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Antoni Moore
Igor Drecki *Editors*

Geospatial Visualisation

Springer

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Geospatial Visualisation

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ISSN 2195-1705 ISSN 2195-1713 (electronic)
ISBN 978-3-642-12288-0 ISBN 978-3-642-12289-7 (eBook)
DOI 10.1007/978-3-642-12289-7
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2012947862

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword

The region of Australasia and Oceania has a rich history and an active presence in cartography. Many important improvements in mapping and cartography are proposed and performed by cartographers and researchers of that region. This book focuses on the contemporary activities in selected realms of cartography in Australasia and Oceania. It covers aspects of theoretical, topographical, thematic and multimedia cartography, which have been presented at the first ICA Regional Symposium on Cartography for Australasia and Oceania, which took place from September 1 to 3, 2010 in Auckland, New Zealand and was organised by the International Cartographic Association (ICA) and the New Zealand Cartographic Society.

The symposium's aim was to bring together cartographers, GI scientists and those working in related disciplines from Australasia and Oceania with the goal of offering a platform for discussion and exchange, and stimulation of joint projects. A selection of fully reviewed contributions is edited in this book and is meant as a mirror of the wide range of activities in the realm of cartography in this region. The innovative and contemporary character of these topics has led to a great variety of interdisciplinary contributions. By trying to make use of available contemporary technologies, cartography and a variety of related disciplines look specifically at user-centred system development, as well as new forms of visual analytics, Web and mobile cartography, cognitive aspects and temporal cartography. Contributions are provided in four main sections and they cover all of these aspects and give a picture of the new and expanding field of contemporary cartography.

The production of this book would not have been possible without the professional and formidable work of the editors Tony Moore and Igor Drecki. Thanks to them, their initiative and excellent work, the symposium and this post-conference publication became a reality.

Georg Gartner
President, International Cartographic Association, Vienna

Preface

This book is a selection of papers that, with one exception, started life as either conference papers or abstracts submitted to GeoCart'2010/the 1st ICA Regional Symposium on Cartography for Australasia and Oceania, held in Auckland, New Zealand. It follows on from the selection of papers published from the GeoCart' 2008 conference as "Geospatial Vision", also published by Springer. All of the chapters have since been updated and revised thoroughly or, in the case of conference abstracts, worked up into full chapters. They have been blind peer reviewed by two referees of international research standing in geospatial science, mostly in the subdisciplines of cartography and geovisualisation.

The first section **The Changing Face of Cartography** has three chapters, two covering critical and historical cartography, the third an account of current true-3D mapping technologies.

To begin the book we have Mick Abbott's chapter which considers time in particular, a deeply argued piece of critical cartography for transforming conventional topographic maps so that they have a consistent temporal scale for a line of travel. In so doing, traditionally inexpressive cartographic depictions of wilderness in particular become richer, revealing cultural and experiential facets of the landscape.

Next, William Cartwright gives an account of the Gallipoli campaign in World War I (the 100th anniversary of which will be commemorated in 2015) and the various maps and cartographic artefacts that existed or were produced in response to the campaign in military contexts (on both sides of the conflict) and relating geospatial aspects of the battle to people back home.

To now and the future: Manfred Buchroithner and Claudia Knust's chapter represents one of the major branches of cartographic display available today with increasing ubiquity—that of 3D. They provide a comprehensive review of "true-3D" techniques (analogue and digital), taking in lenticular foil displays, solid landscape embodiments, tactile maps, Internet-linked 3D display and holography.

The next set of chapters is grouped in the **Space, Time and Cognition** section, though these themes are echoed throughout the book; Abbott's mapping of wilderness could be interpreted as a cognitive mapping and most of the chapters in the sections of the book following this one are strongly embedded in a spatiotemporal context.

To kick off, Antoni Moore, Jared Hayes and William Wong re-examine Human–Computer Interaction (HCI) and cognitive science studies applied to ambulance dispatch displays, which must critically convey spatiotemporal data to emergency workers. Their approach hinges on a geographic approach to these studies, through linking similar proximity-based principles that have been developed independently and the novel application of cartographic symbolisation and generalisation to the time-critical interface domain.

Next, Chayn Sun, Pip Forer, Jinfeng Zhao and David Simmons perform a thorough data quality analysis on a valuable field-collected space–time dataset describing tourist flows into, within and out of the West Coast of New Zealand's South Island. As well as revealing characteristic anomalies such as incompleteness and inconsistency in the minority of data collected, they apply solutions to these issues, such as interpolation, extrapolation and use of surrogate variables.

Lastly in this section, Jean-Philippe Aurambout, Falak Sheth, Ian Bishop and Christopher Pettit present findings from a project that assesses various local and regional geovisualisation techniques featuring Google Earth. The context is the critical communication of climate change scenarios and impacts. When tested on stakeholders the spatiotemporal representations were generally effective, though variation in feedback indicated that a visualisation suite rather than a single representation would be of most value.

Around the globe, most people will be using **geovisualisation tools enabled by mobile technologies and/or Web 2.0** if they are at all. The third section of the book has two diverse examples of this, though as implied in the previous chapter and doubly emphasised in the final section, Web 2.0 is a dominant theme in this book.

In the first offering, James O'Brien and Ken Field demonstrate the innovative use of the social network microblogging service Twitter and SMS to enable geocollaboration in a distributed student fieldwork context. Subsequent to this was the visualisation of the spatial footprint of discussions and the collaborative Tweet Map (with a temporal as well as spatial mode to emphasise the discussion thread) built for the purpose of land use classification.

Mariusz Nowostawski and Julian Münster continue the Web 2.0 theme, dealing explicitly with the mobile context. In their chapter they demonstrate their Virtual Stickies spatiotemporal annotation system, which combines mobile augmented reality and Google Maps on an Android platform.

In the first chapter demonstrating **geovisual analytics** perspectives, there is an investigation of complex volunteered crime data (from the Google Maps-based WikiCrimes resource) by Antoni Moore, Marcos de Oliveira, Carlos Caminha, Vasco Furtado, Victor Basso and Leonardo Ayres. Using the National Visualization and Analytics Center's eXplorer tool they were able to identify patterns within and between attributes of crime at the Brazilian state level and degree grid cell level.

The analytical theme continues with Slava Kisilevich, Daniel Keim, Natalia Andrienko and Gennady Andrienko applying a powerful multi-stage geovisual analytics methodology to a massive database of geotagged Flickr photos (extending the Web 2.0 theme). Through spatial clustering, time series analysis, analysis of text and linking to Point of Interest data, they were able to identify meaningful spatiotemporal clusters reflecting stationary, reappearing, occasional and regular moving behaviour.

The final chapter uses the innovative ringmap spatiotemporal visualisation method as a tool for geovisual analytics. Jinfeng Zhao, Pip Forer, Mike Walker and Todd Dennis report on the application of the ringmap to gain insights into the spatiotemporal behaviour of the possum, a switch from the predominant use of such techniques on human temporal geography. Furthermore, they adapt the ringmap to represent possum GPS collar data at day as well as year scales, and utilise the established space-time aquarium of Hägerstrand's time geography.

We would like to gratefully acknowledge the efforts of the authors who supported this book by either responding to our call for papers or contributing their chapters afterwards. Their innovative and cutting-edge research, predominantly undertaken in the Australasia and Oceania region, contributes to the advancement of cartography and GIScience internationally. Their commitment to the project by meeting tight deadlines and promptly responding to editorial comments is very much appreciated.

We wish to express our gratitude to the international experts, who agreed to serve on the Paper Committee. Their prompt and in-depth reviews and notes helped to refine this book and assisted us in the editorial work.

Special thanks go to Professor Pip Forer for suggesting (again) a contemporary and inspiring theme "*Cartographies for Tomorrow*: *Mapping in a mash-up world*" for GeoCart'2010 and the ICA Regional Symposium on Cartography for Australasia and Oceania. Thanks to our sponsors: Statistics New Zealand, School of Environment at The University of Auckland and New Zealand Cartographic Society, without which these events and subsequently the book would not have been possible.

The book publication process was enjoyable and seamless, thanks to the professional and dedicated publishing team at Springer-Verlag in Heidelberg. In particular we wish to express our gratitude to Agata Oelschläger and Solaimuthu Thambidurai who managed the entire process and were always available to assist.

Finally, we would like to thank our families for their continuous support, understanding and love, for enduring many months of our editorial (and professional) commitments.

To Kirsten, Alex, Danny and Cormac...

Dziękuje Ci Iwono, Natalio i Wando za Wasze kochąjace serca, troskę, uśmiech i wyrozumiałość.

March 2012

Antoni Moore
Igor Drecki

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Contents

Part I
The Changing Face of Cartography

Visualising a Temporal Cartography of Travel

Mick Abbott

Abstract This study asserts that contemporary cultural perceptions of wilderness have been heavily influenced by topographic cartography. It compares different historical conceptualizations of wilderness in the cartographies of Aotearoa New Zealand's Southern Fiordland, and finds that certain tropes have shaped how the region is now characterized and managed as an unspoilt, remote, threatened and culturally-empty wilderness. The author argues that this cartography-influenced understanding of Fiordland has come at the expense of other, experiential and phenomenological qualities of wilderness relating to participation and performance. The author explores alternative cartographies of wilderness with a particular emphasis on phenomenological engagement. Instead of tracing a route onto a uniform spatial scale, the reverse is attempted: a cartography in which intervals of time (hours and days) rather than space (metres and kilometres) are elevated as the primary axis of uniform determination. Then, a topographic representation is morphed to match these varying rates of travel: the resulting cartography, particularly as subsequent journeys are overlaid, reveals temporal dimensions that are as folded and contorted as the physically undulating terrain through which such journeys are made. Corner has critiqued wilderness landscapes as "nothing more than an empty sign, a dead event" (Corner 1999a, p 156). By contrast, this paper concludes that a phenomenological cartography may open up—through mapping wilderness's eidetic and temporal qualities—our capacity to understand wilderness areas as sites which are rich not only in ecological but also cultural relationships.

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7_1,

Keywords Space–time cartograms · Wilderness · Visualizing journeys

1 Introduction

Cartography does not merely describe a landscape's qualities. Rather, by playing an instrumental role in how landscape is conceptualized, it creates them (Turnbull 2000; Cosgrove 2003; Wood and Fels 2008; Dodge et al. 2009). Cartographer J. Brian Harley asserts that, despite an appearance of mimetic truth, the map "is not a mirror of nature" (1989, p 234). Instead maps are devices whose spatial precision and technical sophistication disguises their culturally-bound structure and content. Hence maps should be considered 'slippery', 'dangerous' and 'unreliable' and therefore treated with caution (Harley 2001, p 34).

Harley uses this critique to highlight cartography's hegemonic outcomes; however landscape architect James Corner, considering these same qualities, draws attention to the generative potential of maps to elicit innovative qualities of landscape. Because a landscape image is neither 'neutral nor passive', the agency of mapping can be enlisted to intentionally shape the capacity to perceive, understand and direct landscape. Hence, for the landscape architect mapping is a creative method by which landscapes can be designed. Corner considers images of landscape must develop beyond the pictorial and instead "emphasize the experiential intimacies of engagement, participation and use over time" (1999a, p 159). By visualising a range of landscape's eidetic qualities, cartography can act as "fundamental stimuli to creativity and invention; they do not represent the reality of an idea but rather inaugurate its possibility" (Ibid, p 163).

This study investigates the relationship between the cartography of forested national parks and related values of wilderness. It is the capacity of cartography to create, modify and subsume landscape qualities that has led Raymond Dasmann to reflect: "sometimes I wonder if our final act of wilderness destruction did not lie in designating formal wilderness areas for preservation. In defining the boundaries, writing the rules and publicizing the results, did we not remove the last magic and make us realize that the remote and unknown was available to all" (quoted in Molloy 1983, p 16).

Dasmann is suggesting that a cartographic practice changed the very qualities of wilderness it was attempting to record and preserve. We must ask, what might the instrumentality of cartography offer in modifying attitudes to wilderness, and how might alternative cartographies prompt different engagements with, and conceptualizations of, wilderness landscapes?

2 The Topographic Map

The modern topographical map has a precision that earlier efforts struggled to achieve. In terms of Southern Fiordland, the first settler maps left those lands that were not visited—or at least the land which could not be gazed on—as blanks on the map.

These blank spaces sparked the would-be settler's imagination. Their emptiness suggested both opportunity and an imperative to act before the land was all 'taken up'. Figure 1 shows a section of a subsequent map in which an unsurveyed segment is marked "unexplored at present". Such labeling clearly conveys the temporary nature of this condition, while also acting as a prompt for further investigation.

This blankness, it has been argued, also served other deeper purposes. Colonial historian John Noyes writes that the production of empty space was "one of the most important spatial strategies of capitalism in the age of empire" (Noyes 1992, p 7). For a blank area not only recorded a space that was empty of the explorer's knowledge, but also implied that it was empty of all knowledge, and fostered "the notion of a socially empty space" in which indigenous people were absent (Harley 2001, p 60). In the blank interiors was a land "fertile yet vacant, auspicious yet undeveloped" (Clayton 2000, p 389), its qualities in some respects not dissimilar to contemporary visions of wilderness which present these landscapes as unspoilt, remote and primeval. It is for this reason that Harley demands cartographic silence be regarded as an active human performance: "that which is absent from maps is as much a proper field of inquiry as that which is present" (Harley 2001, p 86).

New Zealand's recent topographical maps give no immediate impression that they may contain critical silences. Figure 2 is an extract taken from New Zealand's 1:50,000 scale 260 topographical map series. Through the application of orthophotographic imaging techniques, it allows information of a previously unattainable detail and precision. Clearly identified is the course of rivers, the expanse of forests, and the form of mountainous ridges. Yet instead of the particular quality of these features, what is described is their size, location and boundary. Consider for a moment the left hand edge of Fig. 2, west of the Waitutu River, where the contour lines have been removed. Despite earlier studies in the region identifying thirty-two distinct categories of forest (Nicholls 1977), the most recent topographical maps renders all native forests, across the whole country, as a single tone of color. Given that the one third of Aotearoa New Zealand that is set aside as public conservation lands is principally made up of native forest, the prevalence of Pantone® PMS 367 green is almost all-encompassing. Map upon map in the 1:50,000 scale 260 topographical map series is a monochromatic expanse of this green tone. All that can be noted is where the native forest ends and either individual trees, forest clearings, or scattered scrub begins.

Instead of an ecological interpretation of the forest, with its localized varieties of canopies, species interactions, soil conditions and climatic conditions, what is mapped is the almost binary presence or absence of a generalized attribute. What

Fig. 1 Excerpt from map accompanying Moir's Guide to the Southern Lakes. Note the words in the centre stating 'unexplored at present' (Moir 1925)

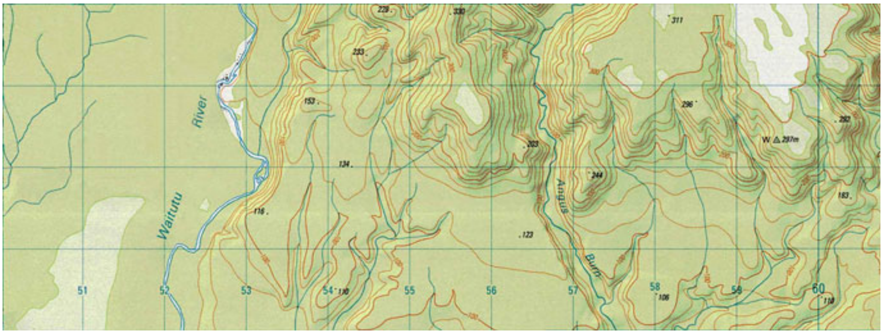

Fig. 2 Extract taken from Infomap 260 Series Map B45, Edition 1 1995

results from these very broad definitions, coupled with the precision of GIS database standards, is a homogenization rather than differentiation of the multiple qualities of the forest, rivers, flats and mountains to be found there. Indeed it can be argued that this singular treatment is not dissimilar to the use of white by the first coastal surveys to describe a similarly barely-discernible blank interior.

Other absences also exist. Histories that relate to past and present activities of people are left unidentified because of the adoption of a cartographic instruction that notes only selected structures. In New Zealand's national parks, only those facilities maintained for visitors are shown. Huts, bridges and tracks maintained for large-budget conservation management programs but not available for public use are excluded; likewise many wharfs, mines, tramlines, and settlements of only archaeological significance remain unidentified. This is at odds with the region's history, in which the sheltered harbours and plentiful fish meant the region was a popular base for pre-European Māori, and also for early European settlers who extensively prospected and mined the region. Today it is recreational fishers, hunters and hikers who routinely set up camps here.

With only a toponymic trace of past engagements, the topographical map silences the manner and frequency of people's activities and relationship with this region. As a result the landscape that is presented in Fig. 2 is one without people. While such regions have been the subject of much human activity—both now and in the past—its cartographic image constructs an appearance of being remote, historically empty and untouched: an approach that reinforces an ideation of wilderness as a landscape separate from culture.

3 Contours and Topographical Truth

The primary information that gives such maps their sense of coherence comes from the contour lines. These describe an imagined line where the land meets the atmosphere at regular increments above sea level. They provide a sustained and detailed description of the changes in height in the terrain. With training, it is possible to read these and compare the folds of the land as it undulates, steepens or flattens.

The first surveys by the settlers produced a boundary of where the coast meets the sea. However, while these surveys described the coast in accurate detail, the maps themselves were not made on the coast but from the distance afforded by a boat sailing beyond landfall. Similarly, the contours in the modern topographical map produce a second coast; but in this modern scenario, it is a surface formed from flying over the land's boundary with the atmosphere. In each is a graphical representation of a container: one linear, the other planar but, significantly, both derived from a position that is external to that being described. Each map brings "into being the terra firma" (Carter 1999, p 145) in which the unknown and blank lands, bounded by a 'finite' coastal envelope, can now be located on a map that pre-exists any knowledge of the land derived by being 'on the ground'. In the first, where the coastlines join, an island is created; while in the latter, where the surfaces meet, a globe is made. This second coastline survey from the air produces an image of a world below, whose laminar surface constructs a site on which activities, artifacts and life can now be located.

Anthropologist Tim Ingold states such representations convey "a theatrical stage from which all the actors have disappeared, the world—as it is represented in the map—appears deserted, devoid of life. No-one is there; nothing is going on" (2000, p 234). Karen Piper considers innovative techniques including 'triangulation', 'aerial photography', and 'space imaging' mean cartography doesn't require being on the ground. Instead, data is removed from its context, verified and calibrated against other data sets (Piper 2002, p 168). Data, rather than 'ground-truth', contains significance, and it is the loss of information gathered from within the land being mapped that constitutes a fundamental silence in modern topographical cartography (Pickles 2004).

In this panoptic framing of landscape, a sense of separation between people and the land is constructed. From such a position comes a dual sense of placelessness.

First, the viewer's stance is excluded from their gaze and hence rendered superfluous. Second, what is viewed can be understood in terms not of localized idiosyncrasies and specific ecologies but of models whose structures are applied to, rather than drawn from, the region. This panoptic perspective institutionalizes in landscape an ambivalence which separates the observer and observed and that is, as Brynes comments, "voyeuristic in that it assume[s] a neutrality on behalf of the viewer and a passivity on behalf of the subject" (2001, p 34).

There are further silences in respect of the many journeys made across the region. In not recording them, the modern topographical map constructs an image of landscape in which journeys appear to be made anew each time through a virgin empty space. In such a map, neither wilderness nor landscape is cumulative. It does not "grow or develop, it is *made* … so the world it describes is not a world in the making but one ready-made for life to occupy" (Ingold 2000, p 234).

The philosopher Michel de Certeau describes the stillness of New York, when viewed late last century from the top of the Twin Towers, as one whose "agitation [was] momentarily arrested by vision" (de Certeau 1984, p 91). De Certeau argues that this gaze from above enables a totalizing conception of the city that, in turn, directs cultural mechanisms to bound, standardize and organize. When one descends to the hustle and bustle, the fabric of urban landscape changes. Here "bodies follow the thicks and thins of an urban 'text', … use the spaces that cannot be seen … [and] compose a manifold story that has neither author or spectator, shaped out of trajectories and alterations" (Ibid).

De Certeau explores the dimension of walking as a form of spatial practice, and a spatial acting out of place. It is with the 'chorus of idle footsteps' that the properties of practice are articulated: "They are myriad, but do not compose a series …. Their intertwined paths give shape to places. They weave places together" (de Certeau 1984, p 93).

An act of walking, like speech, is performative, rhetorical, particular, and potentially limitless in its diversity. Walking expresses place, in that it is a form of 'phatic topoi' and a tactile making of place. Walking is not, however, merely the acting out of an already-known place; place is generated in the process of being known by its manifestations in the human subject's movements. It is through practices like walking the land, rather than flying over it, that a landscape is made. It is in such nuances that these 'forests of gestures' speak, and through which landscape becomes local, particular and participatory.

Ingold considers a path "is to be understood not as an infinite series of discrete points, occupied at successive instants, but as a continuous itinerary of movements" (Ingold 2000, p 226). A path is by its nature dynamic, even transient. It directs the passage of people along its course. Yet it is also the product of that activity being made and remade by its use, by the practice of feet, hooves and wheels being pushed on and into the earth. It follows that a track, while established by earlier journeys, is also the result of subsequent journeys, and that the quality of passage that the path affords occurs both on the ground and through time. It is this quality of conversation between movement and land that prompts Paul Carter to contemplate whether "the manner of going over ground were itself a poetic act, and not merely a prosaic means of getting from one place to another?” (Carter 1996, p 295). Only from above is the path ‘planarised’ into a flowing line. Yet while the dotted line on the topographic map may well position the location of a track, it reveals few of these experiential qualities. How then might movement, rather than its site, be imaged in a map?

4 Temporal Maps

The links between journey and cartographic trace can be clearly seen in many early maps, including the earliest European maps of New Zealand (Maling 1996, p 31). While their purpose is to describe Abel Tasman’s discoveries of 1642, one senses in the irregular dotted line of his route that the coastlines discovered are almost arbitrary adjuncts to his journey. The size of interval between consecutive dates and his zigzagged and occasionally criss-crossing course describes the manner of his travel as much as reveals his route. Maps drawn by indigenous peoples during these periods of encounter with European explorers and settlers elicit similar qualities (see for example Harley 1992; Turnbull and Watson 1993; Aberley 1993 and Edney 1999).

In Fig. 3 this relationship is made clear. This map, redrawn and published in 1894, is a ‘Sketch of the Middle Island of New Zealand’. Rather than portray the spatial arrangement of the island, its configuration describes patterns of movement around the coast. Stretches of the coastline expand or contract according to the degree of activity in an area. Hence areas with little safe harbour are collapsed spatially, while areas with more settlement, resources and activity are rendered more substantially. The island itself is drawn long and very thin. This accentuates the importance of the coastline while features including harbours, reefs, tidal zones, rivers and settlements are recorded for their role as waypoints when following different routes.

When compared with the spatially accurate representation of the same area, the map is unrecognizable (added in black on the lower left of Fig. 3). Yet, this cartogram-like representation offers an innovative method of evocatively describing the ways by which the land was inhabited at the time. Turnbull states such maps operate by “conserving connectivity between the parts but distorting distance, angles and, hence, shape” (1993, p 19). Indeed, this map can be read not as an amalgam of form but as the congealing of many journeys. Dimensioned by the directions and time taken to travel, it images landscape as fundamentally temporal and ongoing.

A further quality is the map’s composite nature. It is not the record of a single journey of survey or the result of steadfast adherence to a set of standards. Instead, the map is the accumulation of multiple descriptions that have been passed on, not through earlier maps, but in iterative conversational exchanges. Such exchanges were necessarily improvised, transient and timely; the resulting cartographic description presents a knowing of the land that is ever-evolving rather than

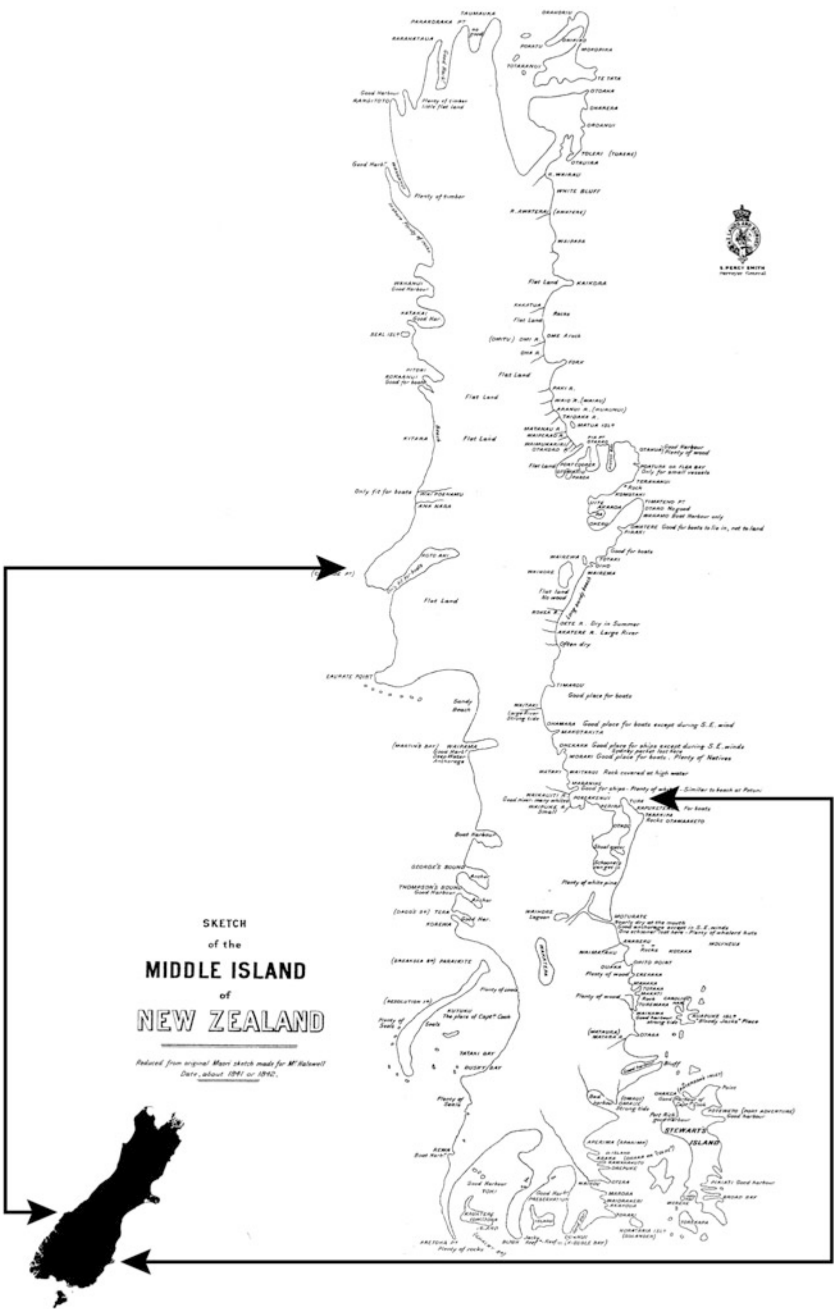

Fig. 3 "Sketch of the Middle Island of New Zealand reduced from an original Maori sketch made for Mr. Halswell' in either 1841 or 1842," published in Appendix to Journals of House of Representatives, 1894. Note the *arrows* in both the spatially accurate map of the same island (on the *bottom left* hand side) correspond with the locations identified by the *larger arrows* on the main map

conclusive. *In it is an image of landscape formed through the movements made within it.*

Following studies by Hägerstrand (1957), who incorporated temporal dimensions to existing spatial descriptions, there have been ongoing attempts to describe contemporary time-spaces (Tobler 2004). Subsequent work has sought to resolve issues of conflicting scales and modeling complexity through the development of sophisticated algorithms (Ahmed and Miller 2007). This work, which attempts to examine what Forer terms 'plastic space' (1978), has been applied to a number of travel, resource and sporting contexts (see for example Taylor et al. 2001; Janelle and Gillespie 2004; Dorling 2006; Moore et al. 2003; Carroll and Moore 2008; L'Hostis 2009).

Time–space cartograms have also been used to re-examine historical and sociological descriptions of place. Perkins and Seeman argue such cartographies can be considered subversive in that "offer alternative representations to established social and political norms. Maps are no longer cast as mirrors of reality, instead they are increasingly conceived as diverse ways of thinking, perceiving and representing space and place which express values, world-views and emotions" (2008). Corner strongly argues for an explicit experimentation of cartography's instrumentality (1999a, b), and this has become a strong thread of inquiry within his field of landscape architecture (see for example Berger 2002; Weller and Barnett 2005; Kamvasinou 2006), and which in turn provides the intellectual context for the following experiments that develop cartograms which foreground itineraries of movement within wilderness landscapes.

As noted, current topographic imagery creates an impression of wilderness regions as being empty of people. Yet many activities continue to take place. In Fig. 4, the route of two different journeys has been overlaid on the same map. The first took place in 1894 and is found in a newspaper account from that time (Watt 1971, pp 113–115). During their progressively difficult journey, the tiring party of three lost first the means to make fire, then their food, their bearings, and finally, with the drowning of one in their party, their clothes. Their account is provided by one member of their party who, suffering severely from hypothermia, was found 'in a state of nature' by a survey party in the area. Another is based on a journey undertaken by the author in 2006, following a similar route but in this instance uneventful due to the affordance of a track, map, long-range weather forecast and modern equipment.

In Fig. 5 the topographical map has been adjusted so that spatial distances are the same for each day's duration. This was constructed using a warp mesh in the drawing software program (Adobe Illustrator CS3) so that sections of the initial topographic map could be readily stretched and compressed.

By applying this method two contrasting images of the same region are produced. For instance, the surrounding region is made large in scale as the progress of the 1894 party slows prior to the party splitting up at the Wairaurahiri River. Immediately after crossing this river easier travel was found along the beach, and as a result the surrounding region contracts.

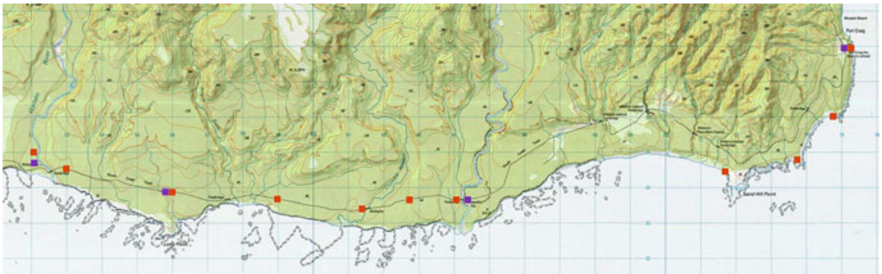

Fig. 4 The 1894 and 2006 journeys overlaid on the same topographic map (spatial scale remains constant). 1894 campsites at beginning of each day marked *red*, 2006 campsites at beginning of each day marked *purple*

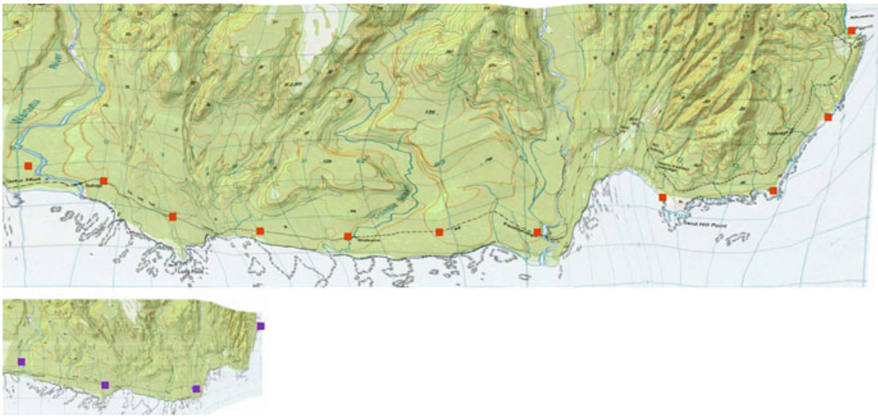

Fig. 5 Two distinct cartographic images of the same locale produced by keeping temporal duration rather than spatial distance constant. *Upper* image is 1894 journey by Evans, Harvey and Kelly (temporal scale constant). *Lower* image is 2006 journey by author (temporal scale is constant)

In this topographical morphing comes a sense of what L'Hostis terms 'crumpled space' (2010), and also the depths and folds of a landscape that Wylie considers comes from "knit[ting] biographies, events, visions, and topographies" (2006, p 533).

Also significant, when both journeys are compared, is the variation in the overall temporal 'distance' of the region. In the more recent journey, a readily followed track has meant the 'temporal scope' of the landscape has been significantly reduced. This is also due to the technological changes in the type of equipment carried which requires less time be spent making camp and echoes Tobler's observation of a world that "shrivel[s] as it shrinks (cited in L'Hostis 2009). In terms of these journeys, the reasons for this lessening relate to the building of a readily followed track which also includes bridges over the very

Fig. 6 1988–89 journey by the author on *upper left* and 2006–07 journey by Lani Evans, Helen Nortje and Bronwen Waters on *upper right* (spatial scale). Note the only significant difference in route is in the lower region of Fiordland. 1988–89 journey on *lower left*; 2006–07 journey on *lower right* (temporal scale). The gap between each dot is one eighth of the total number of days each journey took

difficult to ford Waitutu and Wairaurahirihiri Rivers, and also technological changes in the type of equipment carried which demand less time to be spent making camp, making fires and finding food. From a design perspective such findings suggest the development of pathway and equipment solutions that might encourage ‘slow travel’ akin to recent directions in ‘slow food’ and ‘slow learning’, as these may assist in a re-expansion of the temporal scope of such places.

In Fig. 6 this cartographic method is applied to describing another set of two journeys that followed very similar routes along the length of Aotearoa New Zealand’s South Island. However in the first (undertaken by the author in 1988–1989) the difficult terrain of Fiordland was negotiated on foot, while the latter journey (undertaken by Lani Evans, Helen Nortje and Bronwen Waters in 2006–2007) speedily negotiated this section with the use of kayaks on Lakes Manapouri and Te Anau.

The resulting cartograms again reveal contrasting tempos of topographical experience, with the map of the 1988–1989 journey resembling that of the early Māori Map shown in Fig. 3.

5 Conclusions

When the temporal elements of the 1894 party are mapped, they show a dimension that is as folded, refolded and contorted as the physically undulating terrain through which such travel is undertaken. What is revealed in this temporal cartography is a more qualitative and experientially-layered understanding of landscape. The mapped temporal elements also indicate why different activities in such landscape may prove to be incompatible in combination. They suggest that subsequent journeys, and modes and rates of travel, have the potential to shift the experiential qualities of a landscape in other multiple and diverse directions. This phenomenological description conceptualizes landscape as open-ended and determined by the various modes by which it is and will be practiced. Indeed what these exploratory cartograms note is that relationships with landscapes are profoundly shaped through the tempo and manner in which they are travelled.

This phenomenology is at odds with most management approaches to preserving and fostering wilderness values. As Dassmann noted, these approaches primarily involve setting suitable boundaries, controlling access, and limiting commercial activities in such sites. However, this more temporal cartography suggests that careful consideration is required by both the manager and wilderness user when selecting technologies and facilities that might alter the experiential qualities of wilderness landscapes (Abbott 2011a). Wilderness management approaches should focus less on portraying the pristine and remote qualities of the land and reflect more on the activities undertaken there, and the sense of landscape they foster (Abbott 2011b).

It is important, however, to note that such maps suggest rather than resolve ways in which cartography can be enlisted as a means to generate new understandings. For instance determining how much of the surrounding land to ‘drag’ and ‘compress’ requires further consideration. Both the knowledge spaces and methods that ‘emerge’ from this type of work remain experimental (Dodge et al. 2009). Diagramming movement and mobility involves more parameters than the single metric of journey duration examined in this paper (see for example Halprin 1965; Ingold 2004; Cresswell 2006). Nonetheless such difficulties are opportunities. Pearce, in her work on place and narrative in cartography, notes “I do not wish to overstate the extent to which I was able to bring place into cartographic language through narrative… Yet I hope it is enough to demonstrate the potential that is there, to contribute not only to theoretical research in cartographic language, but to the practice of cartography as well” (2008, p 30).

Turnbull considers maps have been instrumental in changing not just what we think but how we think (2007). He argues the world is increasingly becoming organized around the cartographic trope. Innovative methods of mapping suggest new routes within the worlds of ideas, activity and environment (Turnbull 2007). Crang states "we need a sense of the event and the process of time, rather than letting thinking be dominated by static representations. It may be that we can develop representations that within them encode the forces and movement of time" (2001).

In this vein Doreen Massey asserts that landscape's generativity is heightened at its interface with practices. She calls for a "reimaging of landscape and place" that understands these both "as events, as happenings, as moments that will again be dispersed", and from which "a future is—has to be—negotiated" (Massey 2006, p 46). Similarly, this study suggests that wilderness need not be conceptualized on the basis of a panoptic and undifferentiated cartography, but rather along the always-being-negotiated vectors of journeys undertaken. Indeed, it is in a cartography that accentuates the liminal qualities of meeting and moving, between space and place, practice and agency, and between journey and narrative, that an opportunity to create a new understanding of landscape can be found.

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An Investigation of Maps and Cartographic Artefacts of the Gallipoli Campaign 1915: Military, Commercial and Personal

William Cartwright

Abstract Producing maps and related representations of geography in warfare provides information about the terrain and the positions of troops. They are also used in strategic planning and as operational tools. They are an integral part of a military campaign. Maps are provided by military topographic agencies as the main resource for operations. However, many complementary products have been produced by commercial map publishers and as support for newspaper articles reporting on battles. As well, combatants produce many 'informal' maps and diagrams before, during and after a campaign. These products can be considered to be more personal and to provide a different 'view' of a battle than the official maps provided by conventional publishing methods. An international collaborative research project is studying the geographical information resources and geographical representations used for analysis, planning, conducting and post-event analysis of large-scale operations. The research is focussing on the geographical information resources used in the Gallipoli Campaign in World War 1, so as to appreciate mapping resources used to visualise the political and physical geography that contributed to the selection of the Gallipoli peninsula as a site for a second front during World War 1, the determination of possible landing sites, developing 'at location' troop deployment and movement plans and the eventual evacuation of forces from Gallipoli. This chapter provides an insight into some of the mapping and geographical artefacts that were found during research into the availability of cartographic resources from the Dardenelles campaign of 1915. These can generally be described as official, commercial and personal. It describes samples of the maps and drawings that were found in historical map collections. These products were published by the military, by commercial map producers and

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7_2,

in newspapers. As well, soldiers recorded things like their journey to the Gallipoli campaign, general observations of battle situations and field-drawn base maps and pictorial representations of troop positions and emplacements.

Keywords Cartography · History · Gallipoli · Personal geographies

1 The Gallipoli Campaign

The Gallipoli campaign of 1915–1916 came about because of the deadlock on the Western Front, which turned British eyes towards other possible theatres, plus appeals for assistance from Russia early in January 1915 (Travers 2001a; Velsley 1997). A plan preferred by Winston Churchill, then the First Lord of the Admiralty was to be a naval operation (Heffernan 1996). The original plan was for a combined Anglo-Franco naval fleet, using mainly outdated battleships; to force the Narrows, sail into the Sea of Marmara and then on to Istanbul. Once this was done, three Divisions of the Greek Army would advance on Istanbul.

However, this was later amended to be a naval engagement, after Russian opposition to the use of Greek troops. The revised naval plan was to force the Narrows, penetrate the Sea of Marmara and bombard Istanbul, compelling Turkey to surrender (Sea Power Centre 2005). This was attempted on March 18, 1915, with seventeen allied warships, supported by an assortment of other craft, like mine sweepers (Millett 2000). Mine fields and hidden guns prevented the success of this plan. Six battleships were sunk or severely damaged (Millett 2000). Some military analysts considered that this plan would have never worked. *I am still of the opinion however, that the Royal Navy could not have "rushed" the Narrows and go through in sufficient numbers to tackle the hostile fleet it would have met in the Sea of Marmara* (Aiguillette 1962, p 63). The entrance to the Dardanelles and the Narrows is shown in Fig. 1.

Then Britain prepared another plan, for a larger military operation that would capture the Gallipoli Peninsula, allow the waters to be cleared of mines and opening it for the fleet to sail to Istanbul (Sea Power Centre 2005). To support the military operation, France provided a Division (the first division of the *Corps Expédition d'Orient* made up of North African (Arab and European), Foreign Legion and Sengalese troops (Hughes 2005)), Britain its 29th Division, Australian and New Zealand troops (moved from Egypt) (Travers 2001a) and the Zion Mule Corps. The stage was set for the invasion and subsequent landings on the beaches of the Turkish Gallipoli (Chanakale) Peninsula by British, ANZAC and Indian troops and at Kum Kale (on the Asiatic shore) by French troops (who acted as a diversionary force by capturing a Turkish fort on the Eastern shores of the Dardanelles (Millett 2000)) (who were moved to Cape Helles on 26 April, where they held the eastern part of the Allied line) (Hughes 2005) on April 25, and the Allied attacks of 28 April at Helles, 1915 (Travers 2001b).

Fig. 1 The entrance to the Dardanelles to the straights. *Source* http://www.firstworldwar.com/photos/graphics/gw_dardanellesdardanellesentr_01.jpg (free online download)

The Allied forces fought ashore, but were unable to seize the strategic heights which dominate the lower third of the Peninsula (the Sari Bair Ridge complex, shown on the map in Fig. 2) (Millett 2000). The Australasian landings took place at “Beach Z” and the Anglo French landings were at Cape Hellas, to the south. The map in Fig. 2 shows the allied and Turkish positions on April 27, 1915, 2 days after the landings.

The campaign extended over a 10-month period (Millett 2000), until the final evacuation in January 1916 (Mason 1936; Millett 2000).

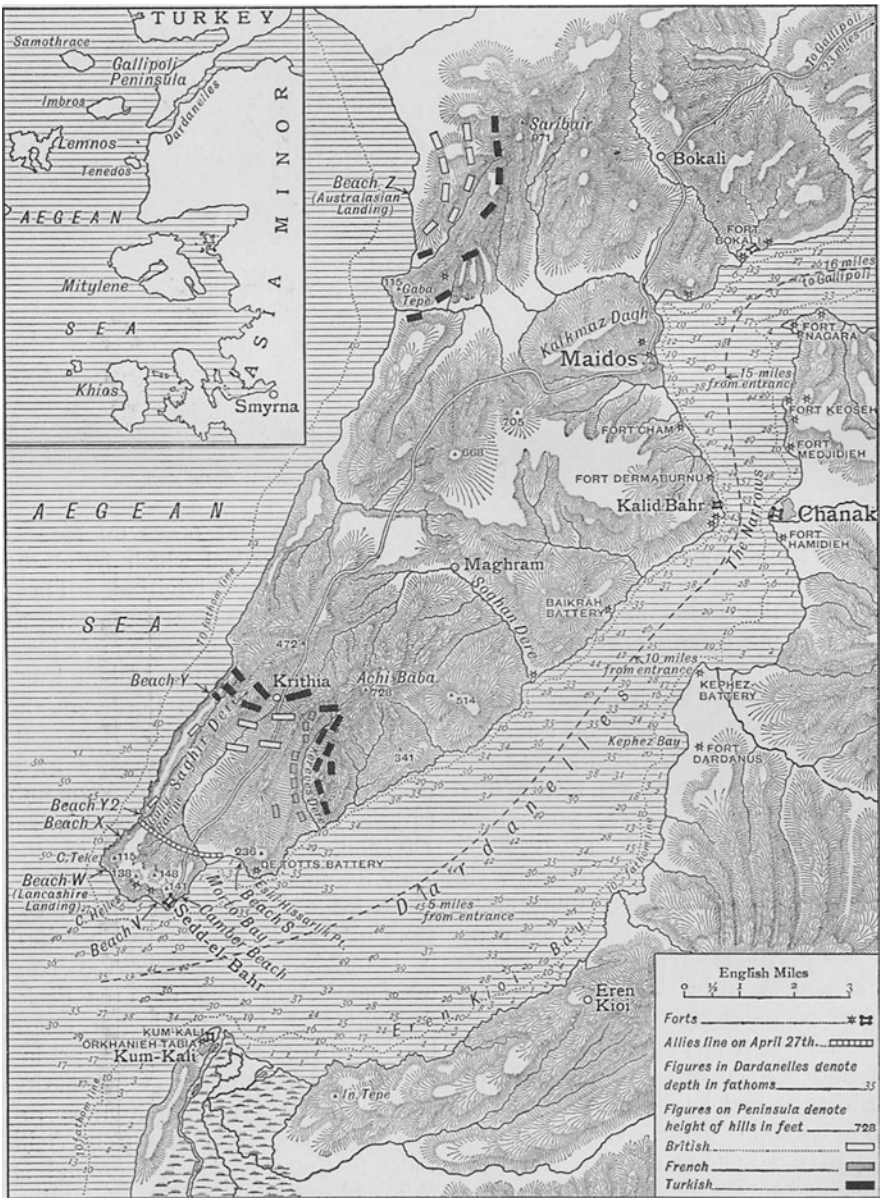

Fig. 2 Map of Allied operations at Gallipoli, 25 April to 30 May 1915. *Source* firstworldwar.com (free online download) http://www.firstworldwar.com/photos/graphics/gw_gallipcampaign_01.jpg

2 Towards Gallipoli 2015 Project Overview

The initial overtures of a research project began in 2009. The project being developed will study the geographical information resources and geographical representations used for analysis, planning, conducting and post-event analysis of large-scale operations. As well, the project will develop and assess methodologies for analysing and visualising the accuracy of historical maps, imagery and geographical artefacts related to strategic planning and decision-making.

It aims to leverage on the combined strengths of an international research team in cartography/geographical visualization, surveying and positioning, photogrammetry, remote sensing, Geographic Information Systems analysis and modelling to undertake research and visualisation tool development that can be used to determine the accuracy (and therefore usefulness) of maps, imagery and geographical artefacts for strategic planning and operational management. Also, the results of the research will have the additional benefit, whereby, due to the study area selected, the results from the studies will be available to the Australian, New Zealand, British, French and Turkish communities to better understand the role that political geography had in sending troops to the Dardenelles in the first place and how the terrain of the Gallipoli Peninsula impacted on the operation of the campaign.

3 Exploring Collections to Determine the Availability of Maps and Geo-artefacts from the Gallipoli Campaign

Exploratory research to identify maps and geographical artefacts was undertaken in mid to late 2009 at the Australian War Memorial, Canberra, the Imperial War Museum, the British Library, the Royal Geographical Society map library and archive, the Army Museum and archive, all in London, the Département des Cartes et Plans, Bibliothèque nationale de France, and the Service Historique de la Defense, Department de l'Armee de Terre Division, France in Paris.

This initial research provided valuable information regarding the maps and drawings available at the beginning of the Gallipoli campaign, maps used to plan and execute military activities and maps and drawings published 'at home' by commercial map publishers and newspapers. This paper provides an overview of this 'first cut' of these investigations into maps and drawings produced for Gallipoli and will illustrate the diversity and richness of the artefacts found. As well, some of the maps sourced during research have been used to illustrate the next section—The Gallipoli Campaign.

4 Maps and Geo-located Artefacts from the Gallipoli Campaign

World War I generated an unprecedented demand for maps at scales from 1:200, for detailed trench maps (Chasseaud 1999; cited in Collier 2002), to 1:1,000,000 and smaller for strategic planning maps (Heffernan 1996; cited in Collier 2002). On the Western Front mapping was provided via proven channels of information provision.

The campaign in the Dardanelles needed accurate maps to depict the terrain where landings would take place. This would be difficult terrain to traverse and maps were needed for assessment of possible landing sites and for later strategic deliberations. Due to the hurried planning of the Gallipoli campaign, very few maps were available for planning and the execution of landings in the Dardanelles.

According to Piersig (1994) the lack of accurate maps caused many problems, including:

- Tactical planning
- Use of naval firepower; and
- Communication between ground units.

Many references were made to this in Moorhead's book, *Gallipoli* (Moorhead 1997).

> In the absence of maps staff officers scoured the shops (of Alexandra and Cairo) for guidebooks" (p 99). … "There was a shortage of almost everything …" (p 99). "… and the maps which were supplied to the officers were incomplete and downright inaccurate" (p 113). "… the Gaba Tepe region, where the ANZAC troops were to land, was unmapped and almost wholly unknown (p 113).

Piersig (1994) also made comments about the problems:

> Intelligence at the tactical level was woefully inadequate—for example, accurate maps were not available" (p 4). Hamilton's plan hinged on effective communication and coordination between his forces ashore and the forces at sea. Poor communications were caused by equipment problems; by doctrinal and language difficulties … and the lack of accurate maps hindered the operation (p 18). "Lacking reliable ship-to-shore communications and accurate maps, the army was unable to utilize the fleet's firepower effectively (p 18).

But, in time accurate maps were obtained (Piersig 1994).

As the campaign continued the number of maps and drawings produced increased, and the range of artefacts widened. These were produced at Gallipoli, to support troop movements, 'at home' by commercial map producers and newspapers for a civilian population eager for news from the front and geographical depictions of the campaign area. Some of these products are outlined in the following sections.

4.1 Maps

Sinclair (1999) studying maps of the Gallipoli campaign stored at the National Library of Australia and the Australian War Memorial archive identified a number of map types:

- Maps produced by Australian Staff Officers;
- Captured German maps;
- Situation maps;
- Field sketches;
- Artillery maps;
- Intelligence maps; and
- Administrative maps.

As well as the military topographic maps identified by Sinclair (1999), additional geospatial artefacts were found during research at the Australian and European archives listed earlier in this paper. These include:

- 3D perspective drawings from British and French map publishers and newspapers;
- General maps for consumption 'at home' that described the conflict in the Dardenelles;
- Field interpretations and sketches reproduced via diazo printing methods;
- Field perspective drawings;
- Newspaper maps;
- Trench maps;
- 'Marked-up' topographic maps;
- Air photographs;
- Glass lantern slides used to brief troop commanders; and
- Annotated maps—hand annotations of commercially-published 'general purpose' maps.

4.1.1 Allied Topographic Maps

The allies needed a topographic map of the Dardenelles. To produce this map they used 1:25,000 Turkish maps, captured in a previous Balkans war, and reduced the information therein to produce their 1:50,000 topographic map—the "Orographical map of the Dardanelles" (Fig. 3).

Further topographic maps were made available, like the Survey of Egypt 1:20,000 series maps (Fig. 4).

The first attempts to use aerial photography to construct original mapping took place during the Gallipoli campaign. However, this was not entirely successful (Dowson 1921; cited in Collier 2002). However, by the end of World War I aerial

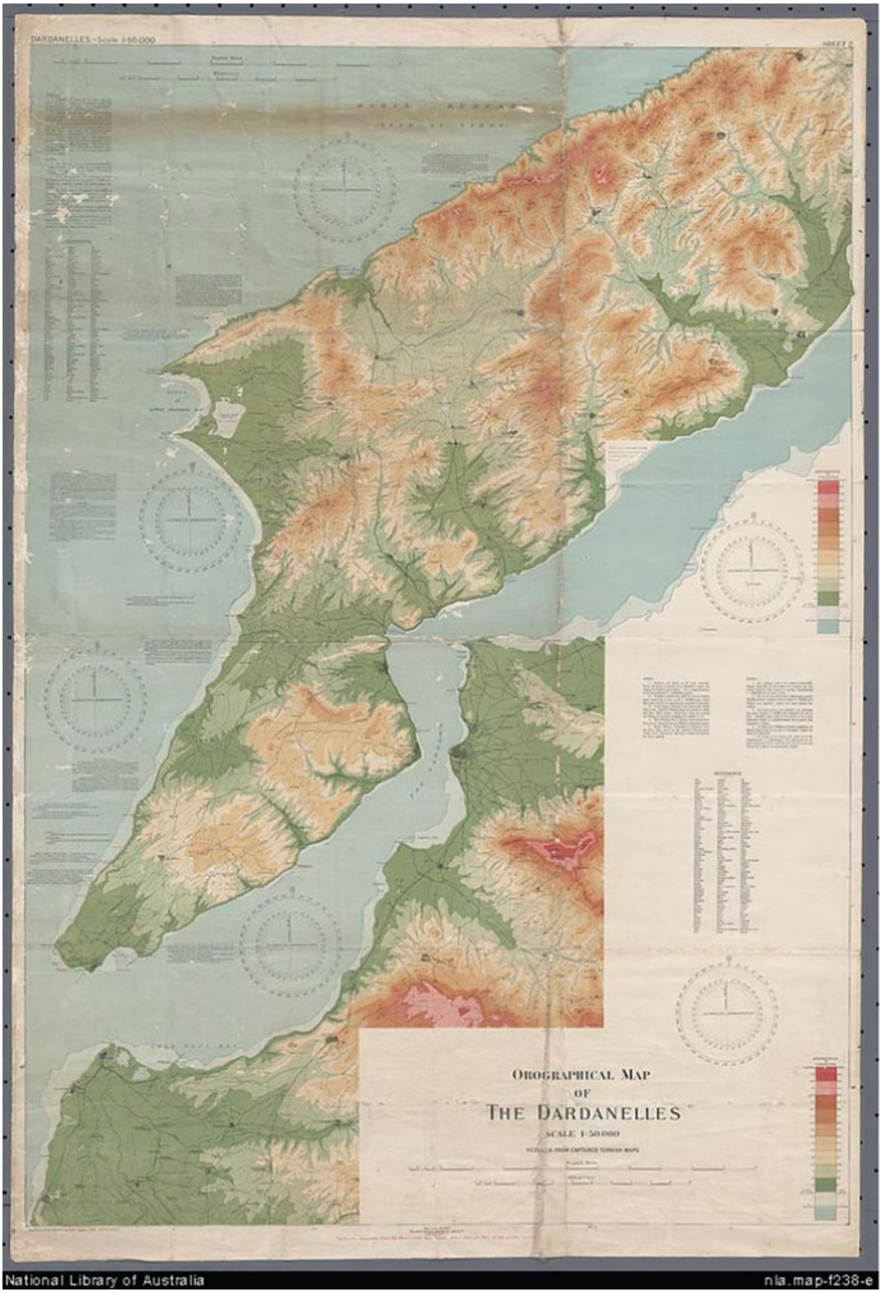

Fig. 3 Orographical map of the Dardanelles 1:50,000. *Source* National Library of Australia (free online download). http://nla.gov.au/nla.map-f238

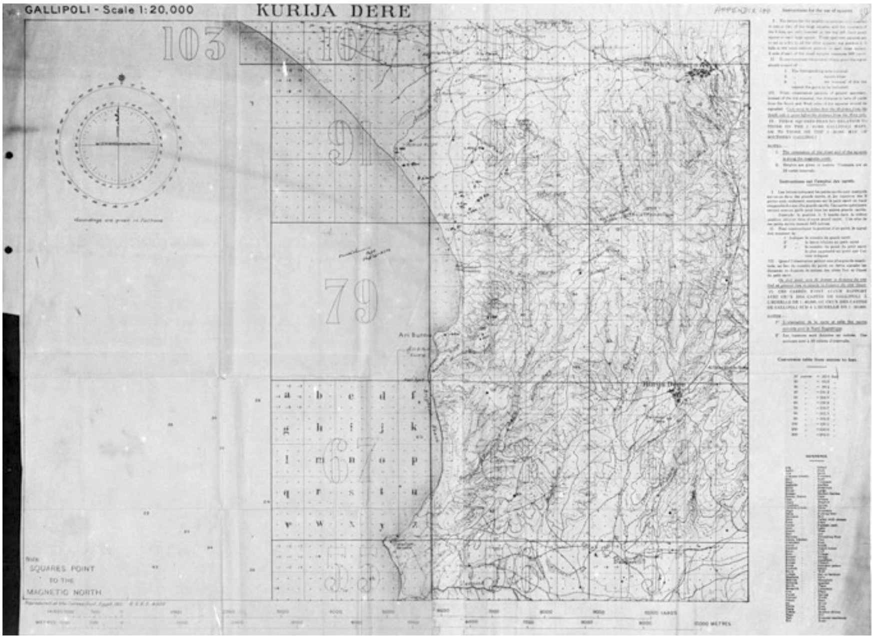

Fig. 4 0939 Map of Gallipoli-Kurija Dere-Koja Dere 1915. Scale 1:20,000. *Source* MAPCO—Map and Plan Collective Online http://archivemaps.com/mapco/kurijadere/kurijadere.htm (free online download)

photography had become the accepted source material for map revision on the Western Front (MacLeod 1919; Jack 1920; Chasseaud 1999; all cited in Collier 2006).

4.1.2 German Military Topographic Maps

The German forces supporting Turkey had access to small-scale Military mapping from Austria Hungary. This was the 3rd Military Mapping Survey of Austria-Hungary, produced in 1910 and covering the Austria-Hungary Empire and areas of military interest to Austria-Hungary. An example map, covering the Dardanelles, is provided in Fig. 5. Whilst small-scale maps were not appropriate for engaging in close military operations, the existence of the Austria-Hungary map series reflects the geographical intelligence had by Turkey and its allies and the lack of such information by the Anglo-French military planners.

Fig. 5 Third military mapping survey Austria-Hungary 1910 sheet 44-40 (Gallipoli). *Source* Department of Cartography, Eötvös University, Budapest, Hungary. http://lazarus.elte.hu/hun/digkonyv/topo/200e/44-40.jpg (free online download)

4.1.3 Sketch Maps

Sinclair (Sinclair 1999) notes that there were few military maps of Gallipoli in existence in 1915. As a result, Australian Staff Officers at Gallipoli had to produce

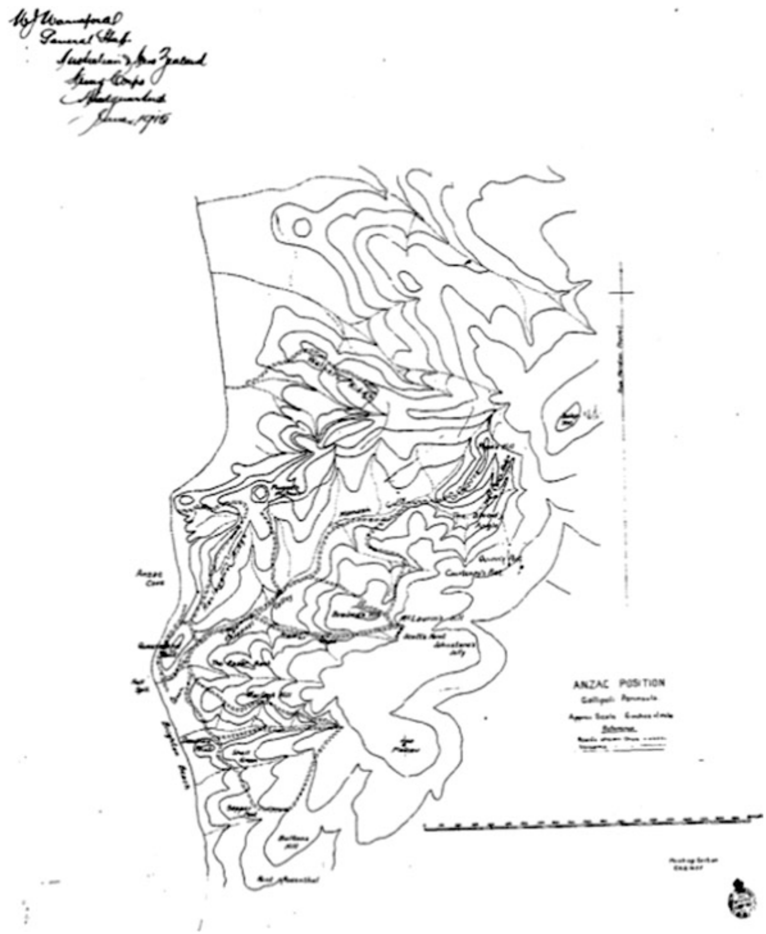

Fig. 6 ANZAC position, Gallipoli, drawn by W. J. Warneford, General Staff, Australian and New Zealand Army Corps, in June 1915. Scale: 6 inches to 1 mile. *Source* Sinclair Sinclair 1999, p 2

their own maps until military surveyors produced suitable maps. Figure 6 shows a typical type map of this type, drafted two months after the landing.

4.1.4 Combined Forces Maps

As well, since these was one of the earliest combined naval/land engagements, a new type of map was required. Whilst the military campaign took centre stage for the remainder of the campaign, at its peak 250 British and French ships were involved (Sea Power Centre 2005). According to the Sea Power Centre (2005) this

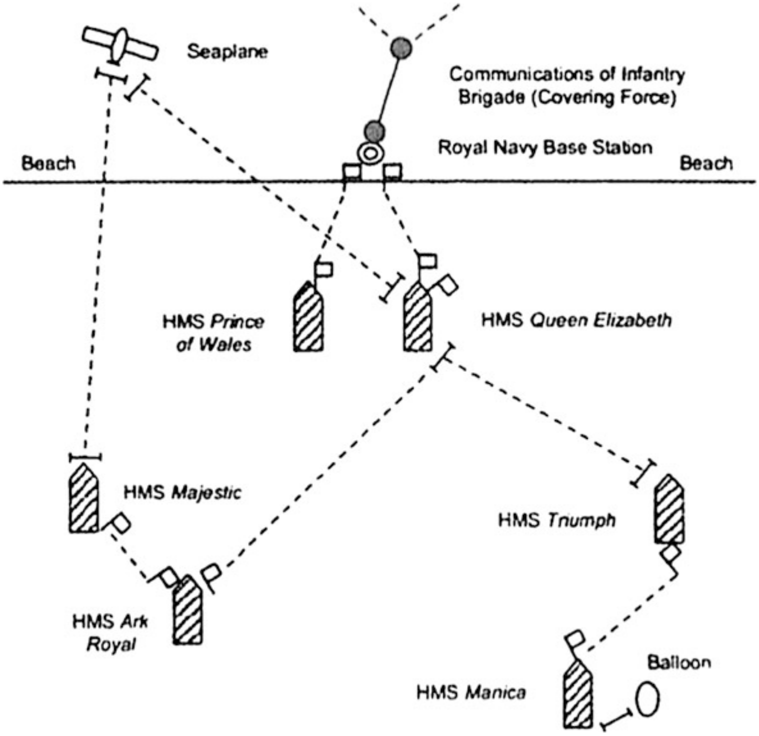

Fig. 7 Fire support plans for initial ANZAC landings at Gaba Tepe, 25 April 1915. *Source* Sea Power Centre 2005, p 56

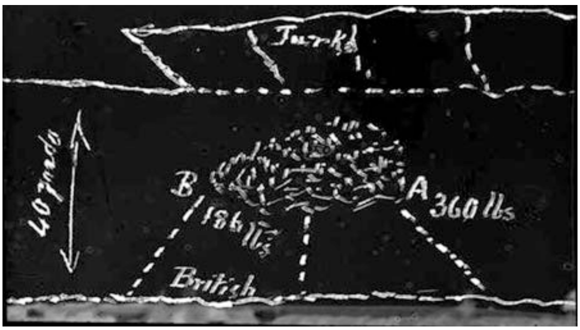

Fig. 8 Diagram of British and Turkish lines of Gallipoli campaign—glass lantern slide transparency (8.5 × 8.5 cm). *Source* State Library of Victoria. http://catalogue.slv.vic.gov.au/vwebv/holdingsInfo?bibId=1787764

needed the coordination of land, sea and air assets, which demanded the generation of new drawings like fire support plans (Fig. 7), which did not exist prior to these combined operations.

Fig. 9 Section of British topographic map with mark-ups—detail. *Source* Service Historique de la Defense, Department de l'Armee de Terre Division, Château de Vincennes, Paris

4.2 Diagrams, Drawings and Marked-up Maps

Diagrams and drawings were produced to provide intelligence and to map military installations, trenches, etc. The examples that follow show a field sketch of trench positions produced as a glass lantern slide transparency (8.5 × 8.5 cm) (Fig. 8), marked-up annotations of key facilities on pre- colour topographic maps (Fig. 9), hand-drawn diagrams showing the positions of troop emplacements (Fig. 10) and spirit 'quick print' perspective views (Fig. 11).

4.3 Mapping the War at Home

The 'man and woman in the street' was interested in gaining an appreciation of the battlefronts in World War I. Commercial map publishers and newspapers satisfied this need for geographically-placed information. English map publisher Stannard and Son produced a map showing a perspective view of European and Asiatic Turkey, Russia, Austria and Persia. It showed …*the whole of the seaboard, railways, rivers and probable points of attack/compiled from the latest official sources by Alfred Concanen.* The map is shown in Fig. 12.

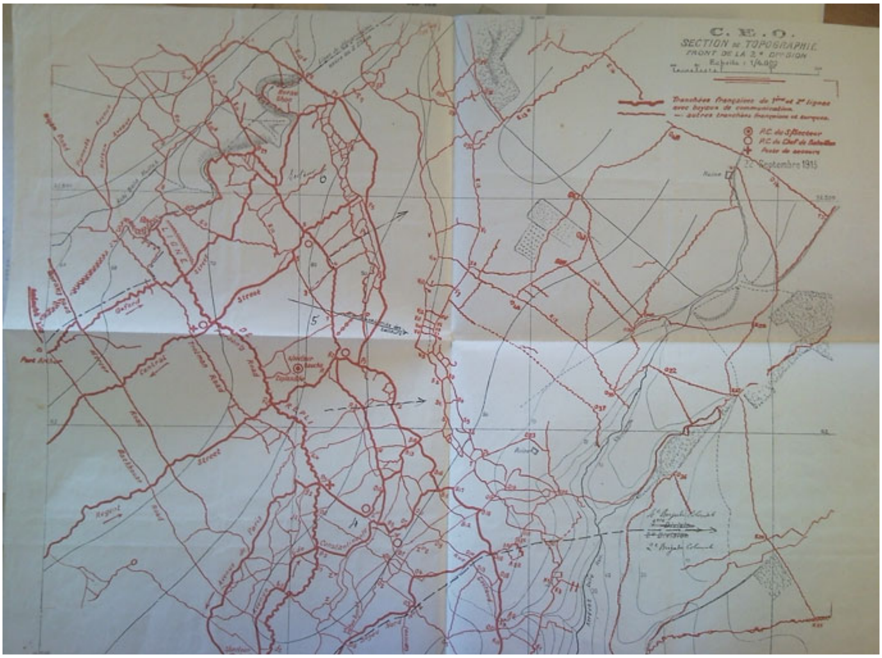

Fig. 10 Spirit print, French troop emplacements 22 September 1915. *Source* Service Historique de la Defense, Department de l'Armee de Terre Division, Château de Vincennes, Paris

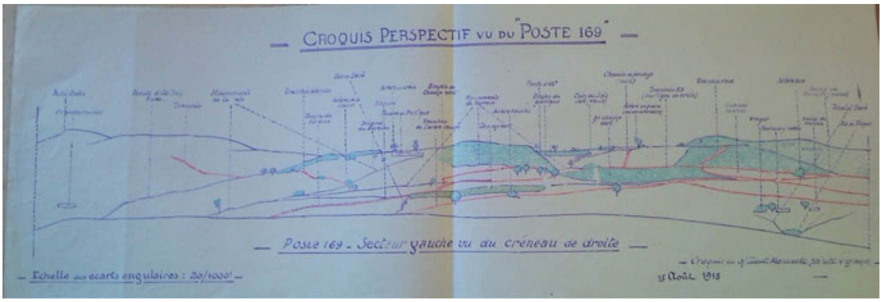

Fig. 11 Spirit print, French Perspective Drawing Post 169, 15 August 1915. *Source* Service Historique de la Defense, Department de l'Armee de Terre Division, Château de Vincennes, Paris

Standford Geographic published a black and white map of Anzac Cove (Fig. 13) and *The Strand Coloured Detail map of the* Dardanelles*, Constantinople, &c., &c.* was published by George Newman Ltd., London.

As well as publishing their own maps, several cartographic companies produced maps for newspapers. London-based cartographic company Geographia produced maps for *The Daily Telegraph*—"The Daily Telegraph War Map No. 12" (Fig. 14).

Fig. 12 Stannard and Son's perspective view of European and Asiatic Turkey, Russia, Austria and Persia. *Source* National Library of Australia. http://nla.gov.au/nla.map-f246

Newspapers also produced more artistic views of the battle, and these were sold as supplements to newspapers. The example shown in Fig. 15 is the *Daily Mail.*

French newspaper, *Le Matin* was also a prolific publisher of maps in its editions. A sample map—"Les Dardenelles"—is shown in Fig. 16.

4.4 Personal Artefacts Representing the 'Geography of Warfare'

During research in 2009 at the Service Historique de la Defense, Department de l'Armee de Terre Division, Château de Vincennes in Paris the author was provided with one particular archive publication: *Inventaire Sommaire des Archives de al Guerre 1914–1918, Ministere d'etat Charge de la Defense Nationale* (Nicot et al. 1972), a general reference to the Service Historique de la Defense, Department de l'Armee de Terre Division collection might provide the key to accessing appropriate documentation stored in the archive. The publication provided a comprehensive catalogue to artefacts in the archive up to 1972. This included maps and other geographically-related documents. The section of interest to research into the French involvement in the Gallipoli campaign was "Grandes Unites Françaises d'Orient and Commandement des Armees Allies en Orient—Corps Expeditionnaire d'Orient

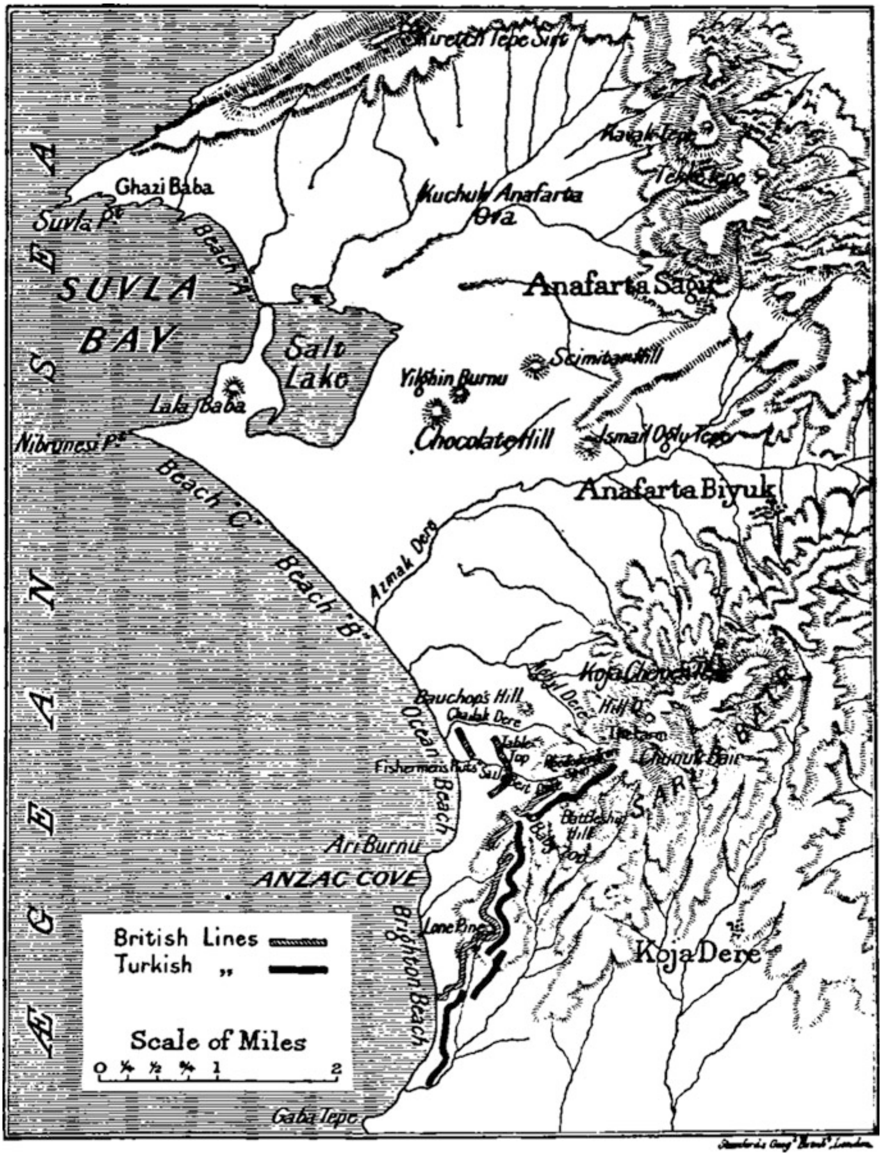

Fig. 13 Standfords geographic—map of Anzac Cove. *Source* Heritage history http://www.heritage-history.com/books/masefield/gallipoli/zpage136.gif (free online download)

(C.E.O.) (22 February to 4 October 1915) puis Corps Expeditionnaire des Dardanelles (C.E.D) (4 October 1915 to 6 January 1916)."

Recorded in the Inventaire Sommaire des Archives de la Guerre 1914–1918 was the contents of all of the archive boxes stored at the Service Historique de la Defense, Department de l'Armee de Terre Division at Château de Vincennes.

Fig. 14 *The daily telegraph* war map no. 12, 1915? *Source* National Library of Australia. http://nla.gov.au/nla.map-gmod1

I was provided with five dust-covered boxes from the archive that held maps and other documents. One particular box—Box 20N33—contained official military maps, sketches and reports. But this box also contained one additional document—a commercially-produced *Colour map of Europe and Turkey,* folded and reinforced with linen at the folds.

Fig. 15 "Scene of the landing operations at the Dardanelles", *Daily Mail* map of the Dardanelles. *Source* MAPCO—Map and Plan Collective Online (free online download) http://archivemaps.com/mapco/gallipmail/cover.htm

This map had been annotated with 'travel line' from Paris to Marseilles to the Dardanelles by its possible owner, H. Barrot. (This name was noted on the verso). The map had a pencil line drawn over the shipping lines that were included in the map. It traced his journey from Paris to the Dardenelles. It was a record of Barrot's involvement in the preliminary movement of troops before the landings at Gallipoli. The map is shown in Fig. 17. Detail from this map is shown in Fig. 18.

The discovery of this particular map led to a related field of research—"Personal Geographies of Warfare"—which will examine how individuals geographically recorded their wartime experiences using everyday artefacts.

5 Further Research: Personal Geographies of Warfare

The unfortunate consequence of any military engagement is the loss of life. Those individuals whose sacrifice is generally lost in the accounting and reporting generalization of warfare 'disappear' without their contribution to a battle—and the individual's departure from family and loved ones, related training, preparation,

Fig. 16 Map ‘Les Dardanelles’ from *Le Matin* depicting aspects of the failed naval action trying to force a passage through ‘The Narrows’. *Source* Département des Cartes et Plans, Bibliothèque nationale de France, Paris

transportation, preparation for battle and aftermath. Their stories are not recorded on maps produced to represent a campaign—these maps are impersonal.

The ‘geography’ of military campaigns can be represented by the assembly of many personal geographies of that campaign—the assembled experiences of military and civilian populations that were directly involved in action or personally effected by the outcome—either directly or indirectly. But how best to ‘map’ these personal geographies of warfare?

The geography portrayed in most maps of military campaigns does not provide any information about the personal geographies of a campaign or battle. These

Fig. 17 Annotated map of Europe and Asia Minor.1. *Source* Service Historique de la Defense, Department de l'Armee de Terre Division, Château de Vincennes, Paris. *Photograph* William Cartwright

elements are missing. Personalisation is impossible when immediate geographical information is required to be represented prior to a battle or afterwards, as a record of the actual clash and its aftermath.

Personal geographies can be used to give an insight into the human stories of traveling to battle, the preliminary movements, the battle itself and combatant's reflections on what has happened. Mapping personal geographies can be done by assembling a montage of geographically-related artefacts, notes, annotations and maps that individuals have used to record their thoughts, feelings and reflections. Further, related research on this topic is being undertaken by the author.

6 Conclusion

The investigation of geographical artefacts and maps related to the Gallipoli campaign in World War I found rich resources in online archives, in map collections and in military archives. The products range from professionally-produced topographic maps to hand-drawn maps from field observations. The military, commercial map publishers and newspapers produced documents. Occasionally individuals produced maps themselves, where no 'official' map was available.

Fig. 18 End of Barrot's voyage from Paris to Marseilles to Asia Minor—at a point (marked '*E*', by hand), just to the east of Lemnos. *Source* Service Historique de la Defense, Department de l'Armee de Terre Division, Château de Vincennes, Paris. Photograph: William Cartwright

As well as illustrating the wide range of maps and drawings generated during the campaign, what was most evident was the different printing methods employed—lithographic to spirit printing. Here, it is assumed that the less time-consuming replication methods were employed when time was of the essence and 'rapid response' mapping was needed.

As noted in the introduction, this paper reports on the findings from the first stage of the project Towards Gallipoli 2015. It provides an overview of the maps and geo-located artefacts that can be accessed for further investigation and analysis.

Acknowledgments Research was funded by a grant from the School of Mathematical and Geospatial Sciences, RMIT. Research at archives in London and Paris was supported by Research Sabbatical leave from RMIT. Thank you to research assistants who sourced references and online map archives. My thanks to staff at the archives and map repositories that were visited during this research. Without this invaluable assistance this stage of the research could not have been completed. Thank you to the two anonymous reviewers whose comments provided valuable input for improving the manuscript.

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True-3D in Cartography—Current Hard- and Softcopy Developments

Manfred F. Buchroithner and Claudia Knust

Abstract According to statistically indicative studies carried out by the first author in the 70s and 80s, more than 60 % of all users of topographic or hiking maps are not able to derive relief information spontaneously. Stereoscopic vision seems essential, for not only an optimised perception of relief but also for other spatial information. If the geodata visualisation is realised in a way that allows a three-dimensional observation beyond perspective viewing, we talk about "true-3D". This term applies to both flat map-like displays and solid landscape embodiments. Both types belong to what is generally called the hardcopy branch of these products. For some years, lenticular-foil maps have been the most prominent examples of hardcopy 3D maps, However, softcopy displays have recently been undergoing a very dynamic development triggered by the TV and game industry. In North America, Europe and Japan various companies and research centres are competing in the realisation of large-format static and small-format portable computer-displays. They have the big advantage that, first, dynamic datasets (e.g. films) can also be displayed and, second, wireless Internet connections enable real-time access to databases. Very recently, physical landscape models of high photorealistic quality are also gaining increasing importance.

Keywords Cartography · Three-dimensionality · True-3D · Autostereoscopy · Geodisplays · Solid landscape embodiments

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7_3,

1 Introduction

The need for “true 3D” is backed up by previous studies carried out by the first author in the 1970 and 1980s, which show that more than 60 % of all users of topographic or hiking maps are not able to derive relief information spontaneously. The participants were members of alpine climbing courses with academic educations.

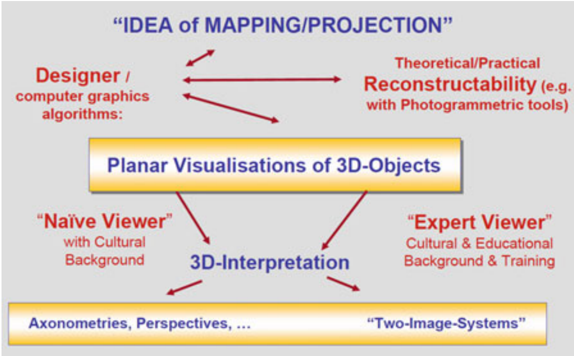
“True” 3D? Is there also an “untrue” or “false” or “pseudo” 3D? Yes, there is. Pseudo-3D depictions are visualised perspective-monoscopically on planar media, e.g. on a monitor screen. They are not autostereoscopic. True-3D visualisations can be parallax-3D or full-3D. While parallax-3D geovisualisations only use selective bi- and monocular depth cues, full-3D geovisualisations use all bi- and monocular depth cues (Buchroithner 2001). Thus, the authors define any scene which can be stereoscopically seen, but not only because of the perspective, as “true-3D”. In this sense, physical landscape embodiments can also be considered “true-3D”. The (only) difference is that in the latter instance we apply natural stereovision (solid models), in the other case we use a special way of artificial stereovision. Hence, one might also talk about displays with touchable reliefs and planar (“flat”) true-3D displays. The essential thing is the provision of two distinct stereomates to the viewer’s eyes, whether created “artificially” or not.

Stereoscopic displays can be analogue, these are the so-called hardcopy displays or they can be digital, the softcopy displays. Furthermore, they can be divided into non-autostereoscopic and autostereoscopic displays. Non-autostereoscopic displays require glasses or similar viewing aids to provide a spatial impression, but autostereoscopic displays allow a spontaneous spatial perception without any additional viewing means (see Knust and Buchroithner 2012). There exist single-user displays for only one user at a time and multi-user displays. With the latter multiple users can perceive a spatial impression simultaneously. The users of stereoscopic displays can be head-tracked, meaning if the viewer moves in front of the display the stereomates are tracked to keep the spatial impression. Furthermore, the ability to visualise 3D images can be switchable or not. Switchable displays can also be used on a normal 2D screen.

By means of an overview of the historical development and technical status Buchroithner (2007) tried to explain the importance of three-dimensionality in cartography. Both physical landscape models as well as pseudo-3D and true-3D autostereoscopic visualisations on planar displays were investigated. Besides reasons for the advantages and necessities for true-3D representations, the author also gave a short preview on the interactive and dynamic possibilities of future 3D visualisation.

In a recent publication Buchroithner and Habermann 2010 introduced the term relief aesthetics, a term which still needs to be defined and investigated in more detail and which has a close connection with relief intensity (German: Reliefenergie, see Bill and Zehner 2001), a parameter which might also allow the quantification of the aesthetic value of the relief of a landscape. In conjunction

Fig. 1 Visualisation and interpretation of 3D scenes based on planar visualisations of 3D objects (from Weiss and Buchroithner 2012)



with cartographic depictions this is an issue which still awaits more in-depth research, aimed at answering the question: to what degree the relief intensity of a landscape determines the possible aesthetics of a map, and—vice versa—how the method of relief representation in a map may bias the aesthetic appearance of the latter. We believe that the level of aesthetics of a cartographic product also facilitates the user's generation of her/his mental ("cognitive") map.

Regardless of these aspects of relief aesthetics, the question of how to optimally convey the cartographer's "3D message" remains. Figure 1 describes the process from an idea of the "map maker" to its spatial interpretation by the viewer via a planar representation. In this regard the designer has to consider that an expert viewer "reads" and interprets a 3D scene in a different way than a "naïve", inexperienced viewer does. The planar visualisation of physical three-dimensional objects is the link between the concepts, algorithms and in general the reconstructability by means of computer graphics and/or photogrammetric tools on one side and the mental reconstruction and, further, interpretation on the other side. It is a model for the 3D object.

A difficult situation arises where, besides the relations between positions of points and objects in Euclidean space, there are hidden and obvious assumptions packed into a visualisation. The viewer interprets the visualisation after having put it into a certain context, be it the explicit verbal description of what should be seen in the picture, or the viewer's own knowledge or imagination. Of course, these facts also rule visualisations in Cartography (Weiss and Buchroithner 2012, Fig. 2).

In summary, the theory behind the aforementioned aspects of stereovision of geo-scenes is rather complicated (see Fig. 2) and by no means resolved, both in terms of methodological structuring and terminology. To this end, the present paper only represents the interim state of developments which are in a state of flux. The reader is kindly referred to the paper by Weiss and Buchroithner 2012. Furthermore, a more comprehensive treatment of the theory and technology regarding the field of "true 3D cartography" by the authors of this article (Knust and Buchroithner 2012) as well as an overview of the role of true-3D visualisation in cartography (Buchroithner and Knust 2012) is in preparation.

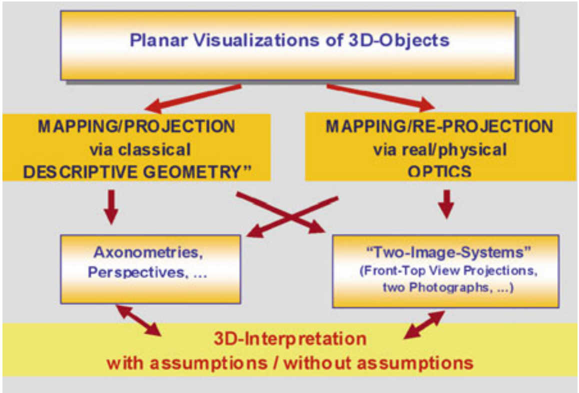


Fig. 2 Perception of 3D objects from planar "3D displays" (from Weiss and Buchroithner 2012)

2 Planar Autostereoscopic Displays

2.1 Lenticular Foil Technique

As the term says, planar autostereoscopic displays are flat displays—either analogue, i.e. hardcopies, or digital screens, i.e. softcopies. One of the well known planar autostereoscopic visualisation techniques is the *lenticular foil technique*. This method has been successfully applied to both softcopy and hardcopy displays. For several years the Dresden company mbm systems Inc., a spin-off of the Institute for Cartography of the TU Dresden, has successfully been producing lenticular foil hardcopy displays for operational use in teaching, tourism and edutainment, their major field of production being geodata visualisation.

The lenticular foil technology is an image display method used for the generation of multi-image effects like 3D visualisations or animations. In order to allow the spontaneous perception of these effects without any additional viewing aids (glasses or other means for image separation), lenticular foil displays consist of two components:

1. the lenticular image, and
2. the lenticular foil.

The transparent lenticular foil serves to separate the individual images that are seen by the left and right eyes. For this purpose, on its upper side there are a series of parallel semi-cylindrical micro-lenses (Latin "lenticulae"). The lower side is smooth and flat and coincides with the plane of the lenticular image. The latter one consists of multiple synthetic views (or in the case of "flat"—i.e. "no relief" depictions, e.g. for flipping: partial images) which are cut into small strips and interlaced in an alternating sequence. Consequently, under each of the semi-cylindrical lenses one strip of each partial image is situated (Fig. 3).

The image separation through the lenticular foil occurs according to its optical properties. The semi-cylindrical lenses focus the parallel incident sight rays onto

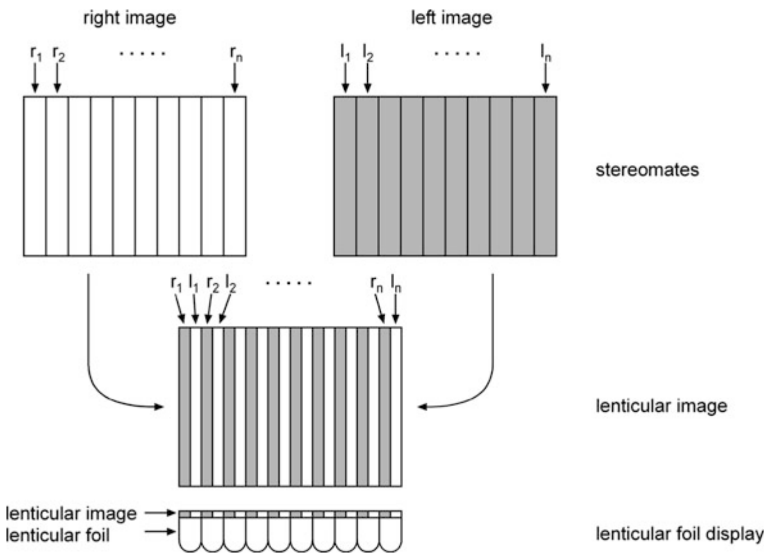


Fig. 3 Principle of the lenticular foil technique (from Gruendemann 2004a, p 15)

particular strips of the lenticular image. If the viewer changes his/her perspective by turning or tilting the lenticular foil display perpendicular to the lenses, the vision rays are focused onto other strips of the display. This enables the perception of the spatially separated image information out of one lenticular image, because from a particular viewing angle the viewer only sees one strip per semi-cylindrical micro-lens. More comprehensive information about the lenticular foil technology can be found in Okoshi (1976), Gruendemann (2004a, b), Buchroithner et al. (2004a, 2005a, b, c), as well as Gruendemann et al. (2006).

A significant strong point of the lenticular foil technology is its versatility concerning displayable effects. They can be divided into two categories: 2D- and 3D effects. Each of these major categories contains special effects (true-3D, flip, morphing, zoom, and animation). Besides 2D- or 3D effects lenticular foil displays also can visualise a combination of 2D- and true-3D effects.

Displays with 2D effect typically have micro-lenses running in a horizontal direction. Thereby a supply of the same image information to both of the viewer's eyes is achieved. Horizontal tilting of the lenticular foil display then changes the image content. For lenticular foil displays with true-3D effect, however, the semicylindrical lenses must be aligned vertically. This configuration results in the visual perception of different images of the same object(s) by the two eyes. In either case, the displays can be generated as reflectance displays (incident light/ "looking at") or transmission displays (transmitting light/"looking through").

Due to the various 2D- and 3D effects the lenticular foil technique offers versatile possibilities for cartographic visualisation. The 3D-effect is only used to visualise relief. For example, the lettering can also be displayed virtually hovering above the terrain. The flip effect can be used to compare different situations like low and high tide, to visualise short animations or to show different languages. If the user tilts the lenticular map or moves his/her head sideways, the perception of different images from the single display is obtained.

Presently, however, flexible hardcopy displays on the basis of lenticular foils are still limited in size, since the foils cannot be folded. (A rare attempt in the non-civilian domain with lenticular rubber-sheets did evidently not yield the expected results and never went into operational production and use.) Once this "problem" is solved, lenticular foil maps could be transported like normal paper maps in a backpack. Another solution would be to mount the individual foldable clips/"tiles" on linen—this had been the case with paper outdoor maps until the 1960s.

Today, the interlacing method is standard for the lenticular foil technique. A recent development at the Berlin University of Technology, however, aims at minimising the disadvantages of the "traditional" interlacing approach such as the reduction of the geometric ("visible") resolution of an image and the notable restrictions of viewing zone and viewing distance. Up to 50 % of the viewing zone of a stereogram might, for example, cause a pseudoscopic 3D-perception, i.e. a relief inversion (Stendel 2012).

With the recently developed Virtual Lenticular Rendering (VLR) method the viewing range becomes wider, the edge depiction is improved etc. According to Stendel (2012) "the VLR method is an integral image technique as well but of comparatively low complexity. Instead of a high number of different lenticular plates the optical system of this technique is reduced to a single coding lenticular plate…" In contrast to the method of Davies and McCormick (Davies et al. 1988) a regular scene camera is used as a recording agent in the 3D model. Therefore, even perspective images may be realised with a high accuracy of position. Instead of half-images this method creates for each lenticular lens its own basic "images". There are, however, further investigations necessary to optimise surface structures and lens sizes for this new method (Stendel 2012). Figures 4 and 5 show the coding process of the VLR method and the coded "parallax panoramagram" of a cube.

2.2 Barrier Stripes Technique

Another technique which is frequently applied to planar autostereoscopic displays is the *barrier stripes technique*. The stereoscopic images the viewer perceives consist of at least two stereomates which are interlaced strip by strip. In front of the display screen, a strip mask, called a parallax barrier, is mounted as a visual barrier. The strip mask consists of transparent and opaque stripes. This will, depending on the viewing angle, hide stripes of the stereoscopic image and leave others visible for the viewer's eyes. Thus, each eye only sees information allotted to it (Okoshi 1976). Figure 6 illustrates the principle of barrier stripes technique.

Within the scope of a true-3D project for the famous Globe Collection in the Mathematical-Physical Salon at the Royal Zwinger Palace in Dresden, Germany,

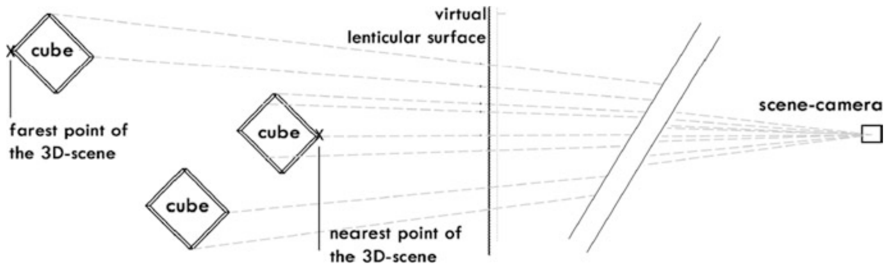


Fig. 4 Coding process by means of the VLR method using the example of a cube (from Stendel 2012)

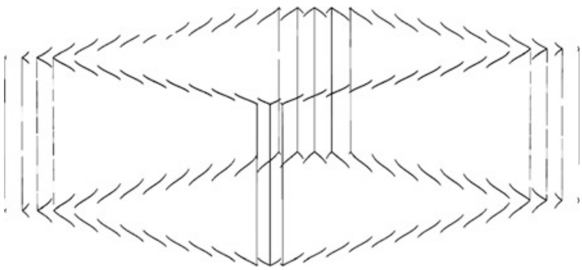


Fig. 5 "Parallax panoramagram" of a cube (generated as indicated in Fig. 4) (from Stendel 2009)

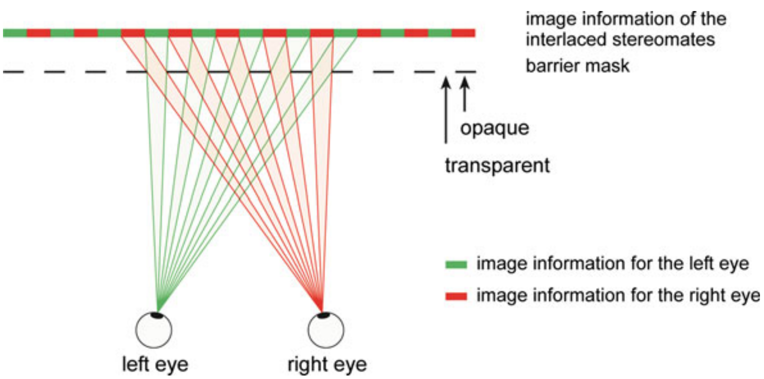


Fig. 6 Principle of the barrier stripes technique (based upon Knust 2007, p 35)

the historical globe of Willem Janszoon Blaeu (Amsterdam, about 1645, 68 cm in diameter), was visualised on a large-format autostereoscopic display (Knust 2007, 2008; Knust et al. 2012). Here a film animation about the historical terrestrial globe was generated, taking the round-the-world expeditions of the Portuguese Fernando Magellan (1519–1522) and of the Dutch Jakob Le Maire and Willem Cornelisz Schouten (1615–1617) as an example to point out various details of the globe in true-3D.

Table 1 Examples of current autostereoscopic digital displays (based on various websites of the display manufacturers; see also Opel and Bergmann 2009)

Lenticular (head-tracked):	SeeFront, SeeReal, Free2C
Lenticular (fix):	Alioscopy, xyZ, Spatial View 3DeeSlide and 3DeeScreen
Barrier stripes (switchable):	Miracube, DTI Virtual Window, Dimen C190S/C190X, Free2C_digital, Hitachi Wooo H001, Sharp
Barrier stripes (not switchable):	Tridelity, 3DInternational

2.3 Digital Autostereoscopic Displays

There exists a series of autostereoscopic displays on the market. Some of the major products are listed below (June 2010, Table 1). The 3DeeSlide of Spatial View Inc. in Dresden consists of a removable lens holder and a special lenticular lens foil to be mounted on an iPhone or iPod and has been available since autumn 2010 (www.SpatialView).

3 Solid Landscape Embodiments

Landscape models allow "simultaneous landscape viewing" of both the whole embodiment and of small details in a totally interactive way. Also for laymen landscape models are easily legible. Instead of a flat map where one has to interpret contour lines and relief shading to perceive the third dimension, a landscape model allows spontaneous derivation of topographic aspects like terrain steepness. It is easier to compare height values in distant parts of a physical landscape model than in distant parts of a flat map (Rase 2012).

Solid landscape embodiments are multi-user models. They give the user a true-3D impression of the depicted situation. Hence, they are an alternative to printed paper maps and digital maps, but they will never replace them.

The largest machine-produced physical terrain model ever made (in this case from a digital data source) is a model of entire province of British Columbia, displaying the landscape at a scale of approximately 1:99,000 (12.2 × 22.6 m). Since June 2006 it is on display as the centrepiece of the "BC Experience" Geographic Discovery Center in the historic Crystal Garden in Victoria, British Columbia (www.STM_USA).

In summer 2006 an incidental discovery of a huge landscape model in China was made in Google Earth. This model at a scale of 1:500 and a size of approximately 900 m by 700 m is situated near Huangyangtan, about 35 kms away from the town of Yinchuan, capital of the Autonomous Region of Ningxia in the northern part of China. The model with man-made snow peaks and glacial lakes represents a region about 2400 km west Huangyangtan, in the border area of Aksai Chin, neighbouring the disputed frontier to Pakistan and India. It is supposed to

Fig. 7 Landscape model near Huangyangtan, China (screenshot Google Earth; © 2012 Google, Image © 2012 GeoEye, © 2012 Mapabc.com)

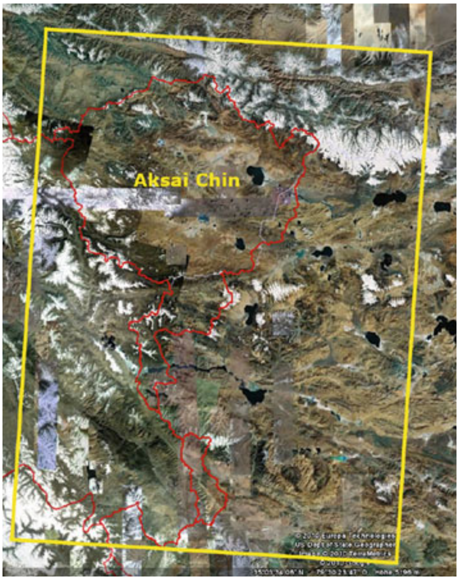


Fig. 8 Corresponding region of the landscape model near Huangyangtan, around Aksai Chin (screenshot Google Earth; © 2012 Google, © 2012 Europa Technologies US Dept. of State Geographer, Image © 2012 Terra Metrics)

have been generated for military use (Hutcheon 2006; Indian Express 2006). Figure 7 shows the landscape model on a Google Earth satellite image, Fig. 8 displays the corresponding region around Aksai Chin.

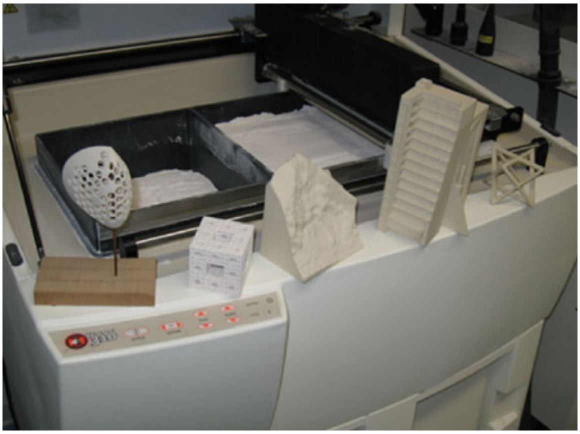


Fig. 9 Rapid Prototyping at the Institute of Geometry, Dresden University of Technology, Germany (from Weiss and Buchroithner 2012). Further explanations: see text below

3.1 Rapid Prototyping

Today it is possible to generate physical landscape models within a short time. Rapid prototyping comprises different methods, e.g. stereolithography, 3D-printing or milling. Rase (2009, 2012) distinguishes between four main groups of rapid prototyping techniques: *removal or milling* (Michelangelo Method), *aggregation* (Rodin Method), *transformation* (Chillida Method), and *laser subsurface engraving or laser etching* (Dürer Method). The removal method implies the removal of material from a block of wood or plastic to form the desired model. *Computer-controlled milling* is such a removal method. In contrast to the removal method the aggregation method works vice versa: loose material like a jelly or a powder is merged layer by layer to form a final model, e.g. by heat or glue. For example *stereolithography* and *3D-printing* use this principle to generate relief models (see Fig. 9). Since the first 3D printer by ZCorporation (www.ZCorp) has been introduced in 2001, a colouring of the model during the printing process is now possible. This has replaced a subsequent manual colouring stage. For the production of 3D models the aggregation method might have the highest potential (see also Rase 2009, 2012). Some USA companies like Cubic Technologies and Stratasys, Inc. (www.CubicTechnologies, www.Stratasys) use different types of "3D-printing" such as laminated object modeling or fused deposition modeling (FDM®). Further, 3D Systems, Inc. runs a production line of 3D-printing, stereolithography (SLA®) and selective laser sintering (SLS®) (www.3DSystems). It is hard to make statements to what extent these technologies have already been applied for the production of physical landscape models.

The central specimen created with a 3D-printer in Fig. 9 represents the famous Eiger Northface in Switzerland based on data generated by the Institute for Cartography at the Dresden University of Technology, Germany.

The transformation method forms material by pressure and heat. With the help of a mould a planar *thermoplastic foil* is transformed into a foil which corresponds to

Fig. 10 Laser subsurface engraving of the high-mountain terrain around the Großglockner (3798 m)

the 3D relief model. Before the transformation process the respective geo-information is printed onto a foil considering the geometry parameters after transformation. This method allows to produce big runs of non-planar relief depictions, and thus the individual copies become comparatively inexpensive. (Rase 2009, 2012).

Laser subsurface engravings or laser etchings, also colloquially called *3D drawings*, are generated with lasers, which engrave opaque points inside a block of glass, e. g. engrave a globe-model (Rase 2009, 2012). Figure 10 shows a small specimen displaying the high-mountain terrain around Austria's highest peak, Großglockner (3798 m) and the largest glacier of the Eastern Alps, the Pasterze.

An attractive possibility for customers who want to create their own relief models is the offer from LandPrint.com™. With the LandPrint DesignerTM software the user can interactively select an area in 3D and even can load own GPS-tracks to integrate them into the relief model. LandPrint.com™ announces that it will be possible to apply own maps or images to a generated 3D model soon. The models are colour-printed with the 3D printers of ZCorporation (www.Landprint, www.ZCorp_press).

Rase (2009) emphasizes the potential of solid 3D models, either topographic (georelief) or thematic (Fig. 11), as demonstration or discussion tools for decision makers or simply as eye-catchers. But since 3D models are haptic, rapid prototyping is not only useful to produce models to look at, but also to generate tactile maps for the blind or visually impaired (see Sect. 6 "Tactile Maps").

3.2 Handmade Landscape Models

Around the 16th century the first landscape models were generated by hand. In the 19th century relief modelling reached its heyday in Switzerland because of the technical developments in both cartography and geodesy (Buchroithner 2007; www.Bergmodelle; www.TerrainModels).

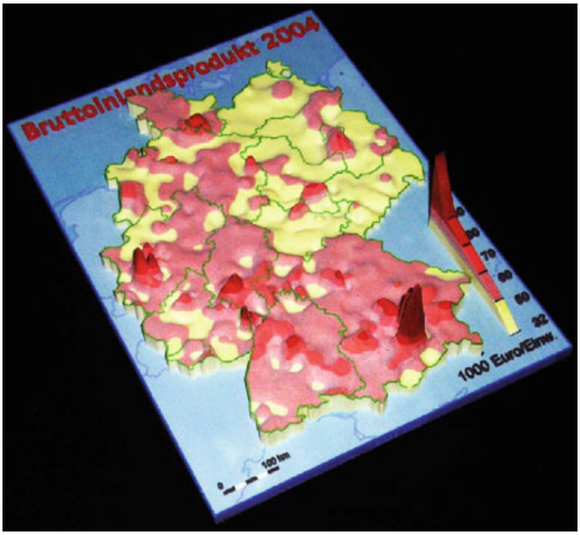


Fig. 11 Physical model visualising the gross domestic product per capita in Germany (from Rase 2009, p 4)

"Producing a steric landscape relief is comparable to making music: the finest details and nuances can only be produced by men and not by machines. My slogan is: Do not give away the most creative work to machines—to create a landscape. I want to do it myself." This statement by Toni Mair (Mair 2012), currently the world-leading relief artist, best describes why today, in a period where cartography is finding its way back to aesthetics (signposted by the founding of the ICA Working Group on Art and Cartography in August 2008—now an ICA Commission), manually generated landscape models are experiencing a sort of renaissance. There exists general consensus that machine-generated landscape models will at least in the near future not be able to replace handmade ones that are produced by "geo sculptors". Only the human processor can really polish and "fine-tune" these landscape embodiments in order to make them look as natural and vivid as the best of them are. Hence, such pieces of "geo-art" will always remain in vogue and never lose their appeal.

4 Omniglobes and Hyperglobes

Besides the analogue, physical globes, which have been existing for several centuries, since the beginning of this millennium more and more digital globes are emerging on the market. Andreas Riedl (Vienna), one of the experts in digital globes, distinguishes between hologlobes, digital hyperglobes and tactile hyperglobes. The latter ones are globes which show their cartographic image in real representation space (instead of a virtual one), i.e. on a real, physical globe body. Digital globes minimize the disadvantages of analogue globes, such as reduced portability, small number of themes and long updating cycles (Riedl 2000, 2012).

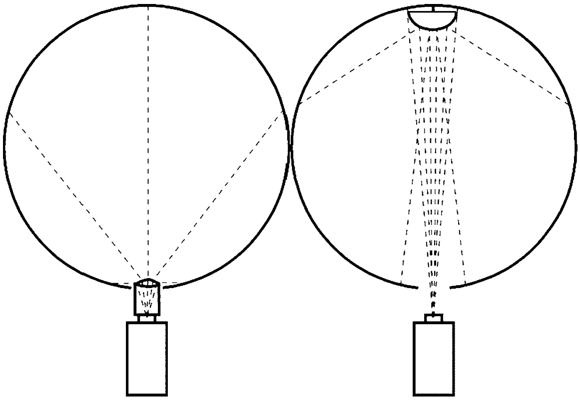


Fig. 12 Inside-projection systems of an OmniGlobe®; *left* fisheye based, *right* mirror based (from Riedl 2012)

In 2005 a tactile hyperglobe was created at the Department of Geography and Regional Research of the University of Vienna, Austria. "Therefore this department is the first European research facility which focused research activities on the visualisation of global topics under the use of spherical displays." (Riedl 2012).

The German Globoccess AG, which closely cooperates with Riedl, offers tactile hyperglobes and the authoring and presentation software for tactile hyperglobes named OmniSuite. Two types are offered: the OmniGlobe®, a spherical display which is based on an inside-projection system (Fig. 12), and the Hyperglobe® with an outside-projection system (Fig. 13). The size of OmniGlobe® globes reaches from 32 to 60 inches, that of Hyperglobe® 80–150 inches. A third possibility—which unfortunately is not yet available—is direct-projection. This could be realised with flexible OLED-Displays (organic light-emitting diodes), but they still need several years of research. With this technique the globe image would have the best image quality with high resolution, no pixel distortion and no shadows of the projection beam, etc. (www.Globoccess; Riedl 2012).

For the sake of completeness, at this point the Dresden globe project is mentioned, since it also deals with a globe, however not a haptic one like those described above (Knust et al. 2012).

5 True-3D in Geophysics and Geology

3D representations are also being increasingly used in Geology. The British Geological Survey developed in cooperation with the INSIGHT Geologische Softwaresysteme GmbH the Subsurface Viewer. With this software 2D geological maps can be created three-dimensionally. The geological models generated in this viewer are a valuable supplement to 2D geological map representations (see Fig. 14).

The single opaque geological layers of the model of Fig. 15 hide much information. To be able to perceive all layers—whether by digital data or in physical material—one has to play with the degree of opacity versus transparency in order to make all subterranean information visible. This will be of benefit for an easier

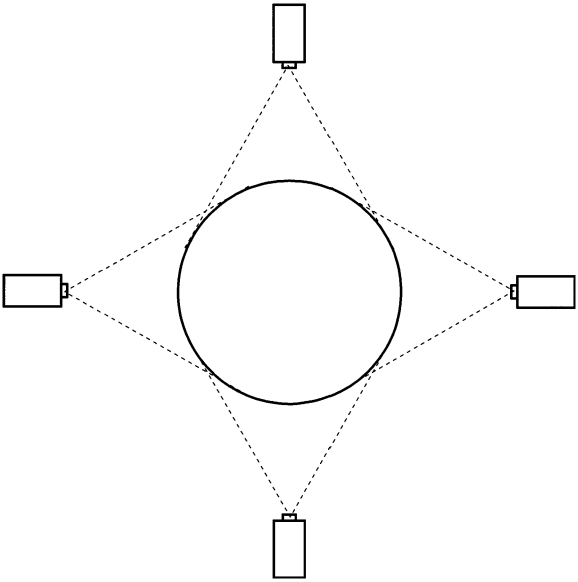


Fig. 13 Top view of an outside-projection system of a Hyperglobe® (from Riedl 2012)

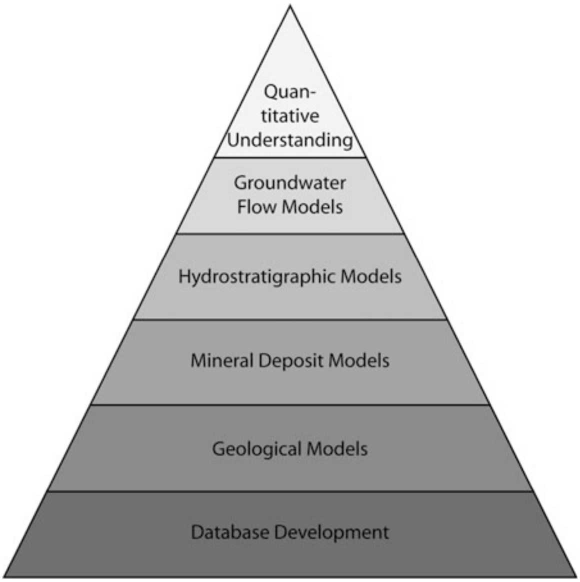


Fig. 14 From geological databases to quantitative understanding (based on Armstrong 2012)

understanding of complex tectono-geological models. It puts, however, high requirements on the production of both planar autostereoscopic and solid 3D models.

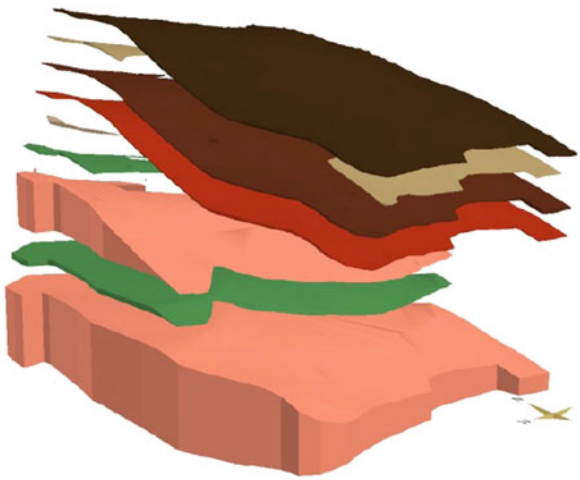


Fig. 15 Geological model split into single, hovering layers (from Armstrong 2012)

6 True-3D for Rural and Urban Landscape Visualisation

Glacier recession is one of the most critical global phenomena in the context of global climate change or global warming. A prominent project using—amongst others—true-3D visualisation methods dealt with glacier recession in the Dachstein Massif in the Eastern Alps of Austria (Bruhm et al. 2012).

The aim was to visualise the changes of the glacier coverage over the last 150 years, taking 1850, 1915 and 2002 as examples (Fig. 16). Historical and recent maps, moraine mappings, a DTM and aerial photographs from 2003 to 2006 served as cartographic data sources. The software packages ERDAS Imagine, ESRI ArcGIS, 3D Visual Nature Studio, Awaron Tucan and Digi-Art 3DZ Extreme V7 were used to generate the depictions of the three time slices. The cartographic results were containing in a range of cross-media products. That means, one and the same dataset was used to generate different visualisations: Several overflight simulations, an animation which shows the changes of the ice thickness, a lenticular foil hardcopy display which uses both the 3D- and the flip-effect and a stereo-overflight for back-projection facilities (Bruhm et al. 2010, 2012). To the authors' knowledge, within this project for the first time cross-media methods have been applied to truly three-dimensional cartographic products. Figure 16 is just a two-dimensional depiction. The original is a lenticular foil map using the flip mode to show the three different states of glacier coverage.

Regarding the three-dimensional visualisation of rural landscapes the well-established and well-tested but basic *anaglyph method* has to be mentioned here. Although it is *not auto-stereoscopic*, it is still frequently used because of its easy application both in terms of data generation for display (free online software) and data observation. An example is the Global Ice Mapping from Space (GLIMS) Project within which—like for the Canadian Rocky Mountains—anaglyphs are used to give stereoscopic impressions (Wheate and Menounos 2012). In this case

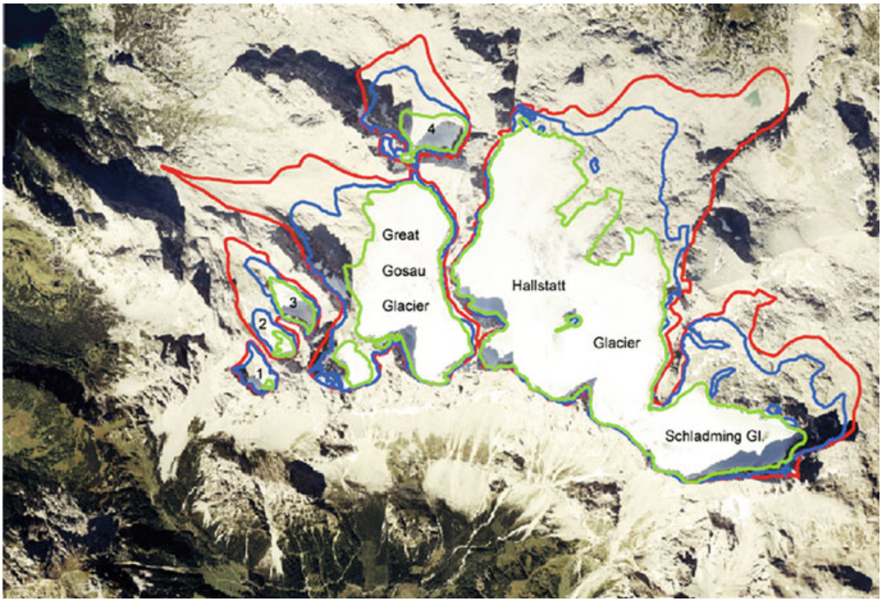


Fig. 16 Orthophoto mosaic of the Dachstein Massif showing selected glacier states. *Red* 1850, *blue* 1915, *green* 2002. 1 Southern Torstein Glacier, 2 Northern Torstein Glacier, 3 Little Gosau Glacier, 4 Schneeloch Glacier (from Bruhm et al. 2012). For further explanation see text

even time slices going back to 1905 were visualised stereoscopically. Besides traditional visualisation methods like hillshading, contouring etc. the aforementioned anaglyph images were also used to visualise surface elevation and glacier changes. Furthermore, stereoscopic perspectives and animations are generated for back-projection facility, a so-called Lab GeoWall (www.WC2N; Wheate and Menounos 2012).

True-3D visualisations of urban x, y, z datasets, so-called 3D city models, are becoming increasingly frequent. Here—like centuries ago—physical models seem to have been the preference of the city planners. In the early years of this millennium Vienna was the first European capital to introduce a haptic city model for planning purposes (see Fig. 17). It comprises 1-square metre plates, capable of being exchanged, as soon as some alteration in the respective city area requires an update of the physical city model.

7 Tactile Maps

Tactile maps are meant for blind or visually impaired people. Instead of visual perception they use their haptic sense to ‘read’ the maps or other cartographic visualisations (Koch 2001). Weißenburg (ca. 1752) was the first blind person

Fig. 17 City model of Vienna (screenshot from www.3DModell)

known to use tactile maps, his teacher Niessen making these maps for him (www.Kalisch).

Today, there exist traditional tactile media like relief models and tactile globes and new tactile cartographic media like virtual tactile displays, audio-tactile dialogue systems and GPS-supported navigation systems. Geiger (2008) investigated structure and function of tactile cartographic media, as well as the interactions between them.

Tactile maps can be generated fully or at least partially automatically. Technologies for the production of tactile maps are for example *thermoplastic transformation, microcapsule paper and fuser, models, tactile print* and *embossing*. With the audio-tactile dialogue systems, which use a combination of tactile and aural perception for cartographic communication, a fully matured multimedia information system is given to blind people. During recent years new technologies were developed in order to be able to also use the internet. But these technologies are not yet sophisticated enough for practical use. Multimodal dynamic computer interfaces are indicated in future development (Koch 2012).

A recent study at the Department of Geoinformatics and Cartography of the Finnish Geodetic Institute investigated the generation of haptic landscape models with rapid prototyping for visually impaired people and aimed at an operational, largely automated production chain. Input for this project were digital orthophotos and laser scanning data from a LIDAR system. Besides generating a DEM (Digital Elevation Model) and a DSM (Digital Surface Model) additional data like buildings and roads were vectorised. These data were divided into object groups and saved as different vector layers. Afterwards, all vector layers were exported to raster files for further processing. Texture for the geometry model was based on an orthophoto, which was adapted to the needs of visually impaired people. Several objects of the orthophoto like sport fields, buildings and roads were coloured to enhance them. The result was exported to a VRML file and printed on a Contex DESIGNmate CX™ printer which created the 3D model like described in Sect. 3.1 and shown in Fig. 9 (Schwarzbach et al. 2012).

8 Internet-Based Stereo Visualisation

In 2006 a first real-time transmission of various large sets of geodata between a university lecture hall in Dresden and a university 3D cave in the town of Trier, 530 km great circle distance from each other, took place. This can today be realised by any private individual, thanks to adequate Internet connections.

The Spanish company Sigrid S.L. offers e.g. map server software named StereoWebMap. This software is based on OGC WMS standard and offers via internet both vector- and raster-based air campaign data as well as airphotos. Besides orthophotos and anaglyph images for visualisation on a standard monitor rendered stereomates can also be requested. This type of image is meant to be used with special stereo-hardware like stereo-projectors and can be three-dimensionally viewed with the help of polarisation glasses. One possibility is to visualise the two stereomates on two TFT (Thin Film Transistor) displays with identical polarisation, which reflect the images onto a semi-reflective glass in between. Therefore, one stereomate has to be mirrored (Fig. 18). The viewer perceives the stereoscopic impression of the scene by using polarisation glasses (www.StereoWebMap; Sanchez 2012). Thus, this technique cannot be considered autostereoscopic, but with an adequate true-3D display in the near future glasses-free viewing of these geodata provided via Internet will be possible.

Buchroithner et al. (2012) present in their paper several "stereoscopic 3-D hardware and software solutions for creating and displaying online maps and virtual globes (such as Google Earth) in 'true-3D', with costs ranging from almost free to several thousand [sic] pounds sterling." Here, only a few samples will be presented.

To create your own stereo images a free software program named StereoPhoto Maker is available. It acts as both a stereo image editor and viewer. A further function allows the easy change of geographical information in the metadata of the image (www.StereoPhotoMaker). Another freeware stereoscopic browser is the Stereo GE Browser (www.StereoGEBrowser). Using the free Google Earth browser plug-in this browser shows three instances of an image: two windows show the left and right stereomate and the third window visualises the stereo image. The user can choose different stereo methods, such as anaglyphs or side-by-side stereograms and set the stereo-base. An interesting tool is the StereoGIS (www.SimWright) from SimWright Inc., an analysis application. For imagery in a 3D stereo format the user can create, edit or extract two- and three-dimensional data products as well as DEMs from the given imagery (Buchroithner et al. 2012).

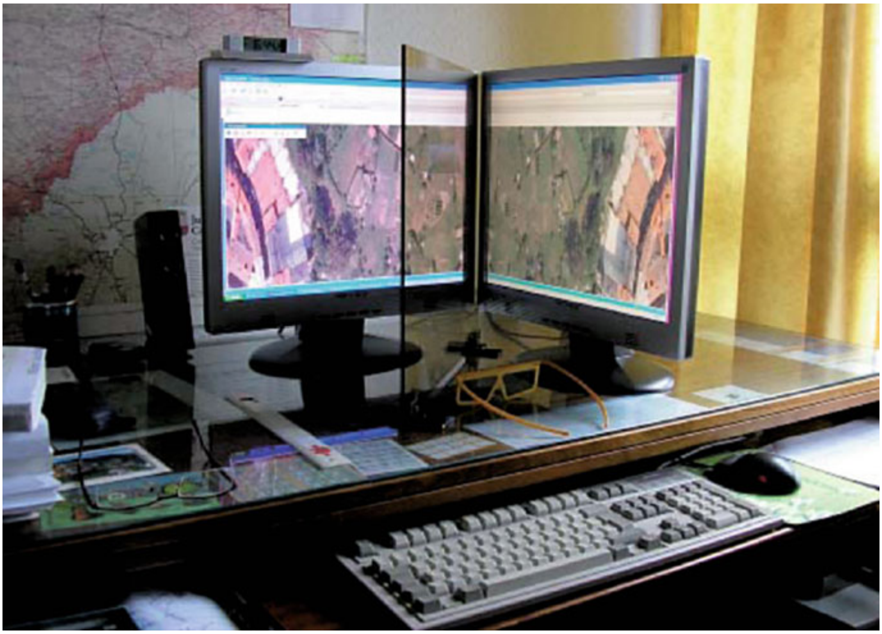


Fig. 18 Mirrored system working with a semi-reflective glass (from Sigrid 2010)

In the USA for the rapid generation of tactile street maps a web-based software tool was developed in the scope of the TMAP (Tactile Maps Automated Production) Project which was initiated by Joshua A. Miele in California in 2003. The user can generate his/her own map by defining the location and size of the final tactile map interactively via web map service. The user either can then print the map him-/herself with a Braille printer or send a request and get it by mail (www.TMAP; Dembski 2009).

9 Holography

Holographic methods allow use of all bi- and monocular depth cues. Since this technology enables the generation of 360° parallax holograms they are considered *full-3D* visualisations. It is one of the techniques with the highest potential for the creation of truly three-dimensional geovisualisations, also including transportable displays.

For holographic visualisations both the intensity of light and the phase information is stored. Therefore, coherent light is required. The wave field which contains the information about the captured object can be completely reconstructed, implying that the viewer sees the object as it has been recorded (Schenkel 1998; Schmid 1999). Holography as such, however, is a very complex technology which, to date, is also very cost-intensive. For further information the reader is referred to Buchroithner and Schenkel (1999), Buchroithner (2000), Buchroithner and Knust (2012), Knust and Buchroithner (2012).

Within the last five years holography has been experiencing a kind of renaissance, at least regarding non-civilian applications. In a mapping unit in Ankara, Turkey, the generation of so-called Holographic Relief Maps (HRMs) has been modified by using standard topographic line map data as well as a DEM and aerial photographs. These HRMs are supposed to combine the advantages of plastic relief maps with the characteristics of holography to enhance spatial perception. Not only the relief, but also the topographic and thematic map contents are spatially depicted as 3D objects (Dalkiran and Özagaç 2012).

10 Recent Developments

In recent years the term "3D" increasingly appears in the media, mostly in connection with TV screens. Leading companies like Philips, Sharp, Panasonic and Samsung informed the public at CeBit 2010 in Hanover, Germany, that they will begin mass-producing small displays, suitable for mobile devices, and predicted that it would not be long before the technology replaces standard mobile displays. 3D television sets have been available since 2010: Samsung, Sony and Panasonic had already announced 3D TV displays in June 2010 (see www.Samsung; www.Sony; www.Panasonic). This was just in time for the FIFA World Cup in South Africa, which ESPN used to kick off the industry's first 3D television network. Others like LG, Philips, Sharp and Toshiba followed soon after (www.LG; www.Philips; www.Sharp; www.Toshiba). However, for the spatial impression provided by these stereoscopic television sets the users need to wear shutter glasses or polarisation glasses, since the two stereomates are visualised on the screen in an alternating way. At IFA 2011 Toshiba presented the first market-ready autostereoscopic TV screen, (blank) featuring Quad HD with a very high resolution of 3840 × 2160 (http://eu.consumer.toshiba.eu/en/products/tv/55ZL2#-productDetailHilights). This progression from stereoscopic to autostereoscopic TV screens is faster than expert expectation. Autostereoscopic monitors have also been enhanced, along with paddles (www.Nintendo), picture frames (www.Jobo) etc.

11 Conclusion

"3D" is ubiquitous in cartography. Even at national level vocational training programmes are currently dealing with this subject (see the recent volume "The Main Problems of Contemporary Cartography" with one more paper "3D in Cartography", Knust and Buchroithner 2010).

The present article is explicitly not meant to elaborate on several "pseudo-3D" methods for dynamic relief modelling which make use of a series of different methods. For the sake of completeness companies like Northrop–Grumman Corp. and TouchTable Inc. (www.NorthropGrumman; www.TouchTable) shall be mentioned. They developed displays which are integrated horizontally on a 'table', even with added interactivity where users can actually manipulate the table and query the data by touching the planar or even relief surface.

Truly three-dimensional hard- and softcopy displays are coming up more and more. They are penetrating various domains of everyday life and scientific disciplines. Cartographers have to be both: "early users" of these new technologies and active contributors to technological developments. In addition, following the "classical definition" of cartography as a science, technology *and* art, manually generated landscape models are experiencing a renaissance. Due to the human attraction to "true-3D"(see Buchroithner and Habermann 2010) its application to geodata visualisation certainly has a bright future.

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Part II
Space, Time and Cognition

Cartographic and Cognitive Perspectives on Ambulance Dispatch Displays

Antoni Moore, Jared Hayes and B. L. William Wong

Abstract This chapter deconstructs the results of cognitive and Human–Computer Interaction (HCI) studies on the ambulance dispatcher displays in two emergency medical dispatch centres in New Zealand from a cartographic perspective. This is based on the recognition that any spatial component in such displays are not necessarily being designed with any geographic or cartographic input in the design process. First, two reported studies on the Southern Region Communication Centre at Dunedin were reinterpreted geographically. In rearranging the dispatcher display so that the listed ambulance stations now assumed their approximate geographical locations (a change that resulted in a significant improvement), with linking lines (not significant), the cognitive principle originally tested, the Proximity Compatibility Principle (PCP), is intuitively geographical as well as using topological representation for effective display. Secondly, the results of a study on the Northern Region Communication Centre (presiding over a more complex domain), specifically the city of Auckland, reflected the use of PCP in the context of a novel multi-layer display (MLD). This display has an opaque back display layer (used in this case to represent background elements) and a transparent front display layer (used to "promote" elements relating to matters of urgency to the foreground). Whether considered as one layer or two layers, the map-like display that the northern dispatchers use was a clear

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7_4,

case for several cartographic symbology, generalisation and transparency layering (afforded by the MLD) initiatives. The strong parallels between display design principles and cartographic theory must be exploited in future display design processes, not just for displays serving emergency time-critical situations but the ubiquitous displays (i.e. mobile smartphones) that millions of people use on a daily basis.

Keywords Complexity · Dynamic · Symbology · Generalisation · Proximity Compatibility Principle (PCP) · Emergency medical dispatch emergency medical dispatch

1 Introduction

Ambulance dispatch or more formally, emergency medical dispatch, is a complex task, involving spatial and temporal modelling in cognitive (dispatcher) and physical (digital) environments for the choice of ambulance to dispatch. In addition, the urgency of the medical emergency also factors into this. The time taken from the receipt of an emergency call to the instruction of the chosen ambulance to respond to that emergency must be minimized. For example, for every minute that treatment is delayed for a cardiac arrest patient, that patient's chances of making a full recovery are reduced by 10 % (National Centre for Early Defibrillation 2002). The interface design can play an important role in the performance of operators controlling complex systems; in this scenario an effective display could improve the decision making performance of the dispatchers, therefore reducing the emergency response time enough to increase the chance of a favourable result in critical cases. Various researchers have illustrated how interfaces designed to complement human information processing and decision making have resulted in improved performance (e.g. Chapanis and Yoblick 2001; Howie et al. 2000; Wong et al. 1998).

The ambulance dispatch display carries inherently spatial information, the current location of ambulances (whether implicit or explicit), and their status, relative to ambulance centres and major settlements. The displays of two New Zealand ambulance centres, the Northern Region Communication Centre in Auckland and the Southern Region Communication Centre in Dunedin, have been subject to cognitive and usability studies from a Human–Computer Interaction (HCI) perspective. This paper will explore the displays from a predominantly cartographic perspective. Some parallels will also be drawn between certain principles of HCI, cognitive science and their geographic or cartographic equivalents (such as spatial autocorrelation and symbology). This multidisciplinary approach is a continuation of the prevalent geovisualization agenda, which was established with interfaces, cognition and usability at their core (Cartwright et al. 2001; Slocum et al. 2001) and since expanded (e.g. Fuhrmann et al. 2005).

The next section will outline and investigate the ambulance dispatch process, followed by a short background on the areas of HCI and cognitive science.

The two case studies of ambulance centres will be described, including an overview of each centre, the displays used and an account of the original experiments performed with the displays. Then there will be an examination from a cartographic perspective before the conclusion highlights the main findings of the chapter.

2 Research Context: The Ambulance Dispatch Process

In a domain such as emergency medical dispatch, the successful operation of the system is dependent on an interrelated network of people, medical resources and technology. At the centre of this network are the call takers who collect the information about an incident, and the dispatchers who, based on information regarding incidents and resources, decide and manage the response for each incident. These specialists operate in one of the key aspects of emergency dispatch command and control, which is formally defined as the "reception and management of requests for emergency medical assistance in an emergency medical services (EMS) system" (Clawson and Dernocoeur 1998, p 662).

The dispatchers have an integral role within the command and control system, where they need to make accurate decisions for the system to function correctly. Therefore, it makes sense that the interfaces, through which the dispatchers obtain and monitor a significant amount of information, be designed in a manner that supports their decision making process. In other words, the interface has to fit the context of use (Haklay et al. 2010). In doing so, the cognitive resources required when undertaking vital stages of the decision making process, such as developing situation awareness, and the level of complexity that an operator experiences, are likely to decrease.

There has been scant research that has specifically examined dispatch interfaces from a cartographic or even a broader GIScience viewpoint. An exception is Wachnian (1992), who outlined an early computer-aided fire and ambulance dispatch system for Winnipeg, Canada (map displays comprised street networks, incident locations, fire halls and hospital/ambulance locations). Though dispatch interfaces *per se* have not yet been investigated from a geospatial science viewpoint, there is growing activity examining the usability of technologies that support the emergency services, such as GIS (Haklay and Zafiri 2008) and in-vehicle navigation systems (Lavie et al. 2011). Marcus and Gasparini (2006) present a case study based on the San Jose Police Department, though not related to the dispatch task. This case study illustrates what happens when the interface does not match the operational context. The more serious issues related to excessive in-car interface complexity and a confusing mapping and routing display. Both themes are covered in an in-office ambulance dispatch context in this chapter. Firstly, a short background on the HCI and cognitive science research pertinent to this chapter is provided.

3 Background: Principles of Display Design

Display design (Wickens et al. 2004) comprise 13 principles, including those that aid the perception of the user and attention-based principles. Geographically speaking, the most important is the Proximity Compatibility Principle (PCP) (Wickens 1992; Wickens et al. 2004). The PCP is intended to exploit the strengths of human attention abilities. It states that information that is used together in a mental operation, should be displayed in a way that is compatible with that mental operation. For example, if the operator requires the integration of two pieces of data (e.g. volume and temperature) into a single value (e.g. pressure in a container), then there would be greater benefits in human performance if the single integrated value were displayed. Alternatively, if the mental task is to compare two pieces of data for anomalies, then it makes sense to display these two pieces of data, perhaps side-by-side or even overlay, to facilitate visual comparison. In this way, we achieve compatibility between the mental task (task proximity) and the display representation (display proximity). The latter one—display proximity—can manifest itself in several ways, all of which are intuitive from a geographic point of view.

The first of these display proximities explored is spatial proximity. This way of promoting PCP has in general, proven useful for interface design of control panels (e.g. Chapanis and Yoblick 2001). A second strategy uses connections (lines) to link related information (enclosure by lines have also been used in previous case studies). In the past, this strategy has not proved to be more effective than proximity in stimulating human attention (see Chapanis and Yoblick 2001; Huotari et al. 2004). Other ways include source similarity (making information that is needed to be mentally integrated similar), code homogeneity (using symbology to classify the information), object manipulation (e.g. aggregation of discrete data to produce higher order continuous information, as in the interpolation of spot heights to produce contours) and proximity through configuration (relies on human ability to recognise patterns, such as with Chernoff faces, e.g. Dorling 1994) (Wickens and Carswell 1995).

Most of these principles can be linked to counterparts in cartographic design. The most pertinent principles will be outlined and discussed in the following two case studies.

4 Case Study 1: Southern Region Communication Centre (SRCC) Study

4.1 Geography and Set-up of the SRCC

The SRCC is based in Dunedin and at the time of the study was one of seven ambulance centres operating in New Zealand. It receives over 30,000 calls per year from a population of approximately 273,500; 60 % of which are in Dunedin

Fig. 1 The SRCC dispatcher setup (from Hayes 2006)

and Invercargill, and the rest are in small towns and rural areas. In the communications centre, two dispatchers are present during normal operating conditions. Usually when an emergency call arrives the dispatchers work in tandem. One takes details of the incident from the caller whilst the other allocates resources when the key details regarding the incident (location, severity) become available (Fig. 1).

4.2 The SRCC Displays

The Computer Aided Dispatch (CAD) system supporting the SRCC is relatively low-tech and consists of two primary displays for each dispatcher and a shared secondary display (for less frequently used volunteer crews). The purpose of the first display is to facilitate the entering and retrieval of information regarding emergency incidents. The second display provides the operators with the status of emergency vehicles and the jobs that they have been assigned to. This display is a text-based list and emergency vehicles are grouped together based upon their 'home station'. For example all the vehicles based at the Dunedin station are grouped under this heading. In support of the dispatcher set up, there is a further computer behind the dispatchers that has an electronic map of the southern region. This is used to locate addresses operators are not familiar with and provide GPS coordinates of, and route information to, an accident, if the ambulance crew needs it. The order of the ambulance station list on the second display betrays some regional groupings of stations (Fig. 2a) but is not geographically true for the province as a whole (in terms of topology, and given the list format a geometric representation is obviously not viable). Two studies have compared the efficiency and effectiveness of the existing display with a topologically true display, both with and without linking lines as an abstraction of the state highway network (Fig. 2b and c). In terms of cognitive science and interface design, the proposed geographically agreeable displays follow the Proximity Compatibility Principle (PCP).

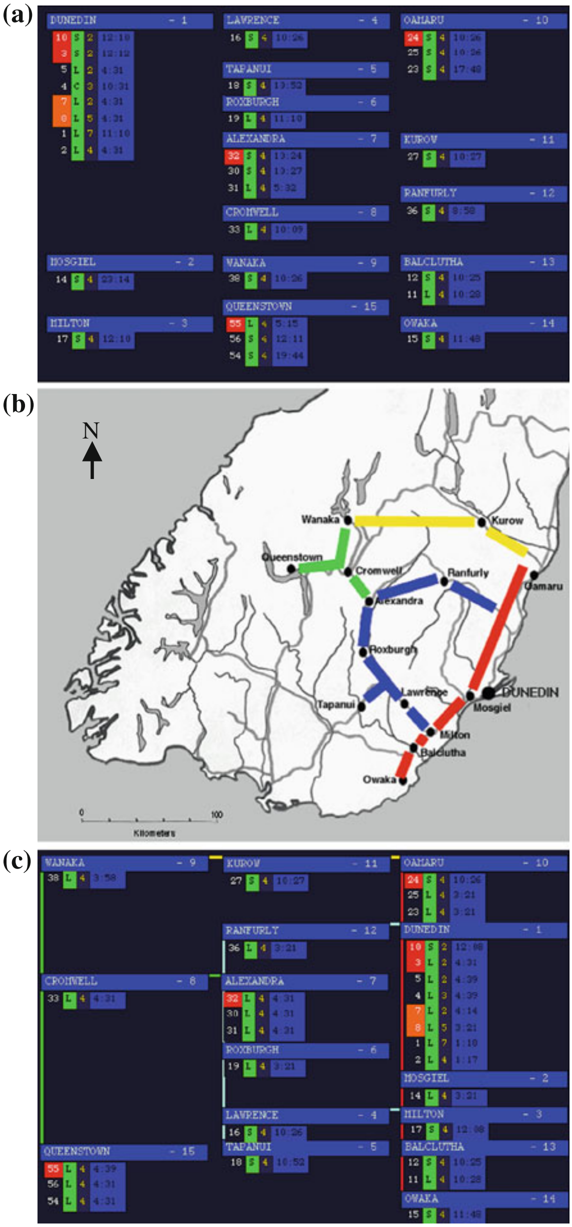

Fig. 2 **a** Original display used in control centre; (from Hayes et al. 2003). **b** Map of dispatch area with abstracted state highway network (from Hayes et al. 2003); **c** Reorganised display for relative location and introduction of connecting lines (from Hayes et al. 2003)

4.3 The Experiments

Two experiments were conducted, based on the display in Fig. 2a, which, when considered in the context of the PCP, could be said to have a poor task-to-display compatibility.

The first study (Wong et al. 1998) reorganised the ambulance status display so that it mirrored the relative geographical positions of the ambulance stations (employing the PCP strategy of fostering spatial proximity—Wickens 1992), reinforced by line links on the display between stations that are connected on the road network (another PCP strategy—Fig. 2c), theoretically giving it a good task-to-display compatibility.

To determine whether this display would result in improved dispatch performance, an experiment was conducted where thirty-seven participants were asked to respond to twelve simulated emergency calls that had four levels of difficulty, i.e. (in order of increasing difficulty):

- simple problem (one incident occurs in a town with one ambulance)
- simple trade-off problem (one incident occurs within a station's catchment—the station has more than one ambulance, hence the trade-off)
- boundary problem (one incident occurs half-way between two stations, each with an ambulance) and;
- balancing problem (a major incident occurs, requiring multiple ambulances from many stations, leaving gaps in coverage which in turn have to be filled).

Participants were randomly assigned to one of two screen design conditions (the original screen or the modified screen). The participants were all novices to dispatch management and participated as part of a class requirement for a University paper.

For the results, the performance of each display was represented by the time elapsed between when the participant finished entering the call details, and when the first ambulance was dispatched. A separate MANOVA (multivariant analysis of variance) was performed on each of the different levels of task difficulty to determine whether the mean differences in performance for each screen condition was significant. Efficiency-wise, the results showed non-expert participants performed approximately 40 % faster with the modified display than the original display on the two more difficult levels of dispatch tasks (average dispatch speed across all difficulty levels was 14.21 s with the old display as opposed to 10.21 s with the new). Effectiveness results recorded errors made in 7.3 % of dispatch tasks (old) as opposed to 5.1 % (new).

However, it was not clear from this study whether the performance improvements were due to the reorganization of the screen or the lines. Therefore, a second study (Hayes et al. 2003) set out to determine whether it was the connecting lines or the semantically compatible display organisation that was responsible for the performance improvements.

This study employed a similar 2 × 4 (display × scenario difficulty) mixed design, where display (lines or no lines) was between subjects and scenario difficulty (same difficulty levels as the Wong et al. study) was within subjects. The participants comprised 13 students, who were proficient computer users having average local geographic knowledge but a novice-level of ambulance dispatch knowledge. The dispatch scenarios used were the same as those in Wong et al. (1998) and the measure of performance was also repeated.

The results of this study show that the difference in average dispatch time for the lines conditions (14.36 s for lines as opposed to 18.27 s for no lines) was not significant according to a repeated measures ANOVA. There was also no significant relationship between the conditions and scenario difficulty. Effectiveness results (number of errors committed) were more clear cut, with errors made on 27.38 % of dispatches under the lines condition as opposed to 18.05 % dispatch error with the no lines display.

Overall, there was no significant difference in dispatch efficiency, between the two conditions, though the introduction of lines seemed to be confounding the effectiveness of the display. This result agreed with the findings of Chapanis and Yoblick (2001). It was concluded that the geographical reorganisation of the display was more likely to be responsible for the performance improvements.

5 Case Study 2: Northern Region Communication Centre (NRCC) Study

5.1 Geography and Set-up of the NRCC

The NRCC is located in the northern part of the North Island of New Zealand and is the busiest centre in the country. Based in the city of Auckland, it receives over 100,000 calls per year from a population in excess of 1.2 million, divided into two high population density urban areas—North and South Auckland; and the Northland/Coromandel regions consisting of low density rural areas interspersed with small urban centres. The NRCC contrasts greatly to the SRCC in a number of characteristics including equipment and work processes. For instance, as well as being based at ambulance stations, ambulances are often located at 'stand-by points', throughout the city to maximise coverage and minimise the time taken to arrive at an incident location.

One significant difference between the NRCC and the SRCC is the presence of dedicated call takers whose primary job is to answer emergency calls, and dedicated dispatchers: one for each of the three regions, whose primary job is to dispatch and manage resources. This means that the dispatcher does not usually become aware of an incident until the call taker passes it on. Also the dispatcher does not hear the original emergency call, and so is totally reliant on the call taker to obtain much of the information they use to make dispatch decisions.

Fig. 3 Cluster of three dispatcher stations at NRCC with whiteboard in background, allowing dispatchers to easily share information when required. Components of dispatcher CAD system are labelled (adapted from Hayes 2006)

5.2 The NRCC Displays

The dispatch system used by the dispatchers comprises three screens. The first screen displays information regarding the status of incidents and the status of ambulances. The second screen is usually configured to show waiting incidents and alerts, such as when a report from a crew at the scene of an incident is overdue. The third screen is an electronic map that dynamically shows ambulance and ambulance station locations (Fig. 3 shows the in-office setup; Fig. 4 shows the map screen).

When compared to the SRCC, there is a more advanced level of computer support and capability in the NRCC, exhibited by the provision of an electronic dynamic map directly to each of the dispatchers there. The various snapshots of the NRCC map consist of street line data (augmented with land/sea and administrative district areas) superimposed with point locations/labels of unallocated incidents, ambulance stations, hospitals, standby points and ambulances of varying status, e.g. on station, assigned to a job—in which case the journey start and end time is specified; or at an incident. The clutter of information that can occur on-screen can lead to difficulties with regard to extracting pertinent information from the display in a timely manner. This is just one of the sources of complexity facing the ambulance dispatcher. Therefore, a study was carried out to compare the existing display with a map modified for display using a novel two-layer screen. The splitting of information into two channels would theoretically reduce clutter.

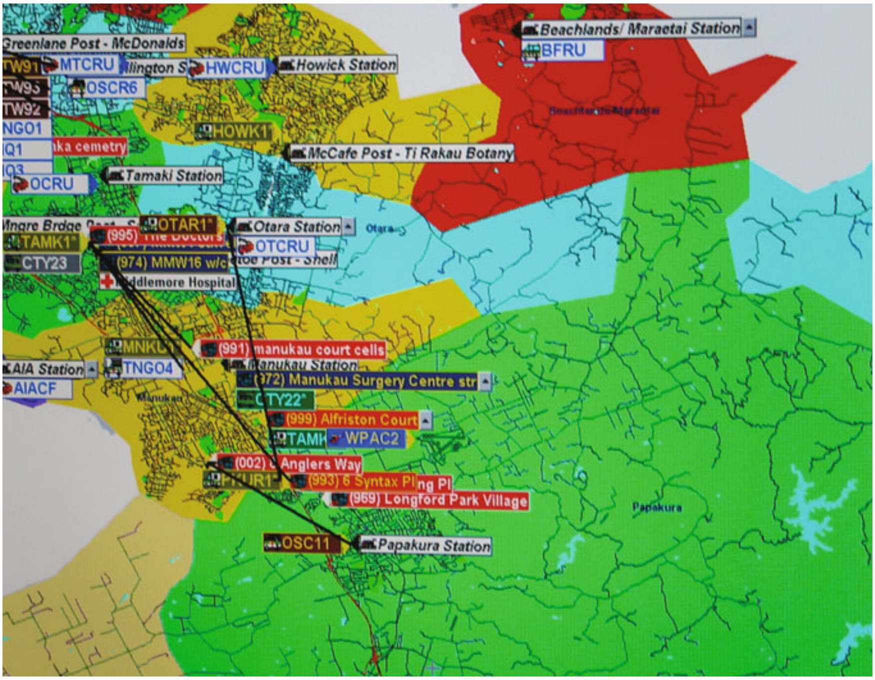

Fig. 4 The NRCC map display and superimposed ambulances, ambulance stations etc. Notice the clutter on the left hand side (from Hayes 2006)

5.3 The Experiment

An experiment was performed using snapshots of the NRCC map display, identified as a source of data overload, and therefore visual clutter adding to perceived complexity (see Fig. 4). The aim for this study was to examine how appropriate information representations can improve the dispatcher's performance on the dispatch task (Hayes et al. 2006). A Multi-Layered Display (MLD) was used in this (Fig. 5), a novel technology consisting of two overlapping LCD (Liquid Crystal Displays) separated by a 10 mm thick transparent Perspex layer. A copy of the actual map-based display used by the emergency ambulance controllers was developed and then re-designed so that key pieces of information needed by the dispatch task were placed on the transparent front layer of the MLD, while contextual information such as the map and location of secondary medical resources, were presented on the rear LCD (Fig. 5). Such information layering offering a contextual grouping by depth is another example of the PCP at work. Also, the operator's cognitive load is believed to be lessened by not having to turn information on and off, adding to the decision making time.

The experiment itself involved 40 participants with normal colour vision. It was designed as a between subjects 2×4 (single Layered Display SLD/

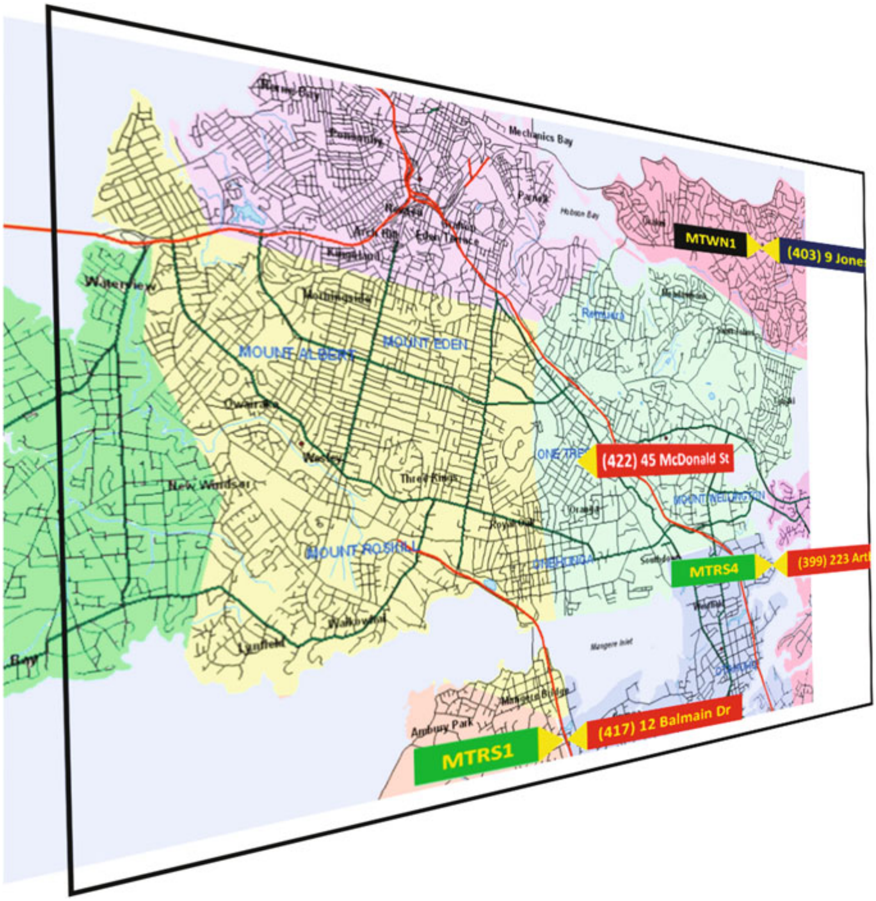

Fig. 5 The MLD, consisting of two overlapping LCD displays. The mission-critical information has been promoted to the front layer (from Hayes et al. 2006)

MLD × levels of task difficulty) factorial design. For each participant the experiment consisted of 24 trials, six tasks in each of the four task difficulty levels or categories of dispatch problem (the same four levels as in study 1). The dispatch decision-making times were measured and analysed by trial and by category like study 1 (as a measure of efficiency); the number of errors made was also noted (i.e. if the nearest ambulance was not dispatched, measuring effectiveness as in study 1).

The results of the study show that participants completing simulated dispatch tasks in the MLD condition performed faster on average (though not significantly so) on all categories of task difficulty (9.57 s) compared to participants using a standard single layer display (10.56 s). Furthermore, there was no significant relationship between efficiency and complexity of task. Finally, there were generally fewer errors made with the MLD (7.5 % as opposed to 8.1 % with the SLD), making it appear more effective.

There was one marked exception to this general pattern, Trial 24. Errors in this trial alone accounted for over 27 % of the total number of errors in the MLD condition). In this case, participants using the MLD made ten times more errors than users of the standard display. As illustrated in Fig. 6, the incident was located mid-way between the Mt Wellington and Howick ambulance stations. Both stations were an equal straight-line distance away from the incident, but the intervening harbour and the road system meant that the Howick station was much further on the network, something not widely picked up by the participants. The reported plausible explanation for this was "attention tunnelling" (see Sect. 1.3 for more discussion on this).

6 Discussion

6.1 Proximity Compatibility Principle Strategies

6.1.1 Spatial Proximity

Spatial proximity (Wickens 1992) is perhaps the most obvious way of promoting PCP and suggests that display proximity can be increased by simply increasing the spatial proximity of information, i.e. relocating associated information together. In a geographic context, to not uphold display proximity to represent spatial proximity would be unthinkable (as with the original configuration of display in Case Study 1). To do otherwise would be to reduce any cognitive benefits derived from having the display arranged like the world it represents. It can be seen that the world behaves in such a way that things situated closer together are more related than those further apart—this is an expression of the First Law of Geography (Tobler 1970). Geographical displays, like the real world they represent, should follow this rule, so much so that to come across a display that does not, makes the mismatch with the real world immediately apparent. However, in Geographical Information Science as a whole, the agreement of the more abstract database table index arrangement with the real world it represents is a cutting-edge issue (van Oosterom 1999): "closeness" in the real world still does not mean "closeness" in the database. Therefore, the link between cognitive processing proximity and display or spatial proximity is a pertinent issue from a geographical viewpoint.

Caveats to this convention would include accounting for the acknowledged distortions between the human's mental spatial model and the portion of the real world that one inhabits, and its surrounding area (Bunge 1962). The mental geographical model is (in the main) faithful to the real world that the person knows, therefore it is natural to use display proximity to attract the attention of the

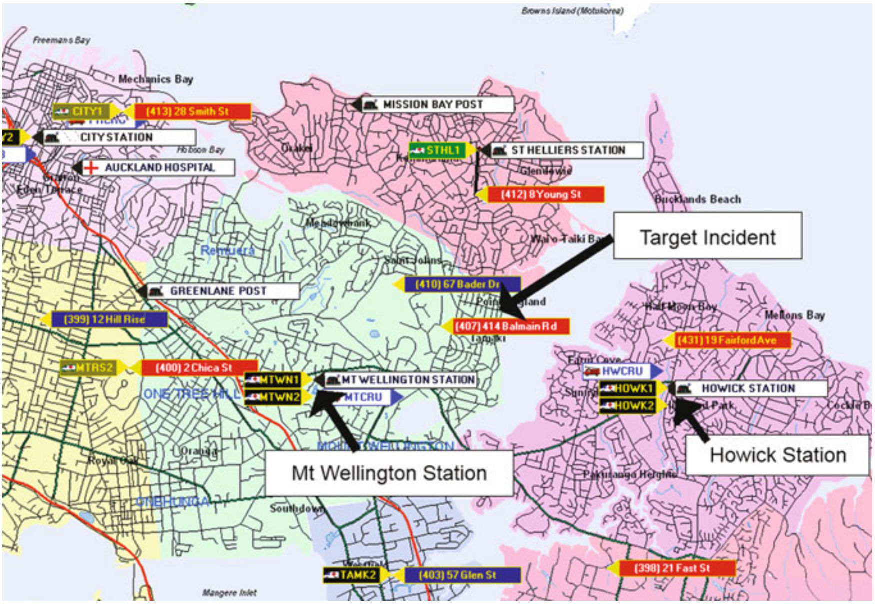

Fig. 6 Trial 24: notice the 'target incident' label almost crossing the small harbour (from Hayes et al. 2006)

person, as it agrees with their spatial knowledge and recognition will follow. However, there is a compression of distance towards the peripheral areas of knowledge—both mentally and geographically. The other caveat is due to the loosening of geometry due to topological representation. This also works on a cognitive level.

Topological relationships are represented implicitly in the amended display by having ambulance stations in their approximate geographical position (or as close as the display screen allows—Fig. 2c). When seen from a more precise Euclidean metric point of view, the represented "distances", if one was to measure them, would be extended in some cases and compressed in others; directions are only loosely maintained (in a North/South/East/West cardinal direction sense—described by Frank (1996)). This would seem to be a distortion of the agreement of the display with the world view, but in fact topological representation is in accord with the mental model; the upholding of PCP by spatial proximity need not be driven by precise metric distances.

6.1.2 Connections

Connections (Wickens 1992) are another approach to increasing display proximity that involves using lines to place borders around related information or using lines to connect related information. As such, they are used in the second sense in the "lines" experiments to foster an explicit topology. The classic London Underground (LU) map is a good example of this category, where the stations are regularly spaced and the various lines are separated, put in parallel and made to adopt a regularized geometry for ease of navigation. In this map, metric distance and direction are not as important as connection and separate identity. It would be inconceivable in the LU case to remove the connecting lines, yet the differing function and the simpler real world transport network of the SRCC display gives a better result without lines. This is despite anisotropic effects in the South Island case, i.e. physical barriers to movement emphasising the connecting role of the roads, suggesting that the simpler geography makes for a more complete mental model, lessening the necessity for lines.

A final note is that connecting lines, where used, are likely to be more effective in topological than Euclidean representations due to the flexibility that topological space affords. Figure 4 from the second case study is a good illustration of what can happen when the Euclidean metric is followed slavishly. Section 6.2 offers an alternative cartographic generalisation solution to the situation—processes such as displacement and typification represent a departure from the precision requirements of Euclidean space, and in doing so, take a step towards topological representation.

6.1.3 Grouping in Layers and Cartographic Generalization

The use of Multi Layer Displays in case study 2 was intended to make use of the Proximity Compatibility Principle again, with like-priority data being integrated on the same physical layer. The aforementioned Trial 24 represented a situation where this effect did not work. This was attributed to attention tunnelling, where participants were so focussed on the incident and resource information on the front layer of the display, they failed to recognise the extent of the harbour on the rear layer. Therefore, while the MLD appears to be successful in making the important information salient, it can be at the expense of background data, which in this case was equally salient.

This finding was reflected in a study by Yeh and Wickens (2001) when they were exploring the reduction of visual clutter through hiding display elements—it is difficult to decide which are primary information and which are secondary. Often this is dependent on the situation encountered by operators and as such information that is considered secondary in some instances may be absolutely critical in others. Another phenomenon Yeh and Wickens (2001) found in their study was that the time cost of turning information on and off (including determining if the hidden information needed consideration) outweighed the time benefits of presenting less information, due to increased cognitive load.

An interesting parallel can be drawn here with the cartographic generalization process of elimination, the use of which seems to be complicated in a dynamic display environment. It is not as easy to eliminate (albeit temporarily) display features in a vital decision-making environment such as that for ambulance dispatch, where eventually they will be needed to be viewed by the dispatcher, possibly in a time-critical situation. It is this possibility that contributes to the extended consideration time, even when the display is less cluttered. Even with a solution such as fisheye views (Furnas 1986; 2006), where the important features are exaggerated relative to the secondary features, the decision remains on what to prioritize. With cartographic generalisation, the expectation is that, for the scale of the map, the objects eliminated will not be missed at some future time. After all, in most map viewing environments, the user has the time and opportunity to view the desired area at a larger scale, should there be an eliminated feature to be sought.

An alternative to elimination could be to add an extra transparent/translucent layer on top of the map, thus adding to the amount of space available in which to fit symbols; this is exactly how the MLD works. Given this, the use of the MLD could be seen to offer an extra option for generalisation, which we will call "promotion". Starting in a state where all features are assumed to occupy the rear layer, instead of applying any of the standard generalisation processes, the feature being considered could be promoted from the rear to the front layer, possibly resolving the source of cartographic conflict.

6.2 Other Display Principles

6.2.1 Display Legibility and Generalization

'Making displays legible' is a perceptual design principle (Wickens et al. 2004); the process of cartographic generalisation is aimed at achieving this goal for maps. The information clutter scenario described in the second case study is a viable case for cartographic generalisation. It is basically excessive display complexity, which in turn has inputs from the system complexity. What is important here is the perceived complexity, i.e. the amalgamated effect of display, cognitive and task complexity, experienced by an individual, which may be greater or less than the real or base level of complexity. If an interface or map presents information effectively, then this perceived complexity can be reduced (Hayes 2006).

It is a situation where too much of the real-world system floods the interface in the form of data. With data being increasingly abundant and the amount of cognitive effort needed to process it into something meaningful, information in the correct form and amount is the most valuable commodity for the interface user in an application such as command and control (Barnes 1997). In generalisation, the problem is not so much one of data display, rather too much information (i.e. symbols), too complex information and/or in the wrong form. Choosing the optimal form of information for a map can reduce the information density to an acceptable level, through processes such as reduction and typification.

6.2.2 Attention-Based Principles and Cartographic Symbology

Unique to a situation such as ambulance command and control or air traffic control is the fact that any interface should have the capability of representing (infrequent) abnormal events as well as (routine) normal events. In terms of a dynamic map, manipulation of animation cartographic variables (MacEachren 1995) to control the behaviour of symbols on a map can ensure that the ephemeral abnormal events do not get lost against the background of normal events. For example, combined use of the duration and frequency variables can create a "blinking" feature that draws attention to itself by cyclically switching itself on and off (e.g. Fisher 1993; Kardos et al. 2006). Similarly, use of longer or shorter phases than normal or altering the order of animation can attract the eye with abnormal events.

Of course, static cartographic variables such as colour (hue, saturation, value), texture, orientation, shape, size, arrangement and focus (Bertin 1983) can be used in the same way. As an illustration, there may be a cartographic reason for the anomalous result in trial 24 of the MLD study. Focusing on the symbol used for all static and dynamic objects, the shape is the function of a unified arrowhead and text label, whether used to represent ambulance, ambulance station, or other. Crucially, this means that a lengthy label (such as with the target incident in Fig. 6) means a lengthy symbol as a whole, increasing the importance that the attached arrow feature indicates where the actual location is. The label in question almost bridges the harbour, which may be causing ambiguity at first glance as to which part of the harbour it is actually pointing to (exacerbated by the arrowhead being dominated by the label). Shifting emphasis towards the point itself, which at the moment is only implied, and lessening the prominence of the label, though not too much so as to jeopardise the purpose of the display, would be a cartographic solution for this scenario (e.g. to use graphic variable terminology, a small circular shape, but in a vivid hue is required—depending on the identity of the object).

Returning to Wickens' principles of display design (Wickens et al. 2004), such a multimodal display is implicit in one of the attention-based principles (that of multiple resources) and principles that aid the perception of the user (avoiding absolute judgment limits by engaging more than one sensory variable). A variation on this satisfies one of the other perceptual principles, design for redundancy gain, expressing a feature in more than one form (e.g. major roads are exaggerated and have vivid colours, to make them noticeable).

These visual cartographic solutions to display both abnormal and normal situations on a dynamic map are the equivalent of a compromise display in interface design terms (Wickens 2000), acknowledging that it is difficult to address both situations on the same display. A solution could be a dual display (Wickens 2000), but this may increase the cognitive demands placed on operators, especially where integration is involved. With its two screens, the MLD display is closest to this category, with the added benefit of superimposition lessening the cognitive load. This only works through the shared simulated geography of the two screens, a spatial overlay association between the two layers that aids the cognitive process yet further.

The MLD achieves its effect by possessing a transparent front screen, capable of presenting digital content that would appear as translucent to the viewer. There are implications here for what is now possible with both symbology and generalisation, as the extra display layer affords extra space, so should that mean room for more symbols? A framework for the symbology of transparency is implied here (the generalisation aspect is discussed in the next section), and should be subject of further study. The study would set out to establish the visual qualities of superimposed feature type layers (i.e. testing all pairwise combinations of points, lines and areas, including point-on-point, line-on-line and area-on-area) at a variety of transparencies (defined by alpha value), also altering graphical variable levels (i.e. different orientations, shapes, sizes etc.).

6.3 Other Factors

Another aspect of cartography that may arise in a command and control context (though has not in the two case studies featured here) is composition. This includes issues such as making sure the map as a whole is visually balanced relative both to the screen extent and any other information content on the screen. This other content may relate to the map (secondary elements such as legend, scalebar or orientation) or be non-spatial information relating to the dispatch task.

The discussion above focuses on display issues, which may add to the overall complexity of the dispatcher's task (other sources of complexity may be stress or workload). By way of an overview, Endsley et al. (2003) characterised several layers of complexity, from system (real world) complexity through operational user perspective dependent complexity to apparent complexity. The latter comprises cognitive complexity (user's mental ability to deal with system complexity), task complexity (i.e. of the actions to be taken) and display complexity. These all affect how the user perceives the situation. Cognitive and display complexity are especially pertinent to the cartographic process. Indeed, the link between the real world (cognitive complexity is largely driven by the characteristics of the system) and the map (or interface) representing it (display) is one of the central foci for cartographic research, encompassed in choice of symbology and generalisation.

7 Conclusions

In this paper, we have seen a cartographic perspective applied to the results of Human–Computer Interaction (HCI) studies on (pseudo-) geographic ambulance dispatch displays. It was found that there was much overlap between the proximity compatibility principle (PCP) and the interdependence with nearness that is innate to all geographic phenomena. This is a real world facet that must be communicated in representational displays to enhance their efficiency and effectiveness. That is, a digital map must be able to communicate effectively by geographically-realistic associations, to borrow PCP terminology, through proximity (working on a largely metric basis) or connecting lines (more topologically compatible). Furthermore, if we were to foster association by assigning a group to a specific plane, as was the case with the multi-planar MLD, then in effect a thematic distinction has been made that draws the user's attention, independent of whether features are proximal or explicitly connected (PCP is also in play in this case).

Aside from parallels between HCI and cartographic theory, straight-forward cartographic tenets such as effective symbology and generalization could be applied to the ambulance dispatch displays. For example, generalization processes such as reduction and elimination can be used to reduce "clutter" on the display (though application of the latter process is more complicated with a display in a dynamic decision-making environment). Also, some attention to symbology may have rectified cases such as "Trial 24" in the NRCC case study experiment (e.g. making the symbols more compact and making sure that they are unequivocally associated with one specific location on the map).

Finally, one of the major findings of the retrospective analysis contained in this paper is the potential research opportunities for cartography that the novel MLD (3D displays too) affords. The suggested research directions are again rooted in fundamental areas of cartography, and have as their basis the fact that layering occurs, where the extra layer could provide another "destination" for data needing to be generalised—"promotion"; and the transparent nature of that layer. This opens out research on the hypothesis of symbology transparency; also the abovementioned generalisation would not work without this transparency.

A lot of the issues described here are applicable to other types of display used in different contexts. For example, exposure to maps via mobile devices such as smartphones is now pervasive. Although there is not the emergency and time criticality of dispatching, the discussion linking display design principles and cartographic concepts in this chapter is potentially of relevance to the millions of phone users who need to receive legible and meaningful spatial data in a mobile context. There is already much research activity in the mobile cartography research area (e.g. Gartner and Rehrl 2009; Paolino et al. 2010—the latter example applies visual analytics techniques on mobile phones for on-site emergency management).

The main concluding statements from this research investigation is a recognition that emergency dispatch displays with a spatial component are not necessarily being designed with any geographic or cartographic input in the design process. However, in this chapter there has been extensive discussion relating to the very strong parallels between display design principles and cartographic theory, which seem to have emerged independent of each other. This commonality must be exploited in future display design processes, not just for displays serving emergency time-critical situations but the ubiquitous displays (i.e. mobile smartphones) that millions of people use on a daily basis.

Acknowledgments The authors would like to thank staff at the (St Johns) ambulance stations and the participants in the experiments. The feedback from the two reviewers is also gratefully acknowledged.

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Space, Time, Activity and Human Error: Using Space–Time Constraints to Interrogate the Degree of Uncertainty in Survey-Based Movement Datasets

Qian Sun, Pip Forer, Jinfeng Zhao and David Simmons

Abstract Tourist activity is generally frenetic even while seemingly being relaxed. A significant change has been the rise in free, independent travellers who choose to tour autonomously and visit multiple destinations to their own schedules. This development has had major ramifications, impacting on local environments and communities by stimulating their economies but simultaneously demanding new facilities, displacing certain activities, and transmitting ideas and even disease as tourists contacting with their hosts becomes wider and more intense. Such tourism is quintessentially tied up with a dynamic geography of movement that generates demand and supply at different spatial scales. A growing recognition of these outcomes has highlighted the significance of movement data as a resource for understanding many aspects of human and animal activity and their geographies. Consequently, research interest has accelerated on the back of enhanced capabilities for tracking individual entities' movements, typically with GPS sensors that collect individual time-tagged locational data cheaply and accurately. Prior to this, most movement studies used a paper-based survey methodology for data capture which was reliant on respondents' recall of movement or the keeping of a diary. Unlike the GPS, this process permitted data capture

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7_5,

which is enriched by information on the respondent's profile, and ongoing activity, time use, and attitude, a distinction which continues to validate this methodology in a number of contexts. Legacy datasets gathered using surveys are known to have (non fatal) sources of inaccurate or incomplete responses, which in general have been documented only to a limited degree. This paper is concerned with using GIS technologies to more fully interrogate a case study database (tourists travel survey) so as to identify: (i) the level of uncertainty in given responses from individuals, (ii) the pattern of missing data and (iii) the degree to which such datasets can be enhanced by models using concepts found in time-geography.

Keywords Tracking individual movement · Spatial–temporal data quality · Space–time constraints · Tourists itinerary · WCTFS · West Coast New Zealand

1 Introduction

Mobility is a key factor in many processes and activities, and it has both positive and negative impacts on society and environment. A better understanding of movement is increasingly valued in fields of research such as transportation, planning, ecology, community health, environmental management, biosecurity, disaster management and surveillance. Although disciplines look at movement in different ways and seek to ask a variety of questions, a common acknowledgement is that it is a complex phenomenon for description and analysis, and to be well understood it needs data including background information on the nature of the moving entity as well as on its tracked position in space and time. A growing desire to create rich datasets with these parameters has led to an increased interest in data collection, but to date this has had an emphasis on electronic devices, most typically the basic GPS. There is a legion of projects obtaining basic movement data (x, y, t), a growing number integrating these with spatial information of the local geographies, but yet far fewer integrating rich human datasets that require human responses as part of the process. Pioneers are working on linking GPS and diary information for this purpose via the unified technology of a smartphone (Halifax STAR Project 2007; Raento et al. 2009), but for various reasons the traditional survey methods of the form-based questionnaire or diary sustain an inhabited niche. This chapter is fundamentally about the performance of traditional survey methods applied to movement data collection, and how this might be improved by retrospectively auditing their data in terms of the probable accuracy of given responses.

Such 'rich' movement surveys typically seek information from a respondent on the route of their journey (usually by a sequence of stops), timing of arrival at (or departure from) visited places, the duration of presence there, the activity while stopped and the reason for stopping. Other variables such as expenditure and source of knowledge about the place may be appended in an effort to understand the movement as well as describe the tourist's routes. Usually this collection process is expensive in time and money but with good design allows relatively comprehensive data. However, recording a dynamic process has logistical and philosophical problems: the former in terms of compliance times and simply juggling the physical survey, and the latter in that the reporting itself can interfere with the very activity being reported and its perception or recall. Thus most surveys use either a one-off retrospective interview of movement episodes or a diary approach allowing sequential completion of questions at certain points in time. The typical interview can suffer from recall deficits, with the earliest events being least well-remembered due to the greatest lag since experiencing them (Clarke et al. 1981; Barnard 1986). Diaries have a lesser gap between experience and reporting if filled regularly, but suffer more from a tendency to forget or overlook regular reporting sessions (Unsworth and Clegg 2004). The availability of a range of GIS tools, along with data describing local areas and transport in some detail, now provide an opportunity to efficiently examine and interrogate individual journeys. Principally the component parts of each journey can be tested for consistency with the known environment: this may involve checking that reported times do not amount to impossible movement speeds between reported places, reported activities comply with the local ability to sustain such a choice, and durations at a stop are consistent with the stop and its facilities. Such an approach can be used to ask a wide range of questions of the data and develop a number of measures of quality, or go a step further and produce modelled (synthetic) responses where a question response appears dubious or is absent.

As a context for this analysis, the chapter draws on a tourist example based on a survey of tourist movements on the West Coast of the South Island of New Zealand: the West Coast Tourism Flow Survey or WCTFS. Neither the field of tourism nor the WCTFS itself is a natural choice for this analysis, but the survey has a number of good points that recommend it, not least the size of the survey (at 2, 500 respondents, large enough to provide variety but small enough to understand closely), its richness in terms of non-spatial attributes, dense data coverage and documentation for the region, and the variety of respondents and the duration of their trips (2–3 days being the norm). Perhaps most important is the attention shown to the capture of the spatial element (864 locations were recorded by recall by place name and the respondent's positioning on the map, the two approaches being cross-referenced for robustness). The nature of the West Coast itself is also helpful in analysis of the movements. It is a clear geographic entity, constrained by a coastline to the West and a chain of mountains to the East that is pierced in only three places. This channels travel in such a way that most people face relatively clear and limited choices. The next section expands on this context and the context of the survey methodology in depth.

1.1 Tourism and the Context of the Survey

For much of this century the tourist industry has been a prime cause and beneficiary of the emergence of hyper-mobility as a phenomenon. In this time tourist movement has moved increasingly further from the historical model of a single destination journey towards itineraries of far greater length, with more stopovers, greater individuality and greater complexity (Forer and Simmons 2011). The increasing number of Free Independent Travellers (FITs) has contributed to the more dynamic and complex modern tourist movement patterns and to the tourists' increasing carbon footprint (Hart et al. 2004). Such individual travellers with multiple purposes visit more places for more reasons and with different satisfaction goals. Not surprisingly a far more complex pattern of movement can be expected to emerge (Tideswell and Faulkner 1999). With greater issues such as environmental footprints and local economies riding on travel patterns and behaviour, an understanding of these patterns and their impacts is coming to command greater resources than in the simpler past, therefore the collection of an enhanced range of information is needed. Contemporary tourism management and development need insights on tourists' itineraries: where they are, when they are there, how long an individual (or individuals) conducts a particular activity and where they are afterwards and what they seek next, what is the nature of their complete itinerary (Zhao 2003; Forer et al. 2005). The WCTFS was designed to provide such information at a regional level with appropriate detail on activity, expenditure, location, stay times, overnight stays and personal backgrounds.

The survey was undertaken in the West Coast of New Zealand between Karamea in the North and Haast in the South (Fig. 1). The Coast is an isolated strip of land separated from the rest of the country by the Southern Alps. These are pierced by just three entry routes, through which close to a million international tourists enter and leave, narrowly outnumbering the often multiple visits of domestic visitors. It is within these portals that most of the respondents are intercepted and questionnaires given to willing participants. The study area, roads, named passes and main attraction points are shown on the map.

The entire 23,000 km^2 of the Coast is dominated by visually spectacular terrain, featuring mountain ramparts, glaciers that come close to sea level, coastal rock formations, caves and wilderness forest. At its widest it measures 30 km East–West on the coastal plain and its population numbers around 30,000. Traditionally tourism was fed by a small international stream of glacier lovers and a much larger domestic pool from the East Coast cities. Its catchment is now far wider, North Island New Zealanders coming more regularly and international visitors topping 800,000 p.a. Before the survey it was generally accepted that the key driver of the growth of international tourists was the circuit that began at the international airport in Christchurch across to the Coast, down via the Glaciers to its Southern exit at Haast and on to the national icons of Queenstown and the Southern Lakes. A final leg to Christchurch completed the circuit. This was the archetypal tourist route, with a typical party spending one to three nights on the Coast. However, as movements

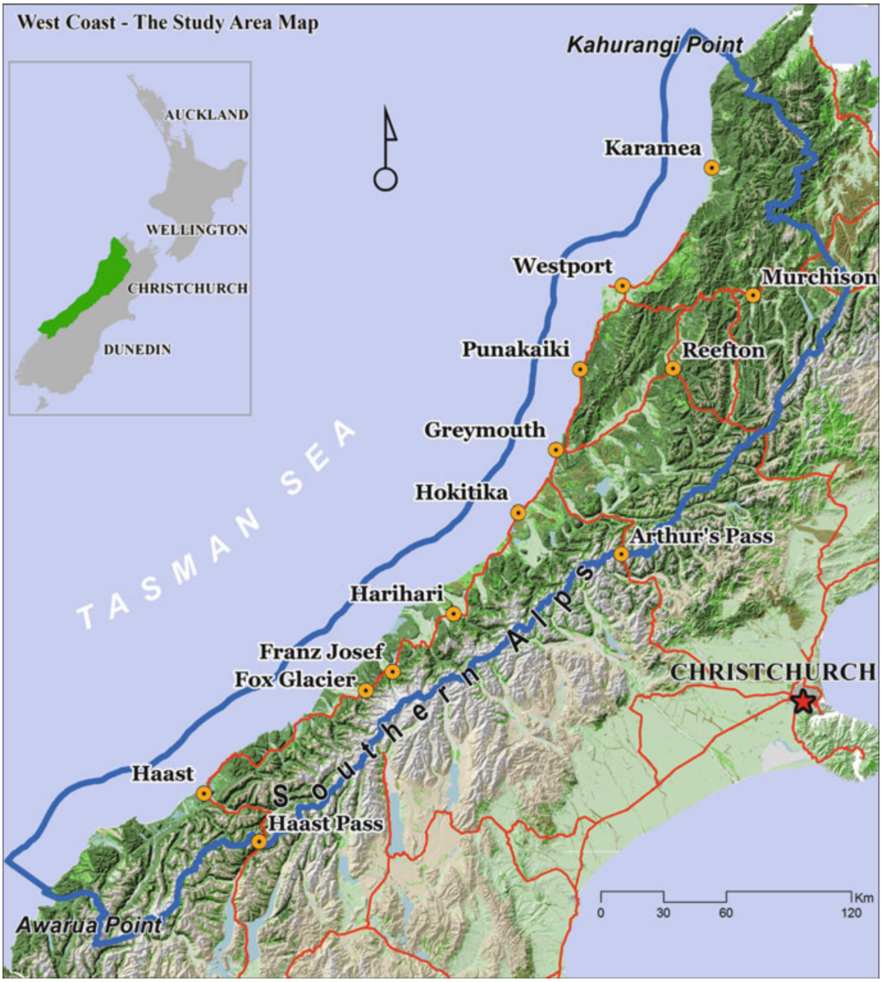

Fig. 1 The study area and its main features

became more complex this broad knowledge of flows became less than adequate in describing tourist impacts and demands. The WCTFS was designed to enhance the knowledge of these flows along with the patterns of local visitations and income generation. Its goal was also to underwrite the development of tourist flow models based on patterns which described ways in which tourists constructed itineraries.

That is a brief background of the milieu and genesis of the WCTFS. The actual analysis of the data proved rather too fruitful to cover comprehensively here, but it can be explored in depth in Forer and Simmons (2011). The actual collection technique is briefly explained below. The positive outcomes of the survey rested largely on a low rejection rate amongst those approached to participate, a high return rate of the diary instrument that was issued, and a fairly robust set of external checks on our flow sampling rates that eventually led to a good framework for weighting of the data. However, as with many surveys conducted over several days or recalling information from the past, it became clear after compiling and cross-validating the data that the anticipated shortcomings in data collection were present. The rest of this chapter discusses an attempt to quantify and ameliorate both absence and error inherent in human responses.

1.2 Collection of the Original WCTFS Data

The data in this research was gathered using stations within the three portal entry points at Arthur's Pass, Murchison/Lewis Pass and Haast Pass. Data were collected from tourists during five representative sample periods between early December 1999 and late January 2001. Respondents were asked to reply to profile questions, and to record details of their travels and any stops of over 5 min duration. Tourists entering the Coast were provided with a diary to be filled while on tour and posted back, those leaving were interviewed on the spot using a map-enabled questionnaire. Spatial information of stops was requested in up to three ways: as a place name; as a description of a venue if no name was known; and as a marked cross on a map location. Respondents were asked to report or indicate their stops using both verbal and map options.

These pairings were cross-checked for consistency before final data entry into personal and geographic tables, which were merged and processed in Microsoft Excel, SPSS, and then transferred into a GIS compatible format which linked the stops' geometry and associated attributes. The GIS format used for WCTFS allows the representation of stop sequences and full itineraries using dynamic segmentation tools so that analyses of both stops and movements are possible. The final record of data collected ran to over 25,000 stops associated with 7,673 overnight stays which were generated by 2,593 respondents. For analysis the key objects were stops, daily run (movement between two overnight stays) and itineraries (for this paper the stop sequences from entering a portal to departing the Coast). In all cases these objects had individual profile data, information on location and timing of the individual or their group, and a range of information on their activity and expenditure at each point. Table 1 provides an example of the information requested in the survey. Vetting this data and retrospectively reclassing certain submissions on temporality and activity took several months, during which the validity and broad compatibility of itineraries with the spatial data was manually checked. Consequently a series of basic tabulations was run on the stops data examining issues such as arrival times, duration of stay, demographics, and expenditure. This was undertaken using a variety of spatial frames that included the entire Coast study area, the locations of greatest activity on the Coast, a sub-regional frame and individual sites.

Table 1 Itinerary information requested in both interview and diary sheets of WCTFS: a day trip spatiotemporal events and activities

Location name	Arrival time	Duration (h)	Purpose and activities including destination	Extra transport	Meals bought	$ Spent
1						
2						
3						
4						
5						
6						
7						

Under analysis it became increasingly clear that for individuals the absence of data items, such as an individual arrival time, was an issue for many respondents. Very few provided fully complete records. However, in general, the sample number who did respond remained high enough that for many tabulations analysis could still be meaningfully undertaken, and these analyses feature in Forer and Simmons (2011). Nonetheless, the gaps were regrettable and undoubtedly reduced accuracy, as did the provision of mis-estimated values such as arrival time or duration.

Absences provide a more significant issue for the proposed analysis and visualisation of full itineraries. This is due to the fact that a single omission breaks the whole itinerary into two or more parts and disrupts the continuity of the individual's known movement. Since failure to complete any particular items was both frequent and predominantly generated by random absent-mindedness this compromised the ability to visualise and analysis the data in a comprehensive way. At this point a thesis (and eventually this chapter) was born, dedicated to assess the quality of what we had and infer what might be missing (Sun 2009).

The aims of the reported research became to assess the spatiotemporal data quality of a mainstream survey of individual movement, to map the patterns of gaps and errors in the datasets, and finally to investigate the possibilities of filling the gaps and enhancing the consistency in order to improve the data quality of the individual records. From the beginning Hägerstrand's idea of the individual *timeline* (Hägerstrand 1970) and his surrounding conceptualization of individual human lives and choice/constraint were seen as a solid background framework. Viewed as "an innovative and instructive approach to the study of time, space, and human activities" (Golledge and Stimson 1997, p 268). Time-geography's concept of the space–time path can help reveal the underlying structure of movement. That perspective, and its associated conceptualisation of space–time constraints, underwrote the space–time reasoning algorithms in this paper. While Hägerstrand's prisms are typically used to illustrate what could be done in the future this approach seeks to show what they could not do in the past and looks to rewrite the past with care.

2 Representing Tourist Movement and Constructing Travel Paths

2.1 The Components and Process of Tourist Itinerary Movement

Movement is controlled by human decisions that are invisible, random to a certain extent, non-periodic and hence difficult to predict (Zhou and Golledge 2000). Xia (2007) defined human decision-making for movement as a subjective travel existence. Tourists often make decisions prior to and during their itinerary. All in all tourist behaviour in time and space is difficult to predict, or even describe. These decisions reflect an ongoing process and changing desires, and are manifest in behaviour that is related to the decisions and actions of the individual at any time. A powerful and increasingly used way to represent these relationships is to conceptualise the phenomenon with three closely associated dimensions: movement in physical **space**, personal presence and episodes in **time**, and **activity**, which may be linked closely to places, and the experiences and attraction of place. For a tourist the actioned spatiotemporal choices eventually form a tourist itinerary. The artefact of an itinerary across space and time which emerges is a timeline in the terms of Hägerstrand, a geometric entity, but it is potentially a smart line, in which the geography it threads through and its owner's states of activity are implicitly linked, and subject to rules of formation which stem from the individual and the geography of their experience. This link both disciplines the line and opens the way to assessing its internal consistency.

To illustrate aspects of a typical daily process, Fig. 2 illustrates the dynamic of the creation of a Hägerstrand timeline as represented by decision making across a tourist day. At the beginning of the day, a provisional schedule for travel and time at attractions has been formulated (Fig. 2a), probably strongly influenced by the need for accommodation by the evening. The main preferred destinations may be identified, as are secondary options. Dotted lines show the prisms where the party could get to in their discretionary time between visits. There are also some unknown attractions represented on the diagram as light green rectangles. One can sense an intended structure and see various options for assembling the day. The following two diagrams (Fig. 2b and c) explore the sequential re-organization and destruction of prisms as an unintended stop occurs due to a photo opportunity or a call of nature. This reduces the duration of available time at one attraction. Another stay gets extended, probably due to a high level of enjoyment, and one missed because there is no longer enough time to spare if accommodation has to be reached. An inescapable logic emerges and various attractions are chosen to be visited, by-passed, or ignored depending on new commitments to earlier stops, or new discoveries (Forer et al. 2007). What is left is a continuous timeline, a statement of the choice and activity of the tourist. We know that a real timeline has to be physically possible and, there is flexibility in choice of what attractions

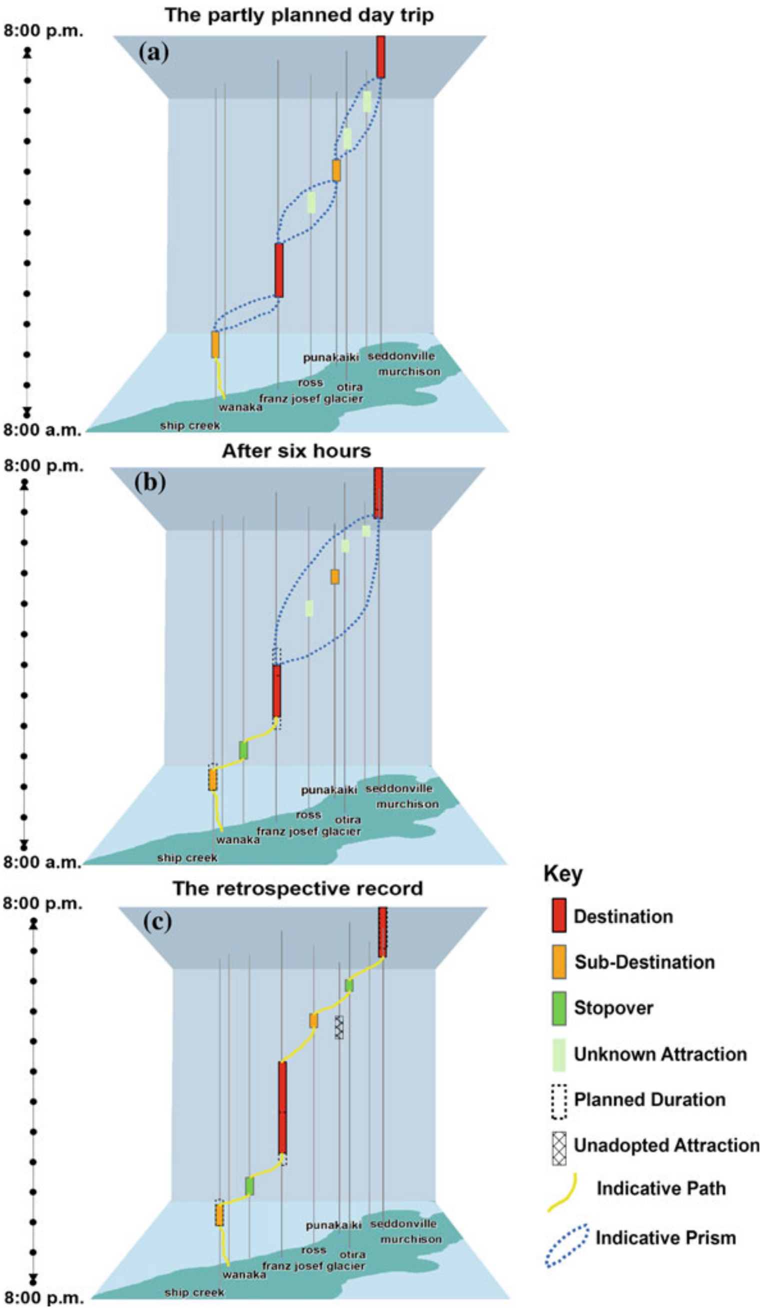

Fig. 2 Evolving process of a tourist's itinerary (after Forer 2005). Space–time aquarium (**c**) shows individual tourist's auctioned overnight itinerary as a set of stops linked by travel paths which emerged from prisms. There is a unique travel path between every sequential stop and time continuing along the stop-travel path-stop itinerary trajectory

are chosen, and in the time taken visiting each place, and even in the route taken between places. However, in the end there is cast iron constraint in that the sum of the travel time plus the sum of the visits en route has to equate to the time lapse between starting the day and ending it. Equally, the travel time between places can not be less than the fastest possible travel available. Different people may drive at different speeds, but there is a practical maximum.

The concept of space–time within time-geography allows us to conceptualize and measure the limited locational and temporal flexibility of a particular activity, and to quantify a person's freedom in choosing where and when to perform the further activities. The individual tourist cannot be in more than one place at the same time, and the tourist movement must be continuous, so eventually there must be a unique and continuous travel path between any two sequential stops but other zones in which movement could have taken place.

Figure 2 also helps illustrate that space and time are two critical resources for tourists which they normally treat carefully to optimise their opportunities during the journey. Cooper (1981) studied and concluded that tourists' drives, goals and motivations differ from other searchers (e.g. retail consumers) especially in the way that tourists have a very limited time to complete their explorations. As an ephemeral and dynamic resource the value of time quickly enters the consciousness of the tourist as a motivating factor in planning the best possible experience. Time acts as an independent variable against which tourists can measure their progress in terms of sites visited and enjoyment derived (Ullman 1974). Lacking the structure of everyday life, and given priority by the scale of financial investment involved, the tourists themselves have to structure the time by their own ongoing decision and actions.

The availability of time during periods of holiday movement influences how deeply tourists explore specific destinations as well as the number of places visited and frequency of visitation. Truong and Henscher (1985) remarked that time is one of the few absolutes tourists must face, for it cannot be stored for use at a future date. Those who have much time available behave differently from those whose time is limited. Constantly time is present as a factor that argues for speedy transport and stops of limited duration, but a factor is always conditioned by the interest and the value of the landscape traversed and the stop that is visited.

Figure 2 provides a demonstration of a possible day in a FIT's life. Examining it we can hypothesise what happened and why, and with the records of many tourists we could assess the impacts of tourism. There is a gap between the pure example of a tourist timeline in that figure, and the information revealed by the WCTFS about the real movement of individuals in the summers of 1999–2001. The diagram provides pure timelines, the survey provides a series of points and slightly incomplete records.

The next section describes the way in which the WCTFS data was transformed from a series of isolated points into timelines that could be visualized and analyzed in terms of error and uncertainty.

2.2 Constructing Travel Paths of Individual Movement

The case study data of WCTFS records the tourists' activities only at stops of known location, not during movement, although each respondent's survey map contains a sketch of the trip and stops. These were used only in validating the written answers. A WCTFS stop location is typically a named location such as a town or attraction. Spatial coordinates are assigned to these locations using a centroid measure or local landmark. Un-named locations are assigned coordinates from positions as shown on the survey's map. Accuracy of the stops in most cases is 250–500 m but with map-marked locations this is harder to ascertain and may be higher.

Presence outside of those times occurs during movement, which we can record as the activity between stops. In the original data this activity is not present, only inferred in both time and space. To infer the missing temporal activity and location a travel path has to be built into the dataset. The critical part of this is to identify the path that the tourist takes and then identify the time at different places along the route. Routes can be roads, tracks, railways, rivers but are predominantly thoroughfares suited for vehicles.

The technique we use for this is a basic minimum-cost path algorithm run on a network comprising various grades of sealed and unsealed roadways and a number of walking tracks. The coverage represents all of the roads on the West Coast and major roads outside the area. Analysis was run using network tools available in ArcInfo (ESRI 2008) and analyzed in ArcMap (ESRI 2008). This approach represents roads as a series of segments, each one representing the location of part of the road. The length in meters can be calculated from this and other information on sections can be stored with the sections in order to provide a means to represent attributes such as nature of the road pavement, travel time, typical speed, restrictions and other variables. Movement between two stops is represented as a number of segments. A series of such groups can be combined to represent the tourist's *itinerary.*

The network analysis tools provide a means to calculate the optimal path between any two points on the network, i.e. for any trip that a tourist records. This allows the trip to be represented as a path along the roads and tracks (rather than as just two points) and for a most likely path to be identified. Furthermore, each section of the network can be calibrated in terms of travel time, with more or less sophistication, allowing individual trips to be expressed in minutes. Significant benefits of this are:

- Travel time estimates can be calculated for any intervening location on the road;
- Movement can be related to the geography and places that are passed through by a tourist;
- Travel times between survey stops can be compared with recorded survey travel times;
- The position of an individual at any time can be estimated, so that a dense point set can be created to allow fast query and visualization of movement;

- Possible travel speeds can be calculated to include the influence of gradient, regulation (speed limit zones) and sinuosity.

In this instance a West Coast terrain model was combined with contemporary road centrelines and speed limit data to build a topologically enabled road network in order to create estimates of the optimal path routes between stops based on travel times. A set of ARC Macro Language (AML) scripts were used in ARC/INFO to execute this process and the computation of the travel times between every pair of stops. These times were added to WCTFS dataset, and as a result each record should have contained the following travel information (although in many cases respondent fatigue or loss of focus resulted in only partial records):

- Spatial information: the location and identity of previous (origin) stop and current (destination) stop. Non-spatial information collected on each record relates to the destination (current) stop.
- Temporal information including: Travel day, Travel time from the previous stop, arrival time at the current stop and duration time at current stop (from which departure time could also be calculated.
- Information on activities that the respondent undertook at the current stop.

At this point it becomes possible to transfer information between the geospatial representation associated with the network and the original database tables derived from the survey. New analyses are possible. Initially these involve parsing the tables for null responses, for instance the absence of a stop duration. As a next step the respondent reports of the durations within the journey and visits can be examined and tested against the estimates from the network analysis. A further series of space-time reasoning algorithms can also be applied in order to assess and enhance the spatiotemporal data quality of the survey.

3 Assessing and Mapping the Patterns of Spatial–Temporal Data Quality of Movement Survey

3.1 Assessing Spatial-Temporal Data Quality of WCTFS

During the survey, tourists were requested to recall facts about the spatiotemporal events of itineraries, couched in terms of movement from one stop to the next. The key queries were ‘Where did you start from’, ‘where did you go to’, ‘when did you arrive at the attraction’, ‘how long did you stay’ (which allowed the calculation of departure from that place). Four types of data uncertainty or quality issues were identified for analysis: (1) absent arrival times; (2) absent durations of stay; (3) inconsistent arrival times; (4) possible unreported stops. Absence is simple to identify. Reporting inconsistent times (reflecting unusual journey times) is a more complex issue, in that a norm is needed for comparison and a model must be established to separate truly unlikely reported values from everyday variation in

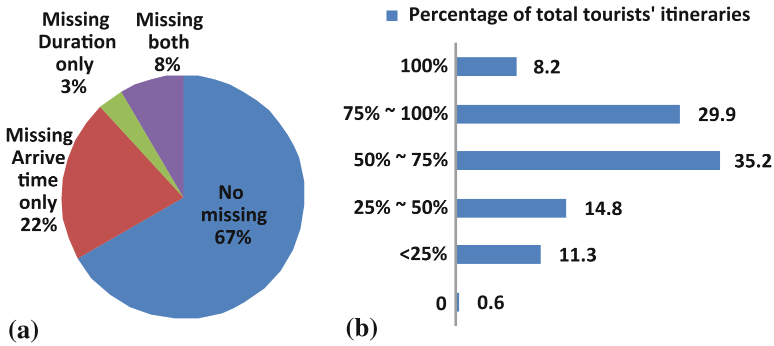

Fig. 3 **a** Percentage of completeness of temporal events by total stops. **b** Percentage of completeness of temporal events by itineraries. Six percentage ranges display the completeness levels of temporal records

reporting. "Unreported stops" is a known issue with survey instruments, and it is likely that a number of minor stops may be overlooked in an itinerary, as well as some major ones.

3.1.1 Assessing the Completeness of Temporal Events in WCTFS

As Fig. 3 illustrates, there are quite significant absences in the data, but nonetheless the great majority of individual stop-to-stop stages are completed fully. 67 of records had fully completed temporal events of arrival times and duration, with the remaining 33 % containing one or two temporal gaps. Individual itineraries fare slightly differently since with an average ten recorded stops per visitor totally complete responses are much rarer. There are only about 8.2 % itineraries with no gaps of temporal events. Roughly 35 % tourists recalled half to three quarters of their arrival time and duration events of their itineraries, while there are over a quarter of the respondents who have not remembered to record over half of the temporal events of their itineraries. Six out of 1,000 tourists did not report any arrival time and durations of their journey at all, recording only the places. The reason behind this pattern is discussed later.

3.1.2 Identifying Inconsistent Records by Reference to GIS Estimations

While absent data compromises our overall dataset we also know that reported spatiotemporal events may contain errors: early or late reporting of arrival times, misquoted durations and missing stops. Recognising and correcting slack reporting is important in assessing data quality. The method used for achieving this goal involves a comparison of the imputed arrival times described in Sect. 2. Figure 4a categorises the results of comparison between these two versions. The negative

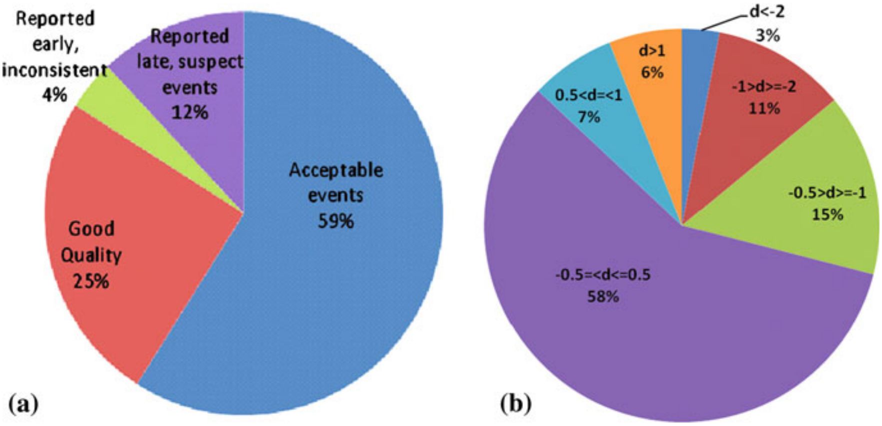

Fig. 4 Comparison results of GIS estimates of arrival times and reported arrival times on selected samples. **a** The differentiations between two versions of arrival times. **b** Rated accuracy levels of reported arrival times

values in the figure indicate that the reported arrival times are later than the estimated values (journey took longer than the model).

Approximately 58 % of records have a variance in arrival time that is less than half an hour from the GIS estimates of arrival times. In addition 13 of reported arrival times are more than half an hour early, and nearly 30 % are half an hour later than GIS estimated arrival times. This seems to imply that the bulk of sections had drivers who complied largely with expected norms but dallied a bit more than expected, while only a third arrived appreciably (over 30 min) early. It is easy to dally, and even easier to forget a small stop that slowed you down, but harder to cut time off a solid driving performance. Clearly there is also a variance in reporting ability as well as in perseverance in completing all the questions.

While variation of driving times is to be expected, a large differentiation between GIS estimates of arrival times and the reported arrival times can indicate that there might be inconsistent temporal values being recorded (misreporting of arrival times) or there could be actual stops omitted between two reported stops. However, to determine the data accuracy only based on the raw difference in minutes is arbitrary. A more suitable assessment matrix for identifying likely anomalies was developed based on the weighting of the impacts from travel time, duration and the difference between the GIS estimates of arrival times and the reported late times. This adjusted for the length of particular legs of the trip, since longer travel times (or longer stays) reduce the relative significance of a particular divergence between estimated and reported travel times. By adding the weighted values together, the accuracy levels of arrival times were rated and summarised into four types which are displayed in Fig. 4b.

Figure 4b shows that there are approximately one out of four reported arrival times matching the GIS estimates of arrival times; 59 % recorded arrival times which are acceptable with reference to the modeled driving times and duration levels of the stop; about 4 arrival times that are not consistent with prior temporal events, and 12 % reported arrival times reported earlier which are later than the estimated times. These notably early and late reported arrival times were tagged as suspect temporal events in the WCTFS dataset.

Legs with possible missing stops were then inspected in respect of the reported late arrival times, which possibly are inaccurately late or are accurate but conceal a missing stop of some length. During the survey, respondents were required to record any stops including stopovers with duration of 5 min and more: we know that not all stops get identified at all. Several criteria might alert us to mis-reporting, including the claimed length of continuous driving and the claimed duration of the activity at the new stop. Excessive driving time between stops may provide some clue to the existence of misunreported stops. Chen (2004) identified that the typical continuous driving time of tourists is close to 2 h. We reason from this that sections of continuous driving over 2 h with no stops recorded are more suspect than shorter sessions in terms of possibly concealing a missing stop and its duration. Stop to stop travel which exceeds the estimated time by more than 30 min is tagged as highly likely to have failed to report at least one stop and the stops with such arrival times are interrogated as inconsistent temporal records. There are a total 159 records out of a total 21,084 that were tagged in this category.

3.2 Patterns in Spatiotemporal Data Quality

We know that the completeness and consistency of the reporting of spatiotemporal events varies from one person to another during a survey. Variation in reporting may occur due to different people having different levels of ability to recall an event. Respondents from different gender groups, age groups, social classes or countries of origin may exhibit different biases of interest and so contribute to different levels of reported data quality. The nature of the stops and their associated events also influence reporting, leaving different impacts on respondents' memories. Some events are easier to retrieve and therefore reported by respondents accurately. In contrast, some events may make less impression and enjoy a lower level of recognition with respondents and are likely to miss out or be recorded incorrectly. In short, many variables affect reporting rates and accuracy.

To use the data within a weighted analysis and look for appreciable patterns or relationships we typically assume that error is randomly generated. We might also hope that absence is similarly distributed with spatiotemporal data. It seems possible and is hoped that error issues and data omissions exhibit regularities that would be valuable to identify. One example would be the increase of missed or poor data with time into the itinerary. Time lapse for recall between experience and reporting is a similar case. This section reviews the revealed patterns of non-reporting (absence) and apparent anomalies in reported data items.

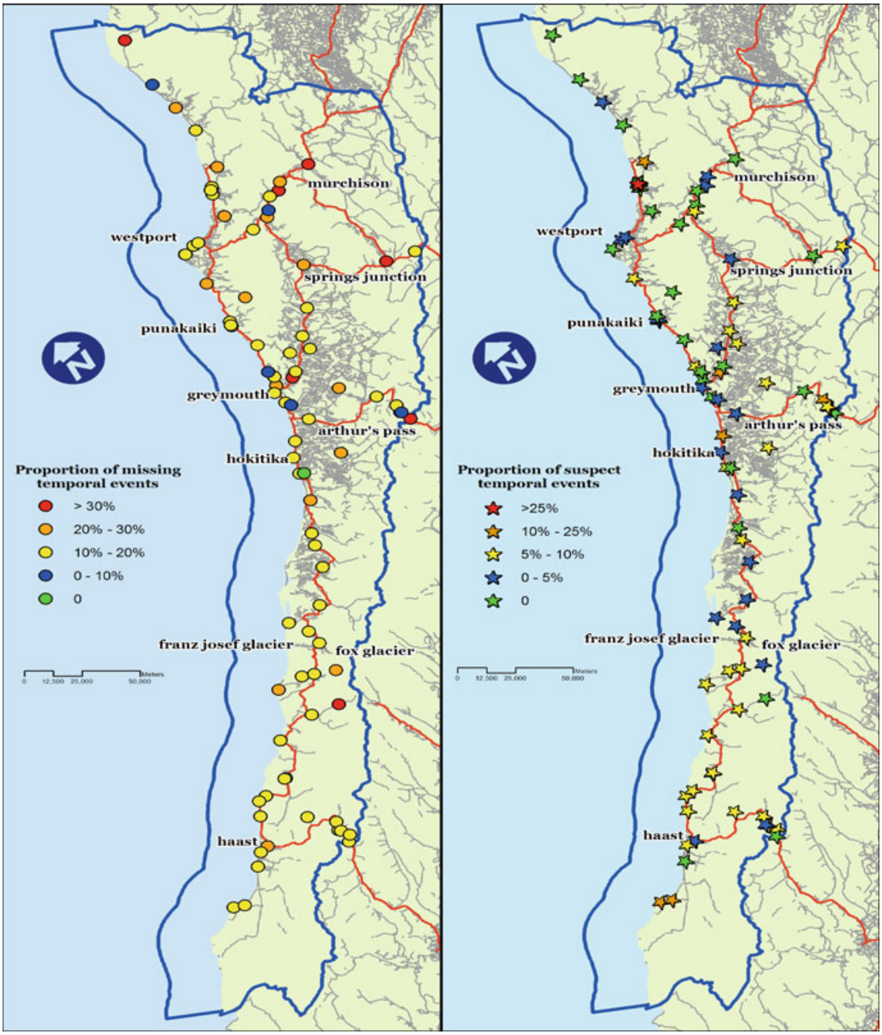

Fig. 5 Spatial distribution of data quality of WCTFS by stops

3.2.1 Spatial Patterns of Gaps and Errors

The pair of maps in Fig. 5 demonstrates the spatial pattern of errors and gaps at stops in WCTFS. The left one shows the proportion of missing temporal events, and the right one displays the occurrence of quality issues for recorded events. Both maps have excluded any stops with less than ten visits.

The map on the left shows that the majority of the stops have approximately 10–20 % missing temporal events, but some variance is discernible. This is less notable in the stops in the southern part of the region where a largely similar set of values dominates. By contrast the northern part of the Coast demonstrates palpably higher variation in the level of data completeness, with extreme proportional values appearing north of Greymouth and more stops further north with missing arrival times or durations in the survey data.

The pattern of gaps in the data differs from the pattern of notable errors. The map on the right in Fig. 5 summarises the proportion of suspect recorded events at stops. The suspect events are identified by comparing the recorded arrival times with the GIS calculated values. It can be seen that the majority of stops have less than ten percent suspect arrival times recorded in the survey data. These suspect times are either earlier or later than GIS estimates of arrival times. The stops in the northern part of West Coast have more accurate recorded arrival times than the stops in the southern part. Such variations along the Coast may be due to the distinct patterns and compositions of tourist flows identified in the WCTFS study (Forer and Simmons 2011), particularly the greater presence of domestic tourists on shorter tours following more limited circuits focussed on Arthur's and Lewis Passes.

In some cases the levels of missing events or suspect recorded values are related to the nature of the stops, with Murchison, Arthur's Pass and Springs Junction have a noticeable proportion of missing temporal events, but the recorded arrival times are accurate. This may indicate their unique location at the border of the Coast and the distraction of entering or leaving this leg of their holiday. Perhaps the events at these stops were easier to forget or engaged less with people's memories. Most tourists arrived at these stops for food or rest, filling petrol or just as a transition. The events are simply less vivid and in the hurry to find their main destinations, stops are few. Generally, overnight stops also elicit specific behaviour and explain the reason for proportionally more stops with missing temporal records, since the ambiguity of arrival and departure and the distractions of multiple attractions may lead to oversight or some confusion.

Spatial pattern of data quality reveals some insights. Further insights can be gained by considering the direction of travel. The travel directions were identified from the overnight trips with multiple stops, specifically, the travel directions refer to the overall day's trip directions. The West Coast is a long narrow area and movement can be easily categorised as having a southerly or northerly direction. There is some imbalance in North and South flows, accompanied by the belief that northward travellers are more focused on returning home and be distracted in a number of ways and may stop less. Psychologically closer to the end of their holiday direction may have impact on people recalling their spatiotemporal events of itineraries during the survey. There are slightly fewer stops when travelling north but more completed records were picked up for consistency checking. The completeness and consistency assessment were carried out on the stops within the region and the results are shown in Fig. 6.

Stops on northward trips have slightly more missing temporal events but possess slightly more accurate records. The reasons could be that there are more temporal events at exit portals like Murchison and Arthur's Pass, on the other hand, there are fewer stops on northern trips but more daily trips, which indicates

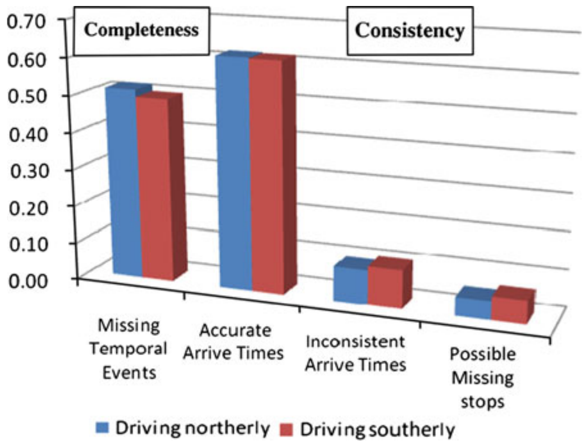

Fig. 6 Percentages of completeness and consistency of WCTFS by day travel directions

that during the latter part of the itineraries, tourists tend to stop less frequently. On the way home, tourists might be reluctant to fill the diaries but the events are comparatively clearer in their minds which result in better data quality.

3.2.2 Temporal Patterns of Gaps and Errors

Events close to temporal boundaries are easier for respondents to recall (Lynn et al. 2005): the closer that the event being recorded is to its actual occurrence, the easier the recall and the greater the likely accuracy of response. Any lag may also have an impact on the recalled vividness of the tourist's impression, as may the time during the day that the event is experienced, or recorded, and other experiences that may have intervened. Various factors have a psychological effect on tourists' recall abilities and these may be related to time of occurrence and time of recording. The actual performance in a specific case may depend on the instrument used (diary or interview) and, at least for the diary, the respondent's choice of timing to achieve completion of the survey paperwork. Whatever the cause of delay, there are patterns of gaps and errors in the survey dataset related to temporal dynamics. It is also expected that there are some general regularities in performance related to recall factors.

Figure 7 addresses some of these issues, with Fig. 7a illustrating variations in quality levels related to the relative timing of an event during the whole itinerary. This is done by percentage of completed temporal events by complete travel days during the itineraries. As can be seen, the stops on the second day of the trip have the highest level of completion of temporal events, after which the percentages keep declining until day seven with the value going up again but dropping down again at day eight.

This summary does not look at the whole itineraries, rather examining the temporal events within the general travel day information. The basic stance is that

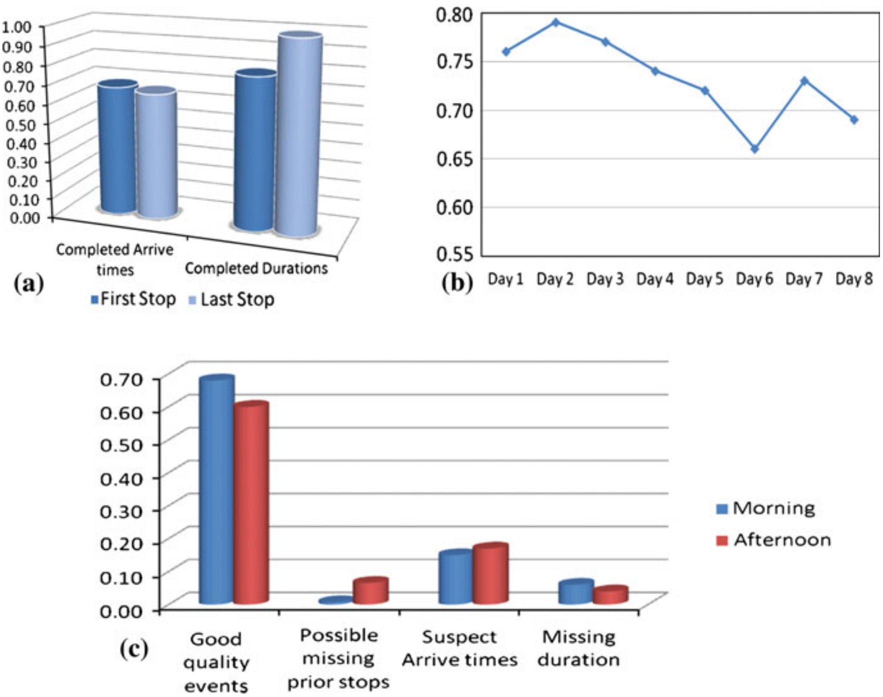

Fig. 7 **a** Percentage of completeness of temporal events by travel days. **b** Percentage of completeness of temporal events by first and last stops of overnight trips. **c** Spatial–temporal data accuracy levels by morning and afternoon stops

each overnight stay resets the clock and coherence across a day rolls through to coherence across the itinerary. Figure 7b shows the completeness with respect to the first stop and the last stop of the morning-to-night trips. Both the first stop and the last stop of these trips are close to temporal boundaries, therefore, both should have better completeness of recording temporal events. Because last stops of the day normally the overnight stop and their durations were recorded as description "overnight" instead of absolute values, thus the durations of the last stops are highly completed, but in an uninformative way.

Figure 7c illustrates variations in data quality within the day, dividing records into morning and afternoon periods and looking in more detail at possible error levels. Morning observations appear to provide higher quality data in general but also suffer most from missing values for duration. The afternoon sees higher levels of suspicious arrival times, an effect which translates into a considerable difference in share of cases classified as a likely missing stop. Overall, the accuracy of recorded data is higher in the morning, although not by much, while possible omissions are far more prevalent as the day progresses.

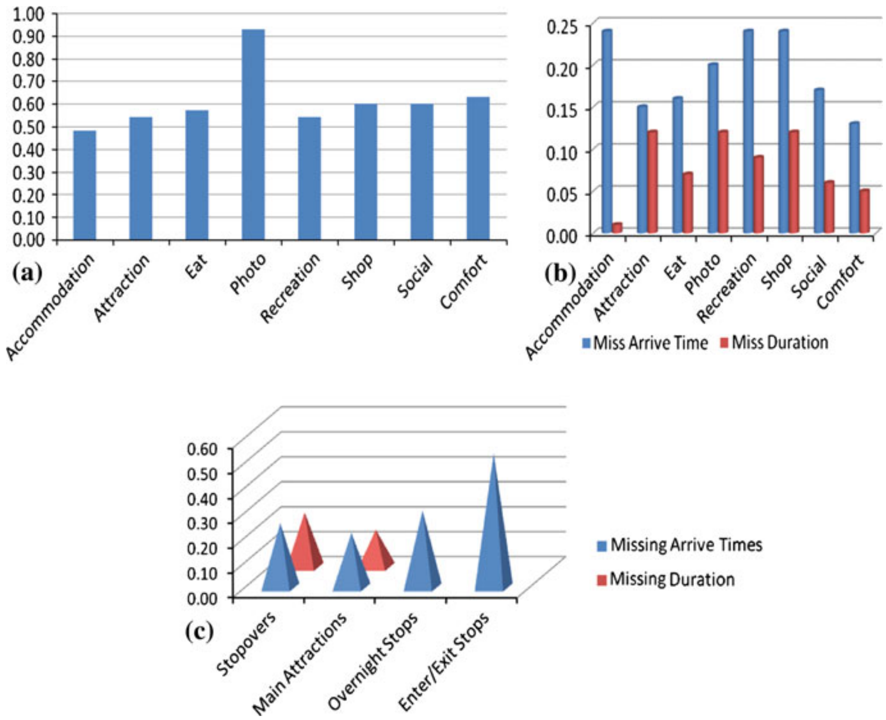

Fig. 8 **a** Percentage of completeness of temporal events by activities. **b** Percentage of arrival time accuracy of temporal events by activities. **c** Percentage of comparison of missing temporal events by types of stops

3.2.3 Patterns of Gaps and Errors by Activities

Analysis to date has identified some variations in data quality associated with space and time. Activity at the stop and associated reasons for stopping, also have a significant impact on people's memory and thus the reporting of spatiotemporal survey data. Describing and coding activity was also an issue. In the original data, tourists provided a free text response when asked for activity. Recoding required close interpretation and in some cases a response was missing or uncodable. In order to examine the data quality patterns associated with the activity data, sample records were chosen and the recorded activities were grouped into eight types as indicated in Fig. 8a and b below.

One interpretation of Fig. 8a is that different activities people chose left different impressions on people's memories. While mundane activities may leave little impact pre-meditated activities with a high motivation factor may often impact significantly and so have a clearer recollection of arrival times, particularly if they have been driving towards a target arrival time as part of planning. This may well be the case with itineraries planned prior to the holiday and so such itineraries enjoy better completeness. Photographs may provide a further prompt through the recallable memory of a tourist stopping and taking photos and this may be one reason why this activity has the most consistent arrival times amongst the eight activities. Activities of having food is often a time related event, which might explain why less arrival times are missed for these stops. Socialising is an activity related to people, the time starts and ends are easy to recall, hence the durations about social activity are less missed. In contrast, events about accommodation and recreation have less completeness and consistency, as they are not very time-restricted. The duration of accommodation is normally simply recorded as "overnight", consequently, it is seldom missed out in the survey. Shopping is a random and additional activity during itineraries; it is not time-restricted either and probably has less impression on the tourists mind compared with other activities, so there are relatively more missing temporal events with respect to this activity in the travel survey data.

The patterns of gaps and errors associated with activities takes samples with solo activity only, therefore the figure shows a lower percentage of gaps than the percentage for the entire dataset since single activity events are easier to recall than multiple activity events. To examine the pattern of gaps associated with visiting characteristics on the whole dataset, the approach can be achieved by categorising stops based on both activity and duration attributes, stops are grouped into four main types: stopover, main attraction, overnight stop and enter/exit stop.

The missing events percentages by types of stops in Fig. 8c demonstrate an identical result to the previous discussion about spatial pattern of incompleteness and the gaps distribution by activities. Those enter or exit stops have more possibility of missing arrival times, the duration events are not included here since the exit stops have no durations. Overnight stops have lower percentage of missing events than those portal stops. Finally, main attractions have better completeness of temporal events followed by stopovers.

3.2.4 Patterns of Gaps and Errors by Tourists' Profiles

Recall ability varies from one person to another, depending on people's ages, gender and other profiles. The reported data quality therefore shows patterns among different types of tourists' profiles.

Gender is an interesting reference for assessing the data quality of spatiotemporal events recorded by tourists as Fig. 9a shows. Females are commonly regarded as having a lower level of spatial awareness and lower capability of memorising times compared with males (Ecuyer-Dab and Robert 2004). However, females probably have more patience to respond to the survey. Although it does not directly show whether male or female tourists did better a job in recording the temporal events in WCTFS, the conclusion is manifest that female respondents performed better in the data completeness but slightly behind male respondents in relation to the accuracy of the temporal events.

Another data quality pattern can be found from the travel group characteristics. Figure 9b shows that the fewer adults in the itinerary group, the lower the

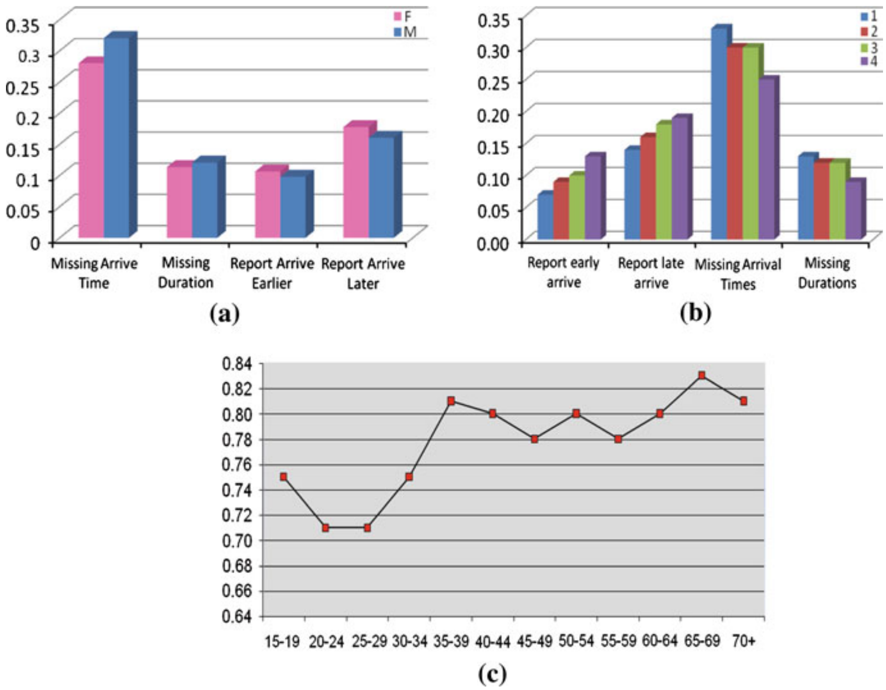

Fig. 9 **a** Percentage of reported temporal data quality by gender. **b** Percentage of reported temporal data quality by number of adults in the group. **c** Percentage of completeness of temporal events by age groups

completeness of temporal events in the survey, but reported arrival times are closer to the estimated times from minimum cost travel times. This could imply that the more people travelling together results in a more random arrival times in the itineraries.

As for the completeness of recording temporal events by age groups, Fig. 9c summarizes the difference of percentages among 12 groups at 5 year intervals. Tourists around 60–65 years old completed most of the temporal events followed by the group of 35–39 years old. General trend is that younger respondents recorded less temporal information in the records of WCTFS.

3.2.5 Patterns of Gaps and Errors by Survey Instruments

WCTFS data was obtained by two survey instruments collected in almost equal numbers: a diary survey completed during the itinerary itself and face-to-face, retrospective, exit interviews at the main portals. Each instrument has advantages and disadvantages of recording itinerary events.

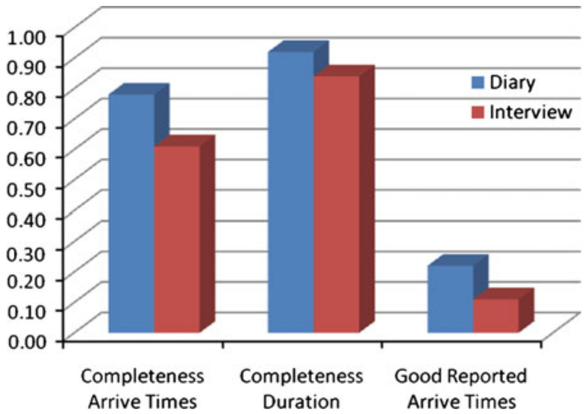

Fig. 10 Data completeness and accuracy by survey means

Figure 10 shows that the self-administered diary approach can achieve better completeness for recording temporal events of tourist movement; in addition, given the time to record the travel events on the day, the diary method captures more accurate spatial–temporal information of the itineraries. The differences are not that great to make either approach redundant, and indeed analysis has shown that the two sets of data provide a similar set of estimates in terms of tabulations of data at key tourist sites (Forer and Simmons 2011).

This section systematically assessed the spatiotemporal data quality of WCTFS. The quality issues were diagnosed in terms of gaps from uncompleted questions, and errors from records that were not consistent with plausible behavior. Three types of gaps were examined in the dataset: missing arrival time, missing duration and possible missing prior stop. The one type of error used is derived from inconsistency between reported arrival times and modeled expectations.

A number of findings have been determined through this assessment. First of all, although the case study data shows a certain level of data confidence in terms of the overall spatiotemporal data accuracy, there are as expected missing temporal events in the movement survey data. There are also a significant number of reported arrival times in the dataset that have notable levels of discrepancy from modeled estimates of arrival time. These are likely to reflect poor time keeping or overlooking a prior stop.

Preliminary exploration of incompleteness and inconsistency has demonstrated a number of latent patterns in the dataset. Several parameters have been used to identify the possible impacts of specific factors such as age, gender, activity at stop and time of capture. These provide evidence of particular factors at work, generally significant but in all cases confounded by each other. A useful finding is the recorded data accuracy of spatiotemporal events is palpably influenced by the activities tourists carried out at the stops.

The locations and functions of places on the West Coast attract tourists taking different activities and staying for different durations. Consequently, the accuracy level of captured spatiotemporal data varies from one stop to another. The main attractions have fewer gaps and errors in the related touring events, occasional stops are missed out altogether, temporal events get overlooked at stops with a large number of visits, and enter/exit stops have lower completeness but more accurate recorded arrival times due to the nature of the experience of entering or leaving the Coast. Against this the profiles of individual tourists have lesser impact. In a number of contexts higher completeness does not result in higher consistency. Tourists tend to round the temporal events into half hour segments and combine with the cumulative impact of slowing down for views and taking micro stops perceived as less than 5 min and so not recorded, this appears to result in reported arrival times that are later than those modeled. Clearly accuracy in a number of forms varies systematically and in a complex way across space, time and circumstance, and although this chapter cannot hope to resolve the issues raised, it can still suggest a way to counter at least some of the issues around absence and anomalous reporting.

4 Enhancing Spatiotemporal Data Quality of Movement Survey

4.1 Filling Temporal Gaps of Movement Data by Cross-Inference

4.1.1 Interpolate/Extrapolate Missing Temporal Events from Known Variables

In any movement dataset temporal processes (and individual tourists) should be represented as moving forward continuously, which is in contrast to the stop-oriented representation from survey data, and for that matter from GPS, but at a finer scale. The original stops recorded on the WCTFS framework are certainly point based with significant gaps, gaps we would like to reduce. We can do this crudely and inaccurately by linking sequential points with straight lines, but this very crude technique can be replaced where movement is channelled within a network such as a road network. Here we can trace possible paths along a continuous line, interpolating back to a finer pattern of intermediate points if we need this for further analysis. At the same time we can model characteristics of the network links to allow estimations of typical transition times for different forms of travel. In this way incomplete data on arrival times and durations as well as anomalies can be augmented by interpolating/extrapolating from known events as a simple formula below explains. Arrival time (T_i^a), duration time (T_i^d), and travel time (T_i^p) values were formatted into decimal times to enable the calculations. Technically, filling gaps by cross-inference is an iterative process designed to eventually achieve maximum retrieval of missing events.

Table 2 Samples of missing durations estimated from activities

Estimated from activities	
Activity	Estimated duration(hr)
Lunch	0.5
Multi-activity including lunch	1
Food, coffee, ice cream, drink	0.25
Petrol, gas, diesel, fuel	0.15
Gold mining	1.5

$$T^a_{i-1} = T^a_i + T^d_i + T^p_{i+1} \quad (i = 1, \ldots, n).$$

4.1.2 Estimate Missing Durations from Related Attributes

The basis of this cross reference is that while significant numbers of data items are not filled in for a specific question, a much greater number of respondents will have filled in answers to that same question, and this establishes a distribution of outcomes: for instance for the likely duration of a stop at Franz Josef Glacier. If the amount known is large enough, which it usually is at significant stops, then this distribution can be used to model a surrogate duration to replace null responses. If there are not sufficient neighbouring arrival times for interpolating/extrapolating in this manner a duration can be assigned using a simpler norm from answered responses. Table 2 presents the allocated durations used that are based on activity attributes and are referenced from the highest-frequency of reported durations.

This method can provide a basic form of estimate for activity classes, and can be modelled in a more sophisticated way using multivariate methods. Once applied this creates the possibility of a set of partly synthetic but complete timelines suitable for consistency checking and wider analysis.

4.2 Identifying and Validating Inconsistent Temporal Events

A valid and coherent itinerary is one that sustains a continuous time line which is consistent with possible travel speed and activities. The method used here for consistency checking is to calculate a referenced arrival time at each stop based on travel times from GIS constructed travel paths. The variation between the arrival time and the modelled value can be taken to check the temporal consistency between the two stops.

As noted, during survey, tourists tended to report their arrival time with rounded values, in addition some of the missing durations and missing arrival times at the first stop after overnight stops were estimated from the high frequency distribution of known values, these values were soon used to process the GIS estimates of arrival times, therefore the variation between arrival times and GIS estimates of arrival times already contains some subjective assumptions. These assumptions need to be considered when determining if an arrival time with a different value from the GIS estimates is an error, or on the other hand, the definition of error in temporal events is influenced by the nature of the stops involved. Certainly, the acceptable levels of consistency of arrival times have been given a higher tolerance for overnight stops than for short stopovers. Finally, taking the above factors into consideration, for overnight stops and stops with a duration of over 4 h, only the difference between arrival times and model estimates that are >1 h are identified as errors for further modelling. By contrast, differences of only half an hour are defined as anomalies for other stops. At the end of the consistency checking, the arrival times were qualified as two types: acceptable events (within anticipated parameters) and error/anomalous events which suggested a need for action. Error events were consequently replaced by GIS estimates of arrival times and/or subject to further analysis.

As the newly assigned arrival times can cause new inconsistency in the dataset the process has to be recursive and repeat the checking and updating. When complete the rectified arrival times are stored in a new field in the attribute table and a comment field is necessary to record the actions. Finally, there are about 2 % records out of the total WCTFS whose arrival times are identified as errors and assigned new arrival times in the dataset.

4.3 Evaluation of Enhancement

In order to verify the enhancement process and assess the validity of the methodologies, an evaluation of the enhancement is undertaken by applying the same space–time algorithms on a sub-sample of complete movement records that have had random arrival times removed. The result of this reconstruction provides a tool to assess the validity of this approach.

Figure 11 shows the variation between evaluation results and original reported values. There are approximately 70 % of the evaluation results have less than about half an hour difference from reported values, and approximately 84 % are within 1 h variation from the original reported temporal events.

The evaluation results above indicate that the enhanced events largely match the reported values. Although there are noticeable variations between them, in considering the fact that original reported events by respondents might contain errors and affect the accuracy of the evaluation, this variation is in line with expectations and the general accuracy of reporting by respondents.

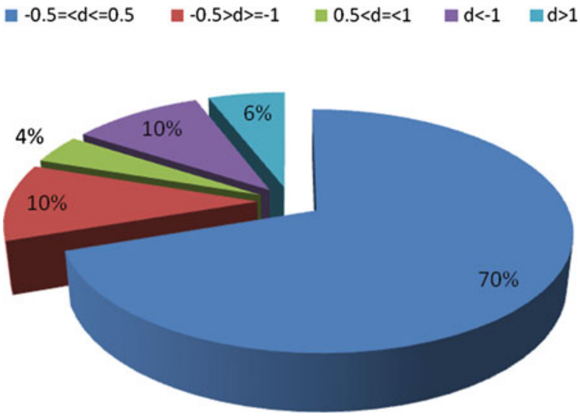

Fig. 11 Proportions of the variation between evaluation results and original reported values

5 Applications and Conclusions

This paper has sought to investigate the accuracy properties of a fairly typical rich movement dataset collected through a non-digital, field based methodology. In small part this has entailed basic stock-taking on non-responses to questions, but the major contribution has been to view these data in the context of the constraints and influences of space, time and process. This has involved the use of GIS in transforming the survey's spatial–temporal information from a discrete, point-oriented representation to a continuous trajectory reflecting actual transport conditions and norm travel times. This has two positive outcomes, it allows both the identification of travel-time anomalies in the dataset and the development of a framework for estimating missing values consistent with space–time constraints and behavioural norms at tourist attractions. In short, we have enhanced insights on the quality of the data (in both time and space) and have gained the option of working with an augmented dataset that amongst other things is formatted in a way that is supportive of sophisticated geovisualisation and query.

The literature on quality assessment of tourist movement datasets is fairly sparse, and close comparison with other research is hard to achieve, but our results are probably not atypical of field interviews constricted by a limitation on delivery time. Certainly the findings confirm expectations on factors affecting response levels and accuracy, and show interesting differences across the two survey instruments. The literature on augmentation of space–time datasets is also fairly brief. The fairly simple model utilised in this paper adds substantial value, and opens the way to use geovisual analytics as a means to interrogate the data in a semi-qualitative way (Zhao et al. 2011). Future research could expand the ability to extract more value by enhancing the models used to allocate activities or timings to blank entries. We cannot hope to recapture the information totally, but as Tobler and Wineberg (1971) speculated on Cappadocia, cross-referencing data and distance can sometimes restore the lost information. At present, although some enhancement steps were based on subjective parameters they account for a small portion of the total dataset, and there is room for improvement on these.

It is tempting to think that field-based surveys such as the WCTFS will be superseded by GPS enabled methodologies, theoretically capable of ensuring complete space-time coherency in individual movement, and unobtrusive to the respondent. Indeed non-obtrusive-non-consensual tracking has its proponents and a very different augmentation research agenda. Even now however the WCTFS could not rely on consistent coverage, nor on adequate smartphone usage, nor on the funding for respondent equipment at a large scale, and realities such as these are likely to persist for a while yet in many domains.

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Simplifying Climate Change Communication: An Application of Data Visualisation at the Regional and Local Scale

Jean-Philippe Aurambout, Falak Sheth, Ian Bishop and Christopher Pettit

Abstract We have limited empirical information on the value of different visualisation techniques and how they may best be applied in a range of situations. The goal of this research was to provide insights into the capacity of various visualisation techniques to communicate projected climate change data and their implications for dairy production in the south-western region of Victoria, Australia. We used a combination of technologies including animation of geographical information system outputs, three-dimensional images and Google Earth. The developed visualisation products were presented to a group of local stakeholders for evaluation and feedback. We found, in this preliminary study, that visualisation technology can provide a user-friendly way to access contextualized data with perspectives relevant to stakeholders who may be dealing with a complex multi-dimensional problem such as climate change. We also used the opportunity to find out more about the current usage patterns and expectations with respect to climate change data.

Keywords Scientific data visualisation · Climate change · Digital globe · 3D realistic visualisation

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7_6,

1 Introduction

The communication to end-users of data that varies across space and time is a constant issue which confronts scientists working with dynamic spatial processes. The communication of climate change information to local and regional agriculture industry stakeholders is particularly difficult for variety of reasons. Climate change projections are typically forecast far in the future (e.g., year 2100) and at a very broad spatial resolution, such as 50 km^2 for a global circulation model (GCM). Such broad scale spatial modeling outputs lack relevance to local stakeholders and the climate impact is usually described in ways that are very difficult for local stakeholders to translate into on-the-ground consequences. What, for example, does a 2 °C increase in average temperature mean for a dairy farmer?

The Victorian Climate Change Adaptation Program (VCCAP) is a multi-disciplinary research program that has generated and collected a large amount of scientific information relative to climate change projections, impact and potential adaptation options for South West Victoria, Australia. The aim of the program was to increase the knowledge and capabilities of stakeholders across the spectrum from policy maker to farmer to prepare and adapt to climate change and to minimize associated socioeconomic and environmental impacts and risks. To assist with the delivery of VCCAP research findings, the Victorian Department of Primary Industries (DPI) VCCAP visualisation team investigated the use of different data visualisation methods to convey a meaningful message to community and government.

This paper describes a set of representations and tools developed to improve the communicability and accessibility of spatio-temporal datasets to stakeholders. We explored the use of various types of data visualisation (ranging from direct display of tabular and graph data to maps, animation and more realistic 3D data representation), brought together through a digital globe interface. The Google Earth digital globe has been used as a development platform as it incorporates high resolution satellite imagery and terrain data and allows easy navigation across multiple levels of resolution. As previously reported, the Google Earth platform has successfully been used to communicate climate change research outputs both in Australia (Pettit et al. 2010) and Canada (Schroth et al. 2009). The digital globe platform provided a suitable interactive and user-friendly environment to visually explore and interact with scientific spatial datasets. A number of data visualisation methods have been applied to communicate climate change data relative to a specific research and demonstration dairy farm in south-western Victoria known as Demo Dairy. Visualisation options were evaluated by a group of local stakeholders which included farmers and catchment managers.

2 Study Region and Dataset

2.1 Region of Interest

The Department of Primary Industries' VCCAP focused on a pilot region in south-western Victoria for investigating potential climate change impact and possible adaptations. This region has the highest rate of population employed in the agricultural sector in Victoria and produces a large number of agricultural commodities. It is also one of the main dairy areas in Australia, generating $2 billion a year and delivering 50 % of the region's exports. (Spencer 2009). As part of an effort to communicate VCCAP research findings and engage stakeholders, the visualisation team developed both landscape- and farm-scale visualisation products which illustrate how the region, and individual farms, may be impacted by, and adapt to, climate change.

2.2 Data Sources

Climate visualisation of maximum temperature, minimum temperature and rainfall were developed from two data sources. Both datasets were obtained for the State of Victoria in a raster format at a resolution of 0.05 degrees (approximately 5 km):

- Data relative to projected changes in climate in Victoria were obtained from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (www.ozclim.com.au). The climate change projections considered in the paper were taken from the CSIRO Mark 3.5 climate change model, Special Report on Emissions Scenarios (SERES) Marker Scenario A1FI (fossil fuel intensive) using a high climate sensitivity.
- Past historical climate variations for the years 1961–1990 (used as baseline by global circulation models) and 1998–2007 (corresponding to the last decade) were calculated using monthly climate records obtained through the Queensland Department of Environment and Resource Management SILO dataset.

Visualisation of potential impact at the local farm scale used three data sources:

- Outputs of the Sustainable Grazing System Pasture (SGS) model, a biophysical simulation model of processes for various grazing practices investigating future changes in pasture growth under different climate change scenarios at the farm scale, including at Demo Dairy (Cullen et al. 2008).
- Aerial imagery, digital elevation model and property information including parcel boundaries and farm infrastructure.
- Digital photographs of farm infrastructure, animals and pastures. These were used to construct landscape objects and textures to build visualisation products.

3 Regional Scale Visualisation

Visualisation of the duration and extent of projected changes in the Victorian climate was achieved through two complementary approaches:

- The creation of an animation providing an overall statewide perspective of the extent of the projected changes in temperature and rainfall and rate at which these changes are likely to occur.
- The creation of tables and graphs associating each centroid point of cells from a 0.05 degree Victoria raster map with its projected monthly and annual average temperatures and rainfall across multiple years.

3.1 Temporal Animation Development

Animations depicting the duration and extent of projected changes in annual average temperature and rainfall, across the state of Victoria, between the year 2000 and 2050 were developed through the following workflow:

Annual average values for temperature and rainfall were calculated in ESRI ArcGIS 9.3 for the year 2000 and 2050 using monthly climate records and climate change projections respectively. In order to create a visually smooth transition between the dataset corresponding to the year 2000 and the projected data for 2050, synthetic data was calculated through a backward propagating method from 2050 using a yearly time step. This was done to avoid the display of unrealistic sharp transitions between the data, and assumed a linear temperature increase from one year to the next. The applied method could easily be altered to take into account intermediate years as they become available, or as derived from a different interpolation formula. In creating such a data visualisation product a certain amount of artistic license is available and corresponding care is required. As reported by Monmonier (1996), all cartographic products including data visualisations may include a number of cartographic 'white lies'. What is most important is that an ethical stance is taken by the visualisation producer to depict and convey the correct context and meaning to the output, as reported by Sheppard and Cizek (2009). In this case, the scale of the changes was felt to be more important than the specific trajectory, especially as data for interpolation was not easily available.

The climate raster data for the years 2000, 2050 and intermediate years was then exported to Keyhole Markup Language (KML) as a series of spatially projected image overlays, using geoprocessing scripts previously developed by Aurambout and Pettit (2008). Next, we made use of the KML 'time-span' functionality to automatically specify the dates and duration for which each overlay should be visible in Google Earth. The use of this functionality enabled the display

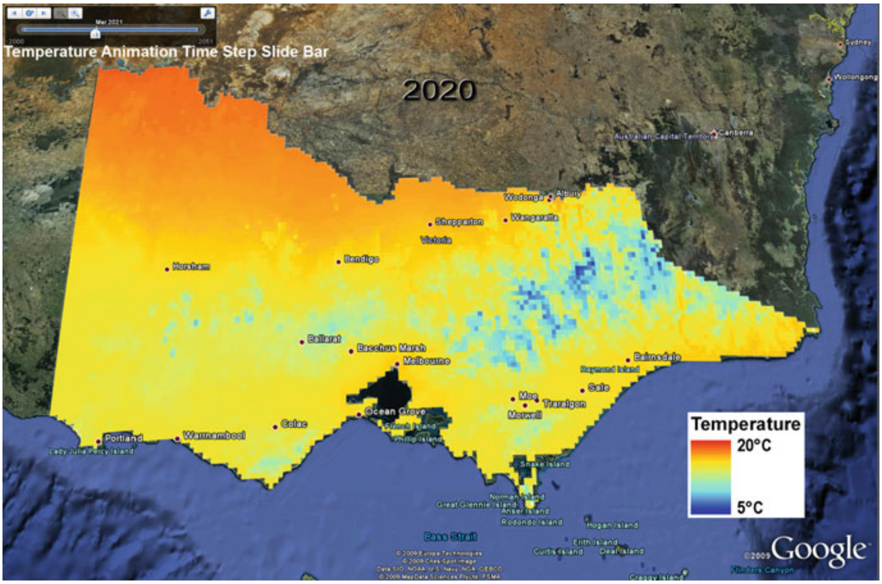

Fig. 1 Screen shot of temperature time series data in Google Earth displaying changes in mean annual average temperatures between the year 2000 and 2050

of spatiotemporal changes in temperature and rainfall across Victoria. End-users could use the Google Earth slider bar to select a year of interest and examine the spatial variations of the selected variable as illustrated. In order to improve the readability of the displayed spatiotemporal data, a graduated colour legend ramp was used. This was produced in ArcGIS and was added as a KML screen overlay. The spatiotemporal temperature change data visualisation across Victoria is illustrated in Fig. 1.

A Python script was written to automate raster data calculation and export routines, allowing the process to be easily repeated with alternate climate datasets. This mode of communication of complex scientific modeling outputs presents advantages over conventional data communication methods such as static maps or two-dimensional animations. The KML output viewable via Google Earth provided the capacity to investigate different locations and zoom in and out of regional areas during the animation or for a specific time step, thereby increasing the relevance of model outputs at the regional and local scales. However, the value of time series image overlays in isolation is limited as it only allows users to view the data without the possibility of querying the underlying dataset (for example, to extract the exact temperature/rainfall values at specific locations). The user also needs to be aware that as one zooms into the farm or paddock level the uncertainty of the forecast climate data increases. Unless such data is calibrated with a specific weather station or other finer-scale data its relevance is predominantly for regional decision making.

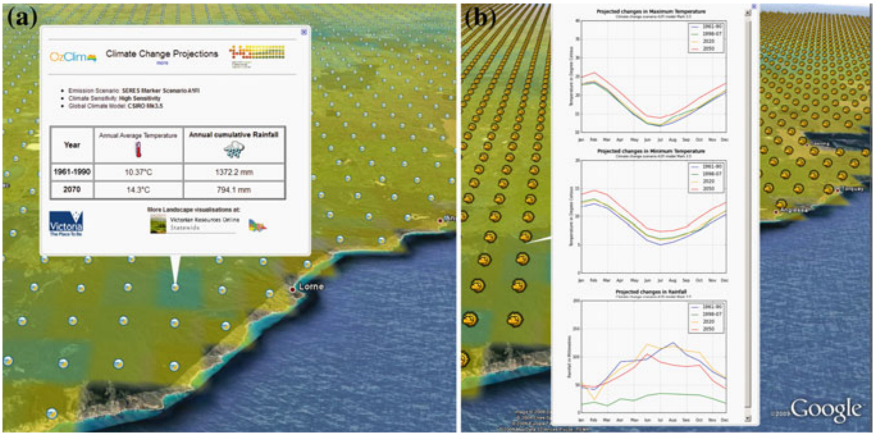

Fig. 2 Screenshots of Google Earth embedded clickable hyperlinks describing **a** tabular data of local climate change conditions and **b** graph illustration of monthly temperature and rainfall variations

3.2 Development of Tabular and Graphical Data

To provide further contextual information and complement the time-series visualisations described above, we developed a method to associate tabular and graph data to the centroid of each raster dataset. The tabular and graph data display are embedded within Google Earth, using the following workflow. This workflow is applied to temperature and rainfall variables across multiple years at each specific point.

The climate data rasters (provided in text (.asc) format) were, through successive GIS processes (later automated through python geoprocessing scripts), georeferenced, and converted to vector point data. The climatic data from each vector file was then combined into a single file by merging their attribute table values. The table data obtained for annual averages temperature and rainfall for the 1961–1990 historical average and the year 2070 were exported directly into a KML file, thought the use of the Export to KML 2.5.4 ArcGIS extension (available from www.esri.com) and formatted into a tabular structure through edition of the 'KMLFeature description' using HTML (see Fig. 2a). Finally, a graph of the monthly changes in maximum, minimum temperature and accumulated rainfall for the year 1961–1990, 1998–2007, 2020 and 2050 were produced for each centroid using the tabular data produced earlier in the process. Graphs were produced as. PNG images via a Python script using the Numpy and Matplotlib libraries. These graphs were then inserted into the KML through the use of the Export to KML extension (see Fig. 2b).

This method allowed the creation of KML files that contained the climate data outputs associated with the centroid for each grid cell. This information is contained within the KML 'placemark' (a clickable point feature) displaying information with relative conditions on the ground for that specific location, either in a table format (Fig. 2a) or a series of graphs (Fig. 2b).

3.3 Advantages and Limitations of Both Approaches

The use of a combined temporal animation and clickable hyperlinks displaying detailed tabular or graphical data within a digital globe environment provides an interactive display and communication of spatio-temporal data. While the created time series products provided a broad scale perspective of changes in climatic conditions, the addition of clickable points provided detailed local information. This functionality enables end-users to zoom-in on any area of interest and point and click to explore the data further.

The use of hyperlinks to retrieve locally relevant information is not new. These functions are available on web mapping tools such as the Bureau of Meteorology Forecast Explorer (http://www.bom.gov.au/vic/forecasts/map.shtml). However, its use within the Google Earth interface greatly enhances the value of the displayed climate datasets by bringing together regional data and localised information in a single, easy to navigate, integrated environment. The availability of high resolution aerial imagery and elevation also provides contextual information that helps users relate more easily with the model climate data. We believe the use of these data visualisation methods represents a significant step forward in communicating complex scientific models which can better support land management decision making.

However, the above described visualisation methods inherits the limitation that the graphs produced by the methodology outlined in Sect. 3.2 need to be generated for all centroid locations of a defined landscape. A more efficient technique would result in an on-demand generation for selected points and locations (area of interest generated rather than complete statewide coverage). Producing such graphs for the State of Victoria, at a 5 degree resolution generates a sizeable KML file (around 300 Mb). This provides a challenge when sharing the results with end-users either via email or online hosting. A possible solution to this problem would be the production of the images ‘on the fly’ by linking the clickable object to a web server that would produce the graph on demand and give access to the produced image only once it is requested.

4 Local Scale Data Visualisation

Complex problems such as climate change (for which the implications appear, to many people, distant and abstract) may be particularly difficult for land managers to relate. A sense that the available data are personally irrelevant may be exacerbated by the lack of localised climate data (most GCM models typically provide data on a 50 km grid cell resolution), but also by the lack of information of what the local changes may mean at the farm scale. For example, a farmer may have great difficulty translating an increase in average annual temperatures of 2 °C in terms of crop yield or farm revenue. Consequently, even localised climate data may not be sufficient, without further interpretation, to allow land managers to relate to climate change and truly understand its potential implications on their livelihood.

Three-dimensional (3D) photo-realistic visualisations have been principally deployed in the urban planning context, to provide more substance to abstract alternative scenarios by making data more concrete in the user's mind and allowing him/her to better relate to it. For example, Hudson-Smith and Evans (2003) modeled a virtual London using 3D Geographical Information Systems (GIS) software.

Sheppard (2005) pioneered the use of such technology to explore future climate change scenarios. Our approach (described below) aimed to make climate change projection and impact data more relevant to local stakeholders by combining the use of local climate data and model outputs with 3D photo-realistic visualisations of how things currently look on the ground and how they may change under future projected climate conditions. Such an approach has previously been used to represent likely agricultural responses to climate change in the United Kingdom (Dockerty et al. 2005). Our approach focused on a single case study farm in south-western Victoria named Demo Dairy. We developed, on the Google Earth digital globe platform, a 'virtual Demo Dairy' (http://www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/geovis_virtual_demoDAIRY) in which local stakeholders could visualise and access local data relevant to their industry.

This virtual farm was based on two components which were integrated into Google Earth through the use of KML functionalities (balloon, object and panorama):

- The first component provided access to general farm information and data on pasture growth under different climate change conditions data (see Sect. 2).
- The second component made use of 3D photo-realistic image rendering software, namely 3D Studio Max and Visual Nature Studio (VNS) to depict local infrastructure and conditions on the ground as well as possible futures.

4.1 Providing Access to Local Data

One of the objectives of this research was to explore the use of a digital globe approach for making climate change data and modeling products more accessible.

Our project made use of Google Earth placemarks: clickable point features to which information can be associated (similar to that described in Sect. 3.2) to embed information at chosen locations. The visualisation product developed

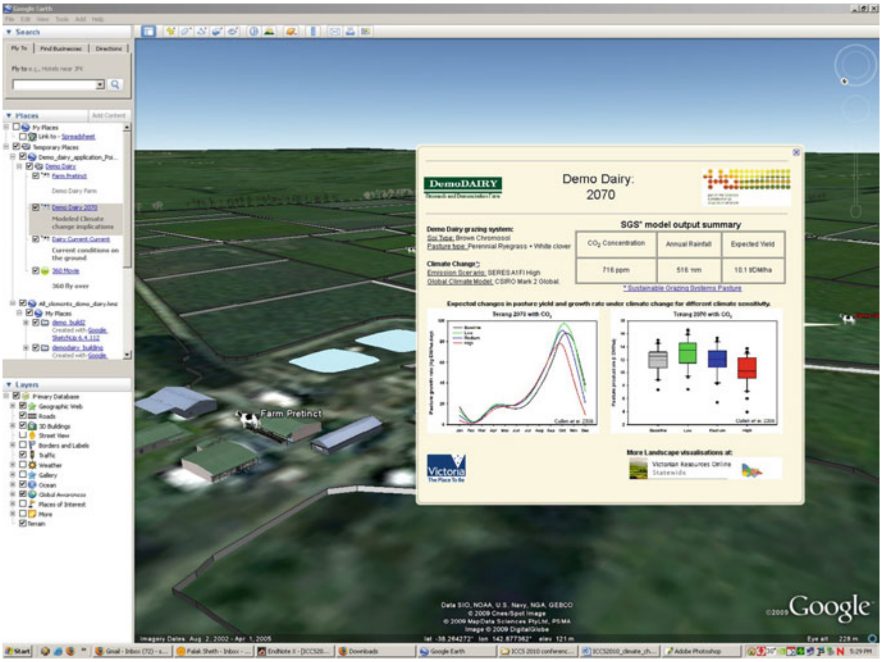

Fig. 3 Illustration of Google Earth placemark at the local scale presenting results from a locally run SGS pasture growth model

incorporated multiple placemarks localised within the Demo Dairy farm boundaries by using Northgate's KML editor (http://www.northgates.ca/kmleditor/) to create each placemark and format its associated HTML balloon content. These placemarks (see Fig. 3) were used to provide point and click access to text, table and graph information. This information was categorised as:

- general information relative to the existing Demo Dairy farm and management practices. Developed to assist users to better understand the current environment and farming conditions.
- outputs from a locally calibrated pasture growth (SGS) model (Cullen et al. 2008). This model was run for different climate change scenarios and reported likely impact on pasture yield and growth pattern (Fig. 3).

4.2 3D Visualisation Development

4.2.1 Setting the Scene in 3D

To further enhance the capacity of the Google Earth KML based visualisation to provide a spatial context to which users may relate, we embedded 3D landscape objects and infrastructure (Pettit et al. 2009) of the Demo Dairy farm precinct (building, trees, fences), adding another level of reality to the normally available aerial imagery (Fig. 4). These 3D objects were created in 3D Studio Max 2008 from photographs, converted into KML format and manually placed on top of the available aerial imagery using Google SketchUp.

4.2.2 Virtual Panorama and Fly-Over

Farming systems are particularly sensitive to climatic conditions. Climate change is likely to impact a large number of variables that impact agricultural productivity. These variables include: temperature, rainfall, solar radiation, number of extreme events, soil moisture and water availability.

The complexity of agricultural systems is such that communicating their overall response can be very difficult through sets of simple graphs or tables. Dynamically linking graphical and tabular information to a spatial polygon or centroid, through a cartographic technique known as ‘brushing’ is one way to try and address the difficulty of communicating the complexity of the system. Research from Wang Baldonado et al. (2000) indicated this technique is useful for identifying statistical outliers, clusters etc. However, in this research we endeavour to explore the use of embedded geographical information through the use of 3D photo-realistic panoramas and fly-overs.

In order to provide a more holistic (multivariate) picture of how agricultural systems may be influenced by climate change on the ground, we investigated the use of two 3D photo-realistic landscape visualisation software products: 3D Nature—Visual Nature Studio (VNS) and Autodesk 3DS Max. Both products support the creation and display of a large number of variables (such as animal stocking rates, crop type and crop phenological stage), which could be individually controlled (size, colour, location) within a 3D landscape environment providing high levels of realism.

The first application used the 3D Studio Max 2008 and Vue xStream 7.5 software packages to create a bird’s eye view fly-over of a virtual representation of the Demo Dairy farm (Fig. 5a). This animation was developed by manually organising 3D trees, cows, wheat crops (in Vue xStream 7.5) in combination with previously developed farm infrastructure and overlaying them above existing aerial imagery draped on a digital elevation model. This animation was then published on YouTube and linked directly into the KML via a placemark.

Fig. 4 Screen shot of the virtual demo dairy site displaying 3D objects of the demo dairy farm infrastructure

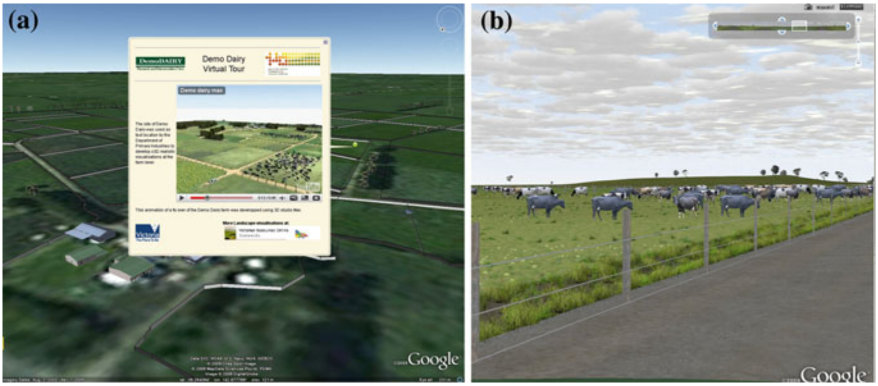

Fig. 5 **a** Example of virtual fly-over imbedded as YouTube video. **b** Example of google earth panorama used to illustrate present local condition at the demo dairy farm

The second application applied VNS to illustrate current and potential future conditions in Demo Dairy at the paddock level. Ecosystems were assembled from crop information data (density, species composition, size, etc.) and on the ground textures were applied in combination with previously developed 3D objects to each specified paddock according to the farm plan. The rendered images were then assembled into a 360 degree panorama viewpoint, using Photo Overlay Creator (www.casa.ucl.ac.uk/software/photooverlaycreator.asp) and displayed in Google Earth as a 'Street View like' interactive photo-overlay (Fig. 5b).

Although the outputs presented in Fig. 5 only show 'current on the ground conditions', they could easily be modified to display potential response scenarios (from crop modeling runs or derived from adaptation strategies) of the considered system to environmental changes.

Both methods described in this section are designed to produce visual outputs for a single location at a specific moment in time. While the development of animations can partially alleviate this issue and display dynamic processes, these outputs offer little interactivity to the viewer, as all movement or changes in the display need to be pre-processed. Each output being a static pre-processed image also lacks the capacity to link-in additional layers of information (such as numerical values of some of the variable displayed). The 360 degree panaroma products offer the most interactivity, and hyperlinks can be further embedded to assist navigation and exploration as reported in Pettit et al. (2004). However, this functionality has not been implemented for the virtual Demo Dairy visualisation product.

4.3 Advantages and Limitations of the Approach

The use of locally relevant climate change impact data is likely to assist local stakeholders relate to possible future scenarios and therefore facilitate discussion and community engagement. The combination of this localised data with 3D photo-realistic multivariate visualisation may further assist stakeholders to understand and explore climate change parameters and their likely impact at the farm scale. Stakeholders may also obtain a more holistic understanding of the likely impact and available adaptation options at the landscape scale.

However the use of localised data and 3D photo-realistic visualisation across multiple regions presents two key challenges. Firstly, the development of 3D realistic multivariate visualisation products requires significant manual input from the 3D modelers. Although new tools are progressively becoming available to automate some of the data import processes, the creation of 3D realistic visualisation is still a time consuming process into which computer rendering time needs to be factored (the higher the level of detail the more time it takes to produce the visualisation). Research is currently being conducted to automate the generation of 3D realistic visualisation by coupling GIS databases with computer game technology, see for example the Spatial Information Exploration Visualisation Environment (SIEVE) (Stock et al. 2008). Also the advances in digital globes such as Google Earth are supporting more automated generation of 3D datasets, in near real-time for any location and from a range of perspectives.

Secondly, there exists a limited data resource for local climate change impact and projections. While some climate change models are being downscaled (Pettit et al. 2010) to provide high resolution outputs and more climate change impact models are making use of those data, the amount of locally relevant data available is still largely insufficient to provide an overall perspective of climate change impact across all variables affecting farming systems. Consequently 3D photo-realistic visualisation developed from this incomplete knowledge of projected system changes may become subjective and potentially convey intentional or unintentional bias from the developer. Therefore as reported by Sheppard (2001)

Fig. 6 Demonstrating the climate change visualisation products at the workshop using touch table technology

there is a clear need for the 3D model builders to take an ethical approach for the development and application of such powerful visual tools.

5 Users' Response and Discussion

There have been a number of studies into the application of information visualisation tools for communicating climate change (Sheppard 2005; Nicholson-Cole 2005; Dockerty et al. 2005), and an integral aspect of this body of research is end-user perceptions. The landscape- and farm-scale climate change visualisation products described in our research have been made available online through the Victorian Resource Online Geographical Visualisation Portal (www.dpi.vic.gov.au\vro\demodairy). This has enabled stakeholders to test and familiarise themselves with the interfaces and data.

Sheppard (2005) pointed out that the use of 3D realistic visualisation without proper warning and context may lead potential end-users to confuse the depicted future with reality, rather than seeing them as a representation of a variety of possible future options. To overcome this risk, our climate change visualisation products were presented in a facilitated environment, during a 1 day workshop at the Demo Dairy site, on 8 December 2009. Workshop participants were allowed to individually interact with the visualisation products using both a standard laptop, (simulating the home environment) and a touch table (Fig. 6). The touch table supported a more open facilitated environment. This workshop was one of the first attempts to use visualisation tools to communicate local climate change impacts to the dairy industry in Australia.

Twenty local stakeholders (a mix of dairy farm managers and staff from the DPI, Farm Services Victoria Division) took part in the workshop. They were asked to complete a questionnaire to provide feedback on the perceived 'usefulness' of

Table 1 Summary of the technology and representational options explored in the survey

Visualisation option	Illustrated by…	Mean rating (1–7) ($N = 15$)
Animated time series of regional rainfall and temperature projections	Fig. 1	5.7
Interactive 3D models and fly-overs (including features such as farm buildings, fence layout, vegetation)	Figs. 4 and 5a	4.5
Hyperlinked outputs of pasture growth modelling results	Fig. 3	5.0
Realistic panoramas of future farm conditions	Fig. 5b	4.8

the visualisation products. Fifteen people submitted their questionnaires for analysis. The major technology options being explored are summarized along with their participant ratings in Table 1. In addition participants were asked a number of questions about their existing sources of climate data and their overall view of visualisation technology.

The workshop was well attended and the participants were generally positive about the visualisation products presented and the potential for extension to other data sets and applications. All the presented products received a positive evaluation (i.e., greater than four on the seven point scale). These are very preliminary findings with a small survey group who were not necessarily representative of the farming community or the general public. Amongst this group however, there is apparently greater support for the more conventional mapping or chart-based representations than for the interactive 3D models and realistic renderings. This result requires further exploration and additional surveys will be conducted which include not only subjective views on the provided representations and tools, but also objective tests of information communication and before-and-after surveys of attitudes to climate change and its implications. In this we are following some of the methodology reported by Schroth et al. (2009).

For this small, pre-test group it is instructive to consider some of the comments made about the different visualisation approaches since these are more likely to be helpful to future development than quantitative analysis. Table 2 presents selected comments.

The comments in Table 2 support the suggested greater ambivalence for 3D and realistic representation suggested in Table 1. There is indeed a significant polarisation of views in which some people are wholly unimpressed and others quite taken by the potential of the technology. This suggests that one solution is not going to suit all users of visualisation products and that reaching an entire audience may require provision of a range of visual media. Nevertheless, when asked for an overall view on the usefulness of the presented visualisation products, all workshop participants viewed visualisation tools as at least as valuable as other forms of data representation to communicate climate change (Fig. 7), with 14 out of 15 perceiving them as more valuable and five out of 15 very valuable. These results confirm the potential of visualisation technologies to communicate climate change data in a format perceived as more valuable than current reporting methods.

Table 2 Comments on the visualisation presentations

Animated time series of regional rainfall and temperature projections	On rather large scale, hard to convert to local/ farm level
	Gave a good impact and easy to understand
	Show a simple visual of the potential changes within rural Victoria, and by inference the implications for different rural industries
	Being able to zoom in/on an area/farm and see future projection of rainfall/temp very good for making all the talk and information real and relevant to one person
Interactive 3D models and fly-overs (including features such as farm buildings, fence layout, vegetation)	I think that applications of the products will develop as we discover new ways to use it
	Don't really think that visualising farm layout in 3D can help a farmer when they can see and understand their property by simply looking at it in real life
	Not really relevant for us in our whole farm planning role, a bit gimmicky, I suspect farmers would find it difficult to use and a bit of a waste of time
	Makes the whole thing more realistic, short of actually going into the paddock. It really gets you oriented on farm
Hyperlinked outputs of pasture growth modelling results	It provides the detail for the framework within which farmers might operate in the future
	Statistical data would give me a more useful impression
	again, a visual image of what might be, is of use
Realistic panoramas of future farm conditions	I think people often take far more in if they can visualise it, so this proves a valuable tool in trying to get the message across
	User friendly and relatively easy to use
	Not the way my mind works! An aerial photo plus data projections is OK for me
	They will be useful, particularly if it can be switched from real-time imagery to historic imagery of same site
	People take-in info. differently—the visualisation makes the info have impact and it's quick to interpret. I think it is something people can relate to and may take it more seriously
	I can't connect panoramas and text/tables. Not sure how a panorama would add value even with change in crop view. What they need is a crop yield value, for example, based on climate change impact

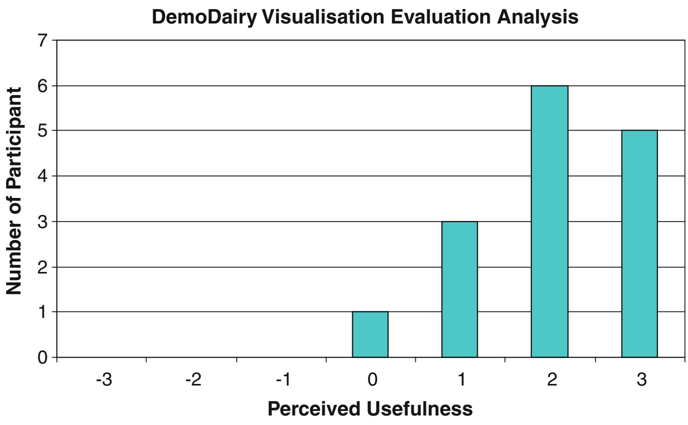

Fig. 7 Participants' (N = 15) responses to question "To what extent do you see visualisation as an improved communication tool relative to other form of data representation after seeing this presentation?"

Other factors affecting the responses could be that the visualisations of future climate could not be based on modeled ground truth data and were mainly illustrative of the potential of the tools. Previous work be Sheppard (2005) illustrating sea level rise using realistic landscape visualisation resulted in more positive responses, possibly because the message communicated was more simple to relate to (a major change in a single environmental variable with clear implications for the urban environment).

The results may also reflect the attendees' existing level of knowledge and expertise. It would be valuable to repeat the exercise with local farmers, as one participant commented: "for these tools to be useful to farmers and used by them, they must be (a) relevant to their farming operation, (b) easy to use".

As a result of this work, the expectation that a combination of multiple visualisation technologies embedded within digital globes could highly enhance the capacity to display and communicate the result of complex scientific spatial models is well supported.

6 Conclusion

There are many visualisation tools and techniques available to represent regional and local scale information. Digital globes such as Google Earth are making scientific information more accessible, including meteorological radar data and satellite images (Butler 2006). However, there is a limited understanding of the utility of various visualisation techniques for engaging different audiences in dealing with complex multi-dimensional problems such as climate change. There are numerous ways datasets and biophysical models can be visualised; but which technique best conveys the scientific information and messages in a way which is most useful and user friendly?

In this research we have presented several techniques for presenting and communicating climate change scenarios and impacts in south-western Victoria. Some preliminary end-user evaluation indicates support for advanced visualisation techniques for communicating complex scientific information. However, there are mixed responses on the effectiveness of various visualisation techniques. Early results indicate a preference for more traditional information visualisation techniques. More research is required to better understand user preferences for accessing scientific information from specific end-user groups and the utility value of preferred visualisation techniques.

Acknowledgments Special thanks to Dr Richard Eckard, science leader of the Victorian Climate Change Adaptation Program for his guidance and support in working with Demo Dairy. Also special thanks to Subhash Sharma and Peter Lanz in developing some of the technical components for the visualisation products.

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Part III
Geovisualization with Web 2.0 and Mobile Technologies

Developing a Geo-Collaborative Web Map to Support Student Fieldwork

James O'Brien and Kenneth Field

Abstract We begin by reiterating the pedagogic benefits of fieldwork and e-Learning individually before demonstrating added value by integrating the two with social networks and a collaborative infrastructure. Utilizing an exercise repeated over 2 days with identical goals but different instructional methodologies, we present the results from students' engagement within our geocollaborative web map environment. We developed an innovative, award winning fieldcourse experience by building on web-based learning undertaken before the trip, enhanced staff—student communication, reflective learning and inquiry-based learning during the trip through widespread use of mobile technology and social networks.

Keywords Web-based cartography · Mashups · Map design · Social media · Fieldwork · Pedagogy · Geocollaboration

1 Introduction

The value of fieldwork in geographical education is generally highlighted as being important (summarized in McGuinness and Simm (2005)). Many of these arguments in favour of fieldwork argue that placing theoretical learning in the practical

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7_7,

world is important. But there exist debates surrounding the type of teaching and learning undertaken on fieldwork. Arguments exist about the relative merits of instructor led versus student centered learning and top-down versus bottom up knowledge discovery and acquisition.

The benefits of eLearning environments are also generally well known and widely discussed (Jones and Newman 2006; Linsey et al. 2010a). Students expect to be able to acquire materials digitally and interact with lecturers via email and discussion boards within virtual learning environments (VLE). Students also make widespread use of social networks (e.g. Facebook) in their personal lives, not to meet learning outcomes. Some research has been undertaken on approaches to merge social networks (and other Web 2.0 technology) with eLearning approaches to create an "eLearning 2.0". mLearning, a mobile adaptation of eLearning 2.0, (using mobile technology in the field) has been suggested as a means to enhance the student experience. Students continue to have this expectation of being able to interact with staff and operate within a familiar learning environment even when away from the University on fieldwork (Linsey et al. 2010b).

What we present here is an implementation that links current eLearning practices with mLearning and social networks within a weeklong fieldwork class for GIS Bachelors and Masters students. We build on current trends of spatially enabled, interacting, data sharing user communities and develop a geocollaboratory (a map based, online collaborative web map environment) where we "mashup" spatial data (to provide context), social network posts from the students (taking place as part of discussions) and spatially reference those discussions.

Our ultimate goal of improving collaborative data gathering arose out of a desire to minimize the time spent by students homogenizing data at the end of each data collection day. Historically this would take several hours as different data categorizations were resolved. Instead we wanted students to conduct these discussions in situ. These discussions would enable a common data collection standard to be used enabling students to focus their end of day efforts on data analysis. To accomplish this we identified a need to:

- Create mechanisms for student–student group interaction when small groups are dispersed across the study area;
- Provide a means for students to collaborate remotely with staff, to develop methodologies as part of the exercise itself, provide technical support for students, collate interim results, and assess interim work to provide formative feedback;
- Manage the data collection process to cater for the in situ modification of the collection methodology by students and/or staff; and
- Develop content that can be delivered remotely in the field to enhance student experiential learning (e.g. to provide challenges during an exercise or to introduce changes to data requirements to assess adaptability and ingenuity).

In achieving this objective we also intended to meet the objectives of a larger project centered on Mobilising Remote Student Engagement (Linsey et al. 2010a) including:

- Understanding the potential for, and the mechanisms by which personal technologies encourage students to reflect on their learning and learner experiences.
- Develop approaches to building academic literacies that access informal skills developed through engaging with personal technologies.
- Investigate how personal technologies can be used to enhance and develop communication, collaboration and interactions between students, students to tutors, and tutors to students.
- Investigate how personal technologies can be integrated in learning activities to maximise the impact of appropriate feedback on student progress.

2 Background

Fieldwork in Geography is seen as essential, providing engagement with the real world through experiential and active learning (QAA 2007; Dummer et al. 2008; Linsey et al. 2010b). This is in contrast with some critiques of fieldwork where “the dominant style of fieldwork which has developed is the excursion-type, commonly called the “Cook’s Tour” which is characterized by a didactic/instructive teaching approach with passive student interaction” (Hawley 1996).

To overcome this non-interactive approach to fieldwork we look to engage the students by incorporating them in the process of building consensus and collaborating towards solving a task. In order to achieve this we draw inspiration from mLearning initiatives (built on eLearning) which permit students to interact remotely, enhancing interaction, collaboration and the development of “communities of practice” (Cobcroft et al. 2006).

Despite the acknowledged importance of fieldwork, eLearning & mLearning approaches, the use of technology in the field has been absent (Fletcher et al. 2007). Teeuw et al. (2005) supported challenging existing fieldtrip practices and the development of new approaches by incorporating new technologies. Technological developments (e.g. wireless technologies) and lower hardware and software costs have also enhanced the potential for using sophisticated technologies in the field with large cohorts (Field et al. 2005).

In order to integrate the mobile, dispersed collaboration and provide a spatial reference we developed a geocollaborative framework. We explore the conceptual elements of this framework below.

2.1 Geodeliberation

Much work has been done on testing and analysing approaches and processes within consensus building efforts to solve geospatial problems as well as the collaborative use of GIS. The idea of (geo)deliberation (Rinner et al. 2008) extended by Cai and Yu (2009) is at the core of our geocollaboratory. To reduce biased, local knowledge influences of traditional PPGIS, (geo)deliberation proposes cooperation and working towards consensus. Cai and Yu (2009) introduce a linear, bottom-up 5 stage process beginning with an introduction to a problem (1), through exploring issues (2), contributing personal observations (3), establishing a common ground (4) and developing actions (5). For student fieldwork we suggest geodeliberation is more accurately visualized as an iterative process of discovering exceptions to previously defined rules requiring modification of previously held beliefs or assumptions (Sandoval 2003; Kirschner et al. 2006).

To facilitate geodeliberation we require tools allowing communication, visualization, discussion tracking and analysis and sharing of data between participants. We place these tools within a *collaboratory*, a virtual space enabling geographically dispersed participants access to data repositories, conversation spaces, and even instrumentation (Cerf 1993; Finholt 2002). Collaboratories have not been explored for supporting geographical work in the field but examples exist for research in physical sciences (Kouzes et al. 1996; Olson et al. 1998; Russell et al. 2001; Keahey et al. 2002; Schissel et al. 2002), health sciences (Craver and Gold 2002; Olson et al. 2002), computational science (Kaur et al. 2001) and interdisciplinary research (MacEachren et al. 2006). Below we outline our infrastructure that attempts to develop a web-enabled fieldwork collaboratory utilizing web 2.0 tools and the Twitter social network.

2.2 Delphi

We have built upon the principles of the Delphi approach and subsequent web-based systems such as e-Delphi (Pike et al. 2009) in using online map-based social networking as a collaboratory. The goal of Delphi is to support asynchronous discussion (Dalkey 1969; Linstone and Turoff 1975; Turoff and Hiltz 1996) by eliciting structured, iterative input from diverse groups to not necessarily reach consensus, but identify key elements of a problem or points of agreement and disagreement. A moderator (an academic staff member in our application) poses questions, prompts interaction, synthesizes feedback, and guides the group (students) toward a goal (standardized data collection schema).

By providing moderation and "expert" oversight to balance the deliberation approaches of Rinner et al. (2008) and Cai and Yu (2009) we impose a top-down structure to ensure that the bottom-up discovery remains within the bounds of the problem to be solved and provide guidance to ensure consistency across iterations of the field course so that data collected from year to year are comparable. This approach also has pedagogic benefits of blending discovery, experiential and guided instruction techniques while answering critiques of unsupervised learning (Kirschner et al. 2006) and providing for inquiry based learning (Spronken-Smith et al. 2007).

2.3 Web 2.0 & GIS Infrastructure & Services

A critical element of the geodeliberation framework is interpersonal communication. This is a central tenet of Web 2.0, together with interoperable datasets, freely available spatial data access tools and application programming interfaces for integrating the communication, data and tools (Hall et al. 2010).

A spatial framework is valuable for underpinning discussion both for Web 2.0 applications and for geocollaboration and geodeliberation. Whether that is to provide spatial context for the users' comments or to spatially reference the users themselves. Web 2.0 map APIs have been widely used to display and augment GIS data on the internet for PPGIS tasks (Ganapati 2011), interactive environmental planning (Ghaemi et al. 2009) and geodeliberation (Cai and Yu 2009).

The typical architecture for web mapping applications (for either PPGIS or geodeliberation) is a database server (for maintaining discussions), a map server and/or spatial database server for providing spatial content (e.g. ArcGIS® geodatabases, map tiles or Google Maps™), a web server for hosting the application, and a series of clients (e.g. web browsers) for interacting with the application (Rinner et al. 2008; Cai and Yu 2009; Ghaemi et al. 2009).

2.4 Accessing & Mapping Social Networking Data

Students are generally familiar with online mapping environments and social networks. The availability of online map and data services (e.g. Google Maps™, Yahoo Maps™, Microsoft Bing™ and Esri® ArcGIS® Server or ArcGIS® Online) and the growth in social networking such as blogs, micro-blogs (e.g. Twitter posts and Facebook status updates) and online forums has created virtual worlds where place often forms part of the discussions. Subsequently students are comfortable with the concept of social network location sharing; providing spatial context for their activities and defining their online presence (Gibin et al. 2008).

Since its creation in 2006, Twitter has become a hugely popular online social networking tool where users post tweets of up to 140 characters in a similar fashion to SMS messaging (Honeycutt and Herring 2009). It was originally based around a simple concept asking users to post tweets to their profile with "what are they doing?" later re-phrased as "What's happening?". This change reflected a change in usage of Twitter as a tool to comment on issues instead of discussing the individual's actions. The spatial representation of tweets had been largely overlooked and the only visible spatial expression was in an individual's profile (Honeycutt and Herring 2009; Field and O'Brien 2010a). In addition to using the location of tweets as a proxy for a tweeter's location, there remains a range of potential ways in which the spatial expression can be enhanced and utilized beyond simple depiction on a map.

Brown (2010) highlights the context of location as important for the learning process in the field. By embedding students in a set of similar locations with varying exemplars of landuse types we are forcing them to interact and collaborate to build an archetype of each landuse. The only way for the students to accomplish this in situ is through mediation and deliberation via mobile devices. As the group of students in question are experienced with spatial reasoning (as a result of their GIS experience) they're also confident map users despite the change in map form from paper to digital.

2.5 Summary

While infrastructures currently exist for collecting volunteered geographic information its use is questionable without imposing a top-down framework to ensure consistency (Goodchild 2008). Web 2.0 provides a set of tools for enabling data contribution, information exchange and negotiation for GIS and the process of data collection from users. The challenge is to link these tools together in a meaningful way to manage spatial and aspatial data collection in a structured manner while facilitating collaboration (Cochrane 2005).

3 Context

While the implementation of the application is explored in the next section it is important to place it in context. Before continuing it is important to correct details of the fieldcourse presented in Beddall-Hill and Raper (2010). As part of a 3 year Bachelor's degree in Geographic Information Science (not Geography as has been reported in Cook (2010), approximately 15 second year students (and 15 GIS MSc students) took a class in Mobile GIS comprising a 1 week field course in Malta for data collection and post field course analysis tasks.

We use web-based learning (WBL) before the trip to familiarize students with the mobile tools they will be using (specifically Esri® Virtual Campus classes on ArcPad®). We utilize the social network Twitter for communication between students and staff during the trip. We incorporate reflective learning through the use of blogs and video diaries completed in the field and stored in the University's familiar VLE. These approaches are justified individually in a number of case-studies: WBL: (Clark et al. 2007; Ullrich et al. 2008; Gillet et al. 2008); Social networking (Ozok et al. 2009; Kamel Boulos and Wheeler 2007; Cole 2009); Blogs and video diaries (Churchill 2009; Cartwright 2008; Gruber 2008; Thompson 2007).

Rejecting the pedagogic crutch of hours of student pre-preparation for fieldwork only the WBL class on ArcPad® was introduced to students prior to the field-course. Past cohorts of students did not demonstrate retention of preparatory classes in the field and during revision exercises on the course expressed a feeling of having “done it all before”. We instead performed in situ training of the devices in the “real-world” replacing the “boredom” of repeated information from preparatory classes with greater enthusiasm and engagement. While the infrastructure of the geocollaboratory requires significant initial preparation by staff it encourages active learning through collaboration rather than passive learning through observation.

The field course introduces a range of mobile data capture technologies to satisfy the set of pedagogic objectives outlined earlier. Malta is chosen deliberately to provide logistical challenges for the students as the familiar data acquisition infrastructure of the UK is absent (together with fast internet access). The students operate under the simple premise that they arrive on the island with no data and by the end of the week will have acquired a range of datasets to support post–fieldcourse analytical work.

A sequence of exercises begins with gaining familiarisation with consumer–grade GPS devices for navigation and the capture of waypoints, tracklogs photos, video and audio recordings for a virtual tourism experience. As the week progresses the use of mobile GIS solutions for land use surveying using hand–held PDAs running Esri® ArcPad® integrated with ArcGIS® Server, differential GPS, Real-time Kinematic GPS and other surveying techniques are introduced.

The dominant learning paradigm is data gathering with mobile devices in small groups in Malta and then collaboration and data analysis at a later stage in a desktop environment at the University. Historically, this data gathering process has created significant difficulties in the field and led to problems in the analysis stage if students have not collected data within a common ontology. The tools demonstrated here are used heavily in the land use surveying exercises after being introduced to students in the navigation exercise.

Fostering a collaborative data gathering approach is only partially served by working in small groups (Drummond et al. 2006) and prior experience has demonstrated productivity and category agreement differences between different groups of students. Student groups are spatially dispersed across a 2 × 2 km (1.6 × 1.6 mi) study area and historically without means of interaction, communication & collaboration. Subsequently they operate autonomously, gathering data with different sampling strategies (e.g. classifying features using different object types, capture resolutions, attribution and detail). These different collection and classification strategies (their ontology of data collection) and/or a different epistemologies about category types lead to inconsistencies when data are combined as demonstrated by Gahegan and Brodaric (2001). Students’ results are often inaccurate due to poor quality analysis resulting from poor data capture techniques.

Satisfying one of our objectives we sought to develop a mobile learning collaboratory where students could interact through their personal smartphones (which were a collection of web-enabled devices from a range of manufacturers). The use of the internet was critical to the development of this collaborative learning environment and provided a suitable mechanism to visualize the progress and quality of student work during the exercises. This visualization was via an online map that underpinned the collaboration. It was intended to act as a spatial reference to improve student familiarity with an unfamiliar environment as well as mapping the locations of student groups, and visualizing productivity of student groups within their study areas. A communication method was required and the project made use of two: TxtTools a University implemented bulk SMS sending and receiving application and the Twitter microblogging service. Twitter enabled us to demonstrate how spatially referenced asynchronous and spatially distant collaboration can take place through this medium. The underlying map is used as a basis for discussion and consensus building and as a visualization aid.

Cook (2010) demonstrates a simple version of this observation and discussion with a small group of students using mobile phones as boundary objects (after Beddall-Hill and Raper (2010)). In our implementation the students use mobile phones as a communication medium for mediation via Twitter. They incorporate the camera functionality of their phones for sharing images of landuse to clarify contested concepts and make use of PDAs to map their environment as well as to gather spatial coordinates to accompany observations. We developed a Twitter map as a collaborative application medium enabling real-time, staff monitored communication to develop a common conceptual understanding in support of data capture.

4 Methodology

Student fieldwork often reflects the way in which geographically dispersed teams or individuals work (similar to the process of geodeliberation and the applications for collaboratories). The first "TweetMap" displaying the tweets over a map was built as a mechanism to explore the value of using social networking as a mechanism for collaborative learning using #uksnow map as a framework (Marsh 2009).

The 2009 iteration of the fieldcourse (Field and O'Brien 2010b) utilized a beta release of the map (Fig. 1) with student and staff feedback used to enhance the design of the interface and types of data displayed on the map. Issues identified through user feedback included how to deal with coincident tweets, how to manage threaded discussions and how to link tweets discussing similar concepts. These improvements were incorporated into the 2010 version of the map.

User feedback from the AGI Geocommunity 2009 conference confirmed psychological and visualization theories that a Twitter avatar provided a good marker symbol and that a visual timeline emphasized the temporal dimension of tweets improving spatial and temporal representation within the TweetMap (Field and O'Brien 2010a).

The students used the map as part of their data collection workflow during 2 days in the study area. The first day was a largely unstructured exercise where the students were given brief instructions about the need to map the landuse of the

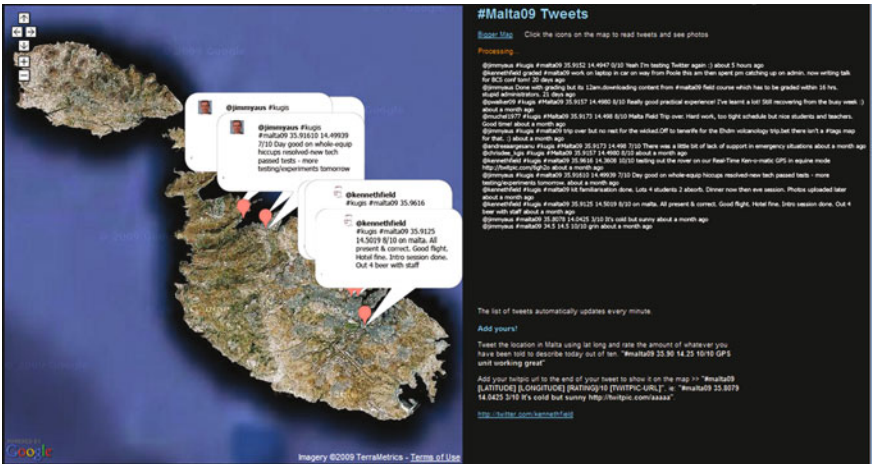

Fig. 1 Twitter as a collaborative mapping tool on Malta in 2009

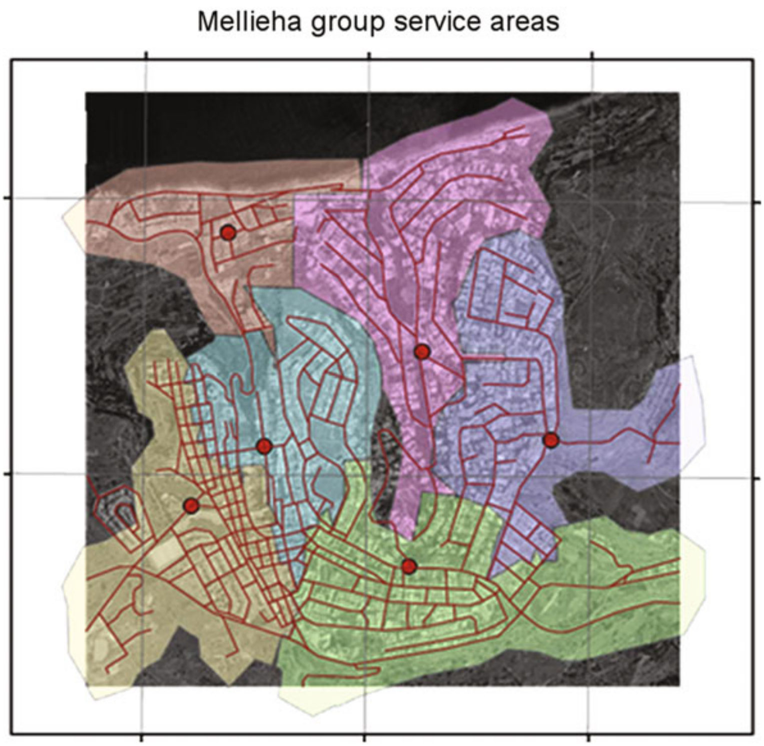

Fig. 2 Work areas assigned to student groups

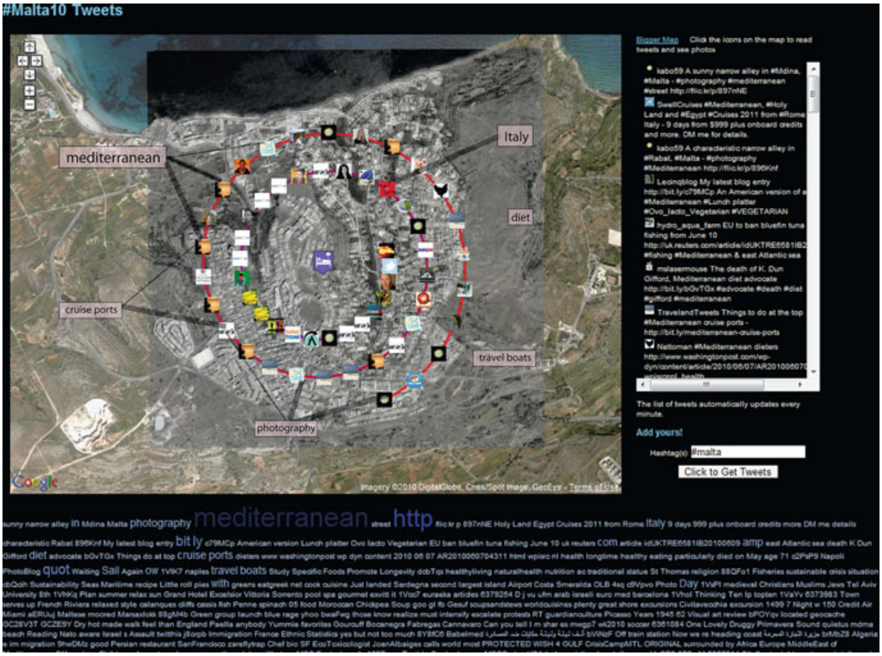

Fig. 3 Tweet visualization environment demonstrating a discussion theme of Maltese tourism

study area. The following day after the students had gained familiarity with the area, small groups were assigned "service areas" (Fig. 2) and given the same instructions. The land categorizations were deliberately vague to encourage the students to use Twitter to collaborate.

Figure 3 illustrates the various elements discussed within the methodology. The greyscale photo overlaying the Google™ base map data is supplied from our ArcGIS® Server. The tweets are reorganized around a central point to depict a discussion theme of tourism with common terms linked to the tweets which make reference to them. Only the most commonly used terms are mapped (no conjunctions or prepositions & greater than 5 uses of the term). The line thickness denotes the position of the term in the tweet as a primitive indicator of significance. The search bar for themes is shown in the bottom right corner and supports logical operators such as AND, OR and NOT.

The students used Trimble™ Juno™ PDAs and ArcPad® for data collection and made supplementary use of Garmin eTrex devices as a backup and for providing tweet coordinates. Students sent tweets via SMS from their mobile phones and had the ability to send and receive data via 3G cellular network to an ArcGIS® Server. The high cost of 3G access in Malta (approx. $8USD/Mb) limited students from sharing data in this manner but they did upload data to the server via local WiFi hotspots and/or via the staff's portable WiFi hotspot located at their initial starting location.

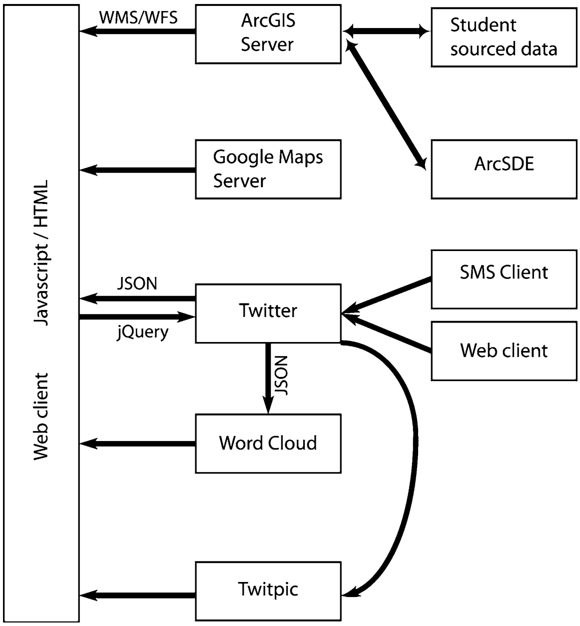

Fig. 4 Fieldwork geocollaboratory architecture

As students surveyed their allocated areas they utilized Twitter and twitpic (via multimedia message service) to communicate with staff about technical issues often with advice from other students, deliberated about data collection and sampling strategies before settling on a common approach which was disseminated using Twitter. A summary of the students' discussions are presented in the Results below.

The geocollaboratory links multiple web map services (using Google Maps™ API and Esri® ArcGIS® Server Javascript API), a social network (Twitter) and other services to visualize the content of tweets and any threaded discussions taking place (Fig. 4).

The outputs of this geocollaboratory are centered on the "TweetMap" which spatially (or temporally) references tweets from the Twitter API overlaid on data from the map services.

We utilized Twitter as our primary communication medium in preference to other social networking tools as earlier surveys of students (Linsey et al. 2010a) indicated a desire for students to keep personal and "professional" social networks separate (most students did not have pre-existing Twitter accounts) and the 140 character limit of Twitter forced students to have focussed discussions. This survey also indicated that all students on the trip had a mobile device capable of sending Twitter messages (either posting messages directly to their Twitter account through a web interface or indirectly as an SMS message through a third party application) minimizing 3G data costs.

The 2010 collaborative map used the Twitter API search function to find the #malta10 (an abbreviation for the Kingston University 2010 Malta field course) hashtag to denote content related to the fieldwork activities. The map illustrates

Fig. 5 #malta10 TweetMap used for the land use mapping exercise in Mellieha and utilizing alternate OpenStreetMap data (base map © 2010 CloudMade Map data CCBYSA 2010 OpenStreetMap.org)

Fig. 6 #malta10 TweetMap showing data arranged temporally (base map © 2010 CloudMade Map data CCBYSA 2010 OpenStreetMap.org)

tweets spatially arranged using GPS coordinates supplied within tweets that took the following form:

Coordinate data are supplied by students using the GPS equipment provided for the exercise or GPS functionality built into their phones. The student's profile or Twitter's geolocation API were not used to ensure accurate locations were recorded—only 22.5 % of tweets (166 out of 738) had correctly formed automatically provided geolocations. Figure 5 shows the spatial distribution of student tweets and therefore students across the study area for the duration of the exercise.

The TweetMap also permits tweets to be arranged temporally to allow a threaded discussion to be visualized with commonly used terms on the outside of the spiral (Fig. 6).

By focussing on the temporal aspect of the discussion we select a spatial location in the area that the exercise is taking place (in this case the city of Valetta in Malta). The avatars of contributors are arranged in a spiral so that the largest, outermost avatar is the most recent contributor. The content of the discussion is arranged around the outside using the visual variables of size and transparency to highlight the most frequently used concepts.

5 Results

The #malta10 TweetMap provides a number of ways of supporting collaborative learning. Firstly, student groups were working in disparate locations (see Fig. 5) and the Tweetmap allowed a common communication framework in which students could post messages, work in collaboration with other groups and communicate with staff.

The TweetMap provided a social network for students that pulled information from individual Twitter accounts into a common, shared platform adding value by defining the spatial context and enabling collaborative learning.

The loosely defined task of the landuse mapping exercise forced students to interact as demonstrated by them sharing images of unfamiliar landuse types via Twitter and asking questions such as "*Is this garrigue?*" and "*establishing whether farm land is derelict or not is difficult twitpic.com/atj12*". Responses from classmates who provided alternate views (bottom-up) and staff who could share textbook examples, images and definitions (top-down) informed and guided the implementation of a data collection schema (ontology) based on the students sharing their epistemologies and experiences.

Students debated this need for consistent data collection via Twitter (e.g. "*we need to sort out standardisation*") and developed an ad-hoc schema after deliberation (e.g. "*@rafchris #malta10 map these cats: ftpth, main rd, resid rd st furn aband agri, agri, agri bld, beach, com bldg, garrigue, maqu/@wedwobin"*) and built on experience of their environment the previous day which was then disseminated via Twitter. As documented by the students:

> Axxxx had looked up the definitions for Maquis and Garrique land types for us to use. Bxxxx then sent out our agreed standards into the Malta10 twittersphere for the other groups.

The students used a Delphi approach sharing potential categories via Twitter while being advised by staff. These categories were refined through iteration as groups shared "what if?" scenarios and individually observed categories were added to the developing schema (e.g. where students observed a new potential data type).

The students also shared technical tips for mapping different land use/landcover types using different technology (e.g. "#malta10 students who are complaining about poor signal quality are you using the external antenna?" and "great experience today, how a combination of diff devices to capture data and get one total output") and students reported a gain in efficiency of data collection over the previous day (e.g. "Efficiency much better—approx. over 1/3 of area done" and "productivity down due to heat and hills but much better than yesterday").

The threaded nature of discussions between students could also be visualized on the map (Fig. 3) using the spiral technique of Fig. 5 either centred over the study area or on the first tweeter to use a term, concept or ask a question (using the search box on the map page). This representation was monitored by staff via wifi and students were encouraged to check in regularly whenever they found publically available wifi (to avoid large data roaming charges over 3G). As previously noted students could send and receive tweets as free SMS messages so they were able to participate in the discussions. Replies to tweets could be extracted, ordered chronologically and added to the map in a Fibonacci spiral. This allowed staff to follow and contribute to a threaded discussion and to monitor the contributions of students for summative assessment.

6 Discussion

As illustrated above, the 2010 #malta10 TweetMap was used in a number of ways during the field course. Students were required to use it as a general collaboratory during the field course which enabled the collection of a chronological field log (Fig. 7). 738 tweets were exchanged during the week on all aspects of the tasks set with approximately half of these occurring during the land use mapping exercise.

The #malta10 TweetMap was used to support the same land use mapping exercise in Mellieha as the #malta09 TweetMap. The architecture and interface improvements, in addition to pedagogic improvements and increased student use of the environment, proved valuable. The students were able to exchange ideas, interpretations of landscapes and the search for common frameworks for data collection. The students reported (via Twitter and daily reflective blog & video diaries) greater productivity on the second of the land use exercises and noted that they felt that the collaboration and deliberation enabled by the Twitter map had improved their productivity:

> I have forgotten to mention the use of twitter so far. Today this has been very useful in resolving issues that have arisen. I took a while to follow everyone and set up text forwarding but it was worth it. If it wasn't for the ridiculous roaming charges, it got me thinking about the use of Skype to contact students and tutors either over video, audio or text. Also you could use the conference calling feature to contact many people at once. I did attempt to geo tag my texts automatically using the phones gps receiver however this did not work well as it did not save the setting and would have to set it up every time I wanted to text twitter.

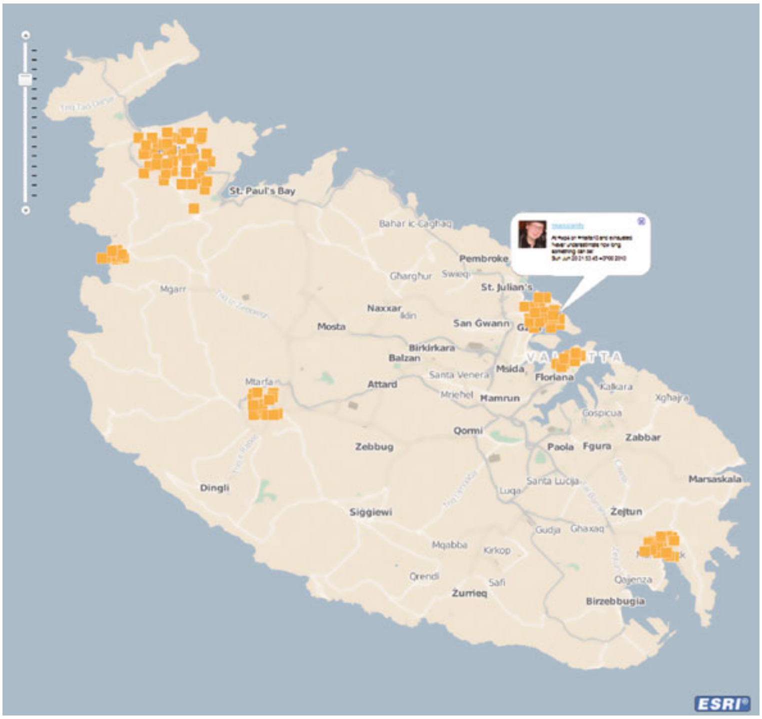

Fig. 7 #malta10 TweetMap at small scale zoom level used as a general fieldcourse log (base map © 2010 CloudMade Map data CCBYSA 2010 OpenStreetMap.org)

and

> As well as this twitter was used between the six groups to work out a specification of what features to map so that data collected between the six groups would have similar characteristics when joined together to create the land cover(not land use!) map.

Twitter also enabled current and former students who had attended the University and other interested followers of the field course to contribute from a distance which widened the participation of the trip *("@Muchel1977: nice sitting in Germany reading #malta10 tweets. Some nice memories. Enjoy your trip")*. None of these external observers contributed to the discussion perhaps highlighting that local observation was important for category formation. A comparison of 2008 versus 2010 data collected by students demonstrates a greater level of consistency and accuracy in data collection (O'Brien and Field 2012; Field and O'Brien 2010a). In 2009 a beta version of the TweetMap was tested with 2008 being the last iteration of the exercise incorporating no m-Learning tools, hence its comparison to the 2010 exercise.

Student/staff collaboration was enhanced through the use of Twitter and the monitoring infrastructure of the TweetMap geocollaboratory. Determining student location based on tweets allowed progress to be coarsely estimated. Data updates from the field provided a more accurate measure of student progress while also allowing potential data capture issues to be noted early enough to allow recapture. The bottom-up student discovery and top-down staff led guidance learning paradigms were also enabled by Twitter and the TweetMap.

Students were able to liaise with staff to gain technical support from remote locations within the study area. Previous experience had demonstrated that students experiencing technical difficulties would cease data collection thereby generating an incomplete data set. Twitter enabled student issues to be resolved and other students could take preventative or adaptive measures if necessary (e.g. fitting an external aerial to their GPS; *"Axxxx couldn't get his mobile to work so I sent out a twitter to air our concerns."*; and *"Twitter proved quite useful in answering a few queries and sorting out our problem with the Juno."*)

The interaction and deliberation of students via Twitter supported collaborative ontology development while the visualization of threaded discussion with basic semantic analysis allowed staff to monitor, guide and influence the ontology to ensure that it was fit for the purposes of the exercise.

The Tweetmap also demonstrates to students the application of skills in computer programming, spatial databases and digital mapping that they have learned during their second year reinforcing learning outcomes from other classes. The geocollaboratory also acts as a demonstration environment for 3rd year and Masters students studying an optional class in GIS client/server technologies. Students gain an understanding of how to build an application that they are familiar with as users.

7 Conclusions

The application presented here has built a collaborative infrastructure that is implemented using cartographic and visualization techniques to not only be effective but also deliver a positive user reaction (Hodza 2009).

We have drawn together the concepts of geodeliberation and geocollaboratories through Web 2.0 and GIS server and web service technology to extract and visualize content derived from Twitter. We impose order on this volunteered geographic information through the e-Delphi approach of structured consensus building to build a common framework and schema for data collection. The individual methods are not necessarily new but by joining them in a unified framework for fieldwork support we link the individual elements and place a greater focus on how data is conceptualized rather than emphasizing the process of collection. The integration of social network tools with the existing techniques is novel.

As noted in the discussion each of the objectives of providing methods of interaction for dispersed student groups, enabling monitored staff–student collaboration, enabling remote technical support and providing methods of managing and communicating adaptations to the requirements for student work were met. Based on positive student feedback and analysis of student work we also enhanced the student experience and the quality of the work produced. This positive student experience and high quality output also vindicates the approach of performing in situ instruction (at least for GIS) over preparatory classes. The requirement to acquire knowledge for an imminent problem (within the next few days) focused students more than for a field trip weeks in the future. The development of a geocollaboratory allowed much greater staff-student and student–student interaction throughout the fieldcourse and meant the need for prior preparation was reduced. This challenges notions of the importance of pre-fieldcourse student preparation and suggests that as much, if not more, engagement is achieved when alternative in situ learning mechanisms are developed.

We have also met the objectives of our larger project by demonstrating the role of students' personal technologies on fieldwork (the use of students' own devices to supplement University provided tools) and how the use of these technologies can enhance the learning experience. We implemented an approach that allowed students to utilize their informal skills (texting, social networking) to achieve academic goals. We were also able to make productive use of the students' personal technologies to provide constructive feedback and direction during field exercises.

A number of further developments are planned for the TweetMap to enhance future fieldtrips. The use of hashtags for the trips will be supplemented with a Twitter fieldtrip username for all students and staff to follow (e.g. @KUMalta). This will enable potentially greater engagement with trip alumni who can follow that user after the trip and interact with subsequent iterations of the fieldtrip. Using SMS notifications to deliver new tweets to followers of the fieldtrip username will also remove the need to use txttools for mass communication with students, streamlining the communication methods.

Acknowledgments This work was part funded by the transforming curriculum delivery through technology JISC e-learning programme Mobilising Remote Student Engagement (MoRSE), a collaborative project between researchers at Kingston University London and De Montfort University, Leicester. It was also part-funded by the Geography, Earth and Environmental Sciences (GEES) Subject Centre Learning and Teaching Development fund programme Mobile Decision-making in the Cloud (MobiDIC) project. The work was undertaken by the authors whilst they were academic staff at Kingston University. The innovative pedagogy led to an Esri (UK)® Innovation in GIS award in 2010 and the TweetMap won an Esri® User Conference award for 'Best Multimedia Map' also in 2010. The authors particularly thank the students who contributed to the research undertaken and the overall enjoyment of the fieldcourse and trust that the work informs future versions of the trip run by Kingston University. Malts!

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A Virtual Spatiotemporal Annotation System: The Virtual Stickies Mobile Augmented Reality Study

Mariusz Nowostawski and Julian Münster

Abstract Smart-phones and other mobile devices are becoming increasingly ubiquitous. Complex sensory and computing features of these devices provide excellent opportunities for advanced, context- and location-aware applications. In this chapter, we discuss the concept of spatiotemporal annotations of real objects in the urban environment. We stress technological challenges, usability, and novelty of spatiotemporal contexts that can be generated and consumed by users of ubiquitous and mobile computing devices. As an example, we present our implementation of the annotation system called Virtual Stickies. The system allows capturing, storing and presenting time-, context- and location-specific annotations to the user of a smartphone. We describe the system architecture and usability challenges of the system. In our conceptual and experimental deployments we have tried two different user interface-based solutions: the augmented camera view and the augmented map view. We provide a short introduction to mobile augmented reality technologies, present existing work in this area and provide technical insights into the solutions that we have investigated. The study has been conducted on the modern mobile platform Android, and utilises some Google-supported technologies. We briefly conclude with the results of case studies conducted with the system.

Keywords Mobile augmented reality · Location based augmented reality · Spatiotemporal annotations · Real landmark annotations · User-generated content

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
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1 Introduction

Mobile smartphones have taken a large share of the mobile phone market and they are no longer the preserve of early technology adopters. All modern smartphones are equipped with at least one camera, relatively large high-resolution display and provide opportunities for complex user interactions. We are particularly interested in the use of mobile devices to provide users with ability to produce and consume time-, context- and location-dependent information. In other words, we are interested in investigating spatiotemporal systems that manage user-generated content through the use of ubiquitous smart mobile devices.

As an initial proof-of-concept we have chosen the problem of annotating physical places or landmarks. The system can be considered a form of virtual graffiti. We have devised a system for capturing, storing and presenting virtual annotations in the context of real-world location. The information about a given place is time- and location-dependent. Our system allows users to place virtual objects, like markers, notes, voice or video annotations at any time in a particular physical location. Users can then retrieve stored virtual notes relevant to their current location, subject to further space- and time-considerations of when the note was left, and when it is being accessed.

1.1 Spatiotemporal Aspects

One of the important challenges for this project is the usability and convenience of the management process of spatiotemporal information. In this article we discuss two different modalities for presenting spatiotemporal annotations of real objects and locations in the urban environment. We discuss these two options in detail: augmentation of the camera view (augmented reality) and augmentation of a 2D map. Augmented reality (AR)—which superimposes virtual content on a real camera view—is an emerging new technology that offers more meaningful and context-dependent user interfaces (UI). We have decided to experiment with mobile AR systems in the context of a spatiotemporal information management system.

1.2 Minimal Requirements

There are certain features a smartphone (or tablet) must have in order to be capable of running a map augmented or a camera augmented view. The map augmentation requires the device to have a GPS unit to collect location information. The camera augmentation also needs the GPS unit in addition to a built-in camera to stream video and an accelerometer to sense the orientation of the phone. Devices capable of all the above usually have a lot more functionality and allow the developer to annotate locations with more than just text messages.

The main objectives of this project were to investigate the two proposed presentation modalities and implement a prototype for each of them. In this article we will present those prototypes then demonstrate the different options available to users interacting with a spatiotemporal annotation application. Both prototypes are capable of storing and presenting the annotations at a particular location. These two prototypes are the first step towards increasing user interaction between the virtual and real environments.

1.3 The System History

The original system was designed and developed in 2009 as a student project in the area of converged, next generation telecommunication networks (NGNs), called Next generation networks Virtual Stickies (NVS). The front-end used Google Android OS 1.5 and the back-end was an integrated IP Multimedia Subsystem (IMS) location based service (LBS). The latest version uses web services and the Google Application Engine as the back end, named Virtual Stickies. We use the Android OS Location Service to obtain the GPS readings from the smartphone built-in GPS unit, and Google Maps for map view augmentations. As there were no AR libraries available at the time, and none of the current AR toolkits support Android 1.5, all the tools were developed in house.

The current system is used in a number of research projects. One is used to provide users with the ability to introduce 3D objects, another is focused on audio-based annotations. Accuracy and efficient placement of digital annotations is an open research question, and projects on these topics are undertaken in our group.

2 Aim and Scope

2.1 Aim

The main goal of these studies is to investigate various technological challenges related to the process of generation and consumption of spatiotemporal information. In particular, we are interested in social media and user-generated content in the context of mobile geographical information systems (mGIS).

The object or information to be stored can be anything from a small text message to a video, sound recording, picture or a virtual 3D model. Every object has metadata associated with itself. In the current version of the system, each object also has an expiry date, a radius, a username and a location attached to it.

Those attributes help to calculate distance, to find its location, to identify the user who placed it and when it expires.

The location is a reference to the real geographical location and contains latitude, longitude and altitude information. This information is stored together with other object metadata. The recording of the position is achieved through the use of industry standard Geographical Positioning System (GPS).

2.2 Presentation Modalities

To visualise the annotations or objects, we have developed and experimented with two different modalities. We refer to them as *map view* or *2D map augmentation*, and *camera view* or *camera augmentation*.

2.2.1 2D Map Augmentation

2D map augmentation has two layers, a map view and an augmentation layer, which can be used as a presentation layer to show where the virtual objects are in the real world. The current user position is depicted as a dot on a map. For the map display we use standard library support provided by the Google Android OS and a map module. The display and management of the visual virtual artifacts is manipulated by the system. The current orientation of the device can be reflected by the appropriate map orientation. We use a number of overlays to manage the complexity of the scene especially the case of multiple annotations. The pitch and roll of the device can be used as a zoom and we are experimenting with a number of User Interface concepts to make it easy and efficient for a user.

2.2.2 Augmented Camera View

To provide users with more immersive, contextual and a richer user experience we have experimented with alternative user interface modalities. We provide users with an Augmented Reality interface to the application, where virtual objects are displayed directly on the video see-through. This approach behaves like a live street view with an augmented layer on top of it. The camera provides a continuous video stream in one layer and the other layer shows if there is a virtual object in the field of view. We will provide more detail and the experimental setups of these modalities in further sections of the chapter.

2.3 Scope

Even though contemporary mobile technologies allow users to actively participate in GIS systems, both, in consumption as well as generation of GIS relevant content, there is currently little work on such systems on mobile smartphones (Cartwright et al. 2007). Mobile spatiotemporal systems are a relatively new research area due to the fact that many technologies were not available to researchers and industry a few years ago. There is, however, a relatively large number of traditional mobile navigation systems where the user is a passive consumer of presented spatial information.

Before the development of our prototype there were no general-purpose mobile Augmented Reality toolkits. For our studies there was a need to investigate deeply both the presentation options of 2D maps on mobile phones and the possibilities of implementing an augmented camera view with location based virtual objects.

3 Background

The Android mobile phone platform (Android 2011) is being actively developed by Google and has grown to be a significant player in the smartphone market. Android is an open source development project and its various OS components can therefore be freely used. It is possible to deploy it on a number of different smartphones and tablets.

There are a large number of applications and libraries that Google has provided in support of the Android platform. Google Maps is one of the most important elements to the mobile phone software infrastructure for applications that process location-aware, contextual information. It enables users to see their current position on a map and has several other plug-ins available to enhance the user experience. This map service provides the basis for the map augmentation of our system. Besides the map support, we use Android OS support to provide GPS information.

3.1 Google Maps

The mobile version of Google Maps is similar to the desktop version. The Google Maps library determines the phone location provided the GPS unit is turned on and moves the center of the map to the acquired location. Figure 1 is an example and shows a Google maps image of where the phone's user currently is. It also has built in routing from the current location to a desired destination.

When developing for the Android platform, one uses a Software Development Kit (SDK). This can be extended with a special Google Maps add-on to the

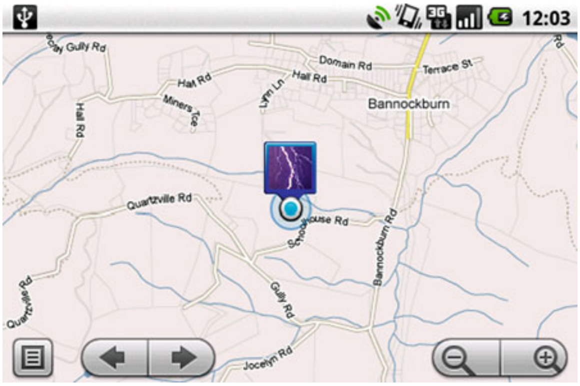

Fig. 1 Mobile Google Maps example

original SDK, which allows the creation of a Google Map application. Our system makes use of the SDK and the Application Programming Interface (API) of the Google Maps library. We will provide more technical details on this later in the chapter.

3.2 Augmented Reality

Augmented Reality (AR) has been established as a research area since the late 1990's. During this time the AR research area has matured remarkably. The survey *Recent Advances in Augmented Reality* (Azuma et al. 2001) defines AR as follows: An AR system supplements the real world with virtual objects that appear to coexist in the same space as the real world. The authors also define that any AR system has to have the following properties:

- combines real and virtual objects in a real environment,
- runs interactively, and in real time,
- registers real and virtual objects with each other.

In other words augmented reality can be described as a live camera stream that has a virtual object augmented on top of each frame. The camera feed shows the user the *reality* as it is seen by the camera. The video feed can be combined with a number of overlays to augment the real objects with virtual ones. Examples of augmentations can vary from 3D objects to images, sounds or text. For the purpose of this study we accept and follow the above mentioned definition of augmented reality.

Mobile platforms such as Android offer a number of features that make them suitable for mobile augmented reality applications. We have taken advantage of some of the features, and developed a system that provides the user with a more enhanced experience of the virtual annotation. This modality can be and often is used in the context of other application domains. It is important to notice that any particular use of AR technologies strongly depends on the actual use case and application domain for which AR is being used. There are a number of different kinds of AR. Most taxonomies (Chimienti et al. 2010) provide 4 broad classes: marker-based AR, location-based AR, natural feature tracking and target-based AR. We will describe various AR types later in this section. This study is focused on the location of the user and therefore uses location-based AR.

3.3 Types of AR

3.3.1 Texture Tracking

This technique is based on extracting a number of key elements of the image, and using those image features to track the position and orientation of the device. A number of algorithms have been developed, among others the use of scale-invariant feature transform (SIFT) filters providing the best results (Ruf et al. 2010). Texture tracking is often referred as 2D tracking, as it does not use the calculations of depth, but relies exclusively on the flat image features.

3.3.2 3D Feature Tracking

This is a more advanced technique that utilises both, 2D feature tracking as well as depth and 3D object estimations. This technique is more accurate, but at the same time more computationally intensive. There are good applications of this technique, and the reader can find details for example in (Vacchetti et al. 2004).

3.3.3 Sensor Based Tracking (Location Based)

Another mechanism for real object tracking is sensor-based tracking. Sensor tracking or location based tracking uses the fusion of several sensors to figure out the location and orientation of the mobile device. This type of augmentation is well suited for place/location systems, and is common on mobile phones. Smartphones usually have a GPS, accelerometer and/or gyroscope and magnetic field sensors built-in. This is an advantage of modern smartphones—no extra dongles are needed.

The GPS supplies the phone with its current location, the Gyroscope or Accelerometer in combination with the Magnetic Field sensor allows the calculation of the orientation of the phone. Together, location and orientation make location based AR possible.

This use of GPS positioning and geographical information in context (e.g. Google Maps data) is an example of a Location Based Service (LBS). For an overview of LBS please refer to Raper et al. (2007).

3.4 Mobile AR Systems

Mobile augmented reality systems represent a challenge due to technological limitations of any mobile device. Only recently there has been an increase in mobile AR systems research and development. Even a device that would hold all the required functionality would quickly run out of battery or be larger than a handheld device.

Advances in mobile AR development started with the development of an ARToolkit (Piekarski and Thomas 2002), which created a way to program mobile AR systems. Smartphones have since upped the same, with their in-built feature and functionality, improving at an incredible pace. Every year multiple new phones are being released. These new advanced features make the smartphone the obvious choice for augmented reality research and development. There is yet a solution to be found to the battery life problem, the lifetime of mobile phones is increasing steadily through advances in hardware and software. It is no longer a limiting factor. It has to be kept in mind and is an active area of research.

3.4.1 Existing Technologies and Applications

A relevant example of location based AR on mobile phones is an Android application from a company called Mixare in Italy (Mixare 2011). This application gets its information from Wikipedia points of interest and displays them in any subscribing phone nearby. This library is open source and reuse of its code base is encouraged.

The StudierstubeES mobile system has ben developed in Austria at the Graz University of Technology and uses various methods to create the effect of AR (Schmalstieg et al. 2002). This library uses natural feature tracking or marker based tracking to determine where and when the camera is pointing at an object to be augmented. This library is closed source.

The micro chip manufacturer Qualcomm has also developed a beta version of its own AR toolkit based on the Studierstube ES technology (Schmalstieg and Wagner 2008). It is only available for beta testing and to enable feedback for completion as an alpha product. This AR toolkit uses the same algorithms as Studierstube for marker or natural feature detection. It is also closed source but available without charge.

4 Related Work

4.1 Augmented Reality

Research on Augmented Reality (AR) in general has started as early as display technology reached sufficiently high levels of complexity to allow dynamic overlays of video streams. We refer the reader to a number of AR survey articles, such as Azuma (1995). However, the work on mobile augmented reality has been prohibited by a number of factors, most of which were related to the complexity and size of the hardware that needed to be carried around. One of the earliest systems was a *Touring machine*, a mobile AR system for exploring the urban environment (Feiner et al. 1997). Since the late 1990s a number of prototypes have been developed, among others the ARToolkit system (Piekarski and Thomas 2002). Two of the more recent widely known mobile AR systems are Layar and Wikitude. Layar (Layar 2011) is a mobile application that augments the real view with a number of overlay layers (free and paid). Wikitude is a bundle of AR software for mobile phones. It includes two different projects, the Wikitude Drive and Wikitude Browser (Karpischek et al. 2009). The content was primarily extracted from the existing web sites, such as Wikipedia.

For social reality annotations there have been a number of research initiatives, such as interactive virtual graffiti (Lim and Aylett 2004; Coulton et al. 2006). Many of these systems share similar overall design and features, but differ in the feature set, underlying technology or actual purpose.

For more detailed analysis of mobile augmented reality we recommend survey articles, for example (Papagiannakis et al. 2008).

4.2 Mobile Annotation Systems

There are many systems that allow location tagging, and many mainstream systems provide the ability to attach location information to their content (e.g. Twitter added this functionality relatively early on). Nevertheless, spatiotemporal annotation systems are relatively uncharted territory. It is widely acknowledged that the area of user-generated content that is time- and location-dependent has potential, especially in the context of geographical information systems, yet there are no standard ways to manage, display and manipulate such content.

An early example of an annotation system that puts space and time to use is ‘‘GeoNote‘‘ (Persson et al. 2002). This system was tested by students using laptops in several specific LAN hotspots. These wireless LAN hotspots were used to identify the area of the current users.

Other more recent systems make use of mobile phones with built in GPS units, which send SMS messages with the location of the mobile device and create a virtual “post it” with this information (Siemens 2005). Another system investigates the possibility of combining mobile phone and RFID tags. The mobile phone senses the RFID tag and can download or add new information unique to that location (Garner et al. 2006; Coulton et al. 2006).

An application called ''Mobispray'' uses the cell phones' orientation sensor and a projector to virtually draw on objects (Scheible and Ojala 2009). The mobile device is in essence a virtual spray can.

Another example related to our own system is MapChat (Chimienti et al. 2010). MapChat is a collaborative social system that takes advantage of the spatio-temporal aspects of any planning or discussion. MapChat supports various modes of participatory input into spatial decision support.

5 General Architecture

5.1 The Basic Architecture

There are a number of location services that can more or less accurately pinpoint the absolute positioning of the device. The Android OS offers the ability to use any of the existing LBS systems as the location source, so it makes it easy to use whatever is available. It can be a built-in GPS receiver, or an external GPS unit connected via Bluetooth. If a GPS fix cannot be found, most telecommunication operators offer a location service that is based on triangulation of the GSM (Groupe Spécial Mobile) transmit/receive towers. Another less accurate method would be to use the unique identifiers of the nearby WiFi hotspots, and estimate the location using this method.

Once the device has its position information determined and is satisfied that the error is small enough it will display the location over the application presentation layer, which is the Google Maps view in our case. Using the location information the map is centered on the device's current location.

After the location information has been obtained, the application needs to establish contact with the Virtual Sticky application server. This can be done via GPRS, 3G, WiFi or any other means to connect to the Internet with a mobile phone. This connection is vital, because all the virtual information about the device's surroundings is stored on the server (Fig. 2).

All requests for data are handled by the server and sent back to the client (mobile device). To lessen the computational load on the phone and to decrease the amount of data sent between the server and phone, the server handles the distance calculations to figure out which data objects are close enough to the device or in the user specified radius to be included in the data transmission.

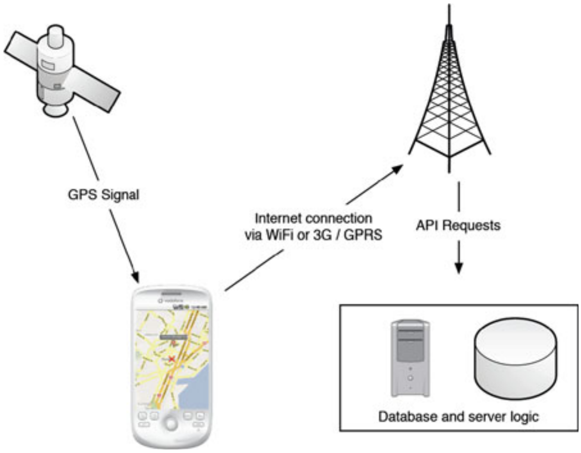

Fig. 2 Virtual stickies architecture

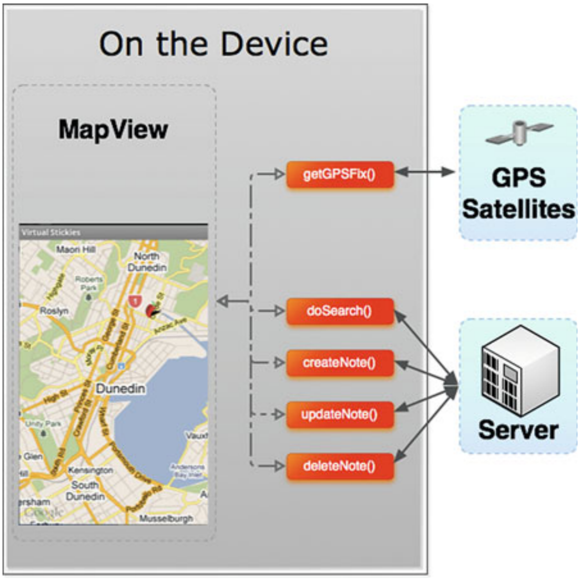

Fig. 3 Inner application architecture

5.2 What Goes on Behind the Scene with the Phone

Assuming the application uses the GPS to find the current location of the device (see Fig. 3) is an accurate model of what happens inside the phone. Virtual Stickies has two parts: a client and a server. The client architecture is being discussed here. The map view is the main class and all operations start there.

5.2.1 Get Current Location: getGPSFix()

In order to get the most accurate location, the application scans through all location providers and chooses the best one. Then it polls that location provider until it has a location with an acceptable error and records the location. Now any other part of the Virtual Stickies application can use the provided location to center the map or add a new note.

5.2.2 Searching for Notes: doSearch()

When the user sends a search request to the server, the current location and a user defined radius will be sent and used as search parameters on the server. It is intended that these parameters can be extended to anything like the category or title of a note.

5.2.3 Adding a New Note: createNote()

When the user adds a new note the application sends the current location, the message and the radius. This is the bare minimum currently available and will be extended in the future. The server responds with the new note and a corresponding unique ID.

5.2.4 Updating a Note: updateNote()

Updating a note requires the user to be the owner of the note in question. Then the application allows the changing of the message text and the radius of the note. As above in future there will be more options to change. Lastly the newly updated note will be sent to the server, which responds with success or failure.

5.2.5 Deleting a Note: deleteNote()

Once the user has chosen a note to delete, the application recovers the unique ID of that note and sends along a deletion request to the server. The server responds with success or failure.

5.3 Submission and Retrieval of Objects

The submission and retrieval of objects is done by the user directly on the phone.

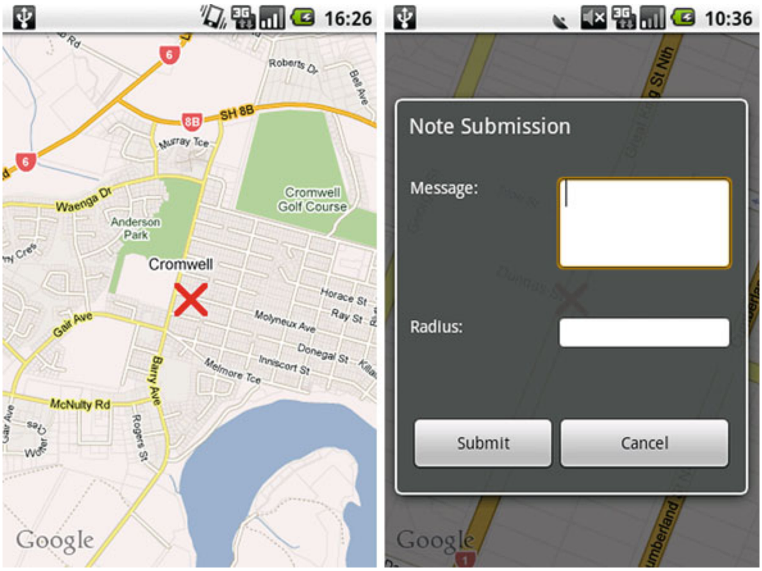

Fig. 4 Submission of an object

5.3.1 Submission

Figure 4 demonstrates what must be done to submit a text note. Before the submission screen the user can align a red cross to the point on the map, where the object is to be placed. Figure 4a, b demonstrate the submission procedure.

5.3.2 Retrieval

Figure 5 shows the process of retrieving surrounding notes. The default radius is 1,000 m, but this may be changed by the user. Figure 5b gives an idea of what the map view could look like after the recovery has been successful and reloaded the map view with the new objects (represented by fine red "bubbles").

5.3.3 The Distance Calculation

This section briefly explains how we determine if a note is within viewing range or not. The following attempts to describe the process of calculating the distance between a note and the device.

Every note has its own radius and location attribute assigned. The device has its own location and collects the radius from the user input. That means the server has the information of two circles including their location as GPS coordinates. If the

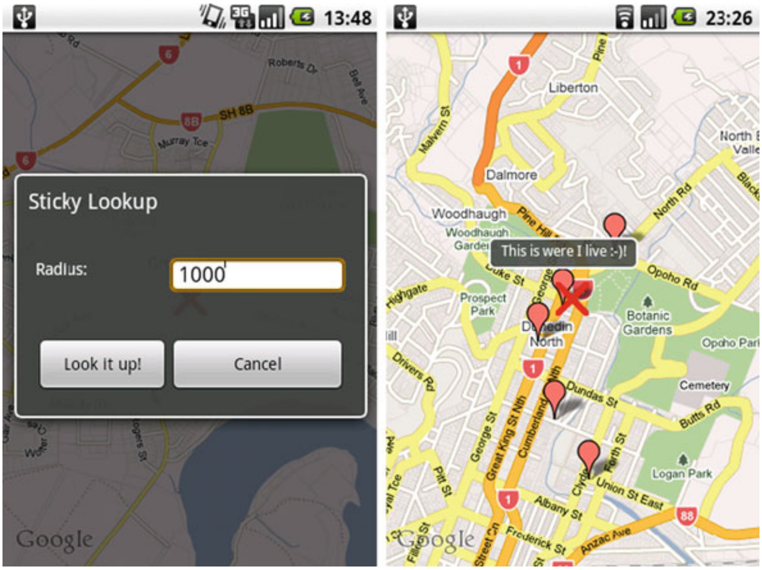

Fig. 5 Retrieval of virtual objects

Fig. 6 No intersection

circles intersect then the Virtual Sticky is retrieved. The use of circles means that Euclidean distance is the metric used (as opposed to, say, network distance).

Figure 6 shows two circles that are not intersecting. That would mean the object in question would not be within the given radius and will not be displayed.

Figure 7 depicts a clear intersection of both circles and consequently this object will be included and presented on the device.

In future, we plan to experiment with geometries of more complex shapes than circles (i.e. a road network) and searches by category or any other field that might be added in future. This introduces the ability to provide more context sensitive information and annotate spaces in more detailed ways.

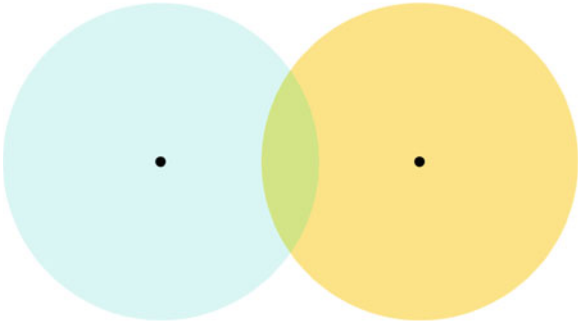

Fig. 7 Intersection

6 2D Map Augmentation

The main focus of this section of the chapter is to present the 2D map augmentation modality. In this section will provide more details of how 2D map view visualisation is implemented.

6.1 Mobile Application

Figure 8a shows the entry screen to the Virtual Stickies application. Figure 8b presents the map view with the menu showing. This menu permits three actions, to submit a new object, to retrieve other objects and to change the map view mode as shown in Fig. 9. The latter menu option allows the user to switch between an actual street map mode, that is equivalent to a real paper map and the satellite map view, which shows an image from space.

6.2 Map Overlay

Map overlays are used to display extra information as a layer on top of the map view. To achieve the best result whilst working on the Android platform we have used the Google Maps library to aid in the implementation. We have used Google provided services to display and manage maps. We have to provide implementation and management support for the map overlays ourselves.

At this stage the prototype allows the user to tap on a red bubble on screen and it will automatically load the message saved with that object. Other possible visualisation techniques can be used to annotate the map view. However, 2D visualisation based on a map provides quite a limited engagement of the user with the surrounding environment. In a way a user of a map view is constantly shifting focus from the map into the real physical reality around and back, which is somewhat cumbersome.

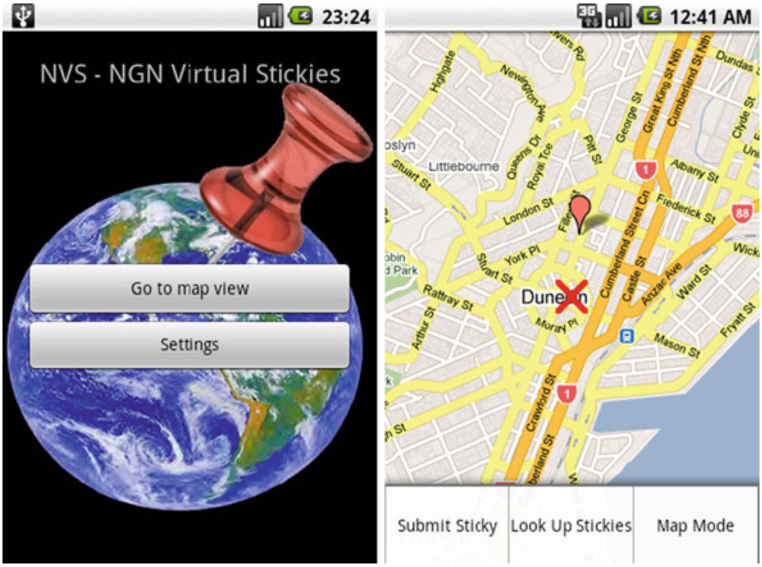

Fig. 8 Main application views

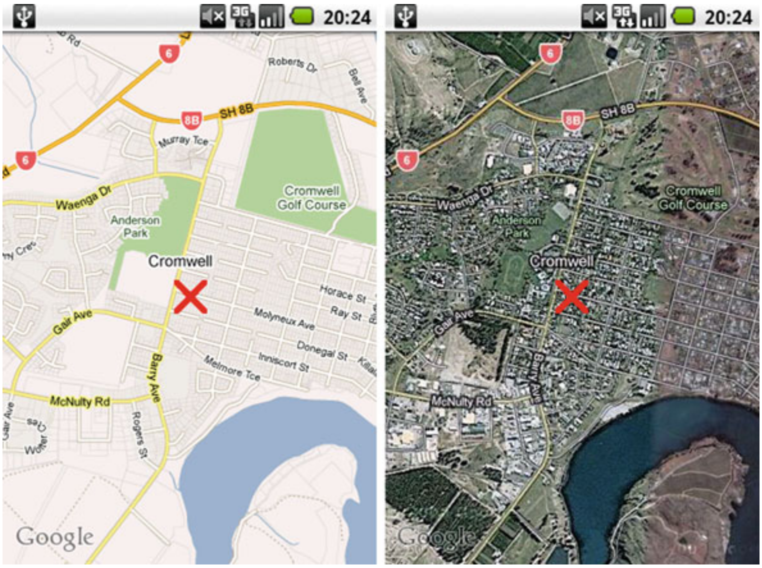

Fig. 9 Map mode change

We experiment on prototypes that combine an AR view together with a map view in a single user interface, as this or a pure AR-based view offer substantial benefits when compared to the plain map view UI.

7 Augmented Camera View

This section discusses the functionality of the location based augmented reality application that was developed for this study. At the current stage we have only implemented a proof-of-concept interface.

7.1 The Sticky Object

The sticky object holds all the information pertaining to a particular sticky note. The following is a list of the fields necessary for the current version of the program. This list and the object may change in future to accommodate new and/or different features.

- A location object containing:
  - Latitude
  - Longitude
  - Altitude
- A radius
- A username
- A description
- A creation date
- An expiry date

The location object is used to determine where the phone is located. Latitude, longitude and altitude are retrieved from the GPS unit in order to do this.

The radius of a note serves the same role as described in Sect. 5.3. The username is added to identify the creator of the note. Another possible attribute can be the owner of a note. The description is the snippet of text attached to a sticky note. It is whatever text the user has entered.

The creation date field records the creation time of the note. This is an important value, because it can be used to refine a search.

The expiry date field records when the note will expire and not be returned in any search by a user.

7.2 The Camera View

The camera view (Fig. 10) is created by dividing the surface of the activity into two layers. The bottom layer is the camera preview. This view does not record anything or take any photos it is simply a preview and shows what the camera can see.

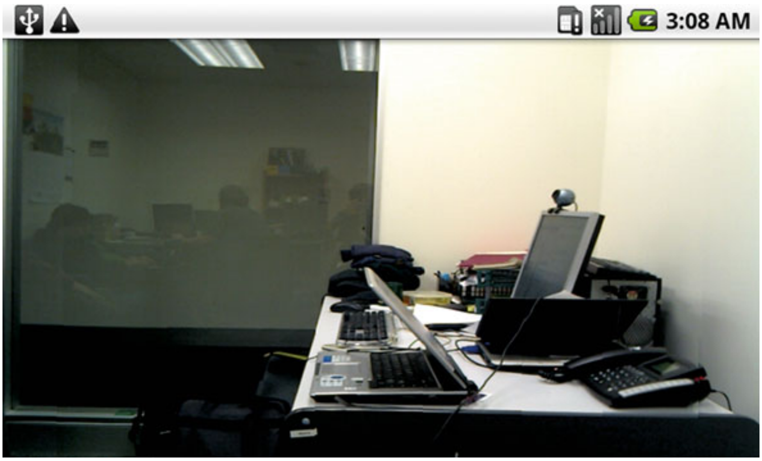

Fig. 10 The basic camera view

On top of that layer is the layer that holds all the augmentation to the application. It is called an overlay (Fig. 11).

7.3 Creating an Overlay

Any image or text or any other object that can be drawn may be used as an overlay. An overlay is not restricted to one object per layer, it can hold as many as space allows on the screen. And there can be many overlays on top of each other organised by priority.

For this particular application the overlay is an image of a red bubble to indicate there is an object. This can be drawn on the overlay layer at any time and in any position and in multiple positions.

This overlay is essentially the same as the map view overlay except the map overlay is planar and this augmented reality overlay is relative to an egocentric view on the geography. Figure 11 illustrates the difference.

7.4 Handling the Device Sensors

To handle the sensor events on a smartphone in a CPU-efficient way they need to be implemented efficiently, and run in the main user thread. On Android, it means they need to be handled in the main activity. They cannot be running as a service or as a background thread. All the other calculations and processing can be done in

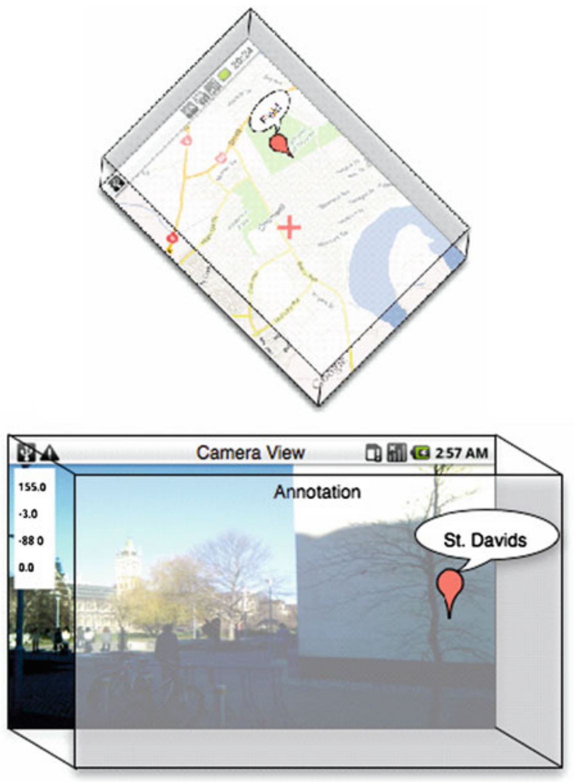

Fig. 11 Overlay layer, the different views

other parts of the applications, in such a way as to not overload the main activity handling the sensory data.

There are two sensor readings that are of interest for calculating the device orientation. These are accordingly: the accelerometer readings and the magnetic field readings. The results are three values called Azimuth, Pitch and Roll.

7.5 Accelerometer Data Collection

The latest augmented camera application accelerometer data was recorded using a HTC Desire 8181 mobile phone. The HTC Desire accelerometer is a Bosch BMA150 Triaxial, digital acceleration sensor (Bosch 2011). The Device restricted the accelerometer sample rate to 23 Hz ± 10 % with a ± 2 g acceleration range. The accelerometer X, Y, and Z axes data were recorded to nine decimal place precision with a time-stamp of the actual sample time in milliseconds and then passed on for further processing. Note that every mobile phone model could have a different accelerometer sensor built in, therefore every phone may perform differently. It is necessary to fine tune this application to each phone, which may be done programmatically in the future.

7.6 *Finding the Device Orientation*

To find the device orientation the Android system libraries provide some useful tools. This means it is a matter of passing the right values through a set of functions to figure out the orientation in radians. The last step is then to convert that into degrees and use the gathered information to determine if the phone is pointing in the right direction to pick up a sticky. The following list describes the process of calculating the device's orientation.

1. Getting the raw values from the sensor listener
2. Passing the values to the 'getRotationMatrix()'
3. Passing the answers to 'remapCoordinateSystem()'
4. Passing the results to 'getOrientation()'
5. Now we convert the values calculated above from radians to degrees.

7.6.1 Sensor Listener

Because of hardware differences in mobile devices there are several sensors that might be available. Relevant to us are the gyroscope, accelerometer and magnetic field sensor.

Usually most phones have the accelerometer and magnetic field sensor, however not the gyroscope. It has higher power consumption, but also delivers more accurate information than the accelerometer. Due to these accuracy benefits inaccuracies the gyroscope is the preferred sensor.

Since the accelerometer can be found in a wide variety of mobile phones it makes an application more accessible to wider range of users. As a result of this the accelerometer was the sensor chosen for the purpose of this research.

7.6.2 Orientation Discovery

Initially a sensor listener is used to collect raw information on two sensors of the phone, the Accelerometer and the Magnetic Field sensor. The listing below shows a code snippet of this process.

```
public void onSensorChanged(SensorEvent event) {
  ....
  mOverlay.update(CalculationsHandler.doCalc(
    CalculationsHandler.
      calculateDeviceOrientation(average)));
  ...
}
```

Since these updates are happening very rapidly and the devices CPU would not be able to keep up with all the calculations it calculates the average of a number of updates and then passes that value on to be used to find the orientation. The variable for the average value may be changed according to the device's capabilities. Once both the Magnetic Field and Accelerometer values have been passed to the CalculationsHandler class it does the following.

```
...
if (SensorManager.getRotationMatrix(
  inR, null, accelerometerData, magneticFieldData)) {
    if (SensorManager.remapCoordinateSystem(
        inR, SensorManager.Axis_X,
        SensorManager.Axis_Z, outR)) {
                SensorManager.getOrientation(outR, orientation);
        }
    }
...
```

7.7 Pointing in the Right Direction?

This section deals with the problem of how to determine if the camera phone is pointing in the right direction. Essentially we have two location tuples and need to find out if one is in line of sight of the other. We also have the device's orientation (the azimuth value), ranging from a bearing of 0°(N) through 90°(E), 180°(S), 270°(W) back to North.

7.8 The End Result

Lastly we take a look at a scenario where we can see all of the components working. Figure 12 shows an example of the camera phone pointing at virtual objects. The same building is displayed from two different angles.

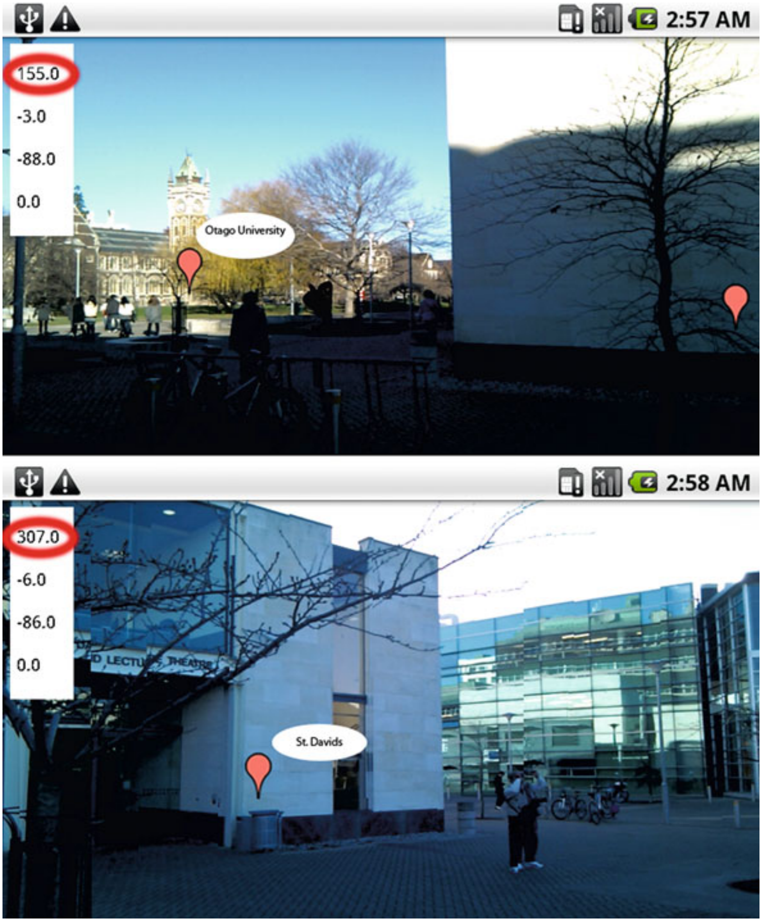

Fig. 12 The augmented camera view **a** Angle 1; **b** Angle 2

Figure 12a and b both have the directional orientation vector highlighted. Figure 12a is pointing approximately north and Fig. 12b is pointing South East.

8 Conclusion and Future Work

In this article we have presented an overview of mobile augmented reality systems, discussed various techniques for scene and object tracking, and presented our Virtual Stickies system. The Virtual Stickies system demonstrates the use of a 2D map view as well as an AR-based camera view presentation over a set of virtual objects placed in the context of real physical space. The system allows users to place, retrieve and browse text notes, sounds, and 3D objects in the context of a particular location. We have presented an architecture overview of our prototype, as well as a walk through demonstration of the current capabilities of the system. We have compared the system to other existing systems.

Mobile augmented reality is a relatively new, but actively developed field for Human Computer Interaction. We are not only interested from the point of view of technological challenges, but most importantly, from the perspective of participatory action research, and social systems. Augmented Reality systems in combination with social networking and a physical context (context in physical space–time realms) provides new and interesting areas for research and experimentation.

We plan to study various techniques of dynamically correcting GPS readings on the mobile phone based on the context in which the reading is being made. We have already started studies to enhance the approximations of absolute positions of particular physical artifacts through the use of multiple recordings by mobile application users. This should provide improved accuracy and better linkage between virtual and physical artifacts. We also plan to expand our prototype system to voice and 3D objects and conduct field trials with users leaving and browsing notes left by other users in the University of Otago campus area. Social open usage and feedback will guide further development of this system. One possible area that our HCI group will explore is the use of mobile annotations in city council systems (notification about road problems) and increased public participation in urban development and planning projects.

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Part IV
Geovisual Analytics

Applying Geovisual Analytics to Volunteered Crime Data

Antoni Moore, Marcos de Oliveira, Carlos Caminha, Vasco Furtado, Victor Basso and Leonardo Ayres

Abstract There is a great deal of volunteered data that is ripe for exploration and discovery. As an example, the Brazilian WikiCrimes web resource is rich with point data containing attributes such as type of crime, crime setting and reason for crime that have great potential for visual mining through geovisual analytics tools. One such tool is eXplorer, a freely-available web-based application. This chapter details the initial application of eXplorer to WikiCrimes data, mapped by both Brazilian state and degree grid cell. In line with one of the objectives of WikiCrimes and serving as a manifesto for similar online applications, it is anticipated that enhanced crime transparency and publicity will emerge more easily from information mined through geovisual analytics than the straightforward pin map display of crimes depicting a point pattern. Furthermore, as a Web 2.0 tool in the public domain, the exploration aspects should become a focus for more active public participation through additional cooperation. Finally, eXplorer embodies a form of spatial

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7_9, © Springer-Verlag Berlin Heidelberg 2013

analysis, the product of which is a level of information processed and extracted from the "raw" point data of WikiCrimes and is therefore in a more digestible and therefore useful form for law enforcement officers and the public alike. Future plans include the introduction of other data such as demographic and car ownership data in an attempt to extract further meaning out of the WikiCrimes dataset

Keywords Web 2.0 · Choropleth · Density · eXplorer · WikiCrimes

1 Introduction

Crime is rife and with only a finite amount of resources to control it, law enforcement agencies need all the help they can get. Technology has stepped into relieve some of the burden in recent years. The rise of the Internet (in particular Web 2.0) and use of mobile devices has put effective spatiotemporal data collection and storage mechanisms in the hands of ordinary people (Goodchild 2007). For crime management the efforts of a small and finite number of law enforcement officers have been augmented by information provided by citizen volunteers. Not only does this give greater coverage but also elicits information that police, for instance, may find hard to get (e.g. if people are ashamed or scared of going to the police to report a crime).

WikiCrimes (Furtado et al. 2010) in Brazil is one such system, a collaborative Web 2.0 application using the Google Maps API (www.WikiCrimes.org). It has three major aims—to make crime information more transparent and public; to address the phenomenon of under-reporting and implicitly; and to prevent future crime from occurring. However, as with other systems of this kind, there are possible issues of data credibility due to its informal sources, though in countries with high violence rates and unreliable reporting of crime, the benefits of such a collaborative system outweigh any such issues and have been recognized politically. Since 2008 there have been over 200,000 crimes logged in this system.

The aim of this research is to take part of that dataset and apply geovisual analytics to it. WikiCrimes beyond point data display can process crime incident data into hotspots of density. However, the dataset is rich with attributes such as type of crime, crime victim type, crime settings and reason for the crime as well as the essential location and date/timestamp that are ripe for exploration. Straightforward pointwise display (and indeed density kernels) can give insight on distribution (it is the intention that such information will have value in the hands of the public) but misses much information of value.

We have applied eXplorer (Jern 2009), a freely-available web-based geovisual analytics tool to the WikiCrimes data. It was hoped that, in line with WikiCrimes' first objective, the anticipated additional insights mined from the data would enhance crime transparency and publicity more than the point display of crime incidence. Furthermore, as a Web 2.0 tool in the public domain the exploration aspects should become a focus for more active public participation through additional cooperation. Like other geovisual analytics tools, eXplorer embodies a form of spatial analysis, the product of which is a level of information processed or extracted from the "raw" point data of WikiCrimes and is in a more digestible and therefore useful form for law enforcement officers and the public alike. Specifically, eXplorer was chosen for its facility for quick and easy publication to the web, relatively uncluttered interface, smooth, fast interaction and ability to display "stories" alongside specific combinations of data. This combination made eXplorer a suitable match with the anticipated public user population.

Finally, the application of geovisual analytics to the WikiCrimes dataset is representative of what could be done to online volunteered data in general. There have been very few such attempts (e.g. Jankowski et al. 2010; Kisilevich et al. 2012); most geovisual analytics endeavours focus on official data (e.g. regional and national statistical data–Jern 2009, 2010), top-down collected data as opposed to the bottom-up nature of volunteered data collection (Sui 2008).

The next section gives some background on visual analytics and geo-collaboration before an overview of the dataset then outlining specifics in piping data from WikiCrimes to eXplorer. Finally, an account of the information gleaned from WikiCrimes through a geovisual analytics approach will be given at the country scale at a state level and one degree grid cell level before some concluding statements.

2 Background

2.1 *Visual Analytics*

We live in a world where data comes to us in voluminous and complex forms and the tools we have to make sense of this data are immature. Visual analytics emerged from NVAC (National Visualization and Analytics Center) in the US in order to address this problem, specifically in the context of preventing/responding to terrorist attack.

NVAC have defined visual analytics as "the science of analytical reasoning facilitated by interactive visual interfaces" (Thomas and Cook 2005, p 4). The mantra here is to "detect the expected and discover the unexpected" from synthesized information elicited from raw data. This is effected in many ways: supporting the human facility for analytical reasoning, transforming data into optimal representations for analysis, and using visual representation and interaction to mine information. The results of a structured assessment of the data using these groups of technologies then has to be packaged and disseminated into an easily digestible and actionable form for public and decision makers alike (Thomas and Cook 2005).

*Geo*visual analytics is distinguished mainly by the enhanced complexity of the geospatial domain (Andrienko et al. 2007), with facets of scale, multidimensionality and autocorrelation, to name but a few. Examples of geovisual analytics research

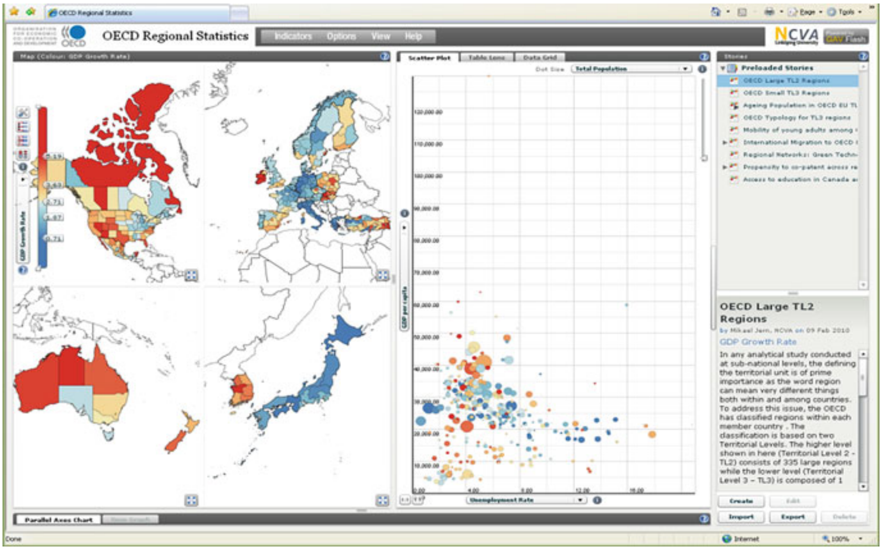


Fig. 1 Organisation for Economic Cooperation and Development (OECD) eXplorer, developed by NComVA (Norrköping Communicative Visual Analytics), Sweden © 2011 NComVA.com

include Weaver et al. (2007) investigation of historic visit data using dimensioned calendars to mine temporal patterns as well as conventional spatial mapping, Guo's (2007) analysis of interaction patterns in pandemic spread and Sips et al. (2007) research into mining spatiotemporal patterns in data warehouses. Jankowski et al. (2010) used geovisual analytics to discover people's spatiotemporal patterns and what landmarks they visited from volunteered photographs (on Flickr) in the greater Seattle area. The geovisual analytics software used in this research is Open Statistics eXplorer, developed by NComVA (Norrköping Communicative Visual Analytics) in Sweden.

2.1.1 OECD eXplorer

The eXplorer web-based software (Fig. 1) was originally developed for the Organisation for Economic Cooperation and Development (OECD) (stats.oecd.org/OECDregionalstatistics/). One of the major aims of OECD is to promote policy analysis and information exchange in the areas of regional development, regional competitiveness as well as urban and rural development (OECD 2011). The OECD Regional Database is a digital resource that helps them in this, and specifically OECD eXplorer facilitates the important role of information exchange. The Regional Database comprises data for about 50 indicators (demographic, economic, social and labour market) in more than 1700 subregions of OECD countries (Jern 2009).

eXplorer itself is an online interface with choropleth, scatterplot and optional histogram/parallel coordinate plot display interactively linked. Thus many data variables can be displayed and linked at one time: the choropleth map depicts regional variables by graduated colour; the scatterplot graphs two variables as well as replicating the choropleth colour on each dot (each dot corresponds to a region), which can also be sized proportional to yet another variable; and the parallel coordinate plot can represent *n* amount of variables, with each line corresponding to a region. Another tab in the same display area leads to a histogram, ordered in decreasing magnitude of the chosen attribute. The three representations are dynamically linked, which means that when the user clicks on a region on the map, the respective dot (on the scatterplot) and line (on the histogram/PCP) are highlighted, and vice versa (Fig. 1). In short, it uses multiple representations and interactivity to foster usage and understanding of (often large amounts of) complex data (Thomas and Cook 2005).

2.2 Mapping and Analysis of Crime

Mapping and analysis of crime using GIS technologies is well-established in law enforcement agencies, though representation-wise is typically limited to 2D static maps (Wolff and Asche 2009) (i.e. detecting and depicting hotspots of crime, a digital version of the traditional pinmap analogue). Wolff and Asche (2009) present a form of 3D crime mapping. See Chainey and Ratcliffe (2005) for an overview of crime mapping.

The applications within law enforcement that geospatial technology can be applied to include operational policing, crime prevention, monitoring spatiotemporal distributions and community liaison (Hirschfield and Bowers 2001). This fits into Andrienko et al. (2007) framework for Spatial Decision Support Systems (as a context for geovisual analytics), divided into long term and short term applications (i.e. analysis of crime distribution as opposed to real-time operational policing). This framework also has a volunteer dimension, which extends community liaison into a more proactive role for the public, with volunteered crime data being submitted and mapped online (i.e. in the Web 2.0 application WikiCrimes).

2.2.1 WikiCrimes

WikiCrimes (Fig. 2) was developed as a Web 2.0 resource for the public, notifying the online community of the details and location of a crime that has occurred. It operates on a principle that the citizens may hold crime information and that they would feel a need to share this resource, especially if they are victims of the crime. Normally it would be someone close who would be notified, but WikiCrimes provides a digital sounding board as well, potentially alerting people well outside of immediate social circles. Active participation by multiple victims of crime will help to build a "global blackboard" of stories, generated collaboratively and potentially helping everyone (Furtado et al. 2010).

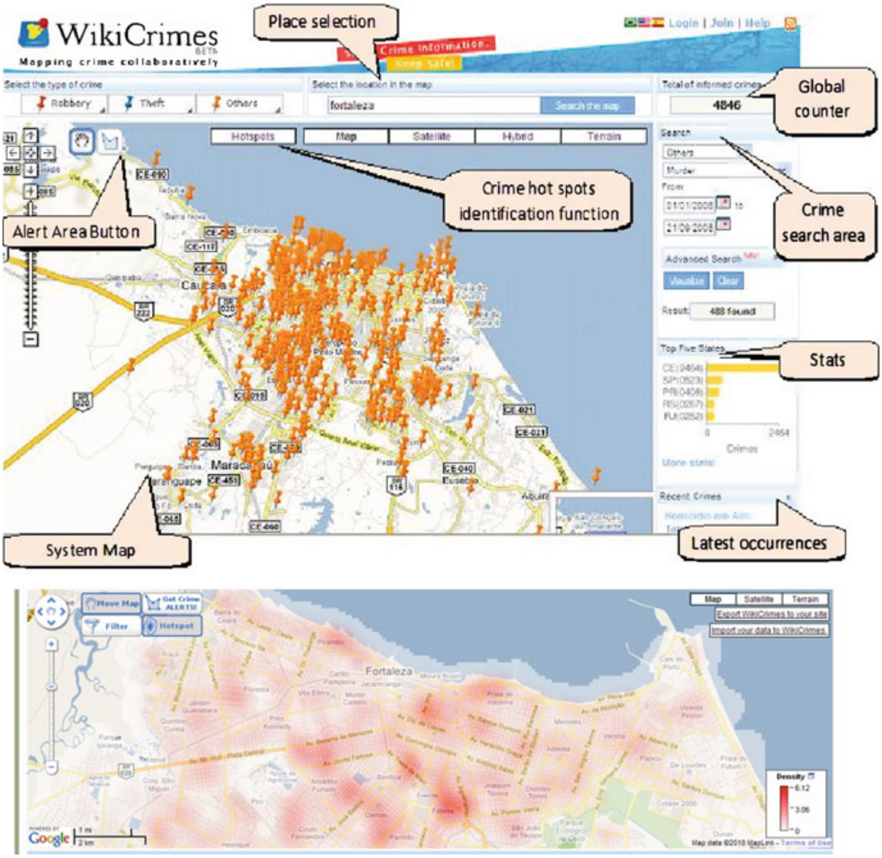


Fig. 2 WikiCrimes, illustrating the pinmap view and generated hotspots for the host city of Fortaleza, NE Brazil (from Furtado et al. 2010). © 2010 Google, © 2010 Map Link

A further impetus for WikiCrimes is the paucity of crime information emanating from law enforcement agencies in Brazil and various other countries, owing to lack of disclosure. Public discussions have also highlighted the damaging phenomenon of under-reporting of crime, due to a lack of trust in those agencies (Kahn 2007) and faith that any positive result would come from filing a crime report. This lack of information dissemination means that certain areas of public policy and police planning are hampered due to inadequate intelligence. WikiCrimes seeks to collaboratively add to that intelligence.

Since WikiCrimes was initiated in January 2008, there has been an initiative on the ground (e.g. via lectures and workshops) promoting the resource in the host city of Fortaleza (Ceará state, NE Brazil). This has led to valuable results, augmenting crime disclosure in that city (over half the crimes have been reported there) (Furtado at al. 2010). Sections 3 and 4 will describe the data and the results of geovisual analytics at the country (by state) and local (by degree grid cell) scale.

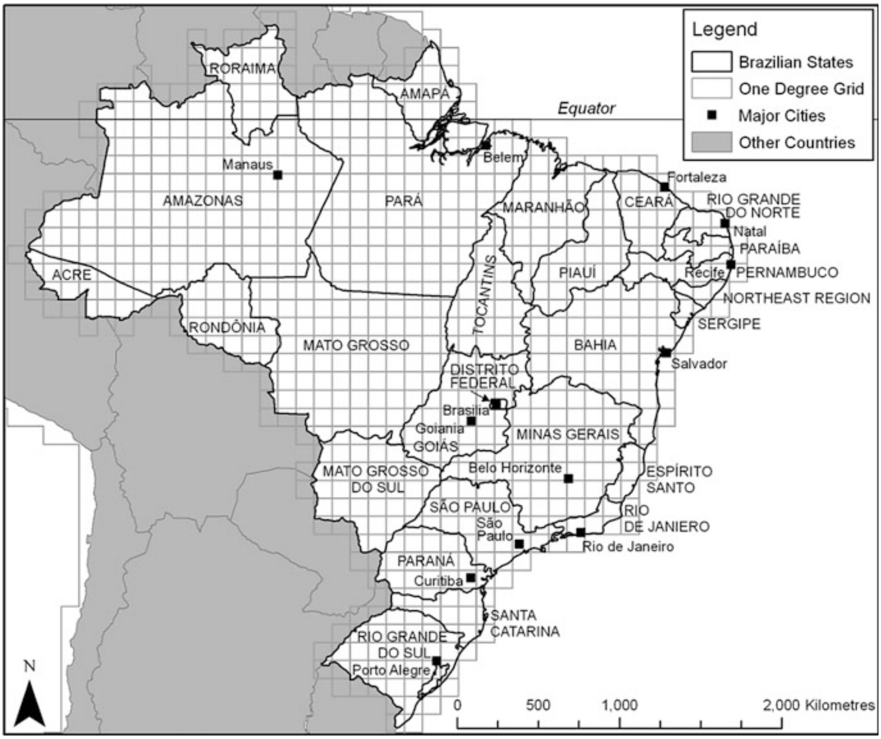


Fig. 3 Context map of Brazil, by state and by degree grid square

3 Overview of Data and Tools

3.1 Overview of the WikiCrimes Data as Recorded

Once a crime has been logged by a member of the public on the WikiCrimes website, it forms a record in a MySQL database. In this way, a resource of records describing over 15,000 crimes had been amassed up to the end of 2009. Since then additional crime data sourced from the Brazilian government has grown the WikiCrimes database to over 200,000 records currently. Although the spatial range of crimes is worldwide, the vast majority of records relate to Brazil, more specifically the state of Ceará and more specifically still the state capital Fortaleza, where WikiCrimes is hosted. For that reason, the data used for this study is restricted to Brazilian data. Furthermore, the dataset analysed will be the volunteered dataset amassed before government crime records were introduced. The groups of attributes provisionally deemed of importance were those to do with location, date and time, crime type, crime victim type, crime setting and reason for the crime.

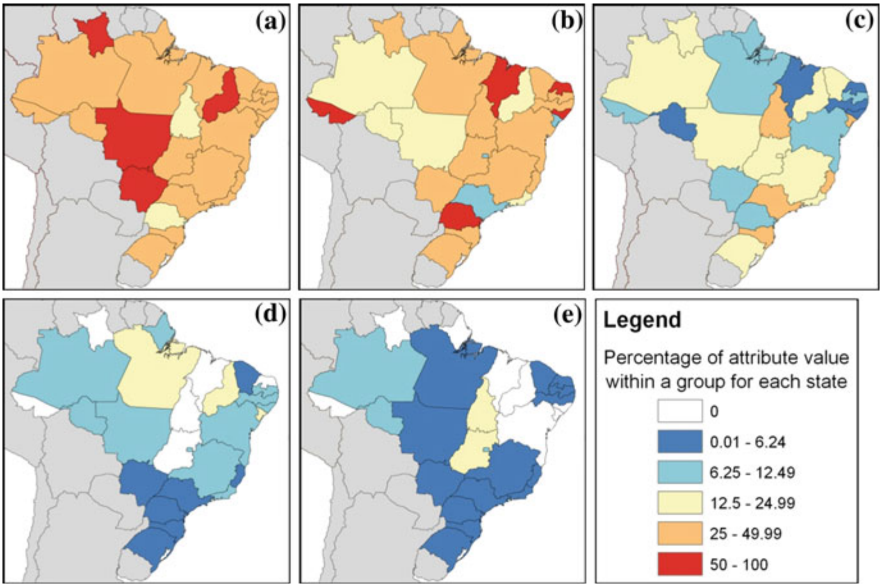


Fig. 4 The Brazilian states mapped by crime type (as % for state): **a** Robbery; **b** Violence; **c** Theft; **d** Attempted robbery; **e** Attempted theft

3.1.1 Initial Data Processing

Spatially, WikiCrimes collects data on crimes that are considered to occur at points in space. However, eXplorer only maps attribute data by polygon as a choropleth map and this implies a process of aggregation to move from one environment to the other (indeed, it is this generalization that marks the approach written about here). This matches Elwood's (2009) characterization of volunteered geographic information (VGI). The WikiCrimes dataset forms an integrated large resource of individual volunteered data whilst the geovisual analytic activities proposed with eXplorer adds further query, retrieval and analysis capabilities that Elwood prescribes for VGI (the shifting nature and heterogeneity of such data is also acknowledged and discussed in the conclusion).

Each record in WikiCrimes is tagged by either Brazilian state/country (choropleth), or by degree grid square, and this facilitates aggregation (see Fig. 3). Even if this didn't occur, it would be simple to perform a spatial join with the polygon boundaries (of country and Brazilian state boundaries) or grid cell boundaries and crime points. For each crime variable, Brazilian states or grid cells were summarized by count of records. Finally, since the number of crimes was heavily weighted towards the Ceará and Fortaleza area, each variable was normalized as a percentage of their variable group (a non-area-related ratio map—Kraak and Ormeling 2010). To illustrate, consider bank-related crime such as armed robbery. In the WikiCrimes database, the bank is recorded as a crime setting along with other types of places such as thoroughfares, homes and even vehicles. The number of crimes occurring in any

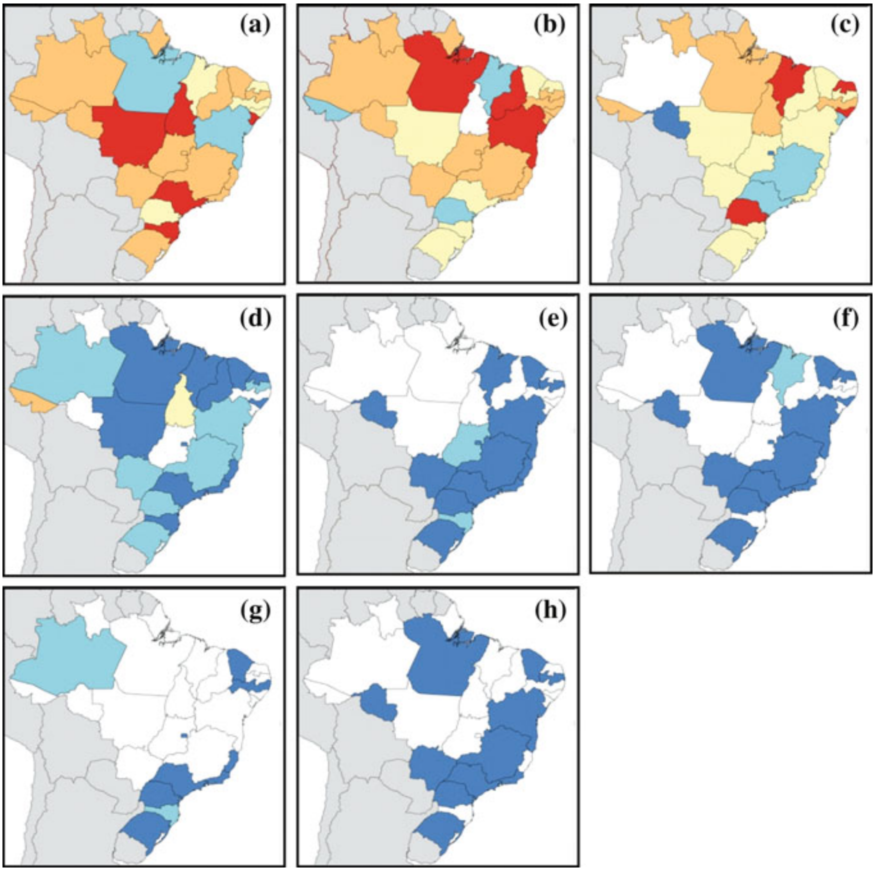


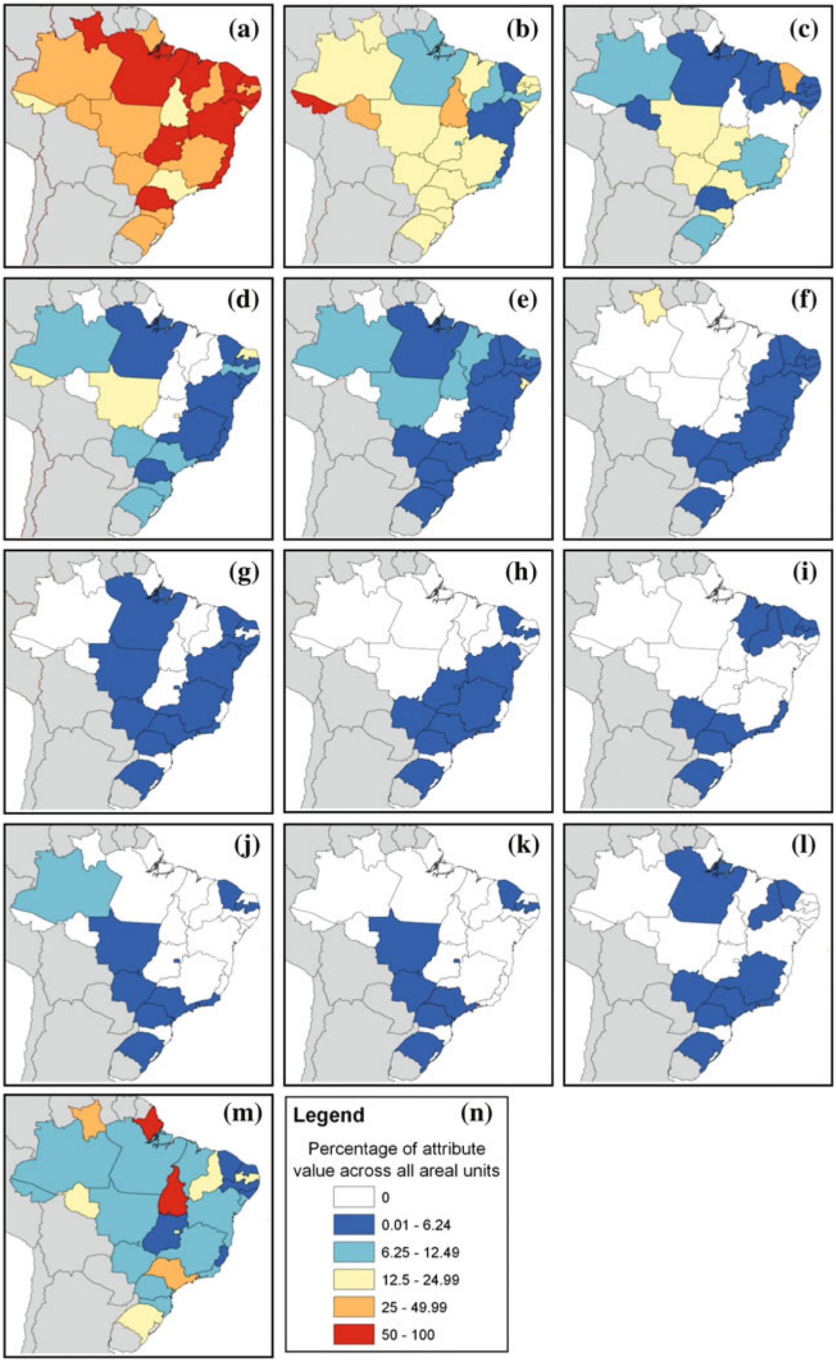
Fig. 5 The Brazilian states mapped by crime victim type (as % for state): **a** Property; **b** Person; **c** Murder; **d** Attempted Murder; **e** Quarrels or fights; **f** Atrocity; **g** Abuse of authority; **h** Domestic violence. Legend same as for Fig. 4

bank in a particular state would be expressed as a percentage of all crimes occurring in that state (i.e. for all places). For example, in the state of Rio Grande do Sul, 12 recorded crimes occurred in banks out of a total of 777 crimes in that state. As a percentage this is expressed as 1.5 % to normalize this figure relative to other states.

In all, 48 variables of interest were extracted, 5 for the crime type group, 8 for the crime victim type group, 13 for the crime setting group and 22 for the reason for crime group.

3.1.2 Maps of Volunteered Crime Data

Figures 4, 5, 6, 7, 8, 9, 10, 11 display the maps for all selected crime-related attributes, by state (choropleth maps) and by degree grid cell (choropleth maps containing polygons of approximately regular size and geometry). All maps use


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
(m)
Legend
(n)
Percentage of attribute value across all areal units
0
0.01 - 6.24
6.25 - 12.49
12.5 - 24.99
25 - 49.99
50 - 100

◀ **Fig. 6** The Brazilian states mapped by crime setting (as % for state): **a** Thoroughfare; **b** Place of residence; **c** Vehicle; **d** Commercial location; **e** Bank; **f** Pharmacy; **g** Public transport station. **h** Public square; **i** Lottery; **j** Shop; **k** Petrol station; **l** School; **m** Other

one of the colour palettes provided by eXplorer, slightly modified to highlight areas with no magnitude in the attribute being mapped.

Where multiple maps are displayed together for comparison, the benefits of best-practice ways of defining class intervals (e.g. optimal breaks or natural breaks) are lessened as there would be no consistent intervals across the maps (MacEachren 1994). Therefore a geometric progression fixed intervals classification is applied here to all maps, a variation on the use of equal intervals for multiple map comparison recommended (with qualifiers) by MacEachren (1994). The chosen classification scheme is a closer approximate fit with the data while the consistent class intervals enable easy comparison, within a group of attributes, but also across groups if needed (e.g. for a quick check of high proportion of some crime type spatially correlating with a high proportion of a specific setting or reason).

The intervals were shifted from the common geometric progression of 1-2-4-8… to enable a better fit with the percentage scale used for all attributes. Therefore, in the six-class representation used here, the intervals are 0 % (no incidence of that attribute - white), 0.01–6.24 % (blue), 6.25–12.49 % (light blue), 12.5–24.99 % (yellow), 25–49.99 % (orange) and 50–100 % (red). The order in which the attribute map figures are displayed in Figs. 4, 5, 6, 7, 8, 9, 10, 11 is according to mean percentage value in descending order.

3.1.3 Choropleth Maps by State

Figure 4 maps each of the 5 identified types of crime by state. In general, only the robbery and violence crime types occurred in any state in a proportion of greater than 50 %; in each case this occurred in only a few states. The five types were found in most states, with only some states having attempted robbery and theft not recorded.

Figure 5 maps each of the 8 identified crime victim types by state. Overall, only crimes on the property, person and murder crime victim types occurred with a proportion of more than 50 %, and even then only in a few states. These 3 crime victim types, along with attempted murder, had majority coverage. However, the other 4 crime victim types had patchy coverage, occurring in roughly a third to a half of the states.

Figure 6 maps each of the 13 identified settings in which crime incidents occur by state. In general, only three of the listed crime settings occur in any state in a proportion of greater than 25 %: Thoroughfare (most states), place of residence and vehicle (Ceará only). Also, in some states, a large proportion of crimes occurred in unspecified settings (Fig. 6m). Commercial locations and banks, in addition to the top three specified crime settings, had majority coverage. The remaining seven specified settings had approximately a third to a half of the states covered.

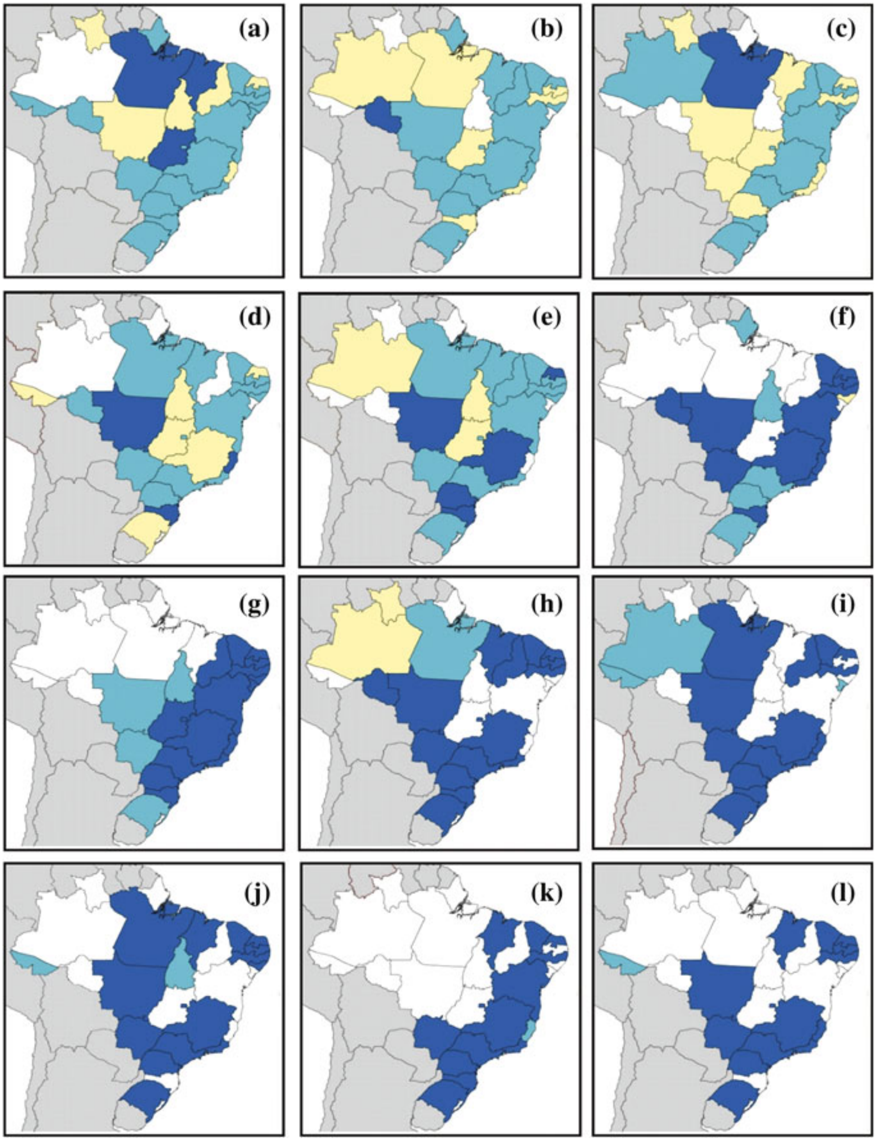


Fig. 7 The Brazilian states mapped by reason for crime (as % for state): **a** Easy access/Escape; **b** Criminal impunity; **c** Lack of policing; **d** Proximity to danger; **e** Drugs; **f** Unemployment; **g** Organised crime; **h** Gunman; **i** Crime of passion; **j** Children or adolescents in the street; **k** Poor Lighting; **l** Alcohol Use; **m** No recreation for children; **n** High concentration of people; **o** Lack of witnesses. **p** Gang dispute; **q** Revenge; **r** Poor urbanization; **s** Police violence; **t** Other; **u** Pending; **v** Unknown

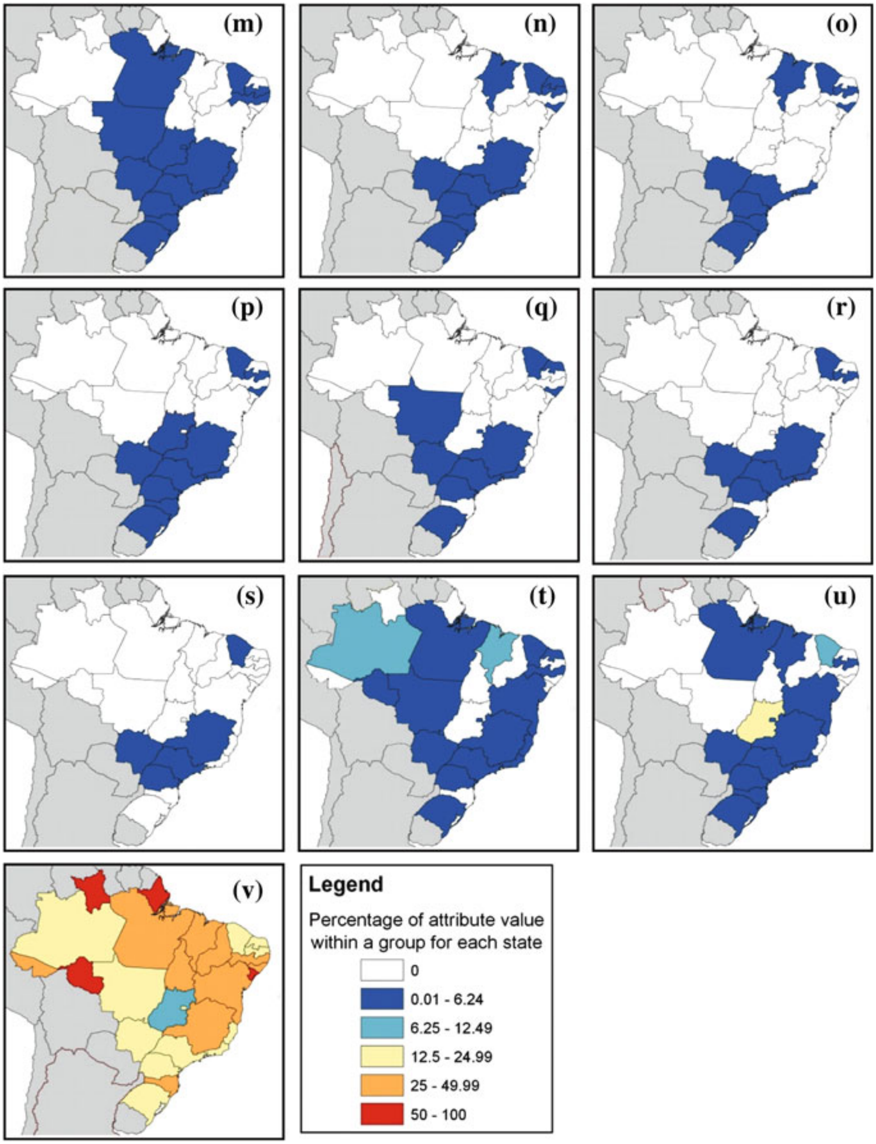


Fig. 7 continued

Figure 7 maps each of the 22 identified reasons for crime incidents by state. In general, only 7 of the specific reasons for crime occur in any state in a proportion of greater than 12.5 %: easy access/escape, criminal impunity, lack of policing, proximity to danger, drugs, unemployment (North East Region only) and gunman (Amazonas and Roraima states only). However, this is not forgetting that a large percentage of crimes are recorded as having happened for unknown reasons

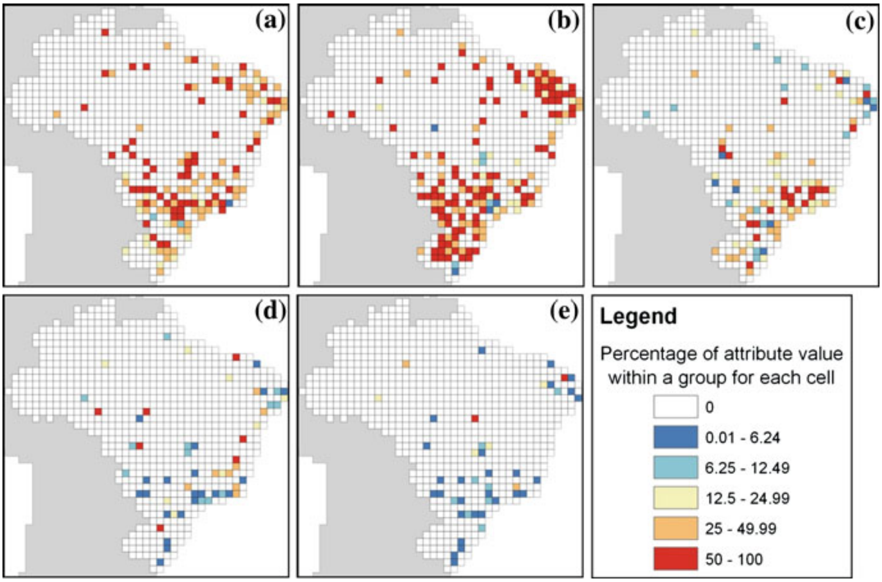


Fig. 8 Crime type mapped to degree grid squares covering Brazil (as % for each grid square): **a** Robbery; **b** Violence; **c** Theft; **d** Attempted robbery; **e** Attempted theft

(Fig. 7v). The top five reasons had large majority coverage. Unemployment and gunman, along with the 12 specific reasons not mentioned above, had about two-thirds of states covered (down to just 5 states out of 27 covered for police violence).

3.1.4 Choropleth Maps By Degree Grid Cell

Figures 8, 9, 10, 11 use a regular one degree grid of polygons covering the Brazilian land area as the geometric basis for the choropleth maps (a grid choropleth—Kraak and Ormeling 2010). This is to address the widely acknowledged ecological fallacy that occurs (Robinson 1950). In this case, an entire state area is assumed to adopt a single attribute value when in fact that value masks a lot of variation in attribute magnitude within that area. Although a degree grid cell suffers from the same effect, it is lessened, and at the Brazil scale, permissible.

The irregular state boundaries also denote an extent that affects the aggregated data values in a misleading manner. Alter the boundaries even slightly and you may derive a very different aggregate value—due to ecological fallacy, most of the point occurrences affecting an aggregate value attributed to an area may occur near the boundary. If the boundary shifts, some or most of the points may be left outside the area, implying a change for the aggregated value. This is the well-known phenomenon of the Modifiable Areal Unit (MAUP—Openshaw and Taylor 1981), the effects of which are minimized by applying a regular grid with an adequate resolution for the scale of a large country.

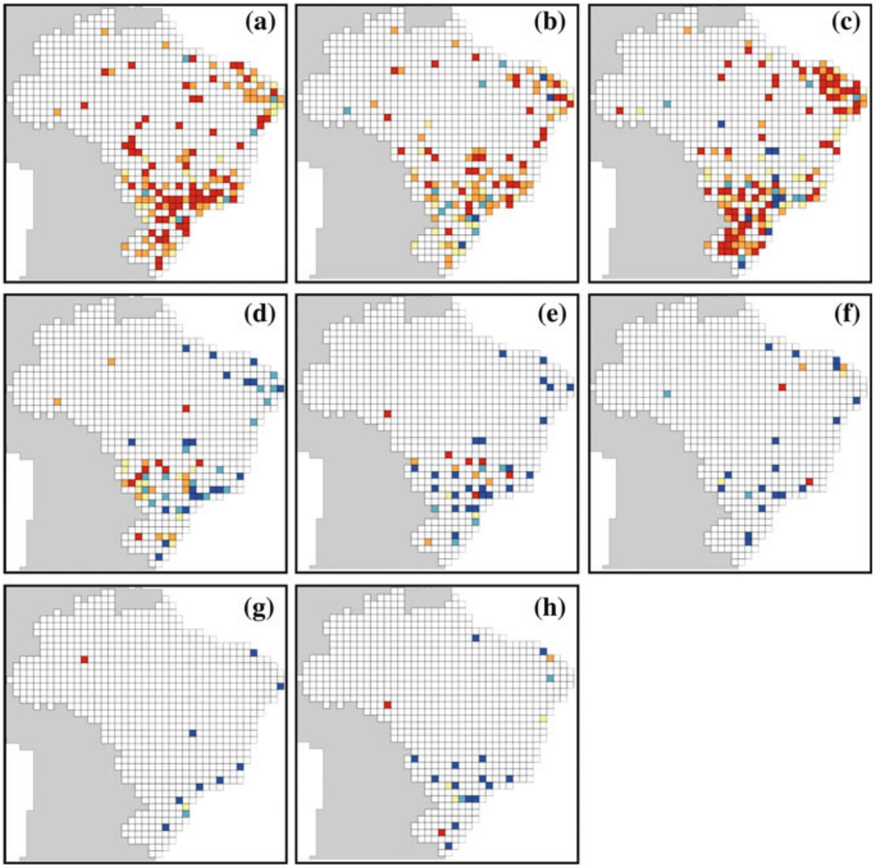
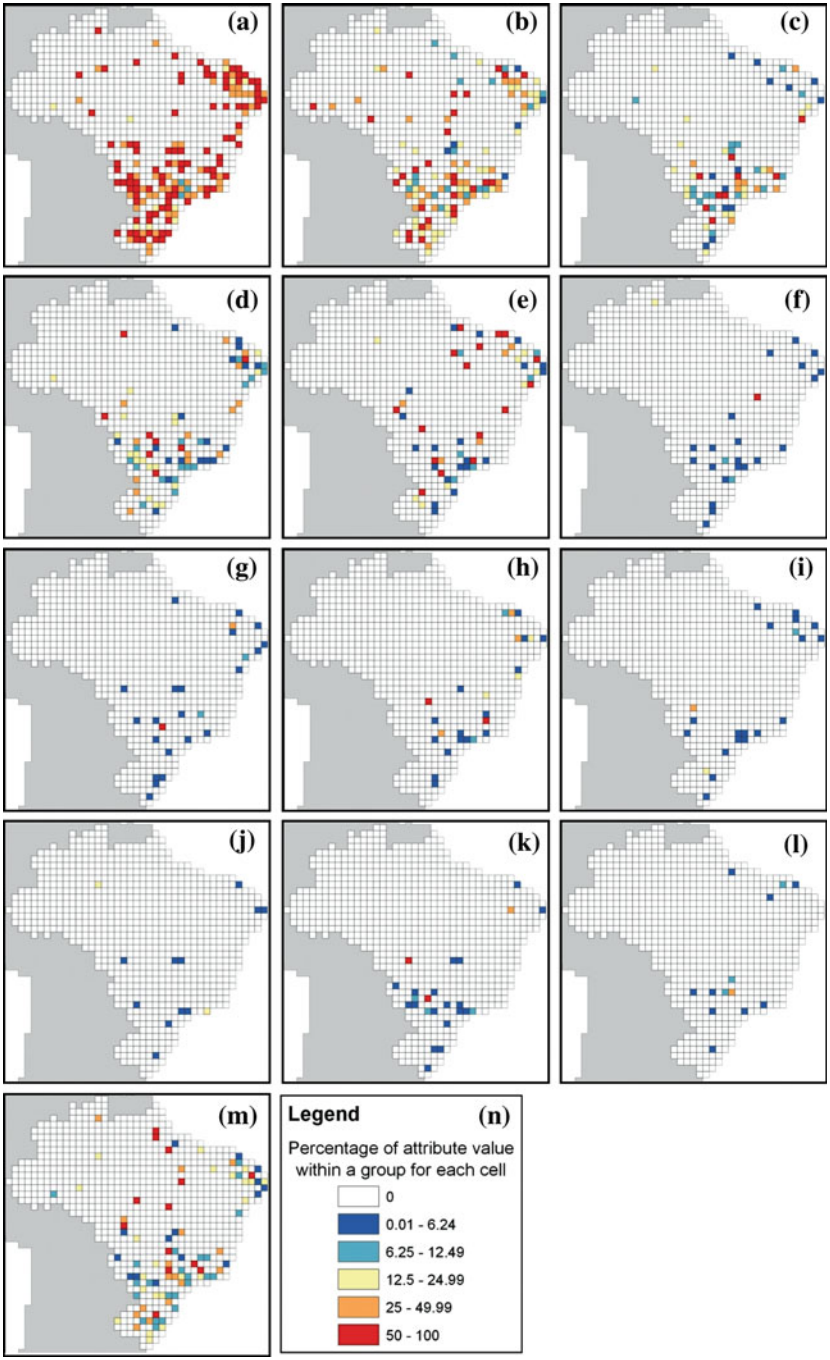


Fig. 9 Crime victim type mapped to degree grid squares covering Brazil (as % for each grid square): **a** Property; **b** Person; **c** Murder; **d** Attempted murder; **e** Quarrels or Fights; **f** Atrocity; **g** Abuse of authority; **h** Domestic violence. Legend same as for Fig. 8

Figure 8 maps each of the 5 identified types of crime by degree grid cell. The effect of using grid cells on coverage is immediately apparent, laying bare the misleading "full" coverage maps by state in Fig. 4 (i.e. there is a greater idea of where crime is occurring, whilst still enjoying the benefits of aggregation). There is also far richer data on variation of crime type due to the finer effective resolution of the degree grid cell. In the case of the southern state areas, it reveals the prevalence of robbery and violence there, not apparent in Fig. 4a or b.

Figure 9 maps each of the 8 identified crime victim types by degree grid cell. As well as more accurate picture of coverage described with the crime type maps, an emphasis on the top crime victim types (person, property, murder) in the north east and south (again not overly apparent in the state maps) is pronounced here.

Figure 10 maps each of the 13 identified settings in which crime incidents occur by degree grid cell. For the top three settings (thoroughfare, place of residence,


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
(m)
Legend
(n)
Percentage of attribute value within a group for each cell
0
0.01 - 6.24
6.25 - 12.49
12.5 - 24.99
25 - 49.99
50 - 100

◀**Fig. 10** Crime setting mapped to degree grid squares covering Brazil (as % for each grid square): **a** Thoroughfare; **b** Place of Residence; **c** Vehicle; **d** Commercial location; **e** Bank; **f** Pharmacy; **g** Public transport station; **h** Public square; **i** Lottery; **j** Shop; **k** Petrol Station; **l** School; **m** Other

vehicle) the comments for the groups in Figs. 8 and 9 apply (coverage; emphasis on the north east though vehicle-based crime is de-emphasised compared with the equivalent state map; emphasis on the south).

Figure 11 maps each of the 22 identified reasons for crime incidents by degree grid cell. The overall coverage and northeast/south emphasis comments for the other groups apply here too, though strong patterns are less apparent here due to the sheer amount of reasons leading to dilution of percentage magnitudes in each of the maps.

In all groups of maps featured in Figs. 8, 9, 10, 11, the sparseness of data for the less chosen attributes, only hinted at by the state maps, is starkly apparent (e.g. Fig. 11s representing police violence).

4 Results and Discussion

The approach taken in exploring the processed dataset with eXplorer was in two parts. The first is the systematic mapping of each of the chosen attributes, to isolate specific attributes that yield significant patterns. This is essentially the process represented and described in Sect. 3, and ultimately, through identification of the attributes with enough variable data to be interesting, effects a filtering of the dataset. The second part of the approach was related to the linked exploration of the dataset. This process roughly follows Shneiderman's (1996) visual information seeking Mantra: overview, zoom/filter then details-on-demand. However, in this case, the overview and filtering effectively occur at the same time. The in-depth exploration was largely unstructured, save for two initial strategies, in effect a starting point or trigger for visual analysis:

(a) Mapping any variable belonging to the crime setting group in the choropleth display. This was adopted for reasons of cognitive affinity, that the attribute most associated with the geography of crime (crime setting) has a locational display method (the choropleth map)
(b) Separating any variables in the crime group from variables in the crime victim group (principally that they would not be plotted against each other in the scatterplot display), due to their semantic proximity (more will be said about this later on).

However, these strategies mostly did not yield any notable discoveries, so the following examples do not follow them rigorously.

Figure 12 shows some screenshots of the visual analysis on the state-based displays. The choropleth maps in Fig. 12 have been classified into six classes according to a natural breaks strategy. This is recommended for standalone display

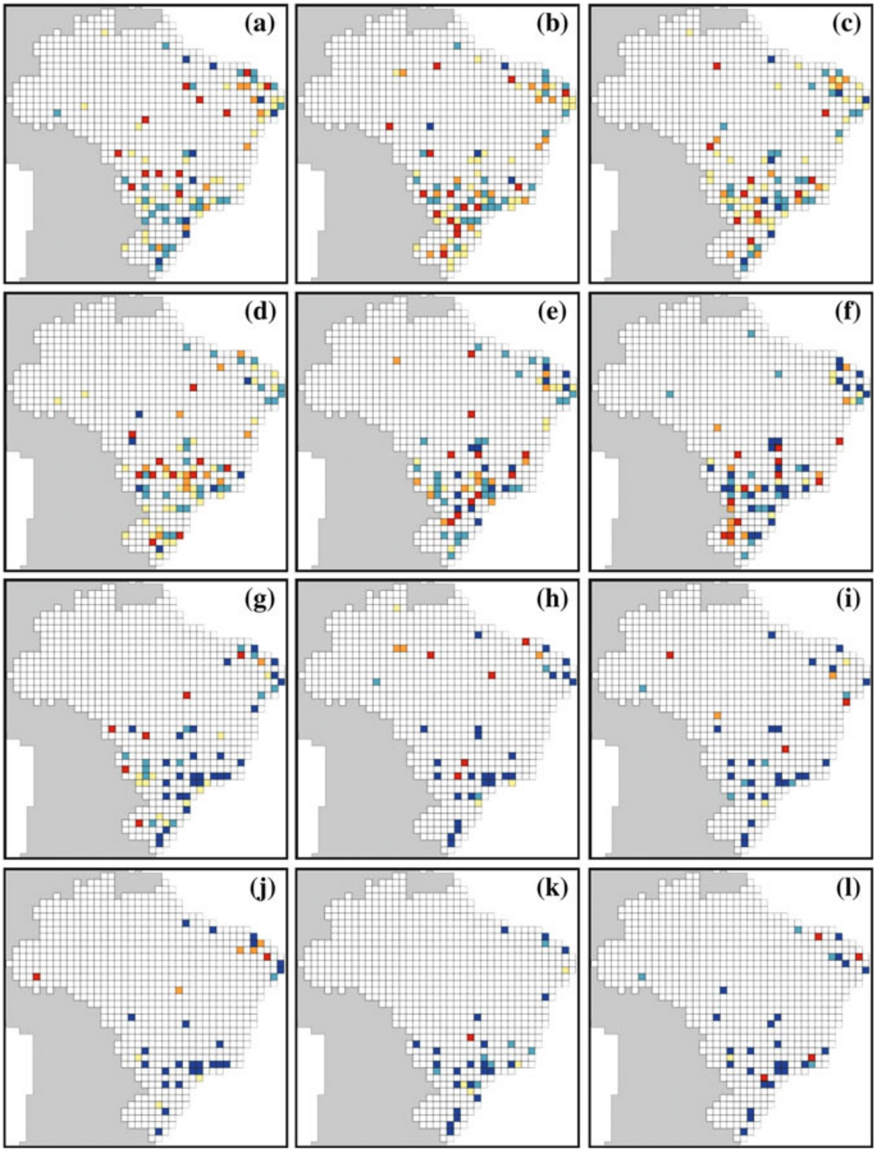


Fig. 11 Reason for crime mapped to degree grid squares covering Brazil (as % for each grid square): **a** Easy Access/Escape; **b** Criminal Impunity; **c** Lack of policing; **d** Proximity to danger; **e** Drugs; **f** Unemployment; **g** Organised crime; **h** Gunman. **i** Crime of Passion; **j** Children or Adolescents in the street; **k** Poor Lighting; **l** Alcohol Use; **m** No recreation for children; **n** High concentration of people; **o** Lack of witnesses; **p** Gang Dispute; **q** Revenge; **r** Poor urbanization; **s** Police violence; **t** Other; **u** Pending; **v** Unknown

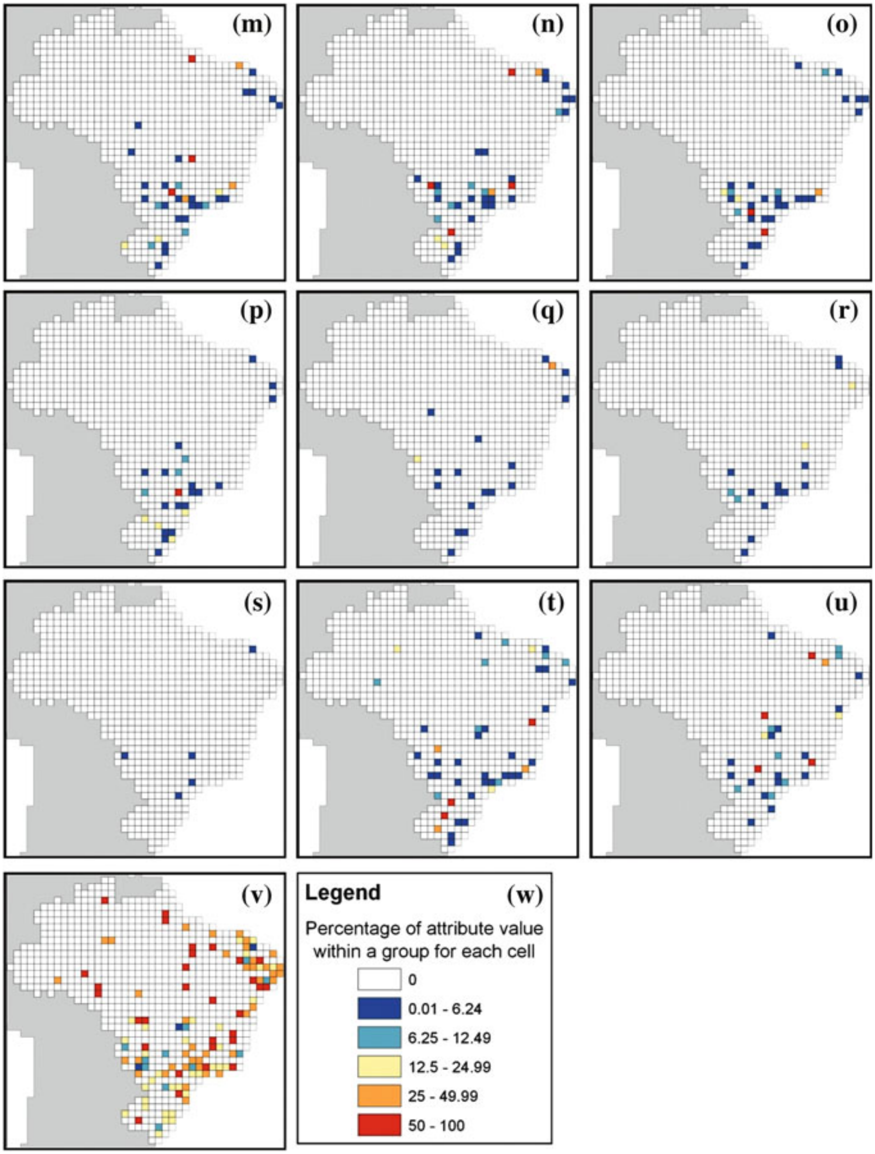
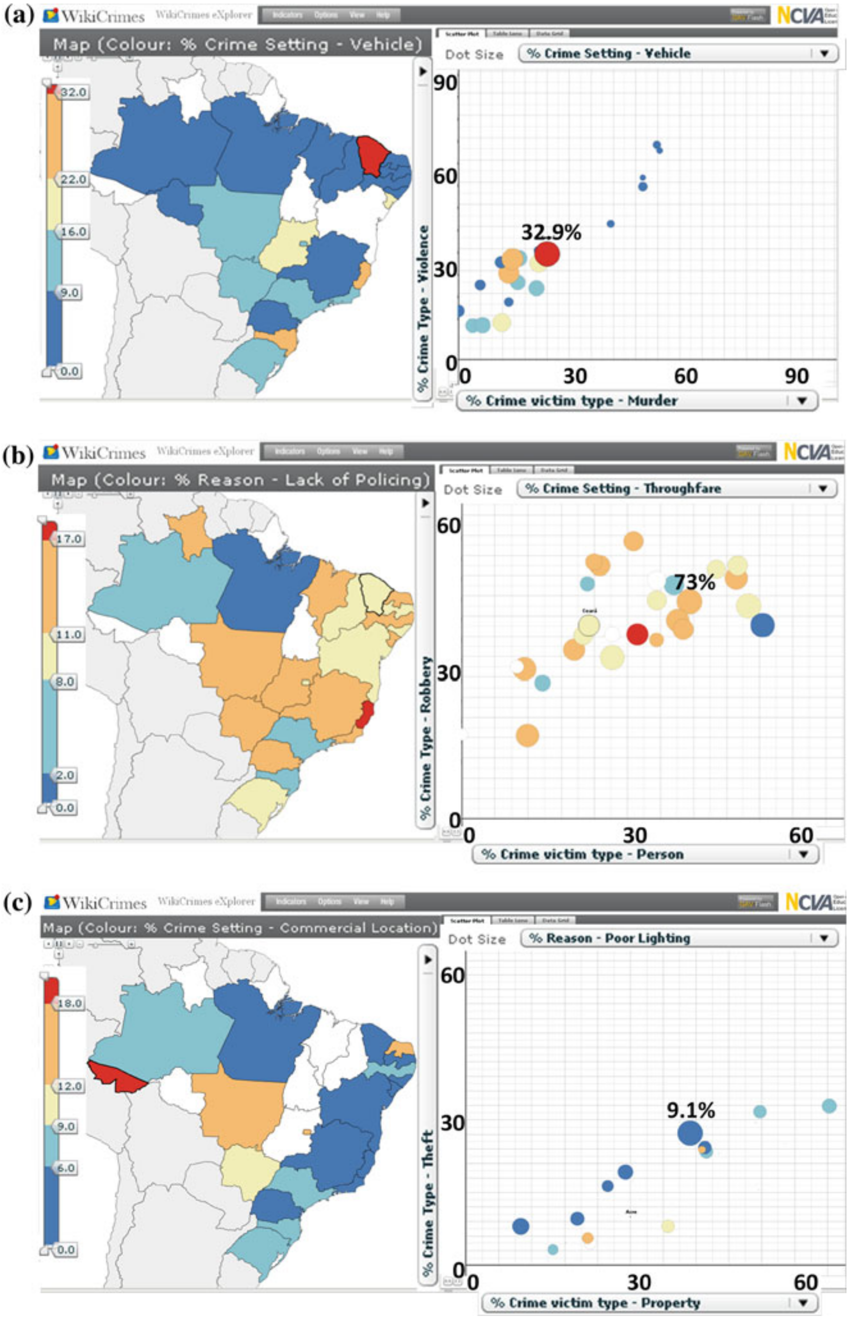


Fig. 11 continued

(rather than the map comparison needed for Figs. 4, 5, 6, 7, 8, 9, 10, 11), following the natural groupings of the data, in practice gleaned by eye from a histogram (MacEachren 1994).

In (a) there is a positive relationship showing on the scatterplot between murder (as crime victim type) and violence (as crime type), which is predictable.


(a)
WikiCrimes
WikiCrimes eXplorer
Map (Colour: % Crime Setting - Vehicle)
32.0
22.0
16.0
9.0
0.0
Dot Size
% Crime Setting - Vehicle
90
60
30
0
32.9%
% Crime Type - Violence
0
30
60
90
% Crime victim type - Murder
(b)
WikiCrimes
WikiCrimes eXplorer
Map (Colour: % Reason - Lack of Policing)
17.0
11.0
8.0
2.0
0.0
Dot Size
% Crime Setting - Throughfare
60
30
0
73%
% Crime Type - Robbery
0
30
60
% Crime victim type - Person
(c)
WikiCrimes
WikiCrimes eXplorer
Map (Colour: % Crime Setting - Commercial Location)
18.0
12.0
9.0
6.0
0.0
Dot Size
% Reason - Poor Lighting
60
30
0
9.1%
% Crime Type - Theft
0
30
60
% Crime victim type - Property

◀**Fig. 12** Some screenshots of WikiCrimes eXplorer (with labeling emphasized for clarity): **a** Choropleth (and *dot colour*) and dot size = % of crimes reported as occurring in a vehicle setting (maximum % labeled for scale), scatterplot (x) = % murder crime victim type, scatterplot (y) = % violence crime type; **b** Choropleth (and *dot colour*) = % lack of policing reason, dot size = % thoroughfare crime setting (maximum % labeled for scale), scatterplot (x) = % person crime victim type, scatterplot (y) = % robbery crime type. **c** Choropleth (and *dot colour*) = % commercial crime setting, dot size = % poor lighting reason (maximum % labeled for scale), scatterplot (x) = % property crime victim type, scatterplot (y) = % theft crime type; details in text. © 2011 NComVA.com

Interestingly, vehicle-based crimes occur mostly in states with low proportionate rates of violence and murder. There is also a spatially-contiguous band of relatively low vehicular crime in the northern states with the exception of Ceará.

(b) shows a generally positive scatterplot relationship between crime on the person and robbery. There is also a certain amount of choropleth evidence that lack of policing may be significant as a crime reason in the southern and eastern states. (c) shows a generally strong positive relationship on the scatterplot between crime on the property and theft crime type. Also, the states with lower rates of crime in commercial settings (colour) and with poor lighting as a reason for the crime (dot size) tend to have higher proportional theft.

Figure 13 shows some screenshots of the visual analysis on the grid-based displays. Like the displays in Fig. 12, the choropleth maps in Fig. 13 adopted a natural breaks strategy for classification. An initial task was to replicate the scenarios in Fig. 12. The results were largely similar, though with significant differences. The positive trend on the murder-violence scatterplot in Fig. 12a is replicated but the vehicle choropleth shows a different pattern (compare Fig. 6c with Fig. 10c). The person-robbery scatterplot positive trend (Fig. 12b) is strengthened in the equivalent plot in the grid implementation. Again, the lack of policing choropleth has changed (Figs. 7c and 11c). The Fig. 12c property-theft scatterplot positive trend remains that way in the grid implementation. However, there is now no observed relationship between poor lighting, commercial setting and theft activity as observed in Fig. 12c. The commercial location choropleth has changed (Figs. 6d and 10d); this and the other choropleth changes is a vivid illustration of MAUP, with the grid-based choropleth having a more objective, therefore more reliable basis.

Figure 13a illustrates a weak positive relationship between easy access and escape for the criminal as a reason, and a commercial crime setting. Also apparent is a strong positive relationship linking thefts and properties, apparent here by linking magnitude of the dot size with intensity of the dot colour value.

Figure 13b shows another weak positive relationship on the scatterplot, this time between lack of policing as a reason for a crime, and a vehicle crime setting linking dot size to dot colour suggests a positive relationship between robbery and crime on the person. In this case and the theft-property link in Fig. 13a, the strong positive relationship is more apparent when plotted against each other, as in Fig. 12b, c. The murder crime victim type and violence crime type is another

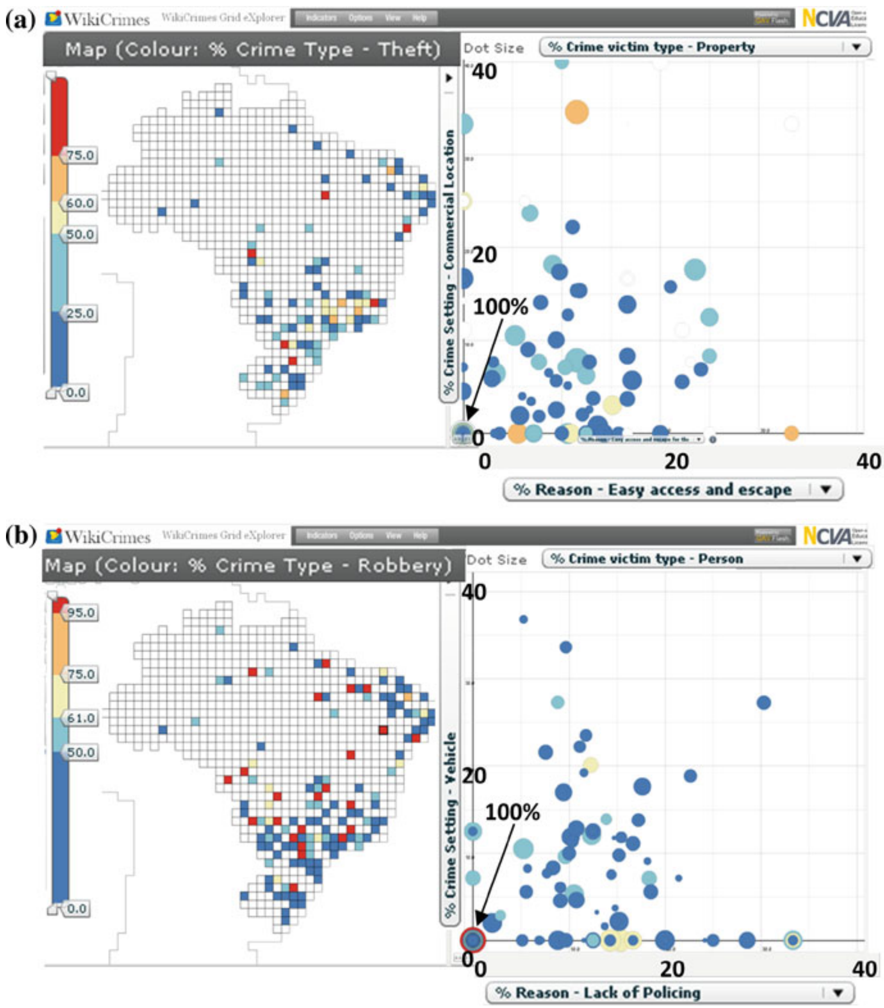


Fig. 13 Some screenshots of WikiCrimes Grid eXplorer (with labeling emphasized for clarity): **a** Choropleth (and *dot colour*) = % theft crime type, dot size = % property crime victim type (maximum % labeled for scale), scatterplot (x) = % easy access/escape crime reason, scatterplot (y) = % commercial location crime setting; **b** Choropleth (and dot colour) = % robbery reason, dot size = % person crime victim type (maximum % labeled for scale), scatterplot (x) = % lack of policing crime reason, scatterplot (y) = % vehicle crime setting. © 2011 NComVA.com

strong relationship (here and in Fig. 12a), and there are also complementary strong negative relationships observed between murder and both robbery and theft; also violence and both person and property.

The results in this section were gleaned through use of the linked display (as opposed to the spatial choropleth relationships described in the previous section). Most of the patterns seen are more a case of "detecting the expected" (e.g.

violence and murder) rather than "discovering the unexpected" (though the negative relationship of vehicular crime with violence and murder may be worth further investigation; also the possibly linked positive relationship of vehicular crime with lack of policing).

These vignettes are important in the communication of discovered information to the public. It is a key stage in Thomas and Cook's (2005) framework for visual analytics: to "communicate assessment effectively for action". This element is made manifest in eXplorer as storyboards that would provide the explanation accompanying a specific linked representation of data.

5 Conclusions

WikiCrimes is a Brazil-based Web 2.0 resource for volunteered crime information. As such, it has a sizeable point-based resource that is ripe for exploration using geovisual analytics tools, a dataset rich with attributes such as type of crime, that simply would not have existed anywhere in the world ten years ago. eXplorer has been used to good effect for this purpose on the WikiCrimes data aggregated to Brazilian state level and to degree grid level, mostly identifying expected relationships but also uncovering unexpected ones that may be worthy of further analysis.

The use of eXplorer in this way is sympathetic to WikiCrimes' aims and as such is a valuable supporting tool. It could promote enhanced crime transparency and generate added publicity for these all too hidden events. It does so by putting the data in a more digestible form for public and law enforcement officers alike. However, by aggregating from conventional pinmap and density hotspot representations to a choropleth one, errors due to ecological fallacy and the MAUP abound, though the effects of these well-known sources of error are mitigated through the grid-based representation.

The crime reporting representations that WikiCrimes uses, straightforward pointwise display (and density kernels) can give insight on distribution (it is the intention that such information will have value in the hands of the public) but misses much information of value. Nevertheless the grid-based implementation retains most of the distribution information lost in the state-based implementation, at an appropriate scale (degree grid) to Brazil's overall size.

The state-based implementation still has value in reporting data in special units that have a history and resonance with the intended audience, though the misleading over-aggregation of the data will outweigh this benefit. Furthermore, representation using recognized political or organisational boundaries facilitates future analysis with census data, which is reported via such aggregation units.

To facilitate these anticipated benefits, the tool will be in the public domain, where it will hopefully become a focus for public collaboration. However, there are issues that any user of the tool should be mindful of. The database builds gradually, and while every effort has been made to anticipate crime types, settings and reasons, inevitably a category that was created to fit a crime entry early on may be an imperfect fit for a later entry of a different crime. Therefore a new category is created that fits that later entry but overlaps semantically with the earlier-created category (e.g. "organised crime" and "gang dispute" as reasons for a crime). This phenomenon creates issues when trying to glean patterns using the eXplorer tool – the imperfect classification may be making patterns less apparent or worse, invisible. The use of categorized crime with close meanings (e.g. robbery and theft) and, at a higher level, the semantic closeness of crime type and crime victim type only adds to the uncertainty. Elwood (2009) acknowledges both this heterogeneity due to 'diverse categorization schemes' and the shifting nature of a dataset such as WikiCrimes' as part and parcel of volunteered data.

Another issue is the trustworthiness of the data itself, as it does not come from an authoritative source and is open to abuse. However, the amount of reports that come in and the fact that for this study the reports are aggregated means that the conclusions derived are based on more robust data than an individual report may be (i.e. there is safety in numbers).

Finally, there is a possible bias towards states with more reports contained within its boundaries. Despite the efforts at normalization from counts to percentage proportions, for states such as Ceará in particular, having the lion's share of reports, bias will manifest itself in having a greater variety of reasons for crime, crime settings and even crime types and crime victim types. The sheer amount of scenarios for reported crime in Ceará and particularly in Fortaleza, and the potential variety it brings, make this more statistically likely.

Future directions include the linked analysis of this volunteered data with census data, which could potentially yield more insights, especially at the (Fortaleza) city scale, for which most of the data exists. Other datasets could be used to link with the volunteered crime data, for example car ownership rates or tourism data (as a group of people least likely to make a wiki entry following a crime—is this a source of silence in the data?) Use of eXplorer's visual time analysis tools could be used to mine temporal trends from data segmented into intervals.

Acknowledgements The authors would like to thank Tobias Åström at Norrköping Communicative Visual Analytics (NComVA) in Sweden for providing access to Open Statistics eXplorer. The feedback from the two reviewers of this chapter is also appreciated.

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Towards Acquisition of Semantics of Places and Events by Multi-perspective Analysis of Geotagged Photo Collections

Slava Kisilevich, Daniel Keim, Natalia Andrienko and Gennady Andrienko

Abstract Due to the pervasiveness of positioning technology combined with the proliferation of socially-oriented web sites, community-contributed spatio-temporal data of people's historical positions are available today in large amounts. The analysis of these data is valuable to scientists and can provide important information about people's behavior, their movement, geographical places, and events. In this paper, we develop a conceptual framework and outline a methodology that allows us to analyze events and places using geotagged photo collections shared by people from many countries. These data are often semantically annotated by titles and tags that are useful for learning facts about the geographical places and for detecting events occurring in these places. The knowledge obtained through our analysis carries an additional benefit. For example, it may also be utilized by local authorities, service providers, tourist agencies, in sociological and anthropological studies or for building user centric applications like tour recommender systems. We provide a conceptual foundation for the analysis of spatio-temporal data of places visited by people worldwide using community contributed geotagged photo collections. First, we define several types of spatio-temporal clusters of people's visits. Second, we discuss methods that can be used for analysis of these clusters. Third, we offer an analysis of tourist activities in Switzerland based on a case study.

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7_10,

Keywords Spatio-temporal clustering · Semantic enrichment · Geotagged photo collections

1 Motivation

Ubiquity of location-aware devices, cheap storage and fast computing power has enabled collection and analysis of large amounts of spatio-temporal data. Different application domains like zoology, activity-based analysis or tourism in which data collection was a tedious and manual process (observation, surveys), benefit from the positioning technology and demand new analysis and techniques to cope with large quantities of these data.

Collections of geotagged photos have recently become available (Goodchild 2007) due to the availability of photo-sharing sites such as Flickr (http://www.flickr.com.com) and Panoramio (http://www.panoramio.com), in which millions of users from all over the world upload their geo-referenced photos. The basic information provided by a person during photo upload is the location *where* the photo was taken, the time of the action, and the textual identifiers including title and tags. The photo may also be a member of some thematic group. A photo taken by a person can be regarded as an event, and collection of photos of a person can be considered as a trajectory. Such user-generated data have already been used in the analysis of attractive places (Crandall et al. 2009; Kisilevich et al. 2010a), movement behavior (Girardin et al. 2008a) and mobility (Andrienko et al. 2009). The advantages of these data are (Girardin et al. 2008b): *unlike the automatic capturing of traces, the manual disclosure of location in the act of geotagging of photo provides additional qualities: positioning a photo on a map is not simply adding information about its location; it is also an act of communication which contains what people consider as relevant for themselves and others*.

Until now, these data were used as an alternative to the GPS-based data, mainly utilizing coordinates and timestamps. However, the title, tags, thematic group name as well as the photo itself, may reveal the context of the photo or describe the place where it was taken: some known event, a landmark or a person. Multimedia, computer vision and text mining communities realized the potential of geotagged data (Toyama et al. 2003) and proposed automatic approaches for such tasks as image summarization (Kennedy et al. 2007; Zheng et al. 2009a), landmark identification (Crandall et al. 2009), automatic event identification (Kennedy et al. 2007; Ahern et al. 2009; Becker et al. 2009), which includes clustering and retrieval of tag representatives. Information retrieval methods allowed automatic gazetteer creation using geotagged images (Popescu et al. 2008), Wikipedia, and web search engines and ontology induction from tagged images (Schmitz 2006). However, pure automatic approaches of event or place exploration have several disadvantages that are important to draw attention to.

1. The automatic approaches usually utilize different constraints and assumptions that assure adequate performance. Such assumptions are for example the following:

   a. The representative tags or events are determined by the semantics of the textual information and not by the geographical constraints. This enables finding only one event per area (cluster). Clearly, if there are several events occurring in one place at different time or at the same time (overlapping events), only the most significant one will be selected. The significance of the events is purely algorithm dependent and can lead to loss of information about other events.
   b. The significance of the place is usually determined by the number of photos, users or other heuristics. Thus, the event with a *few* number of photos or people can be missed. For example, Jaffe et al. (2006) note that more than 1,000 photos on a city scale are required in order to obtain meaningful results.
   c. The significance of the place is determined by the uniqueness of the textual semantics within the cluster. It means that in order to find a significant event in a cluster, other clusters, surrounding that cluster, should be analyzed and semantics extracted from them to be taken into consideration. This makes the algorithms non-scalable when large areas are used for exploration.

2. Experiments are performed using clean-room data samples, where class labels are manually prepared or taken from existing benchmark sources. Therefore, such issues as geographical errors, different languages or mistakes made in textual information are usually not raised.
3. Different representation models as well different algorithms produce different results.
4. Algorithm accuracy is reported with respect to the best-tuned parameters applicable to the training data. No real experiments were performed on arbitrary data.

In addition, all the mentioned approaches are user centric, aiming at providing solutions for exploration but not for analysis. Examples are: the representative tag viewer by Kennedy et al. (2007), tag maps by Jaffe et al. (2006) or tag mapping "world explorer" by Ahern et al. (2009). In contrast to these approaches, our paper aims at the *analysis* of places and events.

We claim, however, that combining the above mentioned techniques with geospatial visual analytics methods, GeoComputation, spatial and spatio-temporal data mining create new opportunities for the analysis of spatio-temporal data. The most important difference between the existing approaches and the methodology proposed by us, is the way in which event clusters are obtained. In contrast to the semantic-centric approach, we use spatio-temporal clustering based on geographical properties of the data as commonly used in geographical analytics. This allows us to apply different techniques like time-series, text or multimedia analysis on the same region in a chain of steps or to investigate different events that occurred at different time intervals or are overlapped.

For the sake of comparison with the existing approaches, we would like to mention the model used for semantic enrichment of trajectories. Furthermore, for the tasks in this paper that we regard as non-applicable, we will provide explanations respectively. Most of the spatio-temporal data is obtained by GPS devices and contains sequences of space-and-time referenced points measured at arbitrarily chosen time intervals.

One of the widely used approaches in working with trajectories is based on extraction of significant places from a single trajectory using an object's stay time heuristic (Andrienko et al. 2007). This approach was later conceptualized by (Spaccapietra et al. 2008) by introducing a model in which trajectories are divided into sequences of *stops* (important places) and *moves* (movement **to** or **from** important places). Two main approaches are used to find important places in trajectories. The first considers only the characteristics of the trajectory (considerable time spent in a place). In the second approach, important places are obtained by intersecting the trajectory with the external application-specific geographical features provided by the user. In the first case, the obtained important places are still expressed in terms of geographic primitives and do not have any additional information, so that the analysis is usually performed by domain experts using visual analytics tools (Andrienko et al. 2007). In the second step, the obtained important places hold semantic information (id, location name) that can be used in the data mining process (Alvares et al. 2007a).

However, there are several problems with this approach: (1) An external database of geographic features should be available. But even if it is available, the algorithm can miss important places if the database is not complete. (2) The real context of a stop is not known. For example a person may be waiting in a traffic jam near a museum on the way to his/her work but the algorithm for finding important places may identify the person as visiting the museum by extracting a stay point (important place were a person spends considerable time) by intersecting the trajectory with the museum. (3) Since the data itself can have many contexts at different time intervals, the important place found may not correspond to the semantics that was attached to it (static semantics enrichment). (4) The extracted semantics describe only the data they are attached to, and cannot be used for other purposes.

Obviously, spatio-temporal data should contain more information to aid the analyst in understanding the context of the data. Since photo-collection data contains visual and textual information explaining the context of a photo, this data has invaluable potential for the analysis of the geographical places to which photos are geo-referenced, and the understanding of events that happen in the place where the photo was taken.

In this paper, we provide a conceptual foundation for the analysis of events and places using geotagged photo collections. We claim that a semantic enrichment of the spatio-temporal data should use additional components available in the data and take into account the temporal aspect. We define several types of semantic spatio-temporal clusters, and discuss methods for creation and analysis of these clusters.

2 Related Work

2.1 Spatio-Temporal Clustering

Many methods were proposed to cluster spatio-temporal data. Trajectory patterns of moving objects were mined in Giannotti et al. (2007) by finding regions-of-interest where many trajectories intersect with similar travel times. To find these places, the geographical space was divided into grids and the density of cells was computed. Then, a sequence mining algorithm was applied on these regions.

Palma et al. (2008) proposed a clustering approach based on the DBSCAN (Ester et al. 1996) algorithm to find important places in trajectories. The original concept of point neighborhood used in DBSCAN was changed to allow finding important places in a single trajectory. According to a new definition, the important places are places where the speed of an object is considerably slower than in other parts of the trajectory.

Zheng et al. (2009a) proposed a model to infer a user's travel experience and the interest of a location. In the first step, trajectories of people were divided into stops and moves. In the second step, density based clustering was applied on stops using different scales (neighborhood, city, country), by forming a tree-based hierarchical graph. For every level of the graph, the interestingness of the location could then be calculated.

Spatial generalization and aggregation of trajectories was proposed in Andrienko and Andrienko (2011). The characteristic points (stops) of trajectories were discovered. Then, the points were grouped into clusters. The centroids of the cluster were used for building a Voronoi tessellation (Okabe et al. 2000). The resulting Voronoi cells were used as splitting regions of the trajectory.

2.2 Place Semantics

2.2.1 Semantic Enrichment of Movement Data

Alvares et al. (2007a, 2007b) proposed a method of semantic enrichment of trajectories using the stop-and-move model. The method combines external geographical features and finds intersections between important places. Ontology-based semantic enrichment was proposed in Baglioni et al. (2009) to interpret moving patterns.

2.2.2 Building Gazetteers

Popescu et al. (2008) used different Internet sources like Wikipedia, Panoramio and web search engines to automatically collect, identify and categorize geographical names.

2.2.3 Working with Photo Collections

An algorithm for summarization of photo collections using textual attributes of a photo was presented in Jaffe et al. (2006). The algorithm, based on Hungarian method (Kuhn 1955), first, performed hierarchical clustering of the region using cluster scoring as a heuristic for cluster creation. The score was composed from such components as *tag-distinguishability, photographer-distinguishability, cluster density, the sum of image qualities*. A visualization environment was proposed to visualize the representative tags for every cluster reflecting the tag's importance. The later work (Ahern et al. 2009) used k-means instead of the Hungarian clustering.

Kennedy et al. (2007) applied content and context based analysis for ranking clusters and finding representative images in a cluster. The cluster ranking was performed to assess how well the photos in a cluster are represented by a tag. They included such aspects as number of users, visual coherence, cluster connectivity, variability in dates. Following, an image analysis was used to select the best representative image from the high ranked clusters. Image organization and an engine for discovering landmark photos was proposed in Zheng et al. (2009b). A worldwide landmark list was generated using geotagged images and articles from travel guides.

Becker et al. (2009) proposed an ensemble clustering approach (combining different features like titles, tags, keywords, description and content creation time) for event identification (concerts, music festivals, etc.) using photo collections. Different combinations of features were evaluated where the combination of all text features and tags alone achieved the highest performance.

3 Our Previous Work

This work is a continuation of a previous work on analysis of event-based movement data (Andrienko et al. 2009), visualization of attractive areas using geotagged photos (Kisilevich et al. 2010a), and on semantic enrichment of visited places and pattern mining (Kisilevich et al. 2010b).

In Andrienko et al. (2009), five space and agent-centered analysis tasks for event and trajectory-based data were defined: *spatio-temporal aggregation of events, spatial clustering of events, spatio-temporal clustering of events, flow analysis* and *interactions in space and time*.

The procedure for the visualization of attractive areas was proposed in Kisilevich et al. (2010a). The process consists of applying a density based clustering algorithm to the photo data and calculating the importance score of a photo using kernel density estimation. The importance score was then used for two purposes: (1) as a value for colour generation and (2) an estimator for importance of the photo. The photo with the largest importance score was selected as a representative photo in a cluster.

A four-step process was proposed in Kisilevich et al. (2010b) to extract movement sequence patterns using a semantic enrichment process. In the first step, every photo was semantically annotated by a nearest point of interest (POI) using an external database of POIs. The photos that were assigned to the same POI created a semantic cluster with the POI being a representative of the cluster. For example, if the POI is a *train station*, the question can be asked: *Are there people who take photos near a train station* or *how many people take photos near a train station?*

In the second step, photos that were not semantically annotated due to the absence of POI in the neighborhood, were clustered into regions. The obtained regions were considered as new unknown POIs. In the third step, a movement sequence was generated for every user, using the POI identifiers assigned to her photos. In the fourth step, a sequence mining algorithm was applied to the sequences in order to find frequent patterns. As a consequence, the pattern of type A → B could be interpreted like this: *people who visit the area A also visit the area B* and pattern of type

A → * → B could be interpreted like: *people who visit the area A may continue to any other place and from any other place come to B*.

The current paper extends the previous work in several aspects:

(1) To reflect the importance of time in cluster creation and analysis, we provide a taxonomy of possible types of spatio-temporal clusters.
(2) The semantics enrichment process is discussed with respect to time.
(3) We discuss the possible external data sources that can facilitate extraction of semantics.
(4) The methods supporting semantics extraction are outlined.

4 Importance of Time in Understanding Space

In Sect. 1 we argued that time is important for understanding spatial patterns. In this section, we provide a taxonomy of spatio-temporal clusters and present possible data sources of semantics knowledge. Additionally, we discuss methods that facilitate semantic extraction and understanding of spatio-temporal clusters.

4.1 Types of Spatio-Temporal Clusters

In her "Mapping Time" monograph, Vasiliev (1997) defines five time categories that are used by geographers: *moments* (moment in time, single instance, dating of an event, no duration), *duration* (intervals, continuance of an event in space), *structured time* (sequences, ordering of events, organization of space by time), *time as distance* (time as a measurement of distance) and *space as clock* (space as a measure of time). These categories define different time interpretations and representations on the map. We derive our taxonomy using the basic definitions of these categories where *moments, duration* and *structured time* are the most important for our definition of types of spatio-temporal clusters.

Note: our definition of *events* is similar to that of Becker et al. (2009)—*an event is something that occurs in a certain place at a certain time and characterized by some photo activity of people.* For the more general definitions of *events* in geo-spatial domain we refer the reader to Worboys and Hornsby (2004), Cole and Hornsby (2005) and Hall and Hornsby (2005).

1. Stationary (moments)—the cluster is called stationary when the subject of a photograph does not change in time. Landmarks like a monument, museum or airport are good candidates to be found in such a cluster.
2. Reappearing (duration, intervals)—clusters can be reappearing when the photographic activity in the area increases in one time period and decreases in another. Two types of reappearing clusters can be expected:
    a. Regular—clusters in which some periodic events take place. Such events attract people at regular periods. For example: new-year fireworks on the main square of the city or Oktoberfest in Munich.
    b. Irregular—clusters in which aperiodic events take place. Such events attract people at irregular periods. For example: a concert or football game.
3. Occasional (moments)—clusters in which some events happen occasionally, e.g. a traffic accident.
4. Regular moving events (structured time)—clusters that represent the same event taking place in different places, e.g. Olympic Games (taking place on a regular basis in different places) or scientific conferences. This is probably the most complex type of a cluster since, for each particular place, it is irregular or occasional, and can only be discovered by inter-place comparisons.

In addition to the types of spatio-temporal clusters, we would like to differentiate between two types of semantics: (1) semantics of places and (2) semantics of user's behavior. Semantics of places and users are interconnected and one can enrich the other. Knowing the semantics of a place, we can infer the semantics of users who take photos in these places. For example, the place that has semantics of sport (stadium, football) will indicate that people who take photos there like sport. Likewise, characteristics of a user can have implication on the analysis of the event, user's behavior or a place. Using the profile of the person, we can interpret the profile of the cluster. For example, if we know that a person often takes photos of sport events and nature, then occurrences of his photos in a cluster may help us to identify the semantics of a cluster.

4.2 Potential Sources of Semantic Data

The following is the list of potential data that can be used to extract semantic information about the places or events. The primary source of information is the photo collection data that include all the relevant information like coordinates, tags and titles. Additional sources of information are Wikipedia encyclopedic pages and the GeoNames database.

4.2.1 Geo-referenced Photo Collections

Panoramio contains millions of geotagged photos. It is used by Google Maps and Google Earth as one of the visualization layers. Its publically available API allows the downloading of photo metadata by providing a bounding box of the desired area. The following is the most important information provided by the API: *photo id* and *coordinates, owner id* and *name, photo url* and *title*.

Another source of geotagged photos is Flickr. Flickr has a larger user database and its API allows for receiving more meta information than Panoramio, such as *thematic photo groups, contacts (favourites) of users* and *user information including place of residence (filled by 13 % of users)*. The Flickr API does not allow downloading metadata by specifying exact boundaries of the area of interest. Therefore, we used an approach similar to Web crawling. We downloaded all the photo metadata of arbitrarily selected subjects and obtained the list of their contacts as well as the list of groups their photos belong to. The same procedure was iteratively applied on other retrieved users. We began collecting the data from the beginning of June, 2009. By the end of March 2010, we collected 87,665,970 entries from 7,449,723 users and 394,830 thematic photo groups. This amount of data allows us to analyze virtually every place on the Earth if it was previously visited by photographers.

We are aware that user-generated data like photo collections can include incorrect spatial and temporal information. For example, 10,117 photos did not include the date and 55,176 photos are dated after 2010 after the time of collection. These photos have to be excluded from the temporal analysis. However, there are cases in which it is difficult or impossible to detect incorrect entry: adjustment of the camera clock to the local time (in most cases adjusted manually by the person) or correct geotagging during the upload process (if the camera was not equipped with GPS). Still, not all of these problems are critical. Spatial aggregation does not require timestamps. Aggregation level in space and time may be larger than position or time reference errors.

Table 1 Methods for semantic enrichment

Method	Achieves
Spatial and spatio-temporal clusters	Grouping of the photos into clusters using distance metrics and timestamps
Text analysis	Grouping of the photos into contexts using textual information (title, tags)
Content-based analysis	Grouping of the photos into contexts using visual similarity
Analysis of events (time series)	Temporal characteristics of the cluster. Frequency of events
POI database and entity relations	Retrieving photo topics (nature, landmarks) and hierarchies of concepts
User profiling	Profiling of users in a cluster using photo semantics

4.2.2 Points of Interest

The Wikipedia database (http://de.wikipedia.org/wiki/Wikipedia:WikiProjekt_Georeferenzierung/Wikipedia-World/en#Static_layer) can be used as a source of POI data. This database is an on-going community project aimed at applying geographic annotation to articles describing interesting sites around the world. The database that is currently available contains 815,085 entries of various sites such as cities, landmarks, monuments, buildings, towers annotated with coordinates and titles.

4.2.3 Geographical Features

GeoNames (http://www.geonames.org), a geographical database contains over eight million geographical names and consists of 7 million unique features, 2.6 million populated places and 2.8 million alternate names. All features are categorized into one out of nine feature classes, and are further subcategorized into one out of 645 feature codes (mountains, lakes, monuments). The elements of the dataset are organized into *isA* (conceptual inheritance) or *partOf* (spatial inclusion) relations. This dataset is freely available for download or accessible through web services.

4.3 Methods for Semantic Enrichment

In this section we describe six main methods for semantic enrichment. Table 1 briefly summarizes the proposed methods.

4.3.1 Detection of Spatial and Spatio-Temporal Clusters

Clustering can serve as a primary tool for organizing the collection of photos into groups. Among the possible methods used for spatial clustering are: grid based (Girardin et al. 2008a), density based (Andrienko et al. 2009; Kisilevich et al. 2010a) and hierarchical clustering (Zheng et al. 2009a).

Clustering based on grids is data independent and does not take into consideration the distribution of points. The number of cells should be known in advance and many trial and errors are required to find the suitable number and size of the cells. Density based clustering is based on the neighborhood density (min points) and minimum distance between points using (usually Euclidean) distance functions. The method produces an arbitrary number of clusters based on the selected parameters. In general, variations of density based clustering can be applied where the time component is taken into consideration (Andrienko and Andrienko 2009). For example, the spatio-temporal cluster will be formed if there are more than five people that took photos within the range of 1 h and the distance between them is no more than 100 m. Such an approach would create event-centered temporal clusters.

Hierarchical clustering can be applied to form clusters at different scale levels. Clusters on every level can be analyzed separately and different semantics can be applied at different scales. For example, the tag that identifies the name of a city can be assigned to the cluster on the city scale, while tags that identify names of neighborhoods will be assigned to clusters at the neighborhood scale. Spatial clusters can be produced by bounding the data with time limits. In this way, only the data that falls into the time interval will be clustered whereas the clustering algorithm will cluster points without taking the temporal aspect explicitly.

4.3.2 Text Analysis

Text analysis of titles and tags can be used for finding events that happen in a cluster or in different parts of the world at the same time or at different times. For this, the representative tags and titles can be obtained for several clusters and matched for similarity. Examples of such events are New-Year celebrations that take place at the same time in different parts of the country or the world. At the global scale, difference in time zones should be taken into account by clustering every region separately with adjusted time intervals.

4.3.3 Content-Based Analysis

Similarity between images in a cluster can facilitate finding different contexts. For example a photo may not have title and tags, or its title is meaningless for analysis (written in a language not known to the analyst or does not represent any event or place). The visual similarity can be still found between other images in a cluster.

Thus, if we know that a photo is visually similar to a nearby photo, then these two photos can be grouped together. If needed, the representative photo can then be found. Content-based analysis can also reveal the heterogeneity of the cluster. If people take photos of a single point of interest, then a large amount of photos will be similar to each other.

4.3.4 Analysis of Time Series of Counts of Events

Time series analysis helps to understand the type of the cluster in terms of its temporal characteristics. For example, we can count the number of people who take photos in the area every day within a 1 year period. The shape of the time series indicates the type of a cluster. If the number of events does not differ significantly, the cluster can be classified as stationary. If there are bursts in activity at several intervals, the cluster can be classified as reappearing. If there is a single high peak, the cluster can be classified as occasional.

Additionally, the change of contexts can be detected by using time series analysis. Following the context detection using text and content based analysis, we can classify clusters to any of the spatio-temporal types that we already defined in terms of number and variety of events occurring in a cluster during some time period. Let us consider an example: There is a cluster in which sport events such as alpine skiing are held in winter. In the summer time, most of the photographers take pictures of nature. In this case, we can classify the cluster as reappearing if the context (winter sport, nature photography) appears in the cluster several times. If the context appears only once, it is probable that the cluster is occasional.

4.3.5 POI Database and Entity Relations

POI database is a valuable source of semantics. The methods used in automatic gazetteer construction may be employed in retrieving the topic of the photo (the title on the photo relates to a landmark or nature) or build an ontology of types from thematic photo groups. In this case, the photos that are in the group *birds* can be classified in general as being of type *nature*.

4.3.6 User Profiling

As was shown above, cluster semantics may help to determine the semantics of user behavior and vice versa. The user profiling can be performed statically, by using information from all the photos that belong to the user or dynamically, for every cluster or for different time periods.

5 Case Study: Using Time-Series Analysis and Text Clustering for Extracting Semantics of Events and Places

In this section, we demonstrate analysis of temporal patterns and semantic acquisition using combination of time series, text analysis and external data sources presented in Sect. 4.

5.1 General Scenario

Let us briefly consider a possible scenario by employing the methods presented in Sect. 4 in the analysis of a geographic region.

1. We apply a clustering algorithm to outline areas of people's visits. Although the cluster and its size reveal spatial information, it explains neither the dynamics of the interest nor why the place was interesting to the photographers. Therefore, additional investigation should be performed.
2. We apply time-series analysis to investigate peaks of activity. The dynamics of the subject of interest can change over time and the same cluster can encompass different events that also change over time. The temporal component of the semantic enrichment will change the way we analyze spatio-temporal processes and as a result, different patterns of spatio-temporal clusters will appear. The number of taken photos or number of people can be used as the dependent variable. At this level, we can already infer the spatio-temporal type of the cluster according to the selected dependent variables. While peaks of activity can point to some interesting time periods, we still cannot deduct what was the reason of such activity.
3. We apply clustering techniques for extracting significant keywords using photo tags and/or titles that can show the photographers' intended subjects and points of interest when taking the photos. In fact, text clustering techniques can be applied on all the photos in a cluster or separately on photos for each time interval. This approach can reveal changing trends of place interest.
4. We can use external POI databases like Wikipedia to acquire additional information about the cluster if there are points of interest in the area. This information can be matched against the topics obtained from the text clustering step.
5. We can apply image clustering to find representatives that visually highlight the place or in cases where the text clustering does not provide meaningful categories.
6. Methods used in gazetteer creation supported by the domain expert can be employed in building hierarchies of concepts for the given cluster, e.g. a photo of an animal will be classified as nature. Retrieval of other places with similar events can be performed by searching for areas with similar semantics.

5.2 Spatial Clustering

We used a subset of photos referring to the territory of Switzerland.[1] For discretizing the space we use a method (Andrienko and Andrienko 2011) that divides the territory to non-overlapping polygons of given size in a way that reflects the distribution of points. In brief, the generalization method groups points into spatial clusters and uses the centroids of the clusters as generating points for Voronoi tessellation (Okabe et al. 2000) of the territory. We applied spatial clustering to the positions of the photos and built Voronoi cells (1,183 in total) with average diameter of 2 km around the obtained clusters. The whole operation took between 3 and 5 s using sampling approach with about 20,000 points. The general steps of the algorithm are described below:

Algorithm 1: Territory tessellation
Given: Sequence of positions of points P = {xi, yi} and desired radius *r*
Output: A set of Voronoi cells V
Description of the algorithm:
1. Group the points of P in spatial clusters with desired radius r
   S = SpatialClusters(P; r)
2. Compute the centroids of the spatial clusters C = Centroids(S);
3. Generate Voronoi cells around the centroids
   V = Voronoi Tessellation(C);

5.3 Time Series Analysis

For every cluster, we calculated frequencies of people's visits and the number of taken photos aggregated by month and built a time series graph spanning 5 years (2005–2009 inclusive). Figures 1 and 2 show a part of Switzerland with examples of different temporal patterns of events for selected regions denoted as A, B, C, D, E. Figure 1 shows frequencies of people's visits while Fig. 2 displays frequencies of the taken photos.

According to Fig. 1, people visit the region labeled A in all seasons. In total, 71 people visited this region and took 1,721 photos. We can observe a sharp increase in the number of photos taken in every year in January. A possible explanation is that

[1] We do not present results of a complete analysis of the photos on the territory of Switzerland but only provide several examples as illustrations of what can be detected. It is clear that many more events occurred, and the challenge is to develop such methods that will find as many of them as the available data permit.

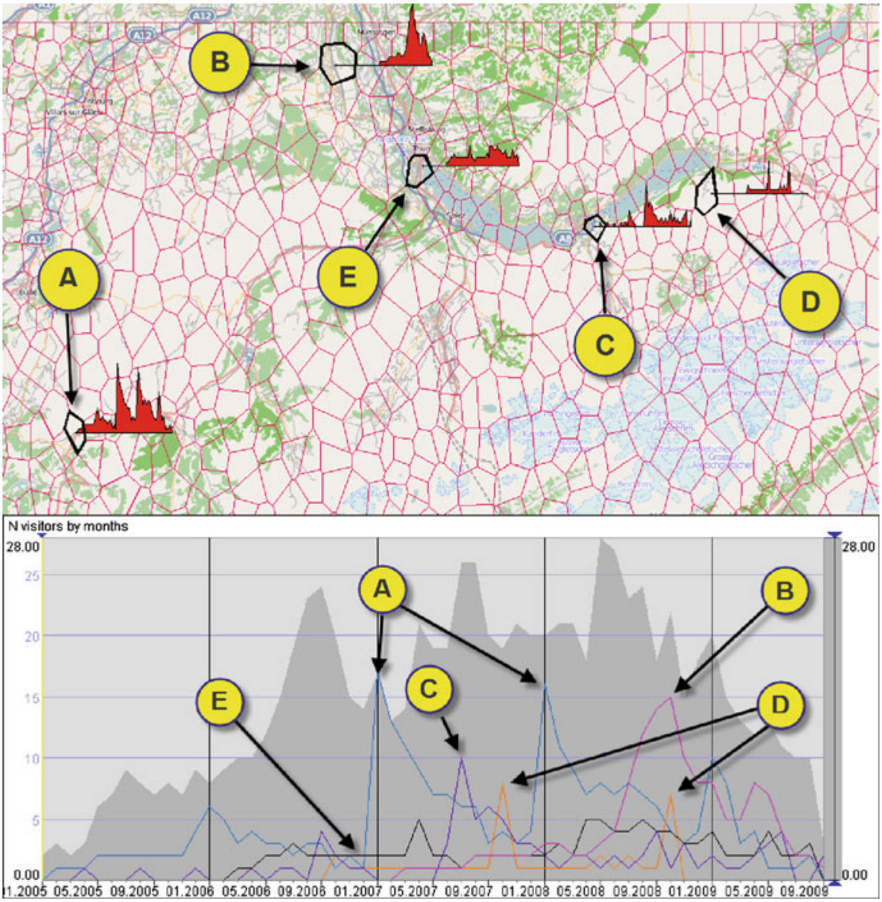

Fig. 1 Switzerland. Time series (*top*) and graph (*bottom*) of frequencies of people's visits

some local repeated event takes place during the winter. Figure 2 shows that the event pattern corresponds to a *regularly reappearing* type of the spatio-temporal cluster.

A photo activity in the area near Muensingen (labeled as B) starts in May 2008 showing a smooth increase until July 2008. In total, 38 people (1,576 photos) visited the area. Starting in August 2008, there is a steep increase in the number of photos until October 2008 followed by steep decrease until January 2009. Afterwards, there is little activity in April. According to the activity pattern, this cluster can be classified as *occassional*.

Regions labeled C (45 visitors, 1,637 photos) and D (17 visitors, 1,071 photos) have two high peaks in the number of taken photos in July, 2007 (C) and October, 2007 (D) according to Fig. 2. For the region C, the number of photos taken in July 2007 constitutes 87 % of all photos taken from 2005, while in D almost 90 % of

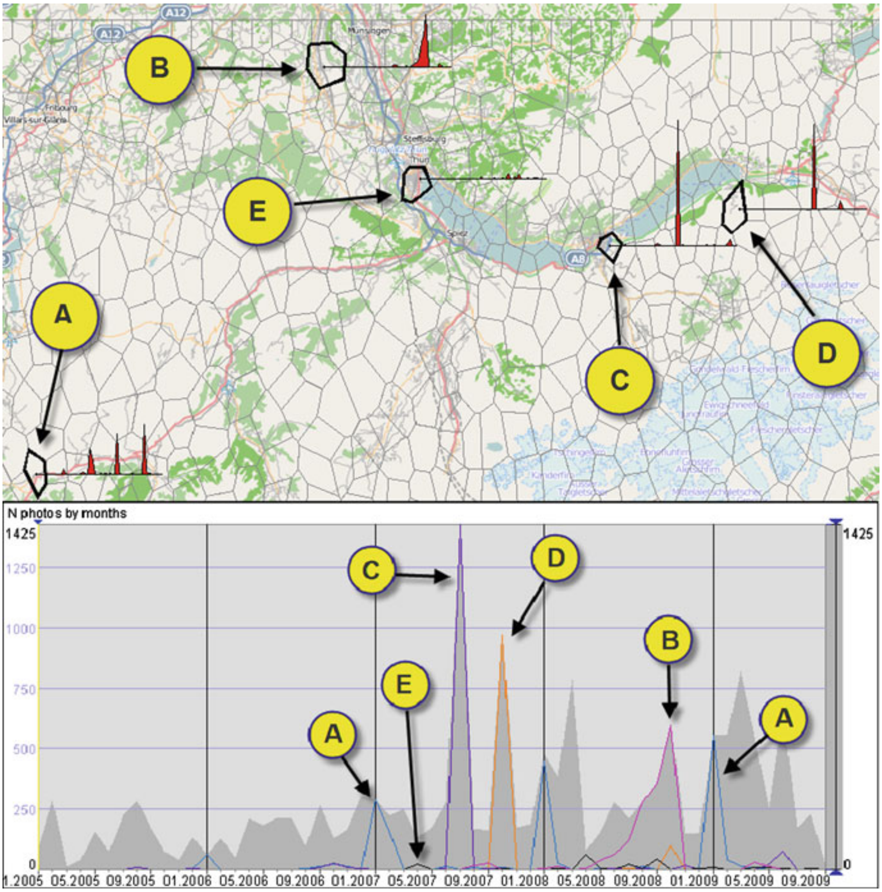

Fig. 2 Switzerland. Time series (*top*) and graph (*bottom*) of frequencies of taken photos

photos were taken on October, 2007. According to Fig. 1, there are two peaks of visits in October 2007 and 2008. This fact allows us to conclude that while region C and D can be classified as *occasional* in terms of taken photos, cluster D can be classified also as *irregular* with respect to visits of people.

The inspection of visits and photo activities in region E (25 visitors, 224 photos) shows that there is no variance in the number of photos (30 photos on average) and number of visits (2–3 people on average visit the place each month). This fact suggests that the cluster is of *stationary* type. The area that the cluster occupies corresponds to the town of Thun. The possible reason of this stable activity is that the city attracts photographers during all seasons and there are no important local events taking place during a specific time that could attract more people than during any other period.

5.4 Text Clustering

To understand the observed temporal patterns, we extracted tags from photos taken in places A, B, C, D, and E and created two model representations. In one representation, a photo was treated as a separate document (all tags of a photo were saved as one document). In another model the owner of all photos in a cluster was treated as a document, so all unique tags from photos of the owner were collected and saved as one document. We applied two clustering algorithms (the operation took about 1 s per algorithm) on these models: Lingo (Osiriski et al. 2004, Osiriski and Weiss 2004) and suffix tree clustering (STC) with default parameters (Part of the Carrot2 workbench, http://project.carrot2.org). These algorithms use different clustering approaches [term-document matrix (Lingo) versus suffix tree clustering (STC)] and produce different cluster quality [high cluster diversity (Lingo) versus low cluster diversity (STC)]. However, they create overlapping cluster categories. This is an advantage over the methods for automatic representative tag and event extraction proposed in the literature (see Sect. 2.2), since the photo can have different tags that may describe several categories like (trees, sun, summer). In addition to the understanding of the observed temporal patterns, our goal is to show how results may differ due to model representations, clustering algorithms, language differences or mistakes made during tagging, and stress the importance of visual analytics. Tables 2 and 3 present the ten most frequent categories extracted from region A and B using two model representations (owners and photos) and two clustering algorithms applied on them (Lingo and STC). The number of occurrences of every category in documents is given on the right side of each category in parentheses. The tag syntax is preserved.

Let us inspect the obtained cluster categories. A quick look on the categories suggest that people use four languages to tag their photos (Table 2, Lingo owner): English (Snow, 9), Spanish (Suiza, 10), French (Suisse Vaud, 1), German (Schweiz, 3). At least three different contexts can be extracted from the categories: *places* (Vaud—the Swiss canton, Gstaad—small village, Chateux Doex—municipality), *events* (balloon, Montgolfiere, festival), *season* (Snow). *Balloon* is the most frequently used term but different variations are used like *hotairabolloon, ballon, ballons* that are treated as different entities by the clustering algorithms. Similarly, categories of region B are expressed in different languages (Table 3, Lingo owner): German (Autofriedhof, 1), English (Carwreck, 8) and French (Suisse, 5, Lingo photos). Several contexts can be extracted: *places* (Gürbetal, Bern, Kaufdorf), *cars* (Volkswagen Beetle, Ford Zephyr, VW, Fiat), *objects' state* (Abandoned, Cemetery, Carwreck, Rost, Old, Oldtimer, Junkyard, Scrapyard), *nature* (Forest).

Table 2 Region A. Cluster categories using 2 model representations and 2 clustering algorithms

#	Lingo (owner) 25 clusters	Lingo (photos) 77 clusters	STC (owner) 16 clusters	STC (photos) 16 clusters
1	Suisse Vaud (12)	Châteaudoex Ballon (962)	Switzerland (39)	Châteaudoex (884)
2	Hotairballoon (10)	Montgolfière Châteaudoex (507)	Châteaudoex (25)	Ballons Châteaudoex, Hotairballoons Montgolfière Paysdenhaut (612)
3	Schweiz Switzerland (9)	Switzerland (485)	Suisse (24)	Switzerland (485)
4	Châteaudoex Ballon (8)	Balloon (440)	Chateaudoex (20)	Balloon, Festival (461)
5	Balloon Chateaudoex (6)	Festival (289)	Balloon (18)	Ballon (324)
6	Montgolfiere (5)	Chateaudoex Switzerland (276)	Vaud (13)	Châteaudoex Ballon (166)
7	Chateux Doex (4)	Ballons Châteaudoex Hotairballoons Montgolfière Paysdenhaut (215)	Ballon (12)	Chateau Doex Balloon, Doex Balloon Fiesta Festival (163)
8	Gstaad (4)	Switzerland Suisse (164)	Schweiz (9)	Balloon Châteaudoex Color Coleur (129)
9	Snow (4)	Ballon Switzerland (142)	Chateau Doex (8)	Hot Airballon Chateaudoex Switzerland (96)
10	Switzerland Suiza (4)	Chateau Doex Balloon (140)	Ballons (8)	Hotairballoons Châteaudoex Ballons Montgolfière (67)

Table 3 Region B. Cluster categories using 2 model representations and 2 clustering algorithms

#	Lingo (owner) 19 clusters	Lingo (photos) 76 clusters	STC (owner) 16 clusters	STC (photos) 16 clusters
1	Autofriedhof (27)	Gürbetal Autofriedhof Junkyard Scrapyard Schweiz Switzerland (775)	Autofriedhof, Kaufdorf, Switzerland (32)	Autofriedhof, Schweiz Switzerland, Schrott Schrottplatz (1444)
2	Switzerland (21)	Oldtimer Old (229)	Old, oldtimer (13)	Car, Auto (610)
3	Volkswagen Beetle (5)	Rusty (281)	Gürbetal (13)	Decay, Classic, Old Oldtimer (520)
4	Carcemetery (4)	Bern Kaufdorf (218)	Bern (12)	Kaufdorf Gürbetal Schweiz Switzerland Autofriedhof (451)
5	Automobile (3)	Schweiz Suisse (206)	Cars (11)	Schrott Schrottplatz Junkyard Scrapyard (209)
6	Lomolca (3)	Archiv2008 Abandoned (193)	Abandoned, Rost, Schrott (11)	Kaufdorf Bern, Switzerland Schweiz, Carcemetery (206)
7	Schrott Schrottplatz (3)	Cars Cemetery (160)	Beetle, Mercedes, Käfer (10)	Schweiz Suisse Switzerland (206)
8	Carwreck (2)	Car Abandoned (153)	VW, Fiat (10)	Gürbetal Schweiz Switzerland Autofriedhof (151)
9	Ford Zephyr (2)	Bern Gürbetal (118)	Suisse (8)	Autofriedhof Schweiz Switzerland Kaufdorf (116)
10	Forest (2)	Auto Autofriedhof Autoverwertung (113)	Auto Autofriedhof (5)	Schrottplatz Kaufdorf Gürbetal Autofriedhof (112)

5.5 External POI Database

We applied a spatial query on external dataset of geotagged Wiki pages using coordinates of the area A and B. One page was retrieved for region A: *Pays-d'Enhaut* (a district in the canton of Vaud in Switzerland). Three municipalities are located within the district: Château-d' Œx, Rossinière, and Rougemont) and three pages for region B: *Gürbetal* (Gürbe Valley)*, Historical Carcemetery Gürbetal* (the page exists only in German) and *Rümligen Castle* (the page exists only in German). Surprisingly, the Rümligen Castle was not among the attractions of the region B. However, it turned out that this castle and its adjacent territory is a private area. Pays-d'Enhaut was not tagged presumably because it represents high level of abstraction of the area or the majority of the visitors do not know the name of the district.

We then tried to find relevant information in the web by supplying the extracted categories to a public web search service. In this way, we managed to obtain the following information:

1. (Chateau-d'Oex): International Hot-air Balloon Festival takes place every January.
2. (Kaufdorf): a car cemetery with many old-time cars. It is probable that the car cemetery existed before summer 2008 but did not attract much attention. On 5th of July, 2008 an article about it was published by the administrator of the Switzerland group of Flickr users on his web site. This article, evidently, attracted many Flickr users to visit this place in summer and autumn 2008.
3. (Interlaken): Red Bull Air Races, July 14, 2007.
4. (Axalp): Air Show, October 10–11, 2007.
5. (Thun): Touristic city with several attractions (that do not change over time) like: the twelfth century Castle, sixteenth century town hall, view of the Alps.

6 Summary

In the use case, we demonstrated the feasibility of the proposed methodology by applying several approaches of spatio-temporal analysis using geotagged photos combined with time series analysis, semantic interpretation based on text clustering, and extraction of additional knowledge from external sources. We succeeded in finding and explaining the events occurring in five selected regions of Switzerland without any prior background knowledge. The overall runtime performance suggests that the most time consuming operations like spatio-temporal and text clustering can be applied countrywide without much time overhead.

7 Conclusion and Future Work

In this paper, we proposed a conceptual framework and methodology that would allow analysis of events and places using geotagged photo collections. We defined four main types of spatio-temporal clusters that can be classified by time series analysis and refined by semantic enrichment process using temporal component: *stationary, reappearing, occasional* and *regular moving*. We discussed methods for analysis of these types of clusters and identified publicly available datasets that can help in the semantics enrichment process. We stressed the importance of the interactively driven analysis that can overcome weaknesses of the purely automatic approaches and help extracting new knowledge from the data. With the example from the selected regions in Switzerland, we showed how time-series analysis, text clustering and additional contextual information can be applied to extract semantics and interpret the region under investigation.

Currently, parts of the framework are implemented as separate services. In our next work, we will build a visual analytics framework integrating the methods proposed in this paper. It will facilitate the discovery and interpretation of the types of spatio-temporal clusters that we defined.

Acknowledgments This work was partially funded by the German Research Society (DFG) under grant GK-1042 (Research Training Group "Explorative Analysis and Visualization of Large Information Spaces"), and by the Priority Research Program on Visual Analytics (SPP 1335), project "Visual Spatio-temporal Pattern Analysis of Movement and Event Data".

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The Space–Time Aquarium is Full of Albatrosses: Time Geography, Lifestyle and Trans-species Geovisual Analytics

Jinfeng Zhao, Pip Forer, Mike Walker and Todd Dennis

Abstract The volume of research that involves movement track data sets of increasing size and complexity has grown significantly as data-capture technologies have developed and expectations for ongoing growth of research opportunities have hardened. Techniques for describing such data vary, some utilising a purely geometric measurement while others seeking to involve activity and purpose as elements of movement description. Such enriched data is typical of sentient entities that interact with their environment and other sentients. This paper is solely about such sentient, self-navigating objects. It is also restricted to consideration of movement fields through the lens of geovisual analytics, or equally, in this case, reviewing geovisual analytics through the lenses of a sample of sentient movement data sets. Fundamentally the paper asks whether different kinds of entity require adjustments to given visualisation tools, and if this is so, how such adjustments might be related to the different processes and geographies of the entities involved. The arguments are largely based around two 'rich' data sets: Halifax time use and Muriwai possum movement data sets.

Keywords Movement visualisation · Geovisual analytics · Sentient movement · Animal tracking · Spatio-temporal activity patterns · Time geography

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7_11,

1 Movements in Space-Times (Plural)

This research is concerned with geovisual analytics and their application to data sets representing the movement of individual or multiple sentient objects. Its goals are threefold. One is to illustrate the use of such analytics to enhance knowledge of the nature of large scale or individual movement patterns and so enhance our ability to understand and describe dynamic geographies. An example based on mundane human urban activity patterns and a customized visualisation tool set deployed in a leading GIS (Esri 2009) will be used to approach this goal. A second goal is to note the parallels and divergences between studies of human movement and those of animal behaviour, using a modified version of the same tool set to visualise movements of common brushtail possum (*Trichosurus vulpecula*) as an example. The final goal is to compare these two contexts and reflect on the nature of the relationship between tool set and data set when seeking to provide a useful framework for generic geovisual analytics across rich data sets from a variety of species and geographies.

To address these goals the paper is in four parts. The first introduces the challenge of visual analytics with sentient movement and the tool set used in the paper and implemented by the first author (Zhao et al. 2008). This toolkit is named *Ringmap*. This section also briefly describes the 'rich' data set gathered from a sample of the citizens of Halifax Nova Scotia in 1971. 'Rich' in this context basically means that the complete data contains information on space, time and activity of each individual over a study period as well as a detailed digital representation of the geography in which movement occurs. Most importantly the section summarises the role of time geography in construction of both the data set and the visualisation tools. (The book format limits the number of coloured examples of visualisations but links to the web book site [*book web site URL*] provide further background).

Part two moves on to include an animal perspective, identifying one proposed research framework for understanding animal movement, and commenting on its crossover with Hägerstrand's view of the factors inspiring and controlling movement and the relative value of the space–time aquarium in visualisation.

Part three presents recent work on possums, using a modified version of the Ringmap suite of representations tailored to the nature of the lifestyle and ambient geography of the possum. The visualisations and the interpretations that can be extracted from them are discussed in more detail, as is the rationale for the adjustments made to the parameters of Ringmap for use with possums.

Part four concludes with a review of the Ringmap project to date and a reflection on the relationship between tool set, data set and conceptual frameworks across a range of lifestyles and geographies.

1.1 The Challenge of Designing a Toolset for Visualisation of Sentient Movement: An Example

Toolsets for visualisation exist in numerous forms, many seeking to provide generic solutions across wide areas of application (Dorling 1996; Jackel 1997) with the more sophisticated offering flexibility in representation and combination of outcome (e.g. Andrienko et al. 2007; Gahegan et al. 2002). For the more technically inclined some provide means to script customized views of data. Due to the relative complexity and scarcity of movement data sets, dedicated tools for representing movement and flows (Marble et al. 1997) have been less numerous. Notwithstanding this there is general agreement that geovisualisation is a priority approach for understanding complex movement patterns (Andrienko and Andrienko 2007; Andrienko et al. 2008) and it is clearly apparent that research on movement data sets is experiencing healthy growth (e.g., the workshop 'GeoVisualization of Dynamics, Movement and Change' conducted at the AGILE Conference in Girona, Spain in 2008). The *Ringmap* project stems from doctoral research and seeks to address the issue of providing effective and flexible tools for enhancing knowledge of movement processes. Currently its display technology is based on a leading GIS (Esri 2009). The initial philosophy of its design was based around rich (space, time, attribute) data sets and centred on the power of using multiple representations[1] at multiple scales to pursue particular movement patterns and anomalies. A further aspect for design was the significance of activity and geography (often land use) in understanding patterns of movement in space–time. Activity was seen as a fundamental driver of movement and so a key variable in movement patterns. Zhao et al. (2008) describe this perspective and provide multiple examples of the visualisations deployed, as well as discussion on their value. These outcomes are based on a pioneering legacy data set from Halifax Nova Scotia (Elliott et al. 1976; Janelle and Goodchild 1983) which involves over a thousand respondents providing full records of location, time and activity. The visualisations are based on these data after their import into ArcInfo, conversion to 5-min observations, geocoding to specific locations, interpolation of pathways during travel, and processing within *Ringmap*.

The complete set of Ringmap representations is expanding but the original project that focused on the Halifax data set generated more than 10 visualisations[2] of which only two are illustrated here. The underlying strategy for approaching visualisation was to be exploratory, creating visualisations which emphasised or removed certain dimensions and catered for data expressed at different scales or levels of aggregation. We present two examples. The first (Fig. 1) combines a population-based cartogram of Halifax Census Tracts with a very basic space–time

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[1] Multiple representations refers to many inter-linked representations, in same or different forms, that are displayed simultaneously. They can be shown in the same (by overlaying, e.g., Figs. 1 and 5c or intertwining e.g., Figs. 2, 6 and 7) or different windows at the same or different scales.

[2] These visualizations showed several different activities that drive movements in varied forms and at different spatial, temporal and activity scales in order to gain insights.

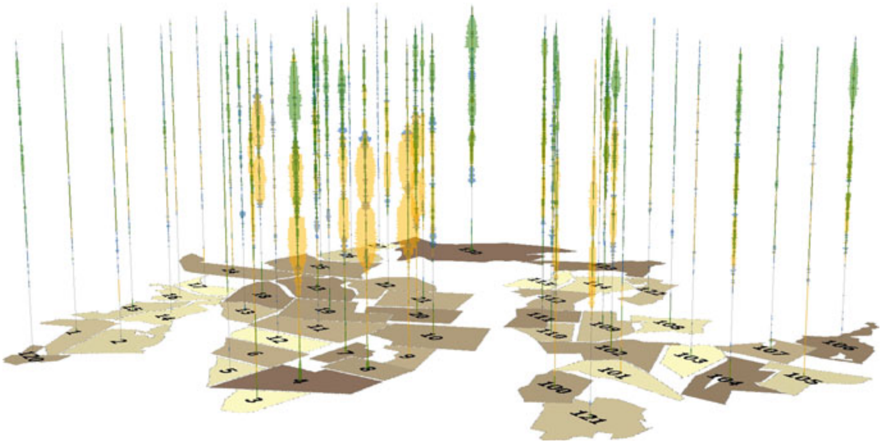

Fig. 1 Daily patterns of three out of a total of nine activities for a population cartogram of Halifax CTs. The three activities shown are work (*orange*), travel (*blue*) and leisure (*green*). The vertical dimension is time of day with 0:00 am at the *bottom*. Granularity of the data is 5 min. Colours of the cartogram represent volume of all 9 activities, the darker the colour, the more activities occurred in the CT (Zhao et al. 2008, p. 202)

cube: a 2-D representation of the geography of zones combined with a vertical z dimension showing time. This is a very simple diagram which retains space as a basic factor and attaches to each area a vertical line supporting the temporal record of three heavily generalised activities in each zone over the course of a day. Partial opacity is used to allow comparison of the three activity levels across the day. Although the actual movement of individuals is not shown at all, the aggregate activity patterns at different times tell us a great deal about the functioning of Halifax and its suburbs. It utilizes the acknowledged power of Hägerstrand's aquarium (Parkes and Thrift 1980) to show the major time use patterns in Halifax, but on a geography that is represented as a cartogram to allow a better communication of the densely populated downtown area. To facilitate user interpretation and a closer link between the cartogram and the geographical map of Halifax, the shape of each Census Tract (CT) in the cartogram remains identical to that in a geographical map and CTs are labeled with their identification codes. The vertical, overlain columns show the differentiated patterns of activity across the city over time. This clearly reveals the spatio-temporal pattern of the city's key drivers: traveling, working and leisure.

The Ringmap itself is our second demonstration (Fig. 2) and features a portrayal of the levels of a specific activity divided by 5-minute intervals, which are ordered clockwise on a 24-h time wheel. Gone is the aquarium and dimensionalised space and time as the focus is on the detail of a specific activity in high resolution. Figure 2 shows two intertwining ringmaps, where each ring represents an abstract spatial zone, a CT, and each sector depicts a 5-minute interval of a 24-h day. An extra spatial dimension is provided by serialising the CTs in order of physical distance from the

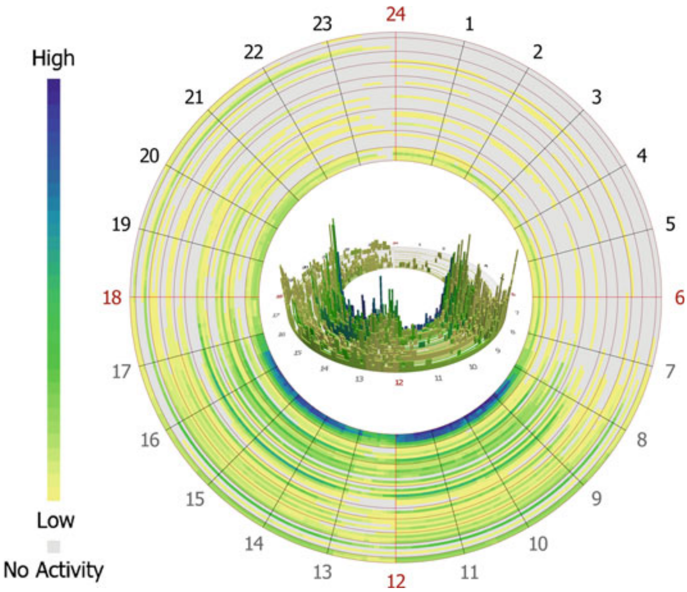

Fig. 2 A spatialised ringmap of 'main job' (*colour*), with an inset layering this on 'job travel' (scaled to extrusion). Each ring represents a CT of Halifax, Canada in the 1970s and each sector displays a 5-min interval of a 24-h day. Rings are arranged from the inside outwards in order of proximity to the city centre to assist in relating urban structure to activity patterns (Zhao et al. 2008, p 203)

city centre, so the spatial dimension is effectively abstracted down to relative centrality. Against this a single selected activity can be viewed with a very explicit and detailed focus. To do this and to stress temporal patterns, time is accentuated through the detail of its reporting and by its illustration in a circular, cyclic pattern. Combined with the coding of space into a centrality measure, the rhythms of work and travel, the linkage between them and offsets with location of different suburbs, can be detected quickly and easily. The patterns show that the 'main job' activity (depicted by colours) was spatially concentrated in CTs that were close to the CBD and temporally concentrated between 8 am and 5 pm with an hour long low (i.e., lunch break) in the middle. Meanwhile the 'job travel' activity (depicted by extrusion) peaked around the start and end times of the 'main job' activity, exhibiting a small peak around lunch time that was more evident for the CTs that were not far from the CBD. The patterns suggest that the two activities were closely related, as one might expect. Such clarity may not emerge for a larger city, but the concept of relative accessibility to multiple centres of core functionality can possibly be explored to unpack movement in a polycentric metropolis.

These two examples are given to provide an insight into visualisation performance for a urban movement pattern of commuting that is fairly familiar to a general audience. Two things are clearly missing. The first is a mention of timelines (Hägerstrand 1970), the ubiquitous but ephemeral product of all animals and humans. As corporeal beings, we all carve paths through space and time. Where researchers have made individual movement paths manifest, they have sought to identify them with Hägerstrand's concepts of time geography. Timelines have been utilized in a range of customised applications to illustrate movements including tourist movement (Zhao 2003; Zhao and Forer 2003), gender issues (Forer and Kivell 1981; Kwan 1999), student lifestyles (Huisman and Forer 1998), accessibility (Miller 1991), and activity-travel patterns (Kwan 2000), usually to underpin commentary on the nature and causes of the movement, particularly where the notion of constraints as part of an organizing principle for the individual is to the fore. With the generation of large GPS data sets and their simplified import into 3-D viewers the generation of space–time aquaria has become popular, but due to the visual overload in many such data sets, spaghetti in the aquaria, the outcomes have not all been totally successful. Nonetheless, the timeline and its conceptual foundation remain attractively powerful as a way of combining knowledge of the individual and contextualizing it within their environment and its potential to meet their needs.

The environment is the second missing item in our first two examples, but features more in Sect. 3.1. We know that aspects of the urban ecology sustain certain needs and generate certain movement patterns. To some degree we can add value to movement paths by being able to infer what presence in a certain part of the city implies. We can also use knowledge of the facilities' distribution in an urban environment to generate synthetic measurements of space and proximity and capability therein. We can also use that knowledge to test the reliability of movement data in certain circumstances (Sun et al. 2012). It is important to recall that timelines, and Hägerstrand's theorizing, embrace the ideas of a choreography (Pred 1977) that is driven by motives that require specific environments for their satisfaction and is subject to the availability of access to the environment's capabilities at a practical time. Movement reflects activity, activity reflects environmental capability, which in turn attracts movement. Ringmap seems to provide some multi-faceted insights into rich movement data, but it has been tested only on one idiosyncratic human movement data set. A number of issues arise in terms of the general value of its individual or assembled components. Fortunately there are quite a few contexts in which to explore this question further.

To that end discussion shifts into the animal kingdom for a comparison exercise. Figure 3 illustrates the power of the timeline with small populations, and introduces two anonymous albatrosses in a specific aquarium, one that covers New Zealand and the seas around it (Stahl and Sagar 2000). Seen as 2-dimensional individual trajectories, or even plotted on a map together, the nature of the intricate parenting dance that is taking place is hard to discern. Visualising the same data in time and space, and with a knowledge of the environment, unpacks that tale clearly and quickly. There are cycles of shared duties, individual parenting, and feeding voyages occurring which meet a series of quite complex goals all tied in with environmental cycles.

Figure 3 vividly illustrates aspects of the relationship of a breeding pair of albatrosses in the Snares Islands, New Zealand between 18th of March and 17th of

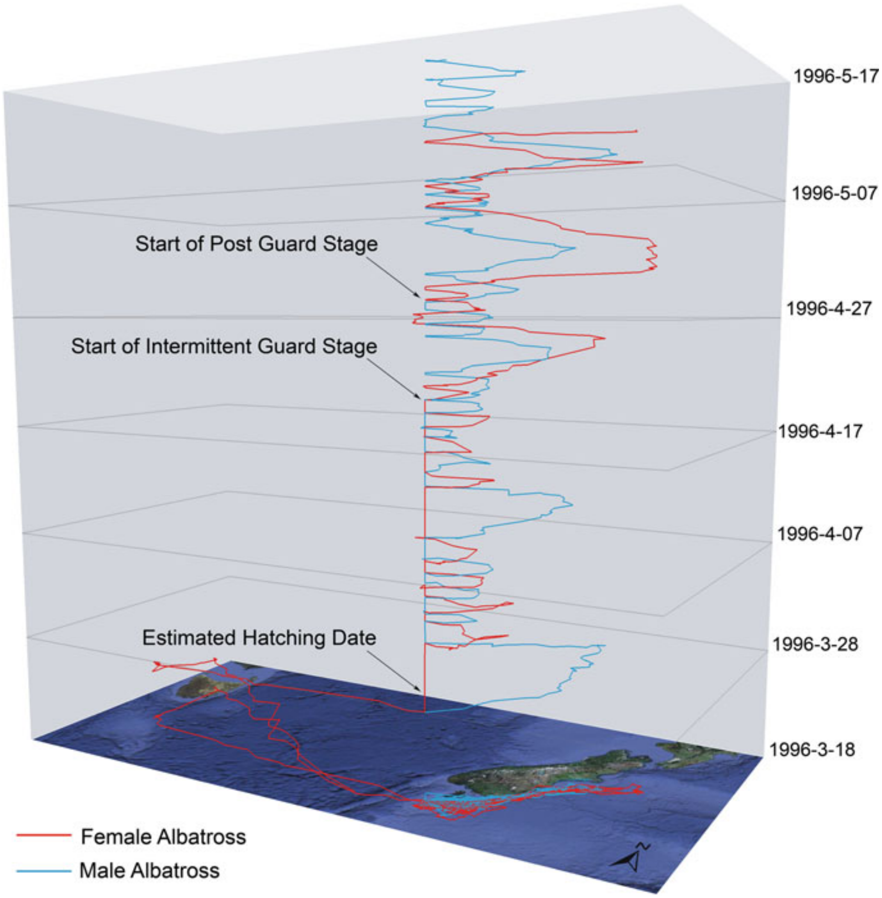

Fig. 3 A breeding pair of albatrosses' 'love dance' in space and time, where blue indicates the male and red indicates the female bird

May, 1996. During the incubation period, the female bird (depicted by the red line) made a 9-day foraging trip westward into the Tasman Sea returning to the nest on 26th of March where her male partner waited (blue line). The male bird then started a long foraging trip towards the northeast of the Snares Islands. During the hatching stage, both partners performed synchronized returns and departures, i.e., when one was foraging, the other guarded the nest. These trips were higher in speed and shorter in length than during the incubation period, except for one long excursion by the male bird during the middle of this period. When entering the intermittent guard stage (c. 21st April) brooding periods became discontinuous, and both birds spent most of the time searching for food northeast of the Snares. The male was the last to brood, ending this stage with a day-long stint on the nest on the 28th of April. During the post-guard stage, the female bird tended to undergo longer distance and duration trips than the male, and both partners spent very little time at the nest (Stahl and Sagar 2000). The estimated hatching date, the start of the intermittent guard stage and of the post guard stage in Fig. 3 are referenced from Stahl and Sagar (2000, p. 305). In comparison with the two-dimensional trajectories, timelines depict a much richer 'story' of the breeding biology of the albatrosses, once again demonstrating the powerful visualisation capabilities of time geography.

This cameo introduction of albatross and animal movement serves to ease the transition to discussion of the second significant data set, that of the possum data captured by Dennis and his colleagues (Dennis et al. 2010) on the outskirts of West Auckland. For the animal domain, the albatross support Lenntorp's early affirmation for humans that the timeline "can provide an equally operational basis for understanding ecological forms as the molecule does in many of the natural sciences" (Lenntorp 2004, p. 223), because the structure of a timeline reflects the basic processes that produce movement (Nathan et al. 2008). The main characteristics of timelines are simplicity; a focus on individuals; and inseparability of space and time (Thrift 1977). They provide a simple but powerful individual view of movement, in which logics of space, time, activity and geography intermesh (Forer 2005). While we may not be comfortable to attribute the notion of formal logic to animal behaviour the various abilities of animals to navigate and efficiently interact with their environment are appreciable, and evidence accruing from the growth in animal movement studies suggests we may have underestimated them considerably in the past. In any event, the above comments on time geography are not totally lost in respect of animal as well as human movement. Hägerstrand's perspective has resonance with that of Nathan et al. (2008) in their proposal for modelling movement ecologies of animals based on four components that affect animal movement behaviour: Navigational capacity, motion capacity, internal state and external factors. Each of these interactive components equally reflects an approach to human movement, but with often substantive qualification. In the next section we cross examine factors that influence movement of both humans and animals.

2 Factors That Influence Movement of Sentient Objects

Although movement is a universal feature of many entities, the primary focus of this paper is movement of sentient objects. Because such objects are capable of perception and are possessed of a certain quality of intelligence, they experience behaviour and establish goals. Sentient objects retain the same identity from birth to death, regularly exhibit cyclic behaviours, and interact with elements in their environment. The unique qualities and characteristics of sentient objects make understanding the causes of their patterns of movement especially challenging. Why do humans and sentient animals move? What similar or unique factors affect their patterns of movements? In this section we discuss these questions with the hope that they may provide support for further developing or modifying techniques for visualisation of the movements of humans to visualising those of animals. Factors influencing the movements of all sentient objects fall in two broad categories: causes and constraints.

We may use very different terms to describe these characteristics in a human context, and human technologies as well as the proven human ability to conceptualise and rationalise, can transform the entire process of living in an environment, but the meta-concepts can be held in common by humans and animals to a large degree. They also permeate the wider expression of time geography by Hägerstrand in his various papers, where he acknowledges the power of timelines to reveal human activity but constantly identifies the intermixing of motive, knowledge, environment, and constraints of various kinds in producing the specific behaviours and resultant geometric patterns. The timeline itself has been described as a choreography (Pred 1977) and as a unique identifier akin to a DNA sample (Nathan et al. 2008). In reality it's closer to the transcript of a conversation with the personal environment in all its aspects. Choreographed dance is perhaps too regulated and internalized to be a satisfying metaphor. DNA is a reflection of a construction blueprint in a relatively stable molecular environment: it is a long bow to draw to compare it with the recording of the activity of a sentient entity in a constantly modifying and reconceptualised four dimensional space where the laws are driven by cognitive rather than physical processes. It can be way more complicated.

2.1 Causes

At this point it may be useful to look in more detail at some of the concepts which we might consider to underlie sentient movement and the links to the geography of the environment that is utilised by the entity. What is the vocabulary of why movement takes place and what influences it?

Activities are fundamental stimuli that work to generate movements in sentient objects (Yuan and Hornsby 2008; Zhao et al. 2008), and it is not surprising that movements are often grouped by the activities that cause them, e.g., 'travel to work'. The links among activity and movements are very strong: some activities are embedded in a phase of movement (e.g., skiing downhill) and some activities induce the need for movement (e.g. foraging); movement creates spatial and temporal connections among activities.

Complementarity may help explain movements between areas of demand and supply. When such movements occur, there is a spatially explicit demand at one location and a matching supply at another. Although demand and supply induce this type of movement, it occurs only if there are no intervening complementary sources of supply (Ullman 1954).

Intervening opportunities are negative factors that may prevent movements between areas from occurring, even where there is specific complementarity. Intervening opportunities offer a closer, cheaper, or more accessible alternative source of supply (Ullman 1954). They encourage sub-optimization and motivate sentient entities to choose a lesser but still-adequate alternative, rather than a more distant but better location (Lowe and Moryadas 1975).

Transferability can be thought of as the affordability/possibility that individuals are relocatable, or that places can be accessed with certain travel modes. Transferability is determined by the comparative differences in terms of cost of moving between areas (Brook 1977). Different travel modes have different costs in terms of time and money, which may influence one's choice of mode. Generally, the higher the distance costs, the lower the transferability. This is the principal issue addressed in network analysis.

Pacemakers are entities which control or influence the rhythm of activities (Halberg and Katinas 1973) and operate to bring coherence (in a sense 'liveability') to places (Parkes and Thrift 1980). The spatial aspect of pacemakers may be certain spaces at various scales (e.g., a university, sports stadium, or city). The temporal aspect of pacemakers may be a set of durations or instants in time (e.g., business hours, school terms, timetables). Some pacemakers are periodic features of a lifetime (e.g., sleeping and eating). Others are irregular but generally recurrent (or fluctuating), such as a significant sporting or musical events (Parkes and Thrift 1980).

The great majority of the concepts above derive from concerns about human movement, but reflect factors which can be found in animal lives also. Putting on different eyes we can appreciate that *pacemakers* influence animal movements and can in fact articulate as well as instigate them, so that regular patterns and the rhythm of movements become apparent. Commuting from home to places of work or study, or movements from locations of breeding colonies to foraging areas, are in many ways parallel examples, and a particularly clear example can be seen in Fig. 4, which illustrates the daily movements of a common brushtail possum from its den location to a patch of blue gum trees where it forages. The comparisons continue.

Place and time utility. Place utility refers to the possibility that sentient objects obtain greater rewards in some places than in others. For example, during the nineteenth-century explosion of European agricultural populations, the new farmlands of America, South Africa, Australia and New Zealand attracted millions of Europeans migrants (Abler et al. 1971, p. 196).

Time utility is the temporal availability of desirable services or facilities at the moment of need. Even if a given place offers certain facilities and services, these may only be available during limited operating hours.

Place and time utility also influence movements of animals. Clear examples are the numerous annual migrations which occur from Polar Regions to more temperate areas, undertaken to take advantage of the great seasonal availability of food during summers and to avoid the harsh climatic conditions of winter.

Nathan et al. (2008, p. 19054) suggested that the dynamic interplay among four principal components, namely internal state, motion capacity, navigation capacity and external factors, generally causes the movements of animals.

Internal state is surely the most complex of Nathan et al. four factors, referring as it does to physiological and, where appropriate, psychological states, which

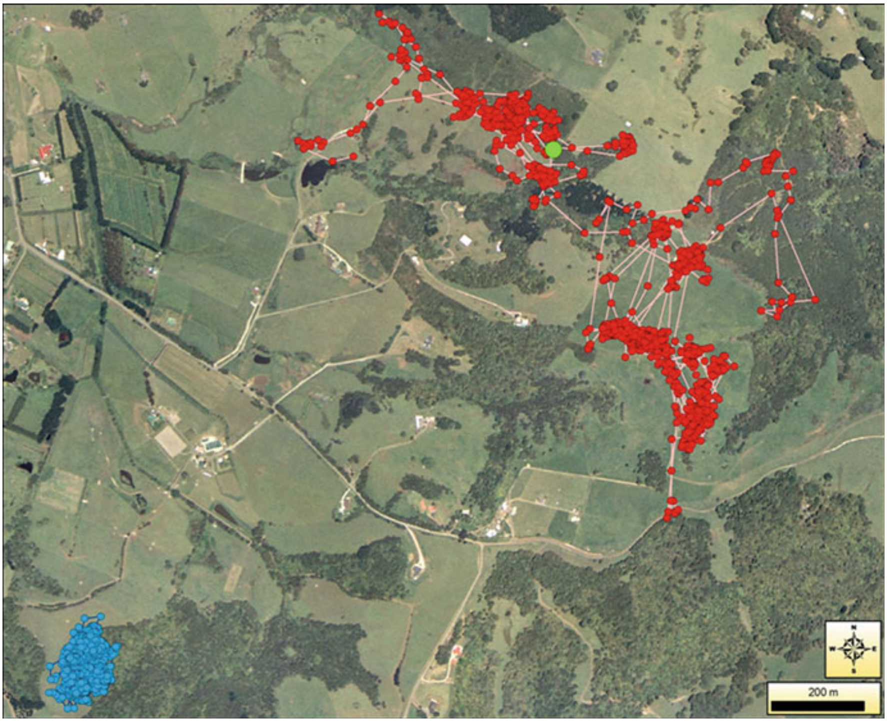

Fig. 4 Movement patterns of a female common brushtail possum before and after translocation to an unfamiliar location, Muriwai, New Zealand, 2009. *Blue points* (*lower left corner*) represent position fixes and trajectories made at 5-min intervals over *c*. 2 weeks by a GPS collar. *Red points* indicate the movement pattern (again over *c*. 2 weeks) after translocation. *Green dot* depicts the release location

drive humans and animals to fulfil one or more goals. This idea covers both proximate and ultimate evolutionary benefits from movement, the degree to which either approach is used depending on species and context. Some activities, such as searching for food, escaping predators, following adults, or searching for mates may indicate proximate payoffs which, in turn, suggest ultimate goals of gaining energy, seeking safety, learning, or reproducing. The comparative importance of different goals may vary over an animal's lifetime and over much shorter periods, and individuals may pursue several goals simultaneously. Thus, the internal state can consist of a multidimensional vector of many sub-states.

In terms of humans, internal state can be linked to factors such as desires, confidence, anxiety, knowledge, motivation and needs, which encourage movement. For example, people may decide to migrate from one place to another place because the latter can better satisfy their needs (Roseman 1971).

Motion capacity refers to an animal's ability to perform self-propelled (motile) locomotion by various means. Ultimately, it is derived from biomechanical properties which enable animals to move either by flying, crawling, walking, running, or swimming. Animals may make use of several operational modes, for example, many birds fly, walk, and swim; motion mechanics may vary, reflecting changes both in an individual's internal state and/or external factors.

In terms of human beings, apart from biological motion capability, the degree and nature of human mobility is also associated with the ability to sense the environment and the ability to traverse the environment. For example, one can extend his/her motion ability over the environment by utilising certain transportation tools, (e.g. planes, ships, cars, bicycles). The improvements in transportation technology have increased the spatial extent of human movement over time (Hägerstrand 1970).

Navigation capacity refers to the ability to orient in space and/or time, selecting where and/or when to move. Navigation requires an ability to sense and respond to information (e.g., direct and indirect cues, memory of previous experiences) regarding the spatiotemporal structure and dynamics of the environment.

Similarly, the skill of orientation in spatial environments is a fundamental human ability and a prerequisite to wayfinding, the process of purposefully determining and following a route from origin to destination (Golledge 1999). The process of human navigation is composed of three activities: positioning (i.e. identify location and orientation in the environment), route planning and movement (Sester and Elias 2007). Human navigational skills are related to knowledge and appreciation of the environment and its characteristics, and they can be facilitated be various wayfinding aids, e.g. maps and known landmarks (Golledge 1999; Sester and Elias 2007).

External factors refer to all features of the abiotic and biotic environment which influence movement, for example, weather, habitat type, threat of predators, the proximity of resources or other organisms. These factors mediate an animal's ability to move and survive, so it is critically important to understanding the relationships between movement and the environment (Patterson et al. 2009).

The impact of the dynamic geography, including other sentient entities, is equally important to movement of humans since the geographies determine what choices and movement combinations are available (Hägerstrand 1978). Clark and Cadwallader (1973) suggest that people's locational stress, which is the stress experienced by an household at a particular location (e.g. neighbourhood decay, accessibility issues, environment pollution), may make them decide to move from one residential location to another (Clark and Cadwallader 1973).

2.2 Constraints

Hägerstrand (1970) believed that movement and activity often are governed by limitations, which constrain possibilities of movement and can be used to explain or deduce reasons as to why particular individuals move along one path rather than others. In this context, it becomes necessary to identify factors which constrain individual movements. Seven major constraints are discussed:

Capability refers to limitations on individual movement due to physical, physiological or biological factors. These constraints restrict the distance and speed of movement, given a certain period of time, mode of transportation or species-specific capabilities of motion. For example, male mammals typically move further than females.

Coupling refers to the limitations imposed by the need to be in a particular place for a given time and period to engage in specific activities with specific objects or entities. This could mean anything from taking a child to visit a doctor to going to school. These constraints "define where, when, and for how long", the individual needs to meet with other individuals, use tools or materials in order to produce something, or consume and transact. Western society over recent years has changed markedly, so that certain coupling constraints are much weaker than they were previously (such as during the 1970s); for example, now there are more flexible working hours, and shopping can be done at home via the internet. These changes have led to more complex movement patterns of individuals (Forer et al. 2007).

Behaviours such as mating/courting, territorial defence and flocking are strongly subject to this constraint.

Authority refers to a 'domain' that is controlled by people or institutions that set limits on the spatial and temporal accessibility to particular individuals or groups. For example, a person's space-time path normally cannot enter sensitive military bases or private property; dogs are forbidden to visit certain conservation reserves at certain periods. In some sense, the territories of animals can be considered to fall within this category.

Knowledge constraints comprise one of the major limitations on movement behaviour, because individuals require sufficient information to make decisions regarding where they will go and what they will do when they arrive there, and access to information often has its own set of geographical limitations. For example, if tourists have no knowledge about a possible destination or how to travel there, they may decide not to visit. This constraint is more significant for non-routine locations (Forer et al. 2007). Lau and McKercher (2006) discovered that tourists who are familiar with the environment are more adventurous and their movement patterns are more diverse and extensive, whereas 'destination naïve' first-timers show more confined movement patterns. Interestingly, animals react to knowledge constraints differently. For instance, when relocated to unfamiliar environments, many individuals travel over much greater distances than when they are in familiar areas (Fig. 4). Such increases in travel distances often reflect the desire of animals to return to their home range, where the locations of food resources, rest areas, or refugia are known. Increased travel in unfamiliar locations also indicates exploratory behaviour.

Temporal constraints have a profound impact on travel behaviour. Lau and McKercher (2006) identified that time scheduling and length of stay are the two primary temporal factors that influence the movement patterns of tourists. The length of stay partially determines the distance travelled to reach resort destinations, i.e., the further one travels to a tourist destination the longer one tends to stay (Debbage 1991).

Available blocks of time and their duration also impact travel patterns (Harvey 2008; Forer et al. 2007). For example, if one wants to travel to the theatre for a play that lasts 2 h from 6 to 8 pm, one needs at least a 2-h block of free time at the right time. Otherwise, even if 2 h are available during the day (say, one hour in the morning and one in the afternoon), but not scheduled *together at the right time*, the theatre visit cannot occur.

Temporal cycles impose significant effects on movement patterns. The movement cycles of humans exhibit a strong weekly periodicity due to 5-day working weeks, whereas the movement patterns of animals (especially those inhabiting areas outside of the tropics) are heavily influenced by seasonal cycles.

Spatial constraints are limitations on access to spaces of interest imposed by physical objects, e.g., road networks, or natural barriers. Such objects apply a 'firm' constraint on the paths and/or extent of movements (Dodge et al. 2008). The routes and range of human movements in automobiles usually are constrained by the layout of transport networks, while the extent of animal movements frequently are restricted by physical barriers such as ecotones, coastlines, or rivers.

Environmental constraints such as weather, spatial distribution of resources and predators, population density of conspecifics, and disturbances may impose what are known as 'soft' limitations on movement. Elk (*Cervus elaphus*) turn more frequently and move shorter distances while foraging within patches with high resource abundance compared to when moving among patches (Fryxell et al. 2008). Crickets travelling through corridors (linear landscape elements) move straighter but slower than in resource patches as a means of reducing exposure to predators (Berggren et al. 2002).

2.3 Commentary

The factors influencing movement which are discussed above are not exhaustive; nevertheless, clearly there are many elements which must be considered when exploring the reasons behind patterns of movement of humans and animals. While identification of these factors can be very challenging, geovisual analytics provides a powerful means of exploring and comprehending rich and complex movement phenomena (Andrienko and Andrienko 2007). The many shared fundamental motivating factors between the movements of humans and animals suggest that it should be possible to adapt some of the visualisation techniques originally developed for the movements of humans to the movements of animals. However, because the nature of animal-movement data is quite different from that of humans, modification of specific aspects of these techniques may be needed. To develop the modification strategy of the geovisualisation toolset for the movements of possums, it is necessary to first understand the lifestyle of possums.

3 Geovisual Analytics and Possum Movement Visualisation

3.1 The Nature of the Possum Lifestyle

In spite of the considerable common ground between species in their drivers, it is relatively unusual to see cross citation of studies of analysis or visualisation of human viz a viz animal movement data sets. This mutual isolation may seem logical to some and regrettable to others. Free of major ethical issues animal behaviourists and ecologists have created strong currents of interest with their innovation in capturing movement data (Hebblewhite and Haydon 2010; Dennis et al. 2010). Eroded control of privacy may see a similar surge in scientific rather than commercial exploration of human movement. In the meantime the Ringmap project has been fortunate in collaborating with local NZ research in high resolution animal data capture and visualising ongoing sample data sets. The albatross flights illustrate that the basic aquarium model can be just as effective for extracting rapid insights in the animal kingdom as it is with human data. However, soaring sea birds live in a different geometry and geography than Halifax commuters and for a more even comparison of species we switch to a small group of strictly terrestrial animals, the common brushtail possum.

The common brushtail possum is a semi-arboreal, nocturnal marsupial native to mainland Australia and Tasmania but introduced to and recognised as a major pest in New Zealand. Brushtail possums are commonly located in tree cavities or perching epiphytes. They usually sleep in their dens during day time, awake and emerge from the dens about half an hour after sunset, and cease active behaviour before dawn. Their nightly activities can be grouped into feeding, grooming, resting, and travelling. Males move further than females but females have more philopatric dens. However peak periods of activity and how activity changes over time, by sex and among seasons have not yet been characterised at fine temporal scales (Koefoed 2009; Dennis et al. 2010). Therefore, the next two sections explore the possum movement data collected at fine temporal scale.

3.2 Viewing Possums Movement and Activity as Timelines

Absolute time was displayed in the albatross timelines (Fig. 3); however, time also can be represented in relative terms for different purposes. For example, Fig. 5 shows time relative to sunset in hours, depicting the timelines of an adult female common brushtail possum (#6012) over a period of 8 consecutive nights. Segments of timelines are colour-coded to represent habitat (Fig. 5a) and behavioural modes (defined by two classes of step lengths and turning angles) that were inferred by a segmentation model (Dennis et al. 2010; Dennis and Shah 2012; Koefoed 2009) (Fig. 5b). When comparing both images, one sees a regular periodicity of behaviour both within and between nights, with rapid movements over grassland during the early hours of active periods, followed by much slower movements of higher turning angles during the middle hours (when the possum was feeding in gum trees), then a return to short intervals of rapid and directed 'commuting' movements at the end of periods of activity as the animal returned to its favoured denning site.

Each segment of the timelines is coded with a single colour in Fig. 5a and b. With transparency several colours can be associated with the same segment of a timeline to explore multiple variables (Fig. 5c).

Figure 5c depicts the same information expressed in Fig. 5a and b in a single image by overlaying wider semi-transparent colour 'masks' of habitat on top of behaviour timelines. While this promotes closer examination of the relationships between habitat and behaviour, the rich information displayed may challenge human abilities in visual information-processing. Interactively switching on and off the 'masks' may help reduce the challenge.

Figure 5d shows an aggregated pattern of the timelines, i.e. flows. We can see that a 'co-incidence in space and time pattern'[3] (Andrienko and Andrienko 2007; Dodge et al. 2008) occurs mostly at 4–8 h after sunset to the north-west of her den (see green to dark blue colours). By comparing Fig. 5a and d, we see that the concentration of locations in the gum trees depicted in Fig. 5a reflects the main co-incidence patterns seen in Fig. 5d, indicating that the gum trees might be a key driver of the possum's co-incidence patterns.

Timelines offer an elegant and intuitive means of expressing patterns of movement, by bringing space, time, activity and geographic context together as a whole. However, timelines only can effectively represent a small amount of data in a single diagram, and they are subject to inherent issues associated with perspective, such as difficulties in relating timelines to exact locations in space and time. Additional approaches providing a compact and flexible means of exploring rich and complex patterns of movement and their geographic context are needed. It is also necessary to develop a geovisualisation toolset which coordinates multiple representations, derived from various approaches and scales, that complement and augment each other, and provide further insights (Zhao et al. 2006). Our next section applies the innovative geovisual analytics method—the Ringmap to movements of possums.

3.3 Visualising Movement Patterns of Possums with Modified Ringmaps

Ringmaps were originally developed to visualise 24-h cyclic patterns of human movement and activities (Zhao et al. 2008). However, the movement patterns of possums and the data used to describe them are substantially different from those of humans: (1) The Halifax data recorded activity and movement of thousands of

[3] Co-incidence in space and time pattern refers to the same spatial locations are attained at the same time or after a time delay.

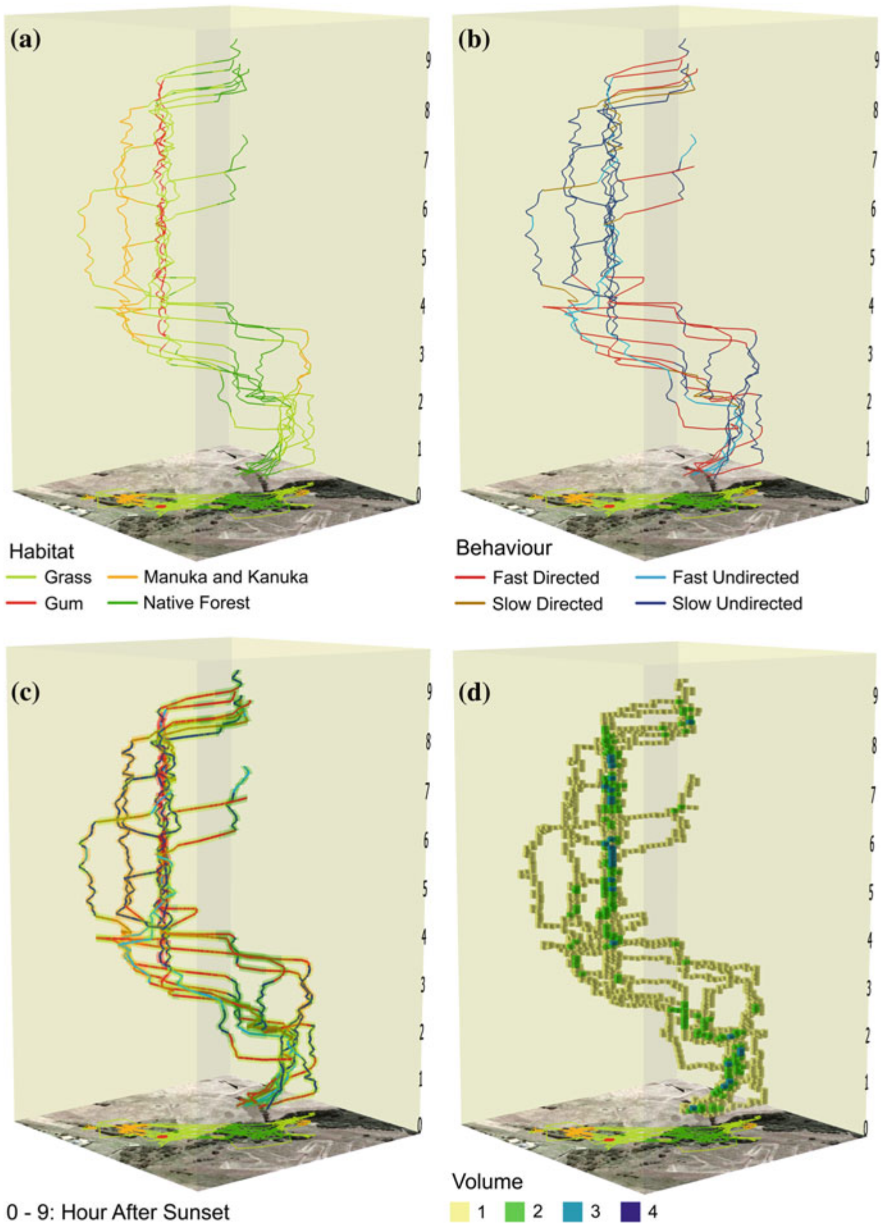

Fig. 5 Nightly GPS-derived timelines of a female common brushtail possum (#6012) over 8 nights, Muriwai, New Zealand, 2008. The timelines are colour coded with habitat (**a**) and movement behaviour mode (**b**). Wider transparent colours of habitat 'masks' overlay behaviour timelines to integrate both variables in (**c**). Aggregated patterns of the timelines are shown in (**d**). Time granularity is 5 min. Spatial resolution is 5 m radius hexagon (**d**)

citizens over a duration of one day per respondent, while the possum data tracked a limited number of individuals, but over a period of more than one year. (2) Possums are nocturnal and they also respond to seasonal cycles while humans are more adapted to 24 h, 7 day cycles. (3) Spatial context is different, e.g., home for humans is relatively permanent and static, while possums' dens are generally semi-permanent and philopatric. There are many convenient spatial areas for associating human movement and activities, e.g., census tracts, while for possums these are much fewer. All these differences should be considered when modifying ringmaps to explore the movements of possums.

Figure 6 depicts a modified ringmap for a single possum (#6012), showing the same information as in Fig. 5a and b, but in a compact and cyclic manner where nightly cycles are shown and space and time are visualised explicitly.

Unlike the 2-D ringmaps made for Halifax data, where only one group of rings shows one variable over a 24-hour cycle (Zhao et al. 2008), the ringmap in Fig. 6 is altered to use two groups of rings to represent two variables, habitat and behaviour, with a nightly cycle over equivalent time periods, 8 nights. Each ring represents patterns of habitat use or behaviour over a night, and each group of rings is ordered similarly. In this case the rings are ordered by date to allow comparison between variables. Sectors represent the time after sunset, ordered clockwise along an arc axis over 5-min intervals. If needed, additional groups of rings can be added to display more variables in order to reveal other relationships among movement behaviour and its motivating factors. The ordering of groups of rings also can be changed to reflect a different variable. Given the fine grain GPS tracking data and the limited number of possums tracked, it is possible to show information at an individual level, unlike aggregated ringmaps for Halifax data. The inset photo map is used only as a background to indicate relevant environmental information. However, the inset possum timelines and the ringmaps of behaviour and habitat are interactively linked to each other. For example, if one selects movement paths for night 1 from the timelines, the two ringmaps will be able to highlight corresponding behaviour and habitat sectors for night 1.

One of the strengths of ringmaps is their ability to illustrate cycles. The types of cycles that can be mapped are flexible, dependent on the nature of data. In the examples, the movement patterns of possums are heavily influenced by season and habitat, and tracking data are available for more than 1 year, so we assessed a seasonal ringmap of habitat use at an individual scale where each sector represented a night in the year (ordered clockwise), while rings displayed time after sunset, projected outwards from the centre with each ring represented a 10-min interval (Fig. 7).

The ringmap in Fig. 7 depicts nightly patterns of habitat use of a single male possum (#1882) expressed over a year, beginning in March 2007. The timelines at multiple temporal scales are processed/interpolated into 10-min intervals. In the example, at the seasonal scale, the possum shifted during the New Zealand spring (September to November) and early summer (December) from extensive use of patches of manuka/kanuka (*Leptospermum spp.)* bushlands, to increased use of dry and wet native forest during the late summer (February), to heightened use of

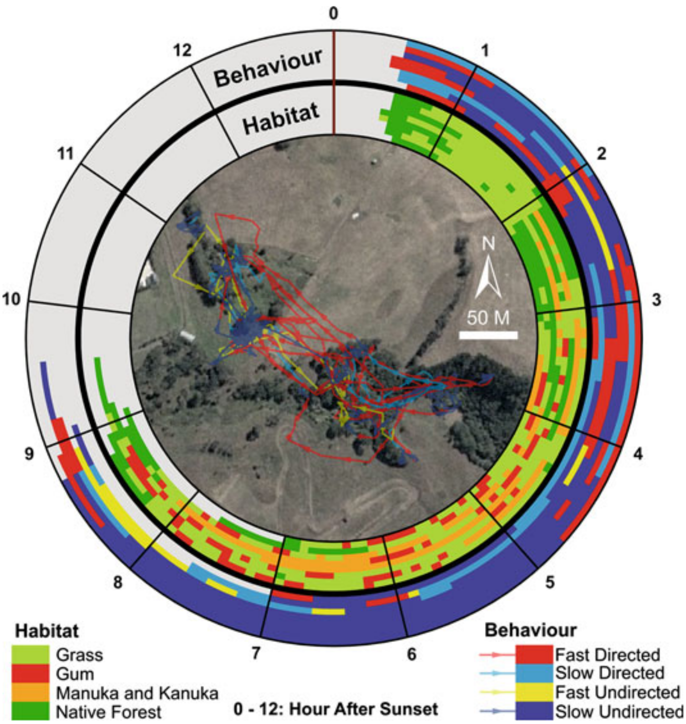

Fig. 6 Two groups of ringmaps showing movement behaviour of female possum (#6012) and her interaction with habitat in Muriwai, New Zealand over 8 nights in 2008. Each *ring* represents a night and each sector represents a 5-min interval during the night

exotic pine plantations (*Pinus spp.)* during autumn and winter (from March to August). These seasonal changes likely reflect variations in the availability of principal food resources. At the nightly scale, the possum clearly exhibited temporal variation in use of habitat, reflecting the tendency of the species to regularly commute from favored den sites to preferred foraging areas. The habitat colour-coded timelines and the geographic background image located in the center of the ringmap provide references to geographical space. Coordinated and interactive visualisation among rings and timelines can facilitate recognition of linkages among space, time and other variables.

Figure 7 suggests that there is a significant seasonal variation in habitat use, so we aggregated the data for two seasons, summer and autumn, because they have the most information available for further investigation of seasonal changes (Fig. 8).

Figure 8 shows a different means of displaying temporally explicit information associated with the timelines of moving animals. Here we see marked seasonal patterns of habitat use during the summer and autumn: manuka and kanuka bush is strongly preferred during summer, while pine and native forest are heavily used in

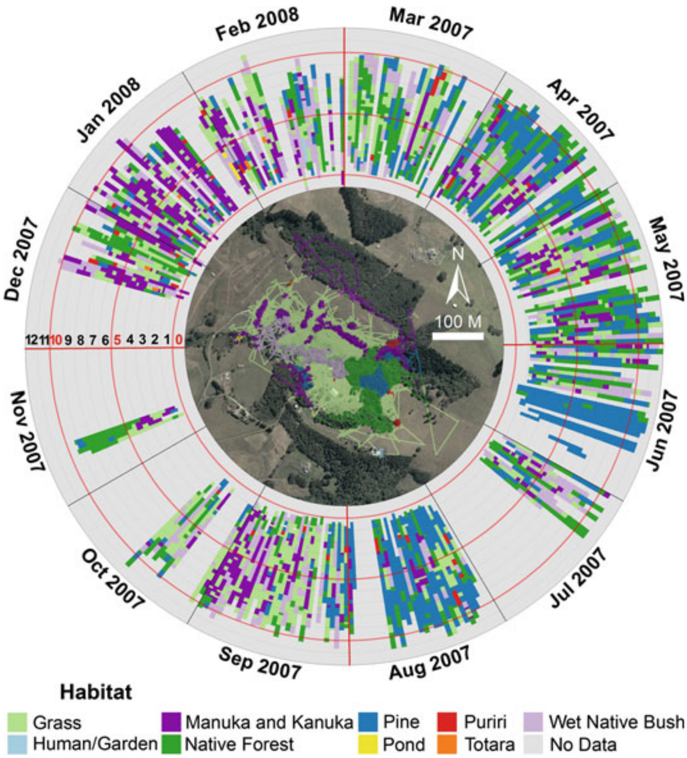

Fig. 7 Ringmap of seasonal and nightly patterns of habitat use (depicted by *colours*) by a male common brushtail possum (#1882). Each *ring* represents a 10-min interval of time after sunset, ordered outwards from the inner ring. Each sector represents one night starting from March 2007 and ending in February 2008. The inset timelines represent spatial movement paths. '0–12' indicates hour after sunset

autumn. These observations further confirm the patterns shown in Fig. 7. In both seasons, there clearly is proportionally higher use of native and pine forests during the early and late hours of the night, suggesting that this possum preferred to locate its den sites in such habitats. Associated with a reduction in the proportional use of these habitats during the middle hour of the night is an increase in the use of wet native bush and grass, preferred foraging areas.

As discussed earlier, ringmaps provide a compact and powerful means of visualising cyclic phenomena, however, the varying sizes of cells in different rings can be misleading. Also, examining patterns within a ring or between rings might not be easy simply because of their shape. When necessary, a ringmap can be stretched into a matrix (Fig. 9) to facilitate comparison and eliminate distortion. Of course, a matrix can be rolled back into a ringmap.

Figure 9 depicts the annual variation in relative rates of travel of possum (#1882) within nightly movement trajectories in a matrix view, using the same data shown in previous figures. Evident are several patterns which reflect seasonal

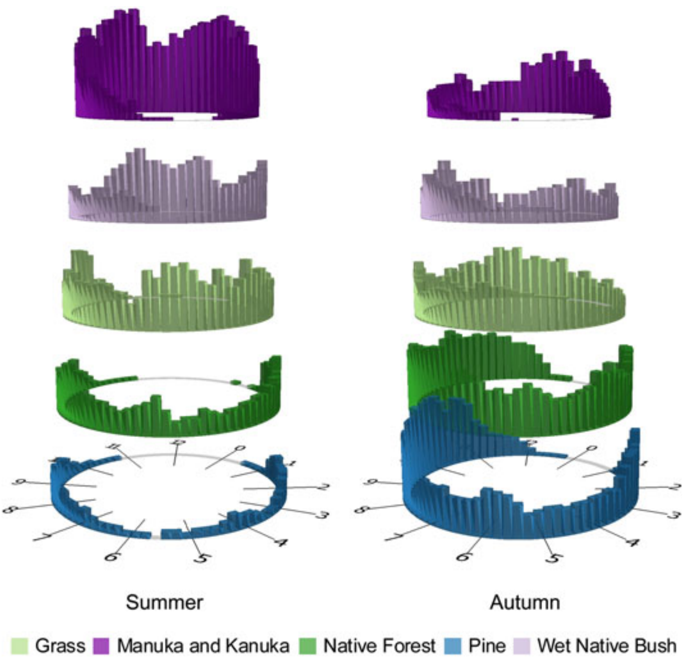

Fig. 8 Aggregated and extruded three-dimensional ringmaps of habitat use of possum (#1882) at Muriwai, New Zealand, autumn and summer, 2007–2008. Height represents the proportion of habitat use. Colours depicting habitat types are the same as Fig. 7 (but semi-transparent). '0–12' indicates hour after sunset

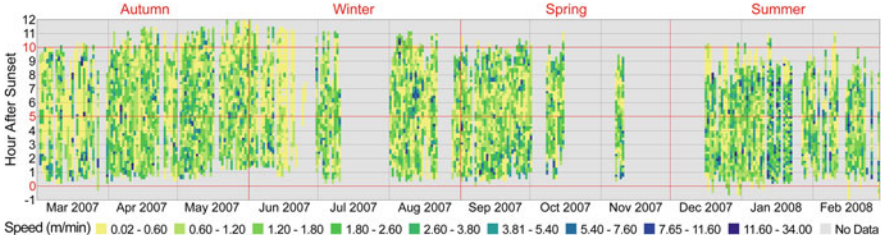

Fig. 9 Annual matrix of nightly rates of travel (depicted by colours) of possum (#1882). Each *row* represents a 10-min interval of hour after sunset, ordered sequentially from the bottom. Each column represents one night starting from March 2007 and ending in February 2008. Southern hemisphere seasons are labelled at the *top* of the image

changes in the behaviour. During June 2007, there was an unusually long period when the possum's movements were much slower than average (these are depicted in yellow). At first we surmised that these slower movements could be the result of periods of heavy rain, which are common at that time of the year, but weather data showed no heavy rain during that period. This phenomenon has aroused our curiosity and will be the subject of future investigation. Periods of markedly faster-than-average movements (shown in dark blue) occurred during December and January, most probably the result of bouts of commuting from the den to seasonally available food resources that were dispersed over long distances. Especially during the austral summer months, movement speeds near the end of nightly active periods were lower than average, suggesting a tendency of the animal to rest or groom outside of the den before retiring to sleep. Also during summer months there were occasions when fixes were recorded before sunset. Most likely these occurred during nights when the possum slept in epiphytes, where it was possible for the GPS collar to determine locations, which usually is not possible when GPS collars are in tree cavities or holes in the ground where satellite signals are occluded by surrounding dense woody or stone materials (Dennis et al. 2010; Dennis and Shah 2012). With the matrix view, it was easy to see horizontal changes. An interesting general shift of the start and finish of active time emerged. There was an upward shift towards later finishing times in the autumn months of March to May, which might reflect the possum's response to increasingly long nights.

4 Discussion and Conclusion

This chapter has introduced an experimental, movement-specific, visualisation toolset that is being tested with both human and animal activity movement data sets. We introduced the tool set with an example of the daily lifestyle of human residents of Halifax, but have concentrated more on presenting outputs from a data set of GPS-tracked possums. The goal of this has been to compare the capabilities of certain visualisation tools in the context of different species in different geographies. The *Ringmap* project has used a time geography approach to explore more powerful tools for visualising movement of animals by focusing on an integration of space, time, activity and environmental factors and coincides with the rapid evolution of sophisticated tracking technologies that foster the conditions for advancing conceptualisation of a 'movement ecology' paradigm aimed at animal studies. The overlaps between these approaches has been noted, as has the parallel gap between the animal and human research communities, and the nature of this common ground has been explored a little within the text. Three specific representations have been compared for this paper.

Not surprisingly, traditional timelines have proven equally capable of adding value to basic two-dimensional maps. However, extra value has been revealed by linking environment factors (vegetation type) and/or derived 'activity' parameters to the timeline display.

The ringmap representation has proved to be flexible in providing a compact means of exploring activity patterns over markedly different spatio-temporal resolutions and observational periods be they generated by humans or possums. For possums it has been successfully improved by integrating the seasonal cyclicity in such a way that it incorporates the fluctuating duration of the possum's low light 'day'. The inner space of a ringmap can also be used flexibly, displaying complementary maps, images, cartograms or other relevant information at appropriate scale. Experience has shown that it is reasonably simple to technically modify these tools, e.g., changing total number of rings and sectors, for use on movement data of possums. However, it may not be simple to determine the optimization of the tools. A proper insight-based evaluation will be conducted to address this aspect. In line with our emphasis on activity and geography, a major challenge is identifying the key factors that drive or influence the movements of study subjects, whether the location of gum trees for possums or malls for shopping. With this perspective, customised strategies for adaptation of the tools can be developed, typically involving domain experts who are familiar with the data and have the twin abilities to identify key movement influences in the landscape and to interpret and recognise patterns and to discover any significant insights. Using this form of team work the application of ringmaps to the movement trajectories of possums, derived through multiple visualisations of individual trajectories over different temporal scales, has produced a range of new insights into patterns of possum chronobehaviour.

Overall, the extent of new understanding gained from the application of the ringmap toolset has been encouraging, and the application with the possum data set has provided insights into the need to customize specific representations to work effectively in different environments. Further research is scheduled to focus on a third data set and expert user, this time exploring tourist movement in New Zealand. Hopefully the power of the ringmap toolset can be further augmented in this context, and more will be learned of the generality of the effective performance of specific tools and coordinated toolsets across human and animal movement fields. A domain expert evaluation framework (using an insight based approach) has been developed and applied to the Halifax dataset, and has gained positive feedback. Two more evaluations will be performed on the possum and tourist datasets soon and will be addressed in a future publication.

Acknowledgments Professor Andy Harvey of Saint Mary's University, Halifax, Nova Scotia, provided access to the 1971 Halifax data set for testing and ongoing advice and encouragement in the further development and exploration of *Ringmap*. We would like to thank the families of Frank and Robert Calis, Simon Webb, and Steve Nobilo for use of their lovely farms during collection of the possum movement data. We would also like to acknowledge Jean Claude Stahl and Paul Hughes for providing access to the Albatross data.

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A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7, © Springer-Verlag Berlin Heidelberg 2013

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Index

A. Moore and I. Drecki (eds.), *Geospatial Visualisation*,
Lecture Notes in Geoinformation and Cartography,
DOI: 10.1007/978-3-642-12289-7,