definition
Accuracy/error	Difference between measurement/estimation and reality
Precision	Exactness of measurement/estimation[a]
Completeness	Comprehensiveness of the information
Consistency	Internal agreement of the information
Lineage	Conduit through which the information passed
Currency	Time between occurring, collecting/processing and using the information
Credibility	Reliability of the information source, for example
Subjectivity	The degree to which information construction involves human interpretation
Interrelatedness	Independence of the information source

Table 1: Characteristics of uncertainty (MacEachren et al. 2005)

[a] Veregin (1999) argues that precision and resolution are synonymous.

caused by vagueness or by ambiguity (Fisher 1999). Whilst vagueness and ambiguity do not have obvious analogues with the characteristics of uncertainty identified by MacEachren et al. (2005), accuracy is clearly common to both. One possible reason for this commonality is that accuracy is well researched in geographic information science (Fisher 1999) and techniques have been developed to estimate the accuracy of point, line and polygon objects (Devillers et al. 2010). However, these techniques involve comparing lower accuracy representations to higher accuracy representations (see, for example, Goodchild & Hunter 1997), meaning that whilst Haklay (2010) is able to evaluate the accuracy of crowdsourced geographic information by comparing an OpenStreetMap dataset to an Ordnance Survey dataset, it is much harder to evaluate the accuracy of crowdsourced crisis information because no higher accuracy representations exist.

Wieczorek et al. (2004) present a possible solution to the problem of evaluating uncertainty without relying on higher accuracy representations—the 'point-radius' georeferencing method. *Georeferencing* is the process of converting geographically relevant text into one or more geographic representations (Goldberg 2011). Whereas many georeferencing methods result in a point that represents geographically relevant text, the point-radius georeferencing method results in a point and a radius: The point represents the most probable location of the geographically relevant text; the radius represents the maximum distance within which the the geographically relevant text is to be found (Wieczorek et al. 2004). Working within the natural history domain, Wieczorek et al. (2004) argue that a 'collecting event' has spatial and temporal components, namely the place and time a specimen was collected. Wieczorek et al. (2004) call the spatial component the 'locality description' because the place a specimen was collected is often descriptive.[2] However, locality descriptions are not exclusive to the natural history domain; Doherty et al. (2011), for example, apply the point-radius georeferencing method to locality descriptions in historical records of search and rescue incidents. Consequently, it is reasonable to conclude that the point-radius georeferencing method can be applied to records of events in space and time, where the spatial component of each record is a description of a place. Within the context of the current research, the purpose of applying this method would be less to identify the location of an event and more to identify the uncertainty associated with the location of an event.

It is clear that of the nine types of locality descriptions Wieczorek et al. (2004)

[2]Similarly, Fisher & Unwin (2005, p.6) highlight the distinction between "socially-produced" *place* and "absolute" *space*.

found within natural history collections (see Table 2), eight are related to classes of well defined geographic objects. In related research, of the ten types of locality descriptions Guo et al. (2008) found within natural history collections (see Table 3), all are related to classes of well defined geographic objects. Consequently, it is not surprising that of the six types of uncertainty identified by Wieczorek et al. (2004) and Guo et al. (2008) (the extent of the locality; the map datum and scale; the precision of distance measurements, direction measurements and coordinate measurements), all relate to accuracy and precision. Clearly, whilst the point-radius georeferencing method has the advantage of not relying on higher accuracy representations, it has the disadvantage of evaluating only two characteristics of uncertainty.

In contrast to Wieczorek et al. (2004), Guo et al. (2008) account for vagueness when they delimit areas of uncertainty associated with locality descriptions. However, like Wieczorek et al. (2004), Guo et al. (2008) base these areas on well defined 'reference objects', such as named places. Whilst well defined reference objects may be present in locality descriptions in the natural history domain and in historical records of search and rescue incidents, locality descriptions from other domains may be different. For example, Jones et al. (2008) contrast well defined administrative geographies with poorly defined vernacular geographies in the same way that Fisher & Unwin (2005) contrast space with place. Services such as Flickr are rich sources of vernacular geographies (Hollenstein & Purves 2010, Purves et al. 2011) and whilst these platforms were not developed to crowdsource tasks, like Ushahidi they were developed to manage information from a heterogeneous group. Consequently, it is reasonable to conclude that vernacular geographies may be present in crowdsourced crisis information; a conclusion supported by Dillingham et al. (2012) (see *Completed work*). This, in turn, questions the application of the point-radius georeferencing method to crowdsourced crisis information.

In summary, the geographic information science and geovisualization domains have contributed a conceptual model of uncertainty. These domains have also contributed methods to evaluate the uncertainty of geographic information, in situations where more certain representations do and do not exist. However, these methods apply to relatively well defined geographic objects. Evidence suggests that relatively poorly defined geographic objects may be present in crowdsourced crisis information.

Type	Example
Dubious	"Isla Boca Brava?"
Cannot be located	"locality not recorded"
Demonstrably inaccurate	"Sonoma County side of the Gualala River, Mendocino County"
Coordinates	"42.4532 84.8429"
Named place	"Alice Springs"
Offset	"5km outside Calgary"
Offset along a path	"1km S of Missoula via Route 93"
Offset in orthogonal directions	"6km N and 4km W of Welna"
Offset at a heading	"50km NE of Mombasa"

Table 2: Types of locality descriptions found within natural history collections (Wieczorek et al. 2004)

Type	Example
Feature	“Springfield”
Path	“Hwy. 1”
Junction	“Confluence of Labarge Creek and South Labarge Creek”
Offset from a feature or a path at a heading	“10km N of Kuala Lumpur”
Near a feature or a path	“Big Bay vicinity”
Subdivision of a feature or a path	“N part of Mono Lake”
Orthogonal offsets from a feature	“1 miles N, 3 miles W of Fairview”
Heading from a feature, no offset	“W of Tucson”
Offset from a feature, no heading	“5km outside Calgary”
Between features or paths	“Between Point Reyes and Inverness”

Table 3: Types of locality descriptions found within natural history collections (Guo et al. 2008)

Gelernter & Mushegian (2011)	Vieweg et al. (2010)
Country	County name
State, region, city	Place name
Abbreviated place	City name
Neighbourhood or district	Address
Topographical or infrastructure feature	Highway
Cluster of buildings	
Geolocatable building, area or organisation	
What and where	
Street address	
Multiple places	
Generic place	
Place with hashtag	

Table 4: Location-types in crisis-related microtext

3.2 Crisis information

There is a growing body of work on the geographic nature of crisis information, especially collections of short text messages ('microtext'), such as 'tweets'. For example, Gelernter & Mushegian (2011) and Vieweg et al. (2010) report the location-types present in three collections of crisis-related microtext (see Table 4). Gelernter & Mushegian (2011) identified twelve location-types in 300 tweets related to the 2011 earthquake in Christchurch, New Zealand. Vieweg et al. (2010) identified five location-types in 19,162 tweets related to a flooding event and 2,779 tweets related to a wildfire event in the USA in 2009.

Both Gelernter & Mushegian (2011) and Vieweg et al. (2010) manually identified then categorised locations to produce their location-types. This makes comparison hard. However, it is clear that geographic information is common in crisis-related microtext: Gelernter & Mushegian (2011) report that in a larger dataset of 1,407 tweets there were 253 locations used 1,207 times. Similarly, Vieweg et al. (2010) report that 18% of tweets (approximately 3,449) relating to the flooding event and 40% of tweets (approximately 1,112) relating to the wildfire event contained geographic information. Interestingly, Vieweg et al. (2010) suggest that the difference relates to the nature and phase of each emergency event. The wildfire event was unpredictable in location and had a relatively short warning phase, meaning most tweets were gathered during the impact and recovery phases. They speculate that the information required during these phases is highly geographic (Where are hazards? Where are resources needed?), whereas the warning phase is characterised by considerable uncertainty. In contrast, the flooding event was predictable in location and had a relatively long warning phase.

In summary, existing work suggests that geographic information is common in crisis-related microtext. However, the degree to which this is the case appears to depend on the nature and phase of the crisis event. In addition, although existing work has identified relatively well defined classes of geographic objects in crisis information, the influence of the nature of the crisis event; the presence of named places at multiple geographic scales; and the presence of location types such as "Generic place" and "Multiple places" suggest vagueness and ambiguity are important considerations.

3.3 Visual analytics

Although crisis information is geographic in nature, the geographies are potentially vague and ambiguous: "In Les Cayes" and "provisional shleter [sic] on Champs-de-Mars" are two example locations from the Haiti Crisis Map (Ushahidi 2009) (see *Data*). Visual analytics is a multi-disciplinary approach that seeks to combine human judgement and computational techniques to "detect the expected and discover the unexpected" in complex situations such as these (Thomas & Cook 2006, p.10). Consequently, visual analytics is an ideal approach to explore uncertainty and bias in crowd-sourced crisis information.

Visual analytics can be defined as "the science of analytical reasoning facilitated by interactive visual interfaces" (Thomas & Cook 2006, p.10). An analyst who applies the analytical reasoning process seeks insight (Thomas & Cook 2006), where insight is complex, deep, qualitative, unexpected and relevant (North 2006). He or she does so using visual representations and interactions, techniques that enhance cognition (Card et al. 1999). In this way, visual analytics is a process supported by techniques where the desired outcome is insight. However, process and techniques are closely interrelated.

The analytical reasoning process and the development of specific visual representations and interactions within the context of the current research are discussed below (see *Methods*). However, the general literature on visual representations and interactions is discussed here. In common with MacEachren et al. (2005), the two areas are discussed separately.

3.3.1 Visual representations

MacEachren et al. (2005) argue that, from the geographic information science and geovisualization perspectives, most research into the visual representation of uncertainty has focused on the application of Bertin's visual variables (Bertin 1967) according to cartographic good practice. However, additional visual variables have not been applied as consistently. For example, although MacEachren (1992) adds transparency (opacity), this addition has been used to represent more certainty and less certainty, depending on the underlying visual metaphor (MacEachren et al. 2005).

As well as visual 'primitives', MacEachren et al. (2005) discuss *glyphs*, or compound symbols. Glyphs have been used to represent data, and the uncertainty associated with data, simultaneously (MacEachren et al. 2005). Similarly, rather than producing a single representation, multiple representations can been produced and compared (MacEachren et al. 2005). In such cases, Beard & Mackaness (1993, cited in MacEachren et al. 2005) suggest there is a fundamental conflict between representing the data and representing the uncertainty associated with the data.

3.3.2 Interactions

Pike et al. (2009) draw on theories of situated cognition and distributed cognition to argue that interaction is fundamental to the analytical reasoning process. In doing so, they distinguish between 'high level' and 'low level' interactions where the former are between the analyst and the problem and the latter are between the analyst and the visual representation. Similarly, Norman (1998) distinguishes between *goals*, or what to achieve and *intentions*, or how to achieve it.

According to Pike et al. (2009), Amar et al. (2005) and Yi et al. (2007) exemplify low level and high level interaction typologies respectively. However, it is unclear as to whether this distinction is meaningful. For example, whilst Amar et al. (2005) describe the elements in their typology as low level and Yi et al. (2007) describe the elements in their typology as high level, both contain a 'filter' element (see Table 5). Are Pike et al. (2009) implying a difference? Similarly, although Amar et al. (2005) argue that the elements in their typology are tasks, Yi et al. (2007) argue that the elements in their typology are interactions (see Table 5). Again, are Pike et al. (2009) implying tasks and interactions are synonymous? Crampton (2002) appears to disagree; tasks and interactions are described separately, although tasks are ordered by degree of interactivity (see Tables 6 and 7). Finally, Amar et al. (2005) and Yi et al. (2007) suggest the elements in their typologies are specific instances, rather than generic types. However, Shneiderman (1996) argues that 'filter' is a type of task (i.e. generic) (see Table 5). To confound this specific–generic dichotomy, Crampton (2002) suggests that 'filter' is a specific instance of both a type of task ('extract and suppress') and a type of interaction ('interaction with the data') (see Tables 6 and 7).

3.3.3 Situating visual analytical approaches

In summary, the literature on visual representations and interactions situates the visual analytical approaches that are at the core of the current research. The visual representation of uncertainty is well researched in geographic information science and geovisualization. Furthermore, a link to cartography is established through these domains. Similarly, the visualization community has considered the nature of interactions, although reconciling this work is problematic. Nevertheless, enumerating interactions, be they general types or specific instances, allows one to imagine, build and evaluate (Crampton 2002) the tools that are necessary to evaluate uncertainty and bias in crowdsourced crisis information.

4 Data

Two datasets have been obtained for the current research. The first relates to the 2010 earthquake in Haiti (Ushahidi 2009); the second to the 2011 armed conflict in Libya (OCHA 2011). Both datasets come from Ushahidi, software for crowdsourcing the gathering, augmenting and verifying of crisis information (Ushahidi 2011*c*).

Clearly, the nature of the crowdsourcing process makes these datasets uncertain. (Indeed, a mechanistic approach would suggest at least 27 types of uncertainty should be present in these datasets—the nine characteristics of uncertainty identified by MacEachren et al. (2005) across space, time and theme.) However, evaluating uncertainty is problematic because of the nature of the software. For example, although Ushahidi records the outcome of the verification process (information that could be used to evaluate accuracy) the nature of the verification process is not recorded (information

Types of tasks (Shneiderman 1996)	Instances of tasks (Amar et al. 2005)	Instances of interactions (Yi et al. 2007)
Overview	Retrieve value	Select
Zoom	Filter	Explore
Filter	Compute derived value	Reconfigure
Details on demand	Find extremum	Encode
Relate	Sort	Abstract/elaborate
History	Determine range	Filter
Extract	Characterise distribution	Connect
	Find anomalies	
	Cluster	
	Correlate	

Table 5: Tasks and interactions according to Shneiderman (1996), Amar et al. (2005) and Yi et al. (2007)

Types of tasks	Description	Degree of interactivity
Test cause and effect	Test the nature and strength of relationships	High
Extract and suppress	Highlight and filter	
(Re)order and (re)sort	View and manipulate the data	Medium
Compare	Understand two or more representations simultaneously	
Examine	Interact with the representation	Low

Table 6: Tasks according to Crampton (2002)

Types of interactions	Instances of interactions
Contextual interaction	Multiple views
	Combining layers
	Juxtaposing windows
	Linking
Interaction with the data	Querying and mining
	Brushing
	Filtering
	Highlighting
Interaction with time	Navigation
	Fly-by/fly-through
	Toggling between time periods
	Sorting
Interaction with the representation	Lighting
	Changing viewpoint
	Changing orientation
	Zooming
	Rescaling
	Remapping symbols

Table 7: Interactions according to Crampton (2002)

that could be used to evaluate lineage). Nevertheless, these problems are likely to be common in other forms of crowdsourced information, making the current research interesting, challenging and applicable beyond the crisis domain.

5 Methods

5.1 Approach to the literature

The approach to the literature is semi-structured and iterative:

- Identify core publications. Identify, read and follow the references in core papers or chapters.
- Identify relevant journals based on the references in core papers or chapters. Monitor recent papers in relevant journals.
- Search relevant databases.
- Monitor the 'grey' literature such as reports produced by humanitarian organisations.

See *Literature sources* for additional information.

5.2 Approach to the research process

5.2.1 Background

Analysts, when reasoning analytically, create and test hypotheses and scenarios and discover relationships in information (Thomas & Cook 2006). In this way, analytical reasoning is similar to the sensemaking process described by Pirolli & Card (2005). In this process the analyst gathers information; represents some of this information in a schema (a task-specific knowledge structure); and generates insight by manipulating the representation (Pirolli & Card 2005). Ideally, the sensemaking process results in knowledge or in action (Pirolli & Card 2005). In summary, analytical reasoning and sensemaking are similar in terms of the tasks the analyst undertakes. However, sensemaking highlights the role of schemas (task-specific knowledge structures) (Pirolli & Card 2005).

The analytical reasoning and sensemaking processes resemble Checkland's model of rational thought (Checkland 1985, cited in Baskerville & Wood-Harper 1996), a model that is central to action research (Oates 2006). This model consists of *f*, an intellectual framework; *m*, a methodology for using the intellectual framework; and *a*, an area of application (Checkland 1985, cited in Baskerville & Wood-Harper 1996). Within the analytical reasoning and sensemaking processes, *f* would include the analyst's schemas, *m* the analyst's tasks and *a* is synonymous with a domain. In summary, the analytical reasoning and sensemaking processes can be abstracted to a more general model. This model is central to action research.

An advantage of abstracting analytical reasoning and sensemaking is that doing so situates these processes within a clear approach to science; an approach that can also be used to develop visual representations and interactions. Action research has been applied to human-computer interaction (Carroll & Rosson 1992), systems theory and systems development (Oates 2006). Indeed, prototyping is arguably a form of action research, although it is seldom acknowledged as such (Oates 2006). Consequently, action research is a means of adding rigour to the analytical reasoning and sensemaking processes and to the development of visual representations and interactions. Rigour is seldom considered in visual analytics; doing so in a systematic way represents a contribution in its own right. In summary, action research brings analytical reasoning and sensemaking, and the development of visual representations and interactions within the scope of a clear approach to science.

There are three relevant criticisms of action research. Firstly, action research may seem unscientific (Baskerville & Wood-Harper 1996). Action research is a collaborative, interventionist approach (Baskerville & Wood-Harper 1996) within which researchers and practitioners follow an iterative cycle of diagnosing the problem situation, planning action, taking action, evaluating action and specifying learning (Susman & Evered 1978, cited in Baskerville & Wood-Harper 1996, Oates 2006). However, collaboration between researchers and practitioners is common in the visualization literature. Lloyd & Dykes (2011) describe a collaborative, interventionist approach to the geovisualization design process. Not only do Lloyd & Dykes consider this process to be subjective, they also consider that "objectivity is neither possible nor necessary … designs should be developed through discourse" (Lloyd & Dykes 2011, p.2501). Furthermore, van Wijk (2006) suggests user-centred approaches help to bridge the gaps between visualization designers (analogous to researchers) and visualization users (analogous to practitioners). In summary, members of the visualization community consider that a collaborative, interventionist approach to the development of visual representations and interactions is acceptable.

Secondly, action research may seem to lack rigour (Baskerville & Wood-Harper 1996). Baskerville & Wood-Harper (1996) distinguish between 'rigorous' and 'liberal' action research. The former is disciplined: It follows an iterative cycle; has a theoretical framework with a testable working hypothesis; and data are collected empirically (Baskerville & Wood-Harper 1996). Furthermore, the researcher should be clear about where they are in the iterative cycle (Oates 2006). However, parallels are found in the visualization literature. For example, Munzner (2009) proposes a model of visualization validation. This model suggests appropriate 'immediate' and 'downstream' empirical data collection methods; staging these methods encourages visualization designers to be clear about where they are in the validation process. Similarly, MacEachren et al. (2011) use scenario-based design to validate their software. According to Carroll & Rosson (1992), scenarios are narratives from which claims can be generated: Claims are essentially the advantages and disadvantages caused by an artifact feature or technique (Carroll & Rosson 1992). In summary, members of the visualization community consider that an iterative approach to the development of visual representations and interactions, rooted in a theoretical framework and empirical data collection methods, is acceptable.

Thirdly, the outcomes of action research are contingent on *f*, *m* and *a*, as well as on the researcher, making it hard to generalise (Baskerville & Wood-Harper 1996). However, whilst reliability (repeatability) is the foundation of generalisation, validity—"the degree to which the research accomplished its intended goals within its scientific paradigm"—is acceptable (Baskerville & Wood-Harper 1996, p.243). Munzner (2009) proposes a similar approach, although without an explicit scientific paradigm, in her model of visualization validation. The 'domain characterisation' stage within this model describes the 'intended goals' as problems (domain tasks) and data. Munzner (2009) argues that the success of this level should be validated using 'grounded evaluation', an approach that attempts to situate the evaluation process within a visualization's context of use (Isenberg et al. 2008). To further address the problem of generalisation, Baskerville & Wood-Harper (1996, p.243) suggest action researchers "must exercise restraint in their conclusions" and circulate their findings amongst the scientific community. This is clearly the case in visual analytics, where good research, such as Meyer et al. (2010), Meyer et al. (2009), Nielsen et al. (2009) and Weaver et al. (2007), is clearly scoped. In summary, members of the visualization community accept that the development of visual representations and interactions is contingent. However, approaches have been developed to address the problem of generalisation.

5.2.2 Implementation

The current research proposes a visual analytical approach to evaluate uncertainty and bias in crowdsourced crisis information that is *informed by* action research. To summarise the rationale:

1. Rigorous action research strongly resembles visual analytics. In other words, the visualization community is aligned with the tenets of action research.
2. Action research applies both to the analytical reasoning process and to the development of visual representations and interactions. This distinction, between analysis and development, is an important one, although it is noted that both process and techniques are closely interrelated.
3. Action research provides two models that allow the current research to be better situated. The first model clearly delimits the intellec-

> tual framework (*f*), the methodology for using the intellectual framework (*m*) and the area of application (*a*) (Checkland 1985, cited in Baskerville & Wood-Harper 1996). The second model, which Oates (2006) suggests instantiates the first model as the research process, specifies an iterative cycle of diagnosing the problem situation, planning action, taking action, evaluating action and specifying learning (Susman & Evered 1978, cited in Baskerville & Wood-Harper 1996, Oates 2006). These models will be used to validate and verify the visual representations and interactions that will be developed to address the working hypotheses, where "*validation* is about whether one has built the right product, and *verification* is about whether one has built the product right" (Munzner 2009, p.923, original emphasis). This is especially important as the current research is not based on a partnership between domain experts and experts in visual analytics; it exemplifies the 'curiosity-driven' approach to a problem suggested by van Wijk (2006).

The intellectual framework (*f*) consists of the characteristics of uncertainty, the nature of crisis information and the literature on visual representations and interactions (see *Literature*). The methodology for using the intellectual framework (*m*) draws on scenario-based design and the model of visualization validation proposed by Munzner (2009). The area of application (*a*) is crisis information.

The research process instantiates the *f*, *m* and *a* as an iterative cycle of diagnosing the problem situation, planning action, taking action, evaluating action and specifying learning. The first iteration involves *diagnosing the problem situation* and *planning action*, where working hypotheses, scenarios and claims are generated. The working hypotheses frame the analytical reasoning process; the scenarios and claims frame the development of the visual representations and interactions to address the working hypotheses. The scenarios and claims allow a context of use to be envisioned before it exists (Carroll 2000).

Carroll & Rosson (1992) describe claims as 'causal schemas' in the form:

> [artifact feature or technique] CAUSES [desirable psychological consequence] BUT MAY ALSO CAUSE [undesirable psychological consequence]

In this way, the claims are linked to either scientific principles or argument (Carroll & Rosson 1992). This allows subsequent 'grounded' evaluation (Isenberg et al. 2008).

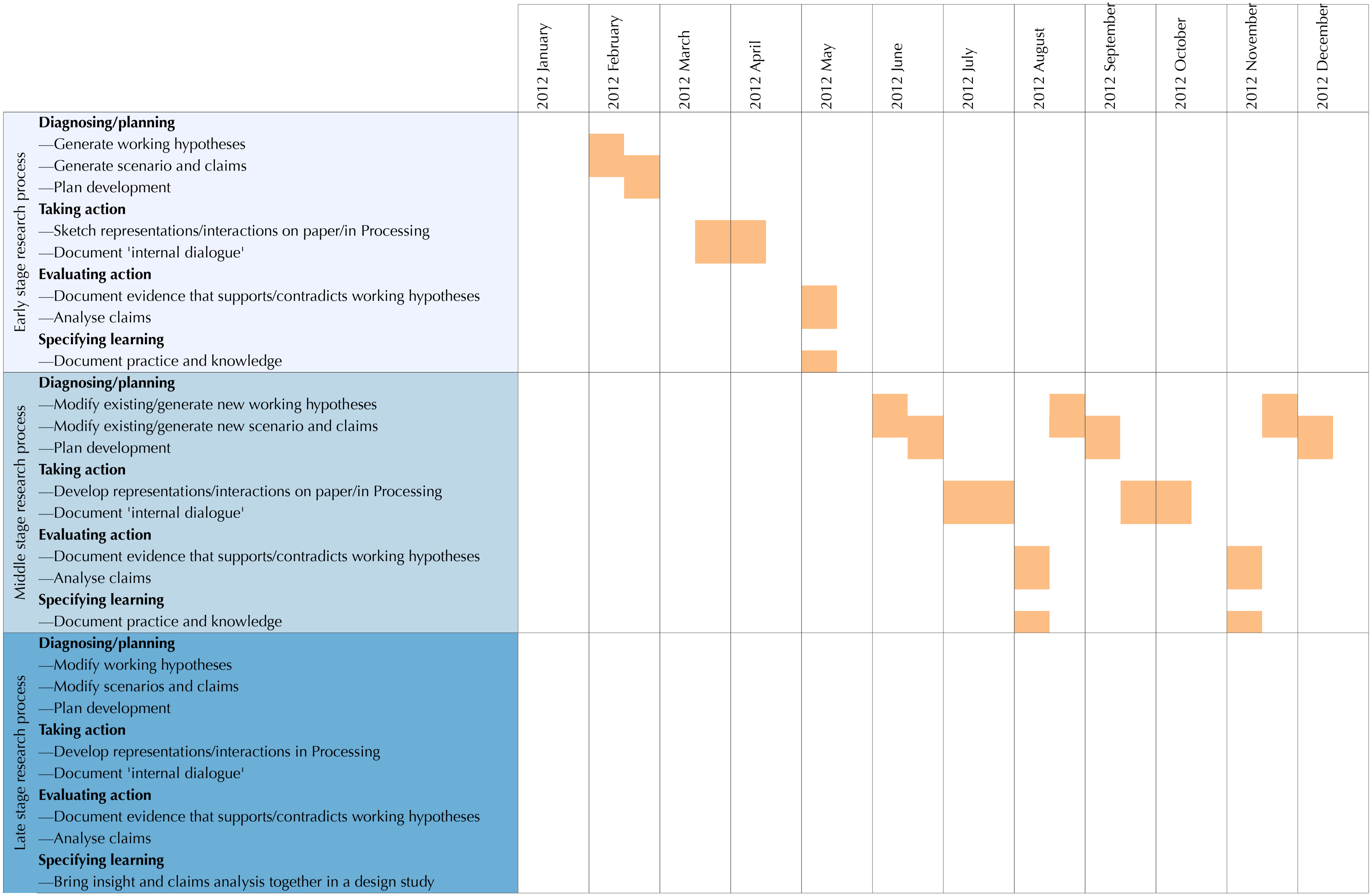
The scenarios and claims act as the basis for *taking action*, where visual representations and interactions are developed based on 'domain data' (Lloyd & Dykes 2011). These visual representations and interactions need not be in software; they may consist of paper sketches that are developed into digital sketches in subsequent iterations. Concurrently, these visual representations and interactions are used to reason analytically about domain data. The continuous 'internal dialogue' (Duncan 2004) of development and analysis is documented using ethnographic methods.

The outcomes of taking action are reflected upon when *evaluating action*. The degree to which the analytical reasoning, facilitated by the visual representations and interactions, have led to insight is assessed; where this is not the case, it may be because the domain characterisation (analogous to scenarios) and domain abstractions (analogous to claims) are misaligned (Munzner 2009). An assessment is made of the degree to which the claims have 'held'. This claims assessment is a precursor to a design study; a form of principled justification and appropriate immediate validation of visual encodings and interactions (Munzner 2009).

Finally, the first iteration concludes with *specifying learning*. This learning is in the form of practice (action) and knowledge (research) and should be directed 'inwards' (to the next iteration) and 'outwards' (to the scientific community) (Susman & Evered 1978, cited in Baskerville & Wood-Harper 1996, Oates 2006). After several iterations, the insight and claims assessment are brought together in a design study, where a design study demonstrates that a design solves a problem in a domain (Munzner 2008).

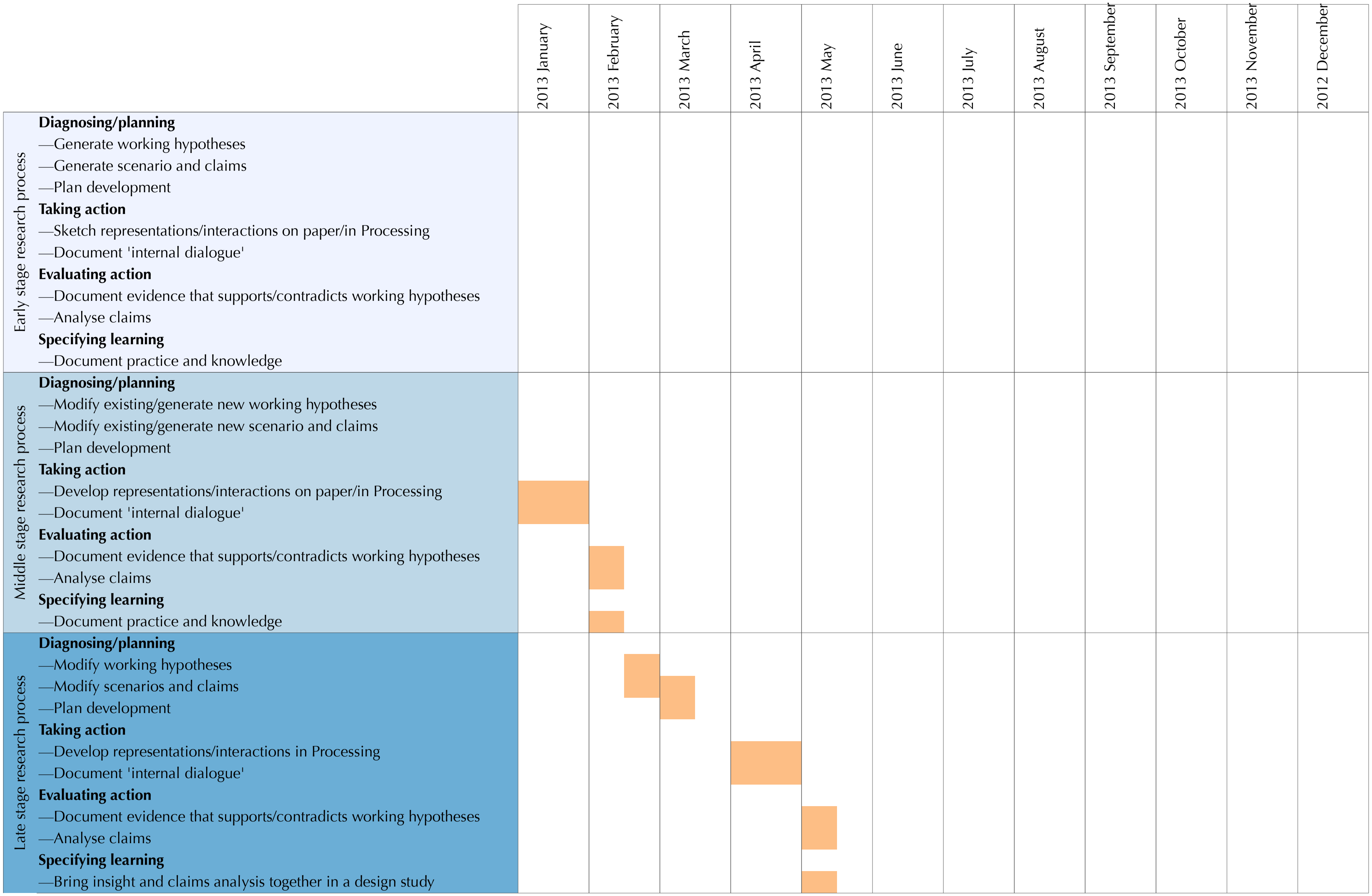
6 Work plan

The work plan specifies three groups corresponding to early, middle and late stages in the research process; one conferences group; one completion group; and one miscellaneous group. Although the activities in the three research process stages are similar (each stage iterates over the same types of activities), together they form a progression: Generation activities characterise the early stage when diagnosing and planning; paper and digital sketches when taking action; and documentation when evaluating action and specifying learning. In the longer middle stage, generation activities are augmented with the modification of earlier working hypotheses, scenarios and claims; and paper and digital sketches are developed. In the later stage, modification takes the place of generation when diagnosing and planning; and a design study is central to specifying learning.



2012 January
2012 February
2012 March
2012 April
2012 May
2012 June
2012 July
2012 August
2012 September
2012 October
2012 November
2012 December
Early stage research process
Diagnosing/planning
—Generate working hypotheses
—Generate scenario and claims
—Plan development
Taking action
—Sketch representations/interactions on paper/in Processing
—Document 'internal dialogue'
Evaluating action
—Document evidence that supports/contradicts working hypotheses
—Analyse claims
Specifying learning
—Document practice and knowledge
Middle stage research process
Diagnosing/planning
—Modify existing/generate new working hypotheses
—Modify existing/generate new scenario and claims
—Plan development
Taking action
—Develop representations/interactions on paper/in Processing
—Document 'internal dialogue'
Evaluating action
—Document evidence that supports/contradicts working hypotheses
—Analyse claims
Specifying learning
—Document practice and knowledge
Late stage research process
Diagnosing/planning
—Modify working hypotheses
—Modify scenarios and claims
—Plan development
Taking action
—Develop representations/interactions in Processing
—Document 'internal dialogue'
Evaluating action
—Document evidence that supports/contradicts working hypotheses
—Analyse claims
Specifying learning
—Bring insight and claims analysis together in a design study

		2012 January	2012 February	2012 March	2012 April	2012 May	2012 June	2012 July	2012 August	2012 September	2012 October	2012 November	2012 December
Conferences	**EuroVis (EuroVA workshop)**												
	—Preparation												
	—Conference												
	Geographic Information Science Research UK annual conference												
	—Preparation												
	—Conference												
	VisWeek												
	—Preparation												
	—Conference												
	—Visual Analytics Science and Technology Challenge												
	Completion												
	—Writing up												
	—Viva												
	Miscellaneous												
	—Annual leave												


2013 January
2013 February
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2012 December
Early stage research process
Diagnosing/planning
—Generate working hypotheses
—Generate scenario and claims
—Plan development
Taking action
—Sketch representations/interactions on paper/in Processing
—Document 'internal dialogue'
Evaluating action
—Document evidence that supports/contradicts working hypotheses
—Analyse claims
Specifying learning
—Document practice and knowledge
Middle stage research process
Diagnosing/planning
—Modify existing/generate new working hypotheses
—Modify existing/generate new scenario and claims
—Plan development
Taking action
—Develop representations/interactions on paper/in Processing
—Document 'internal dialogue'
Evaluating action
—Document evidence that supports/contradicts working hypotheses
—Analyse claims
Specifying learning
—Document practice and knowledge
Late stage research process
Diagnosing/planning
—Modify working hypotheses
—Modify scenarios and claims
—Plan development
Taking action
—Develop representations/interactions in Processing
—Document 'internal dialogue'
Evaluating action
—Document evidence that supports/contradicts working hypotheses
—Analyse claims
Specifying learning
—Bring insight and claims analysis together in a design study

		2013 January	2013 February	2013 March	2013 April	2013 May	2013 June	2013 July	2013 August	2013 September	2013 October	2013 November	2012 December
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	—Conference												
	—Visual Analytics Science and Technology Challenge												
	Completion												
	—Writing up												
	—Viva												
	Miscellaneous												
	—Annual leave												

7 Completed work

In my first 18 months as a PhD student I have had one paper and two peer-reviewed posters and extended abstracts accepted by national and international conferences. In addition, I have developed the skills necessary to complete the current research in the allotted time period (see *Work plan*).

7.1 Publications

A paper has been accepted by the Geographic Information Science Research UK 20th Annual Conference, which will take place in April 2012 (Dillingham et al. 2012). This paper combines the classifications developed by Wieczorek et al. (2004) and Guo et al. (2008) (see *Literature*), applies this combined classification to locations from the Haiti Crisis Map (Ushahidi 2009) (see *Data*) and compares the proportions of locations in each category to those in a similar dataset from MaNIS, the *Mammal Networked Information System*. It concludes that whilst there are similarities between the datasets (see Figure 1), crowdsourced crisis information presents significant challenges with respect to vagueness, ambiguity and precision.

Comments from the reviewers include:

> "This is a fascinating and well referenced paper … This work has the potential to make a significant contribution to humanitarian aid activities during and after disasters and should make a very good GISRUK presentation."

> "[This is an] Interesting paper, addressing a pertinent and contextual question of location inaccuracy…"

A peer-reviewed poster and extended abstract were presented to the IEEE Conference on Visual Analytics Science and Technology, which took place in October 2011 (Dillingham, Dykes & Wood 2011). These documents outline the current research and discuss an interactive software prototype (see Figures 2 and 3). This prototype, called *IncidentExplorer*, allows the visual exploration of a dataset containing crowdsourced crisis information that relates to the 2011 armed conflict in Libya (OCHA 2011) and exemplifies some of the visual representations and interactions that will be developed to address the working hypotheses during the current research.

Comments from the reviewers include:

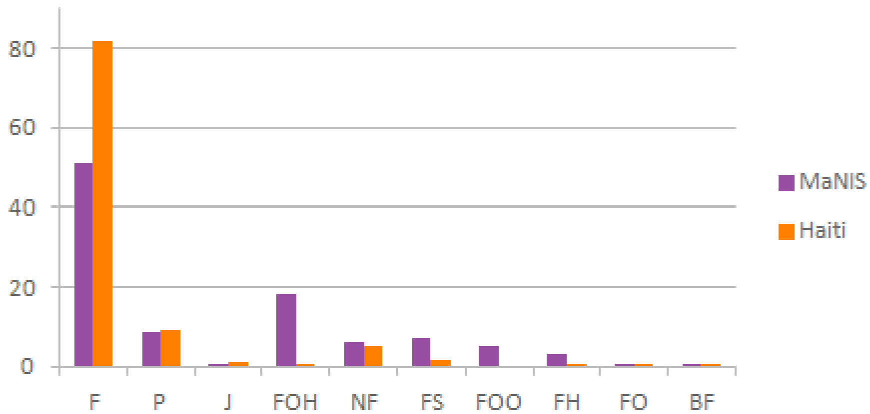

Figure 1: Category distributions (Dillingham et al. 2012)

> "…the proposed project in this poster is very well situated and should generate some interesting discussions…"

A peer-reviewed poster and extended abstract related to an earlier project were presented to the Geographic Information Science Research UK 19th Annual Conference (Dillingham, Mills & Dykes 2011). These documents describe the evaluation of four software prototypes using the model of visualization validation proposed by Munzner (2009). Each software prototype used 'heat mapping' to explore road incident data. The project can be seen as an introduction to many aspects of the current research, such as developing and evaluating visual representations and interactions and undertaking the analytical reasoning process.

The paper and extended abstracts are reproduced below.

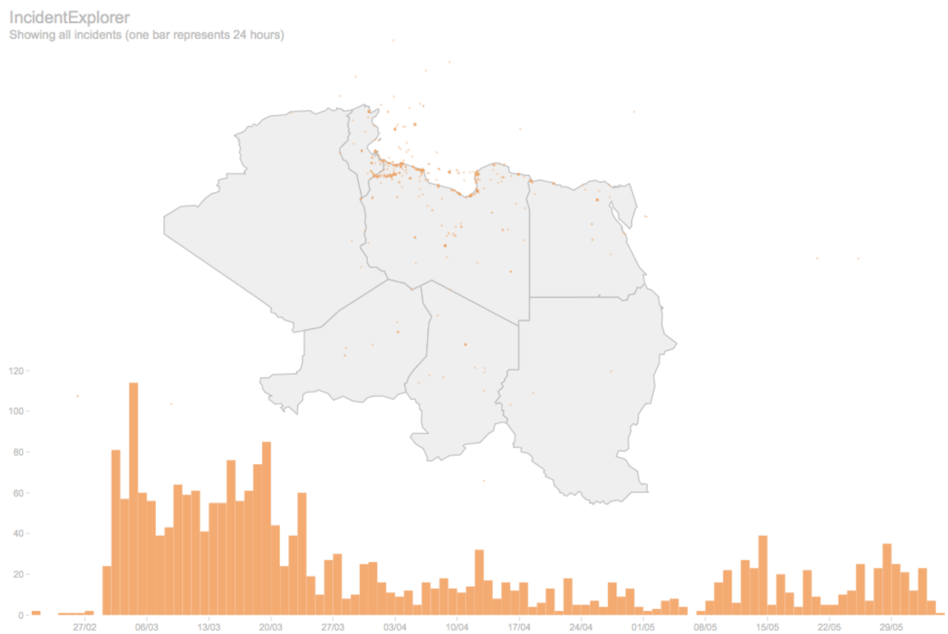

Figure 2: IncidentExplorer, overview (Dillingham, Dykes & Wood 2011)

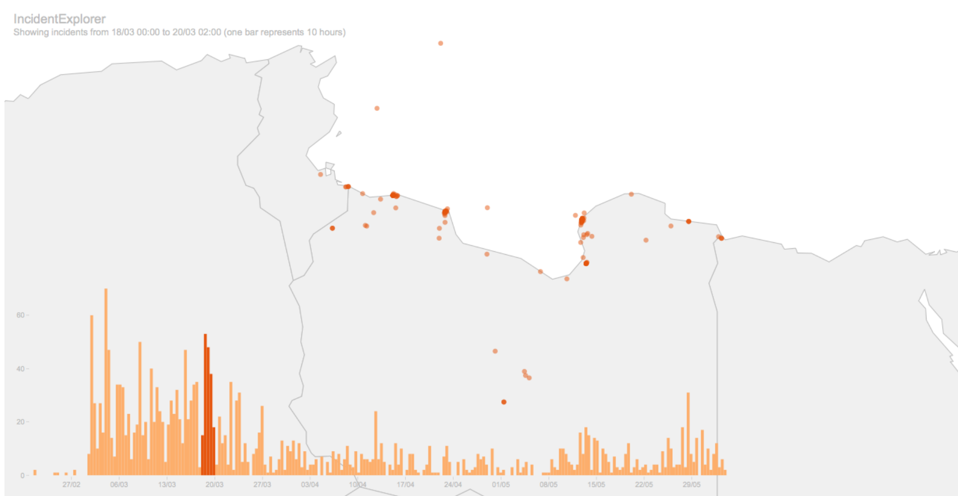

Figure 3: IncidentExplorer, zoom (Dillingham, Dykes & Wood 2011)

Characterising Locality Descriptions in Crowdsourced Crisis Information

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Summary: Humanitarian organisations are reluctant to use information from social media when responding to crises or conflicts, identifying trust and accuracy as principal concerns. However, the Geographic Information Science literature contains significant research into uncertainty, research we draw upon here to characterise locality descriptions in incident reports related to the 2010 earthquake in Haiti. We do so using a classification developed to georeference locality descriptions in MaNIS, the *Mammal Networked Information System*. We found that although there are similarities between the datasets, crowdsourced crisis information presents significant challenges with respect to vagueness, ambiguity and precision (resolution).

KEYWORDS: Uncertainty, Locality Descriptions, Crowdsourced Crisis Information, Ushahidi

1. Introduction

People affected by crisis or conflict events are turning to social media to communicate with the ‘outside’ and the ‘inside’ world (Coyle and Meier, 2009). On the one hand, humanitarian organisations are reluctant to use information from social media in the response effort (Tapia et al., 2011) because the risks of using untrustworthy and inaccurate information are considerable (Coyle and Meier, 2009). On the other hand, organisations such as Ushahidi have sought to mitigate these risks by developing software to gather, augment and verify crisis information (Ushahidi, 2011c). However, unlike similar organisations such as MapAction (MapAction, 2012), within Ushahidi these tasks are *crowdsourced*, or completed by a heterogeneous group in response to an open call (Howe, 2009).

Accuracy and trust (credibility) are characteristics of uncertainty (MacEachren et al., 2005). Geographic Information Science (GISc) has made considerable progress in evaluating and communicating the uncertainty associated with geographic information (Devillers et al., 2010) and uncertainty is a familiar topic in the GISc literature (MacEachren et al., 2005). Consequently, GISc is well placed to help evaluate the uncertainty associated with crowdsourced crisis information. As a first step towards this evaluation, we consider accuracy. We address two research questions: (1) What types of locality descriptions are present in crowdsourced crisis information? (2) Are the proportions of these types different to those present in related datasets? To do so, we adapt an existing classification of locality descriptions present in MaNIS, the *Mammal Networked Information System*, and apply it to crowdsourced crisis information.

2. Literature review

Several studies have explored the geographic nature of crisis information, especially collections of short text messages (‘microtext’) such as ‘tweets’ related to earthquakes, floods and wildfires (Gelernter and Mushegian, 2011; Vieweg et al., 2010). These studies suggest crisis information contains references to well defined geographic objects, especially when the nature of the event does not imply its location (Vieweg et al., 2010). However, these studies do not attempt to account for the uncertainty associated with these geographic objects.

Where geographic objects are well defined, uncertainty is caused by error (Fisher, 1999). Accuracy is well researched in GISc (Fisher, 1999) and techniques have been developed to evaluate the error associated with point, line and polygon objects (Devillers et al., 2010). However, these techniques involve comparing lower accuracy representations to higher accuracy representations (see Goodchild and Hunter, 1997). Consequently, whilst Haklay (2010) is able to evaluate the accuracy of crowdsourced geographic information by comparing an OpenStreetMap dataset to an Ordnance Survey dataset, it is considerably harder to evaluate the accuracy of crowdsourced crisis information because no higher accuracy representations exist.

Wieczorek et al. (2004) present a solution to the problem of evaluating uncertainty without relying on higher accuracy representations—the 'point-radius' georeferencing method. They use this method to georeference records in MaNIS, where the spatial component of each record is a description of the location where the specimen was collected. In addition, the point-radius method has been used to georeference historical search and rescue records (Doherty et al., 2011).

In summary, previous applications of the point-radius method and the geographic nature of crisis information suggest the point-radius method can be applied to crowdsourced crisis information. To assess whether this is the case, and to better understand crowdsourced crisis information, we applied the classification of locality descriptions in the MaNIS dataset to a dataset related to the 2010 earthquake in Haiti (Ushahidi, 2009). However, whilst Wieczorek et al. (2004) and Guo et al. (2008) discuss the categories of locality descriptions in the MaNIS dataset, the categories they identify are slightly different. Consequently, we combined the two classifications to form that shown in Table 1. Table 2 shows a comparison of the three classifications.

Table 1: Combined classification of locality descriptions (following Wieczorek et al., 2004 and Guo et al., 2008)

Code	Category	Example
U	Unsure	
C	Coordinates	
F	Feature	“Springfield”
P	Path	“Hwy. 1”
J	Junction	“Confluence of Labarge Creek and South Labarge Creek”
FOH	Offset from a feature or path at a heading	“10km N of Kuala Lumpur”
NF	Near a feature or path	“Big Bay vicinity”
FS	Subdivision of a feature or path	“N part of Mono Lake”
FOO	Orthogonal offsets from a feature	“1 miles N, 3 miles W of Fairview”
FH	Heading from a feature, no offset	“W of Tucson”
FO	Offset from a feature or path, no heading	“5km outside Calgary”
BF	Between features or paths	“Between Point Reyes and Inverness”

Table 2: Combined classification of locality descriptions compared to Wieczorek et al. (2004) and Guo et al. (2008)

Code	Wieczorek et al. (2004)	Guo et al. (2008)
U	Dubious, Cannot be located, Demonstrably inaccurate	
C	Coordinates	
F	Named place	Feature
P		Path or linear feature
J		Junction
FOH	Offset at a heading	Offset from a feature (or a path) at a heading
NF		Near a feature or a path
FS		Subdivision of a feature or a path
FOO		Orthogonal offsets from a feature
FH		Heading from a feature, no offset
FO	Offset, Offset along a path	Offset from a feature, no heading
BF		Between features or paths

3. Data

The Haiti Crisis Map (Ushahidi, 2009) is an Ushahidi *deployment*—an instance of the Ushahidi software platform—that was set up in response to the 2010 earthquake in Haiti. All 3,606 incident reports that comprise the Haiti Crisis Map were downloaded as a comma-separated values file. Table 3 contains one example.

Table 3: Example incident report from the Haiti Crisis Map (Ushahidi, 2009)

Attribute	Example value
id	3923
title	IDP camp of 250 families has no aid, Cite Soleil
date	2010-03-28 22:00:00
location	Pois Congo, Cite Soleil
description	IDP camp of 250 families in Pois Congo in Cite Soleil ...
category	2b. Penurie d' eau | Water shortage, ...
latitude	18.607433
longitude	-72.319667
approved	YES
verified	YES

Whilst people can report incidents based on their own knowledge or experience, they can also do so based on secondary sources such as SMSs, emails and social media. Consequently, when an incident is reported, several of the attributes in Table 3 may not have values. Typically, one team of volunteers will georeference the 'location' and populate the 'latitude' and 'longitude' attributes (Ushahidi, 2011a), whilst another will approve and verify the incident report (Ushahidi, 2011b). However, incident reports are not versioned, so it is impossible to determine how an incident report changes—and who made those changes—over time.

4. Methodology

The lead author and two additional participants (P1, P2 and P3) independently classified the locality descriptions in the Haiti dataset. Although not experts in the geography of Haiti, all have undergraduate geography degrees, two have postgraduate geographic information systems degrees and all are research students who routinely work with geographic information. In this respect, each participant performed a role that Goodchild (2009) argues is central to academic geography; providing 'quality control' in situations where individuals whose 'activity space' intersects with the study area are unavailable.

To avoid bias, each participant was given a spreadsheet within which row order was randomised and the 'id' attribute was hidden. In addition, each participant was given the information in Table 1 to guide the classification process. In cases where participants were unsure about which category a textual location belonged, they were instructed to select 'Unsure' and comment on their rationale. This captured some of the uncertainty associated with the classification process.

Although time-consuming (it took approximately four hours for each participant to classify the Haiti dataset), a manual classification process has been used in similar research (Gelernter and Mushegian 2011; Vieweg et al., 2010) and captures some of the uncertainty associated with the classification process.

5. Results

For all participants, the most frequent category in the Haiti dataset is 'Feature'. 'Path' is second for P1 and P2, and third for P3; 'Unsure' is second for P3, third for P1 and fifth for P2 (Figure 1). Overall, participants were in agreement in 63.8% of cases (2302), partial agreement in 26.3% of cases (947) and disagreement in 9.9% of cases (357).

To allow a like-for-like comparison between the Haiti and the MaNIS datasets, partial agreement cases were classed by simple majority vote and disagreement cases were classed as 'Uncertain'. All 385 'Uncertain' cases (357 disagreement cases plus 28 'Uncertain' cases) and 19 'Coordinates' cases were then removed. Figure 2 illustrates that in both datasets, the largest proportion of cases are categorised 'F' (51.0% MaNIS, 81.6% Haiti).

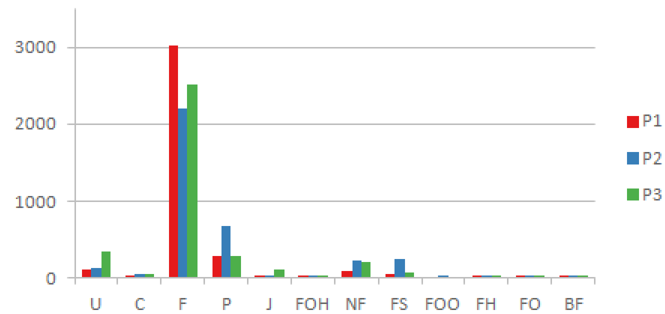

Figure 1: Category frequencies by participant, Haiti dataset

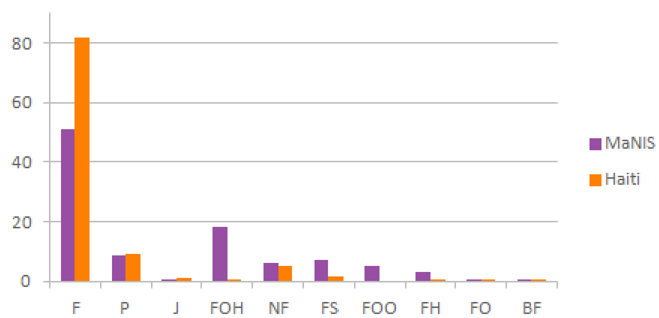

Figure 2: Category distributions, MaNIS and Haiti datasets

6. Discussion

The similarities between the datasets suggest that the point-radius georeferencing method could be applied to the Haiti dataset. However, the results suggest this process would be far from straightforward.

According to Guo et al. (2008), a locality description consists of a target object that may be linked to one or more referenced objects (normally toponyms) by one or more spatial relationships. Implicitly, therefore, a locality description describes a single, unambiguous location. However, participants identified several cases in the Haiti dataset where target objects were ambiguous and referenced objects were vague (for example "Rue Christ-Roi, this is near Hospital Christ-Roi"). Following the instructions, participants classified locality description as 'Unsure' and commented on their rationale. However, the ability to evaluate accuracy by exploring differences within, as well as between, locality descriptions requires further analysis. Certainly the vagueness and ambiguity (Fisher, 1999) and precision (resolution) (Veregin, 1999) associated with locality descriptions present interesting research directions.

Although participants attempted to classify locality descriptions consistently, they were uncertain as to whether they did so accurately. Participants related their uncertainty to limited local knowledge: Not being accustomed to the conventions by which, for example, addresses are recorded in Haiti meant they had difficulty distinguishing road names from district names, or road numbers from address numbers. This uncertainty is evident in the 9.9% of cases (357) where participants were in disagreement and questions the assertion that individuals are able to recognise city or street names easily, even when those names are unfamiliar (Gelernter and Mushegian, 2011). However, we argue that such uncertainty is typical in humanitarian response scenarios, especially when the response effort is crowdsourced.

7. Conclusions

This research is a first step towards evaluating the uncertainty associated with crowdsourced crisis information. Results suggest that locality descriptions in the Haiti dataset are predominantly features and that the distribution of locality descriptions across categories is similar to the MaNIS dataset. In turn, this suggests suitable georeferencing methods exist to allow accuracy to be evaluated.

Nevertheless, this conclusion is partial and hides the complexities present in crowdsourced crisis information. To address these complexities we plan to investigate whether alternative sources of information such as OpenStreetMap can be used to overcome limited local knowledge and explore differences within locality descriptions. We also plan to extend our research to a similar dataset related to the recent conflict in Libya (OCHA, 2011).

8. Acknowledgements

We thank Roger Beecham and Sarah Goodwin for classifying the Haiti dataset and those behind the Haiti Crisis Map for making their data publicly available. The bars in Figures 1 and 2 are elements A to E in ColorBrewer Set 1 (Harrower and Brewer, 2003). This qualitative scheme is well suited to categorical data. These five elements are effective on screen and in print.

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10. Biography

Iain Dillingham is a research student at the giCentre, City University London, applying visual and analytical approaches to user-generated content gathered in the wake of crisis or conflict events.

Dr Jason Dykes is Professor of Visualization at the giCentre, City University London, undertaking applied and theoretical research in, around and between information visualization, interactive analytical cartography and human-centred design.

Dr Jo Wood is a Professor of Visual Analytics at the giCentre, City University London, with research interests in geovisualization and visual analytics of data with a temporal and spatial component.

Visual Analytical Approaches to Evaluating Uncertainty and Bias in Crowdsourced Crisis Information

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City University London

ABSTRACT

Concerns about verification mean the humanitarian community are reluctant to use information collected during crisis events, even though such information could potentially enhance the response effort. Consequently, a program of research is presented that aims to evaluate the degree to which uncertainty and bias are found in public collections of incident reports gathered during crisis events. These datasets exemplify a class whose members have spatial and temporal attributes, are gathered from heterogeneous sources, and do not have readily available attribution information. An interactive software prototype, and existing software, are applied to a dataset related to the current armed conflict in Libya to identify 'intrinsic' characteristics against which uncertainty and bias can be evaluated. Requirements on the prototype are identified, which in time will be expanded into full research objectives.

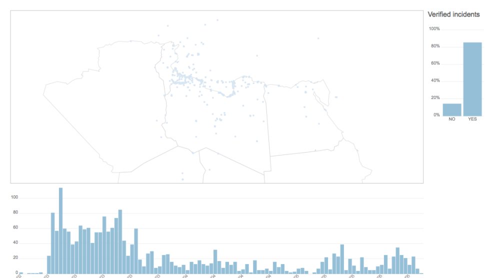

Figure 1: IncidentExplorer, Libya dataset

1 INTRODUCTION

Crowdsourcing describes the process by which tasks are completed by a heterogeneous group in response to an open call [5]. Whilst examples of crowdsourcing are generally business-focused [4, 5], recently the process has been used outside the business community to gather reports about populations directly affected by crisis events, such as the 2010 earthquake in Haiti, or the current armed conflict in Libya. However, whilst it is argued that formal responses to crisis events should accommodate crowdsourced information [8], verifying information collected during a crisis event is problematic [1]. Indeed, verification is the principal obstacle to humanitarian organisations using crowdsourced information to make decisions 'in the field' [10].

Verification, in this context, is associated with accuracy—"the inverse of error" [13, p.178]—and credibility [1]. Accuracy and credibility, alongside precision, completeness, consistency, lineage, currency, subjectivity, and interrelatedness, are components of uncertainty [7]. Many of these components have spatial, temporal, and thematic aspects [13]. Bias, by extension, can be defined as systematic error [13].

In our research, visual analytical approaches are used to evaluate the degree to which uncertainty and bias are found in public collections of incident reports gathered during crisis events. We use visual analytical approaches because they have been effective in studies with similar datasets [14], or with similar aims [16]. Our datasets relate to the 2010 earthquake in Haiti, and the current armed conflict in Libya, and were exported from the Haiti[1] and Libya[2] crisis maps; both are instances of Ushahidi,[3] an open source software platform that was built to gather information from 'tweets,' SMS messages, emails, and the web. Ushahidi allows anyone to report an incident, and incident reports are generally reviewed ('approved' and 'verified') by a restricted group before being made public. Consequently, two forms of crowdsourcing characterise Ushahidi: The first applies to reporting incidents and is consistent with the definition given above; the second applies to reviewing incident reports and is a form of moderation. However, it is important to note that not all of the information contained in each incident report is made public—the reporter's Twitter account, telephone number, and email address are not disclosed, for example—and that our research encompasses only the publicly available information.

Although there are compelling reasons to use the Haiti and Libya datasets specifically, they exemplify a class whose members have spatial and temporal attributes, are gathered from heterogeneous sources, and do not have readily available attribution information (i.e. information about the report, reporter, or reviewer). Visual analytical approaches are well placed to "detect the expected and discover the unexpected" in such circumstances [11, p.10]. Furthermore, exploring the relationships between the components that characterise uncertainty in different domains is a recognised research challenge in geographic information science [7]. Indeed, addressing data quality issues such as uncertainty could also benefit the wider research community [6].

In the following sections we state our aim, and describe how we have addressed our first objective using existing and new software. We describe the nature of the Haiti and Libya datasets, and conclude with possible directions for future research.

2 EXPOSITION

The aim of our research is to evaluate the degree to which uncertainty and bias are found in public collections of incident reports gathered during crisis events. Whilst previous research used the

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[1]http://haiti.ushahidi.com/
[2]http://libyacrisismap.net/
[3]http://www.ushahidi.com/

contribution frequency of users to evaluate bias in collections of user-generated content [9], the Haiti and Libya datasets lack attribution information. However, it should be possible to identify similar 'intrinsic' characteristics against which uncertainty and bias can be evaluated. Our first objective is to identify these characteristics.

Achieving our first objective necessitates 'getting to know' the data, a crucial component in effective data analysis [12]. Exploring the Libya dataset with existing software told us that it contains 2283 incident reports, each with two spatial (a coordinate pair and a location string), one temporal, and five 'thematic' attributes that describe and categorise each incident. The location strings are 'messy' in that they contain toponyms ("Ajdabiya Central Hospital"), coordinate pairs at different levels of precision, 'vernacular geographies' [3] ("Between Sharia as-Sayiti Street [and] Az Zawiyah Street, Tripoli, Libya"), and in some cases additional explanatory information ("Cyrinacia – older regional term meaning eastern coastal region of Libya."). Furthermore, 94% of reports in the Libya dataset are categorised as 'Geo-Located' (Ushahidi categories are similar to social media 'tags' in that they are not mutually exclusive), suggesting they are spatially accurate.

We developed an interactive software prototype called IncidentExplorer (Figure 1) to explore the Libya dataset in linked spatial (upper-left), temporal (bottom-left), and thematic (right) views. Using this tool, we see that:

- Most incidents were reported on or near to the coast, with concentrations on the north-west border with Tunisia, and in the north-east coast (Ras Lanuf to Benghazi).
- The temporal distribution of incident reports has a positive skew, with a peak on 4th March 2011 (day 10 of 102).
- Just over 80% of incident reports were 'verified.' Although on most days the proportion of 'verified' reports exceeds 'unverified' reports, the reverse is true at the 'ends' of the dataset. (All incident reports were 'approved.')

We identified several requirements on IncidentExplorer when exploring the Libya dataset. The first concerns the relationship between the coordinate pair, which locates the incident report on the spatial view, and the location string. Although roughly 78% of latitude and 75% of longitude values have six decimal places of precision, this precision does not appear to be reflected in the location strings: There are 86 "Tripoli, Libya" location strings (or similar), and 85 "Benghazi, Libya" location strings (or similar), for example. Given the desire to reach populations directly affected by crisis events, we would expect to see more location strings with greater precision (i.e. more location strings with finer spatial resolution). To explore the precision of location strings further, we wish to (1) display the location strings of the incident reports selected in the spatial and temporal views; and (2) use the location strings to classify the precision of incident reports, and represent this in IncidentExplorer. Both would allow us to assess whether the spatial precision of incident reports varies in space and time; any systematic variation would suggest bias.

Similarly, we wish to determine whether the coordinate pairs are accurate. Two published methods warrant further investigation; the point-radius method [15] and the probability distribution method [2]. The former would result in an object, and the latter a field within which the incident report is likely to be located.

Further requirements on the software prototype include extending the thematic view to include categorical and descriptive information about each incident report. The latter will require further analysis, as the Libya dataset contains 123 categories, some of which are synonymous (e.g. "Water and Sanitation" and "WATSAN").

3 Conclusion

We present a program of research on uncertainty and bias in crowdsourced crisis information. Having developed a software prototype to address our first objective, we identify several requirements which in time will be expanded into full research objectives. Although these full objectives concern precision and accuracy, the potential exists to explore other components of uncertainty in future work.

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Exploring Road Incident Data with Heat Maps

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ABSTRACT: This research seeks to determine whether heat mapping is an effective technique for the visual exploration of road incident data. Four software prototypes, which adopted map, treemap and spatial treemap layouts, were developed using open source software. Whilst the visualization process described by Fry (2007) informed the development effort, the evaluation methodology was based on the Nested Process Model (Munzner, 2009). The results of two evaluation methods – a design study and the presentation and discussion of results with domain experts – confirm heat mapping's validity and provide requirements for further software development.

KEYWORDS: heat map, visualization, evaluation, open source software

1. Introduction

Every day, thousands of journeys are made on Britain's road network. To avoid congestion, many drivers seek traffic updates on the web, radio and television. Ultimately, these updates are produced by companies such as Trafficlink,[1] who analyse road incident data. Unwin et al. (2008) assert that the first stage of analysis involves getting to know the data, a process where graphical representations play an important role in assessing data quality, cleaning data and highlighting structure and outliers, for example. This research seeks to determine whether one such graphical representation, the heat map, is an effective technique for the visual exploration of road incident data.

Previous work undertaken within Trafficlink suggested that heat mapping could be used to represent and predict congestion. However, the term *heat map* is loosely defined and may refer to the representation of geographic or non-geographic data. In cartography, for example, a heat map is an unclassed isarithmic map used to represent smooth, continuous phenomena (Slocum et al., 2009); in statistics, a cluster heat map is a permutable grid of cells, where each cell is coloured by value (Wilkinson and Friendly, 2009). Ultimately, both approaches informed the software development effort.

Four software prototypes were developed to explore the road incident data, reflecting the requirements of the target domain. The prototypes explored the number and severity of road incidents at multiple spatial and temporal resolutions; compared observed to expected number of road incidents; and represented the number of road incidents and length of road network across three road categories ('A', 'B' and motorways). Three prototypes adopted a map layout, whilst one adopted treemap (Shneiderman, 1992) and spatial treemap (Slingsby et al., 2008) layouts.

The importance of evaluation when developing techniques to visualize geographic information is noted elsewhere (Slocum et al., 2001). Consequently, to determine whether heat mapping is an effective technique, an evaluation methodology based on the Nested Process Model (Munzner, 2009) was used. This

[1]http://www.trafficlink.co.uk/

model consists of four nested levels, where threats to a visualization's validity, alongside appropriate evaluation methods, are identified at each level (Munzner, 2009).

The structure of this paper is as follows: section two describes the software development effort, situating it within the visualization process described by Fry (2007). Section three describes the evaluation methodology, maps the visualization process described by Fry (2007) to the Nested Process Model (Munzner, 2009) and reports the results of immediate and downstream validation. Section four concludes and offers directions for future research.

2. The visualization process

Visualization can be viewed as a seven stage process, where the initial four stages – acquiring the data, parsing (structuring and ordering the data), filtering (obtaining only the data of interest) and mining (discerning patterns in the data or setting the mathematical context) (Fry, 2007) – involve data processing, or the mapping of concrete data to abstract data-types (Munzner, 2009). This visualization process has been successfully used to explore library loans data, for example (Radburn et al., 2010) and structures the following discussion.

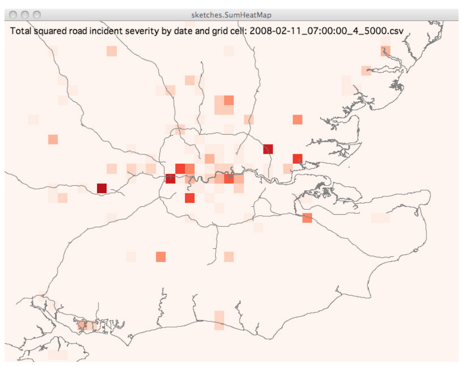

Figure 1: Severity of road incidents, map layout

The road incident data archive was supplied as a single 4.7G tab-separated-values file. The archive contained 14.5 million records, describing 2.5 million road incidents which occurred in Britain between September 2002 and September 2009. Each road incident was described over multiple contiguous lines, leading to considerable data redundancy.

The road incident data archive was parsed and loaded into MySQL[2] using standard Unix and MySQL command-line tools. Although large in size, performing these operations took under 15 minutes. Using MySQL permitted more effective filtering of the road incident data, especially when the command-line interface was used within MySQL Workbench,[3] a graphical tool for interacting with MySQL databases. With appropriate indices, a simple query returning rows relating to a road incident executed in under a second, whilst a more complex query involving a temporal filter executed in under 13 seconds. Although relatively slow, querying the database was quicker than extracting rows directly from the archive.

Querying the database also permitted more effective mining and led to the discovery of several anomalies concerning road incident start and end times. These anomalies illustrated how the problem of characterising a road incident was non-trivial: not only could a road incident change over time but because of errors in the archival process, temporal change was not recorded accurately.

To conclude the data mining stage, a subset of road incidents occurring in February and August 2008 were exported from the database. The OGR Simple Feature Library[4] was then used to perform a coordinate transform operation on the geographic location of each road incident to ensure consistency with the boundary data used in the data representation stage. This library, released by the Open Source Geospatial Foundation, uses an abstract data model to access geographic data stored in standard and

[2] `http://www.mysql.com/`
[3] `http://wb.mysql.com/`
[4] `http://www.gdal.org/ogr/`

non-standard formats. The transformed subset was loaded into MySQL, alongside geometry data generated by a PHP[5] script for polygons covering Britain at six spatial resolutions. MySQL's spatial extensions were then used to produce summary data for the number and the severity of road incidents for each polygon at each spatial resolution over multiple time periods.

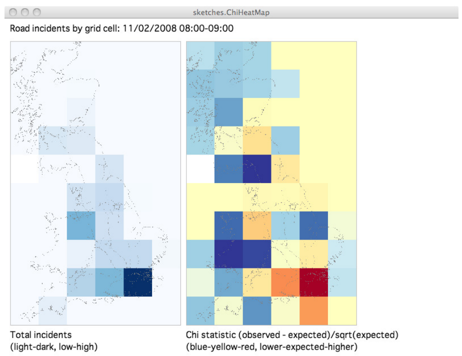

Figure 2: Number and observed versus expected number of road incidents, map layout

The final three stages in the visualization process involve representing the data, refining the representation and adding interaction to the representation (Fry, 2007). As previously noted, map and treemap layouts were selected, with a spatial treemap layout bridging the two. The software prototypes used ColorBrewer.org colour schemes (Harrower and Brewer, 2003) and were developed using Processing[6] with additional functionality provided by the giCentre Utilities.[7] The prototypes which implemented a map layout used boundary data from the Meridian 2 dataset, available under the Ordnance Survey's OpenData initiative.[8] Although screenshots are provided, the reader is encouraged to watch the video presentations on the accompanying web page to learn more:

`http://dillingham.me.uk/modules/dissertation/`

The software prototypes support differing levels of interaction. Collectively, *interaction with the data* consists of brushing cells in the treemap; *interaction with the temporal dimension* consists of stepping forwards and backwards through time periods; and *interaction with the data representation* consists of panning and zooming (Crampton, 2002).

3. Visualization evaluation

To determine whether heat mapping is an effective technique, it is essential to demonstrate that a heat map is appropriate to the task and is suitably well constructed; in short, to demonstrate the technique's validity (Munzner, 2009). The Nested Process Model (NPM) (Munzner, 2009) provides a structure within which the factors threatening heat mapping's validity can be examined. The NPM has four nested levels, where each level has both immediate and downstream evaluation methods. The latter are necessary because errors at outer levels will propagate to inner levels and because the validation of outer levels is often impossible until inner levels are completed (Munzner, 2009).

The elements in the visualization process described by Fry (2007) can be split into data processing (acquiring, parsing, filtering, mining) and data representation (representing, refining, interacting). Data processing maps to level two in the NPM, where the (concrete) vocabulary of the target domain is mapped to the (abstract) vocabulary of visualization (Munzner, 2009). In addition, it should be noted that level two also encompasses requirements gathering. Similarly, data representation maps to level three, where visual encodings and interactions are designed (Munzner, 2009).

To counter threats to validity at level two in the NPM, Munzner (2009) suggests only downstream evaluation methods such as field studies are appropriate. Field studies take place in a natural environment

[5]`http://www.php.net/`
[6]`http://processing.org/`
[7]`http://www.gicentre.org/utils/`
[8]`http://www.ordnancesurvey.co.uk/oswebsite/opendata/`

and encompass interviews, observations, questionnaires and the collection and analysis of design artifacts (Sharp et al., 2007). However, because they are often of extended duration an agile approach to gathering requirements and processing and representing data was adopted. This approach, combined with previous work undertaken within Trafficlink, also countered the principal threat at level one: mischaracterising the problem (Munzner, 2009).

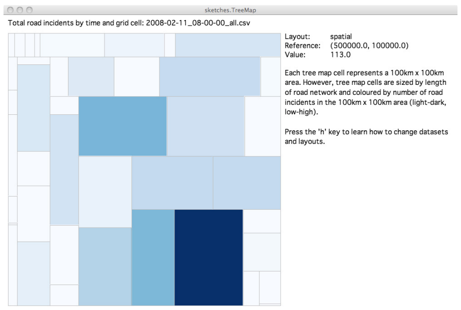

Figure 3: Number of road incidents, spatial treemap layout

In seeking to assess the effectiveness of heat mapping, level three of the NPM is the 'focus' level. Here, the methods suggested by Munzner (2009) for immediate validation are all analytical, in the sense of not involving end users (Sharp et al., 2007). However, although a heuristic evaluation or an expert review would have been appropriate, a design study was selected as this method accords with the 'formalised informal' approach to evaluation which although "seldom explicitly discussed" is commonplace in cartography (Krygier, 1999, 249).

The design study highlighted how the software prototypes followed cartographic practice. The absence of a formal definition of heat mapping allowed some flexibility with the colour scheme, although greater control over the number of data classes and the data classification method would have been a considerable advantage. Whilst an assessment of the interactivity provided by the prototypes based on system provision (Crampton, 2002) suggested that they provided reasonably powerful forms of interaction, an alternative assessment based on user intention highlighted several omissions, such as the ability to (re)encode and select elements in the data representation (Yi et al., 2007).

Munzner (2009) suggests downstream validation at level three of the NPM should encompass presentation and discussion of results, analysis of result images or user studies. The analysis of result images is often used where empirically-derived aesthetic guidelines exist (Munzner, 2009). Given the similarity of this evaluation method to a design study, it was not adopted. Similarly, whilst user studies have many advantages, it has been argued that they conflict with the nature of insight (North, 2006). This conflict is especially problematic as the generation of insight is fundamental to visualization (Card et al., 1999). Consequently, results were presented to and discussed with three traffic analysts and one external expert.

The presentation and discussion of results with domain experts was positive. The requirements to explore deviation from a 'normal state' (i.e. the expected number or severity of road incidents); variation between classes of road incidents; and 'temporal clearance' (i.e. the time between the start of a road incident and a return to the normal state) were noted as well as the requirement to model, as well as to explore, road incident data. One traffic analyst identified the treemap prototype, which implemented spatial and non-spatial layouts, as the most useful. The feedback suggested this prototype, alongside that which compared observed to expected number of road incidents, warranted further development and could make a positive contribution to the domain experts' work.

4. Conclusion

Four software prototypes, which adopted map, treemap and spatial treemap layouts, were developed to determine whether heat mapping is an effective technique for the visual exploration of road incident data. Validation at the visual encoding and interaction design level of the Nested Process Model (Munzner, 2009) was undertaken using a design study and by presenting and discussing results with domain experts. Threats at outer levels were addressed. Based on this validation process, it is possible to assert that heat mapping is indeed an effective technique for the visual exploration of road incident data.

Several recommendations for future research spring from this conclusion. The first is to conduct a comparative study encompassing alternative approaches to data representation, whilst the second is to formalise a definition of heat mapping necessary for such a study. Both address the question of the degree to which heat mapping is an effective technique. Finally, the feedback from domain experts suggested the treemap and spatial treemap layouts had the potential to assist them in their work. Evaluation of these specific techniques would contribute to a greater understanding of how best to represent geographic data.

5. Acknowledgements

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7. Biographies

Iain Dillingham is a research student at the giCentre, City University London with research interests in visualization, geographic information and computer graphics.

Bryn Mills is Chief Technology Officer at Trafficlink.

Prof Jason Dykes is a Senior Lecturer at the giCentre, City University London undertaking applied and theoretical research in, around and between information visualization, interactive analytical cartography and human-centred design.

7.2 Skills

I continue to extend my skills in Java, JavaScript, PHP and SQL—skills that encompass programming visual representations and interactions in Processing[3] (Java-based) and D3[4] (JavaScript-based)—as a teaching assistant on Databases, Data Visualization, Programming with Java and Web Applications Development.

I have contributed code to the giCentre codebase, specifically *geoMap*,[5] a Processing library for creating geographic maps in Processing, *Canvas*,[6] a WordPress theme and *libraryTemplate*,[7] an Eclipse project template for building Processing libraries. I participated in the giCentre entry to the 2011 VAST Challenge and am working on a small 'hobby' project visualising environmental monitoring data for the Victoria and Albert Museum.

7.3 Engagement with the academic community

As well as attending City University events and chairing the weekly giCentre PhD meeting, I contribute to weekly, informal supervisory meetings. These meetings are one-to-one (with Jason Dykes) and group (with Jason Dykes, Sarah Goodwin and Ali Ramathan). In addition, I have had several opportunities to discuss the current research with the wider academic community:

- The Geographic Information Science Research UK 18th and 19th Annual Conferences (2010, 2011)
- The University of Konstanz summer school on the exploratory analysis and visualization of large information spaces (2010)
- The GeoViz workshop on geovisualization, spatial analysis and modelling (2011)
- The Information Visualization 15th Annual Conference (2011)
- The Third International UKVAC Workshop on Visual Analytics (2011)

[3] `http://processing.org/`
[4] `http://mbostock.github.com/d3/`
[5] `http://www.gicentre.org/geomap/`
[6] `https://github.com/iaindillingham/canvas`
[7] `https://github.com/iaindillingham/libraryTemplate`

- VisWeek, which includes the IEEE Information Visualization Conference and the IEEE Conference on Visual Analytics Science and Technology (2011)

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- **Crisis informatics:** Proceedings of the International Conference on Information Systems for Crisis Response and Management (ISCRAM)
- **Geovisualization, information visualization:** IEEE Transactions on Visualization and Computer Graphics; Proceedings of the International Conference on Information Visualization (InfoVis); Dykes et al. (2005)
- **Geographic information science:** Proceedings of Geographic Information Science Research UK (GISRUK); Proceedings of the International Conference on Geographic Information Science (GIScience)
- **Research methods:** Oates (2006)
- **Visual analytics:** Proceedings of the IEEE Conference on Visual Analytics Science and Technology (VAST); Thomas & Cook (2005)

References in core papers or chapters include:

- **Action research:** Baskerville & Wood-Harper (1996), Oates (2006)
- **Crisis informatics:** King (2005), Tapia et al. (2011)

- **Evaluation:** Munzner (2009, 2008)
- **Scenario-based design:** Carroll & Rosson (1992)
- **Uncertainty:** MacEachren et al. (2005), Thomson et al. (2005)
- **Sensemaking and visual analytics:** Pirolli & Card (2005), Thomas & Cook (2006, 2005)

Relevant databases include:

- ACM Digital Library (`http://dl.acm.org/`)
- IEEE Xplore (`http://ieeexplore.ieee.org/`)
- ingentaconnect (`http://www.ingentaconnect.com/`)
- ScienceDirect (`http://www.sciencedirect.com/`)

Relevant journals include:

- ACM Transactions on Computer-Human Interaction
- American Society for Information Science and Technology, Journal of the
- American Statistical Association, Journal of the
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