Multiple view geovisualisation of tourist activities in space and time at different scales

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ABSTRACT: This paper explores various ways to visualise the complexity of sentient movement, in this case the movement of tourists on the West Coast of the South Island of New Zealand. It argues that space, time and activity (s,t,a) are the three main dimensions of sentient movement, but activity is a privileged dimension when visualisation is required. Sentient beings have goals and desires, which can be realised through their environment and reflected in their activities as they move through and interact with the environment and other sentient beings. The purpose of this research is to find more powerful ways to visualise the movement of sentient entities of all kinds in a way that communicates aspects of process by the use of a combination of (s,t,a) and environmental data.

Using tourist movement data as an example, this paper examines various generalisation approaches that emphasise different combinations of (s,t,a) dimensions in order to explore interactions between them. The complexity and richness of sentient movement data demands coordinated multiple view (CMV) visualisation techniques to draw together space, time and activity. New generalisation techniques such as ringmaps and sta-rods are utilised to fully integrate space, time and activity in CMV visualisations of tourist movements.

The research reported here presents a prototype visualisation toolset, called RINGMAPS, which uses a GIS-enabled toolkit to visualise multiple patterns of sentient movement (individual or massive) in an integrated way at different scales for both animals and people. For this paper a tourist data set is explored in order to gain insights into the movements of tourists and to validate the visualisation techniques using a domain expert evaluation. Its results suggest that the toolset works well with tourist movements and that its CMV visualisations show integrated patterns of space, time and activity that encourage deeper insights.

KEYWORDS: space time activity and ringmap, movement of sentient objects, generalisation, coordinated multiple view geovisualisation, time geography

Introduction

It is well recognised that the world we live in is a dynamic place where change and movement over space and through time is the norm. Enhancing our ability to decipher complex dynamics in human and environmental systems is crucial to our understanding of the world (Hornsby and Yuan, 2008; Yuan and Hornsby, 2008).

Dynamics can certainly be applied to representing changing environments; but they can also be applied to representing the spatial behaviour of the ‘denizens’ of that environment and their interactions with it. It is this community of sentient objects (SOs) that is the focus of this research. Sentient beings such as animals and people are complex, influential and dynamic actors in the world, and their movements are ubiquitous and have profound impacts on our environment (Becken et al., 2003). Therefore, the movement of sentient objects (MoSOs) requires special attention. SOs are capable of thinking; they have desires that lead them to conduct various activities to reach their goals and their decision making has an immediate relationship with the environment. These factors generate additional layers of complexity for representing the MoSOs. However, in other ways, the question is simplified because of the crisp physical nature of individual organisms. The physical existence of an SO is quite clear and unambiguous, and the identity of an SO is considered to be persistent. Thus SOs are often modelled as moving point objects, which are more straightforward than vague linear or areal objects (Yuan and Hornsby, 2008).

The MoSOs consists of three main dimensions; space, time and activity (s,t,a), and each dimension opens to various properties and expressions. When representing and visualising sentient movement, space, time and activity should be considered together. However, activity is uniquely located with SOs, it is a privileged dimension which drives movement and is the key to comprehending movement patterns (Zhao et al., 2008).

In the past, relatively few movement data sets were collected. Those that were collected were relatively simple, small in size and low in resolution, although there are some notable exceptions, e.g. the Halifax time use data collected in the 1970's (Janelle, 1993). The causes and consequences of movements could generally only be inferred from data captured at coarse resolution, so crucial events during transitions were often totally unknown. Over recent decades, new technologies such as satellite-based telemetry have freed up an ability to capture information about dynamic phenomena, particularly for the individual and mass movement of objects such as sentient beings and uninformed objects. This is evidenced by the increasing availability and affordability of data on the space and time dimensions of movement in large volumes and with 'seductive' precision. Advanced technology has opened up numerous research topics, enabling the development of sophisticated data mining and pattern recognition techniques that identify patterns and anomalies within many movement fields (Forer and Zhao, 2011). This revolutionary change in technology has offered huge opportunities for understanding the movement process (Department of Ecology of Lund University, 2009), but it has also imposed significant challenges since "our ability to collect and store data has far outpaced our ability to process, analyse and exploit it" (Compieta et al., 2007, p. 256).Clearly, there is a 'hunger' in dynamic domains for improved interpretation of movement data.

Interactive and dynamic visualisation has been widely recognised as an essential and thought-provoking tool for understanding dynamic phenomena (Andrienko and Andrienko, 2007; Kraak, 2008) since "the human eye and brain can scan and interpret information on a map more rapidly than the most elegant software can process the equivalent digital data" (Goodchild, 1988: 311). However, our inability to explore and visualise massive movement data sets is even more pronounced (Dykes et al., 2005). The challenge is to extract knowledge from new forms of movement data using visualisation. To meet this challenge it is necessary to advance visualisation approaches and to integrate visualisation with geocomputational techniques, such as data transformations, generalisation and other computer based operations (Andrienko and Andrienko, 2007; Dykes et al., 2005).

Movement is a scale dependent phenomenon, with an inherent hierarchical structure. According to Hierarchy Theory, in order to fully comprehend movement at one scale it is necessary to analyse it at three scales: the focal scale, one scale higher, and one scale lower. This approach takes into consideration the contexts that afford and constrain the sustainability of the movement (Yuan and Hornsby, 2008, p. 28). Generalising patterns of the entire three dimensions of sentient movement data in different ways and at various scales promises a better comprehension of such data.

Space, time and activity are interwoven in the movement process. Given the richness and complexity of (s,t,a) movement data and its scale dependency, it is almost impossible to effectively visualise all the dimensions of movement, their relationships and interactions, and their generalised representations at various scales, in any single representation. Therefore, coordinated and multiple view (CMV) techniques are needed to explore and visualise movement data. Multiple views may be represented at an individual or an aggregated level, and at the same or different spatial, temporal and activity scales. They can provide richer, reinforced and complementary information and insights (Balley et al., 2004; Hangouët, 2004) and can facilitate an understanding of relationships between different representations and comparisons between views (Aoyama et al., 2007). Cognitively, multiple views can be a powerful aid in visualisation, taking advantage of human abilities to discover patterns and filter information and allowing more intuitive manipulation (Green et al., 2009, p. 3). Multiple views need to be linked and coordinated (Carr, 1999) so that the information displayed in each representation can be visualised interactively and integrated into a coherent image of the data as a whole (Buja et al., 1991). Boukhelifa et al (2003, p. 259) emphasised that “the whole is greater than the sum of its components”.

This research anticipates that the deliberate integration of space, time and activity through the generalisation and CMV visualisation of sentient movement data will provide deeper and more powerful insights into our understanding of the MoSOs. Several generalisation approaches such as ringmaps and sta-rods for (s,t,a) movement data have been developed and discussed elsewhere (Zhao, 2012; Zhao et al., 2008).The next section discusses CMV visualisation of (s,t,a) tourist movement data. Those visualisations are generated using a prototype GIS-enabled visualisation toolset that the first author developed, called RINGMAPS.

Visualising (s,t,a) Tourist Movement Data with Coordinated Multiple Views

The tourist data set

This paper focus on discussion of CMV visualisation for (s,t,a) movement data based on a set of generalised results mainly from a tourist data set that was derived from the West Coast Tourism Flow Survey. A total of 2,630 domestic and international tourists participated in the survey, and they used map-based enquiries to identify about 300 locations at which they stopped. The survey utilised a cordon sampling technique based on three portals to the West Coast, namely Haast, Arthur's Pass and Buller Axis, and collected tourist time use and expenditure using a diary technique (Forer et al., 2003). Detailed activities recorded by respondents were informally classified into 12 classes. The tourist survey data were characterised by rich information about the respondent's profile, motivation, location, activity, time use, and attitude (Sun et al., in press). Such genuine itinerary data are rare to find and very valuable in identifying the impacts associated with tourism at a local scale and in visualising the time geography of tourist movement and activity (Forer, 2005). This paper mainly uses extracted data for 500 tourists whose itinerary lasted 3 days and whose records were complete, or were enhanced to satisfaction using space-time constraints (Sun et al., in press).

Multiple view geovisualisation of tourist activities

CMV geovisualisation has gained acceptance in a wide range of environments (Erbacher, 2007) and it is critical and prevalent in many visualisation systems, e.g. Snap-Together (North and Shneiderman, 1999; North et al., 2003), GeoVista (Gahegan et al., 2002), CommonGIS (Andrienko and Andrienko, 2003), and Improvise (Weaver, 2008). It is encouraging that developers and researchers have created many visual forms to aid multiple view geovisualisation. Multiple forms of representation can be categorised into seven groups: maps, networks, charts/graphs, tables, symbols, diagrams and pictures (Roberts, 2008). They can be used as 'building blocks' at the same or different level of detail in CMV geovisualisation in order to gain a better understanding and greater insights from data.

Baldonado et al. (2000) defined a single view as a set of data plus the specific visualisation of those data. If a view allows the user to learn about different aspects of the data then the view is distinct. Although there is no universally accepted definition among researchers regarding multiple views, the term generally refers to multiple distinct views or representations of the same data displayed simultaneously. This approach enables direct comparison and coordination among multiple representations so that any operation on one view is linked to other views (Roberts, 2007, 2008). Multiple views can display multiple or same form visualisations with different display parameters or attributes at the same or different spatial, temporal and activity scales.

Depending on the relationship between two or more representations, multiple views can be classified into six groups. They are dual views, small-multiples, overlaying views, intertwining views, horizontal views and vertical views.

Dual views, as the term suggests, refer to two side-by-side views in a system. Examples include overview and detail views, focus and context views, and master and slave views (Roberts, 2007).

Small-multiples are matrices of shrunken 'thumbnail' representations that support understanding and comparison of complex information (Tufte, 1983). These small views normally use the same form of representation and they are reorderable, which provides the potential for users to perceive trends and relationships in the data and to gain insights (MacEachren et al., 2003).

Overlaying views show several relevant representations in the same display using techniques such as semi-transparent overlays, partial-total overlays or animated overlays to reduce occlusion. This method allows multiple visualisations to share the same view and prompts close comparison between them. However, the usefulness and appropriateness of this method depends on the graphical technique, the visualisation tasks and the size of the data set of interest (Roberts, 2005).

The sta-rod visualisation in Figure 1 shows an example of overlaying view. This diagram uses 3D overlaying rods to depict aggregated and weighted patterns of tourists' activities on the West Coast of the South Island of New Zealand over 3 days. The green, blue and pink colours of the sta-rods represent travel, sightseeing and eating respectively. One can see that the Haast to Glaciers, Glacier Core, Hokitika, Greymouth and Punakaiki Coast zones attract most of the sightseeing activities, but these exhibit different temporal patterns and different volumes.

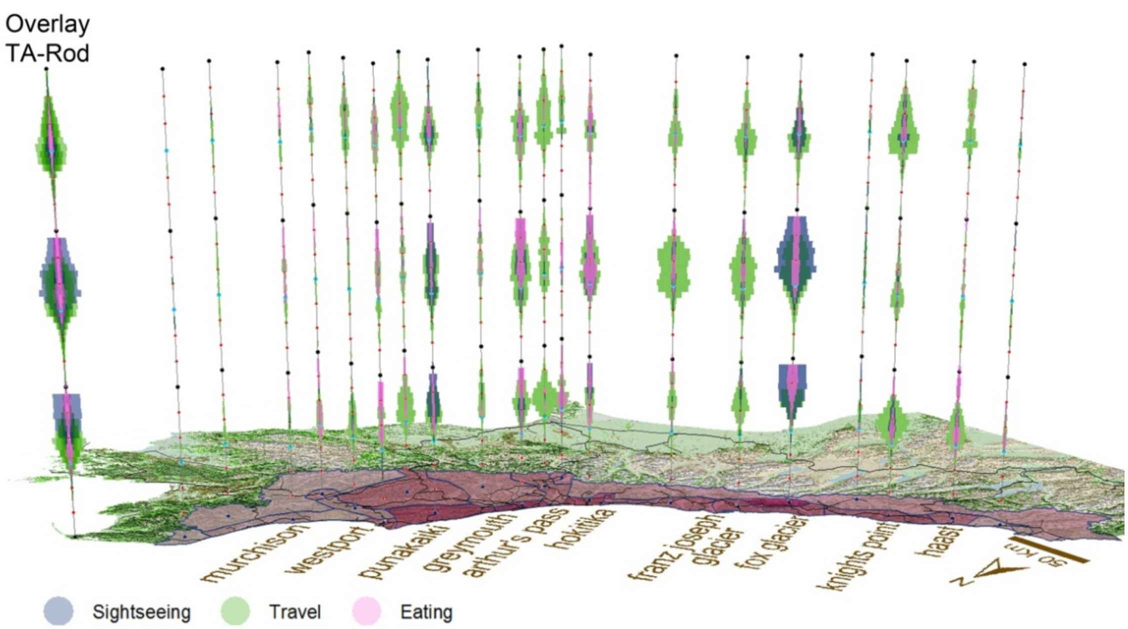


Figure 1: Overlaying views show aggregated patterns of tourists' activities in 20 sub-regional zones: travel (green), sightseeing (blue) and eating (pink) on the West Coast of the South Island of New Zealand over 3 days. The vertical dimension represents time starting from zero o'clock of the first day. A time activity rod (ta-rod) is located on the far left. There is a time marker every 4 hours, the bigger blue and black makers indicate 12 noon and midnight respectively. The temporal intervals are 60 minutes.

The Glacier Core zone appears to be the major driver of tourism, as indicated by the large proportion of the sightseeing activity that occurs on the first afternoon and the second day of tourist's itineraries. Tourists often depart early on their last day of travel and this might explain why on the third day, the volume of the sightseeing activity, which peaks in the morning, has dropped dramatically in comparison with the first two days. Sightseeing in the Greymouth and Hokitika zones seems more attractive to tourists on their second day.

This may be related to their geographical locations as convenient half way points on the trip down the West Coast. The Haast to Glaciers zone attracts first and last day tourists, indicating that it is a 'must see' whether tourists are travelling north to south or south to north. There is only one road that runs right along the West Coast so it is no surprise that travel patterns are generally heavy on the second day in middle zones i.e. in and between the Punakaiki Coast and Glacier Core zones, while the inland and periphery zones have higher volume of travel on the first and last days, indicating that those zones are used as 'funnels' for tourists' to get to their destinations.

The Glacier Core, Hokitika and Greymouth zones hold a relatively high volume of eating activity. This may related to the fact that there are well established towns in these zones. Interestingly, the three zones exhibit different temporal patterns for the eating activity, which peaks on the first afternoon, the second afternoon, and the second evening respectively. The reason for this pattern might be that first day tourists in the Glacier Core zone have usually come a long way (from Haast or even further afield) and there are no dining opportunities until they reach the Glacier Core zone in the afternoon. The peak in the Hokitika zone on the second afternoon is probably related to its central location on the West Coast, with tourists from both directions stopping to eat, but aiming to spend the night elsewhere. Greymouth is also centrally located on the West Coast but it captures diners on the second evening because it is the largest town on the West Coast and offers more dining and accommodation choices. The TA-Rod (time activity rod) on the left hand side in Figure 1 provides a 'pseudo-aggregated' view of the data, which uses transparency and suppresses space.

Intertwining views are made up of two or more representations in an embedded manner so that the multiple representations can be neatly integrated to provide an apparently coherent whole image for visualising complex and rich information. In an interactive visualisation environment, this combination promises closer integration between representations. Figure 2 shows an example where the intertwining view is made up of a spatial ringmap, a geographic map inset and a ring-histogram. The space, time and activity dimensions interplay in a coordinated visualisation.

The spatial ringmap shows the spatial and temporal patterns of sightseeing (colour) and eating (extrusion) activities for tourists on the West Coast over three days, where each ring represents a sub-regional zone ordered from North to South working outwards, and each sector represents one hour. The inset sub-regional zone map displays overall summarised spatial patterns for the two activities. The outermost ring-histogram depicts the overall summarised temporal patterns of this activity. One can see that there are different combinations of sightseeing and eating patterns in different zones. For example, the top three zones for eating are the very popular Glacier Core; Hokitika, which is famous for its annual Wildfoods Festival in early March; and Greymouth Core, the largest town on the West Coast. The Glacier Core has high volumes for both activities on the first two days, while in the Hokitika zone, eating activities are highly concentrated on the second day, suggesting that its position in the middle of the West Coast enables it to receive both north- and southbound dinners passing through on their way to other destinations. This suggestion is reinforced by the fact that Hokitika has relatively low volumes of sightseeing.

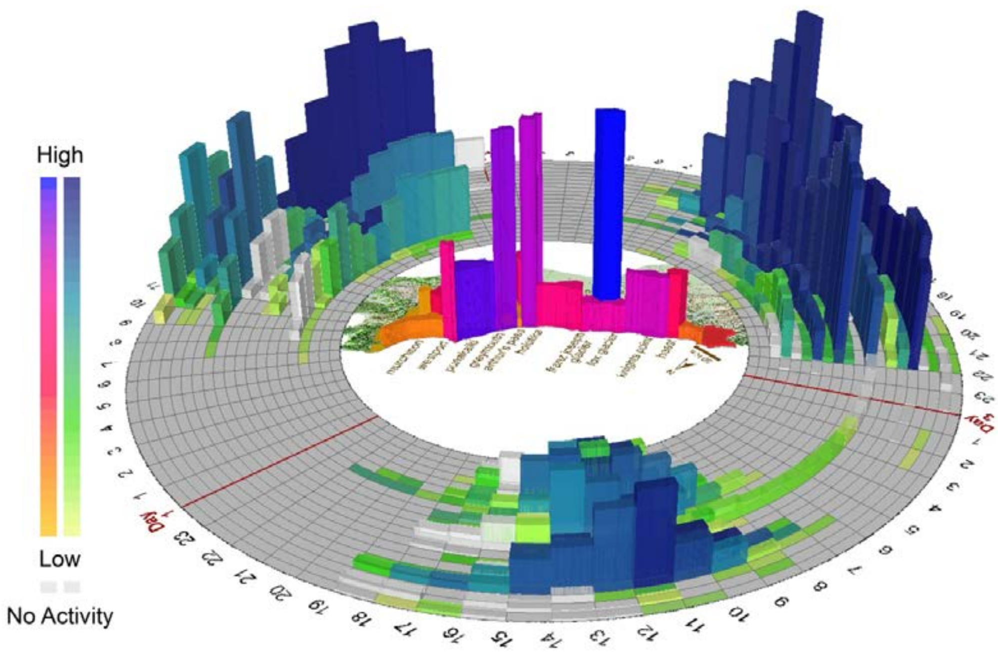


Figure 2: Intertwining views of sightseeing and eating patterns of tourists on the West Coast of New Zealand over 3 days. In spatial ringmap, each ring represents a sub-regional zone ordered from North to South working outwards. Each sector represents one hour starting from zero o'clock of the first day. The spatial ringmap and the inset map display the temporal and the overall volume of sightseeing (colour) and eating (extrusion) activities in the 20 sub-regional zones respectively.

Horizontal views show the same or similar data in various forms of representations at the same level of scale. Well-designed multiple forms of display can complement each other and help users to visualise and understand various dimensions and aspects of the underlying data. Figure 3 shows an example of horizontal view which is generated using a presence shield aggregation technique. In the figure, tourist sightseeing activities over a 3 day itinerary on the West Coast of New Zealand are aggregated into 5 km radius hexagonal grids with 15 minute time intervals. Colours show the volumes of the sightseeing activity. On the left and the right of the diagram we see temporal summary and variance statistics, and on the top of the diagram, in dark blue, we see spatial summary statistics. Form this visualisation we can see that the Franz Joseph Glacier area attracted the highest volumes of sightseeing, which was concentrated on the first two days, particularly the second day. The Punakaiki area is the second most popular place for sightseeing, but its temporal distribution is more even in comparison with the Franz Joseph Glacier area. The highest overall volume of sightseeing occurred on the second afternoon between 12 noon and 4 pm, as did the highest overall variance of this activity. On the first day, the highest volume occurred around 4 pm; but the highest variance happened around 8 pm.

Vertical views represent the same or similar data in various forms of representations at different scales. This approach involves generalisation of the data at multiple scales and poses challenges for existing CMV systems, which are mostly not scalable (Andrienko and Andrienko, 2007). Figure 4 shows such an example, which provides a way to display (s,t,a) data at multiple scales. At the regional scale (the left views in Figure 4), we can see that tourists conducted most sightseeing activity on their second day, while on their last day in the West Coast, we can see an obvious time compression pattern, i.e. tourists run out of time and exit quicker. At the national scale (the right views in Figure 4), we can see that the West Coast RTO receives most of its international visitors from the Canterbury, Queenstown and Nelson RTOs, in that order, and delivers tourist flows to the Queenstown, Nelson, Lake Wanaka, Canterbury and Nelson RTOs in descending order. In line with the national trend, the southward flows are stronger than the northward flows on the West Coast RTO. With a dedicated ring-histogram in the outermost ring, this region's temporal patterns are evident. They are heightened in the summer and autumn months of January to April with a peak during the first two weeks of February, and they decrease between July and September, suggesting that most visitors enjoy the West Coast in warmer seasons.

Although the six types of multiple view geovisualisation have been discussed separately, it is not necessary to limit visualisation to any one of them. In fact, multiple view visualisation systems often apply several types of views. For example, Figure 4 uses a combination of 'intertwining views' and 'vertical views'.

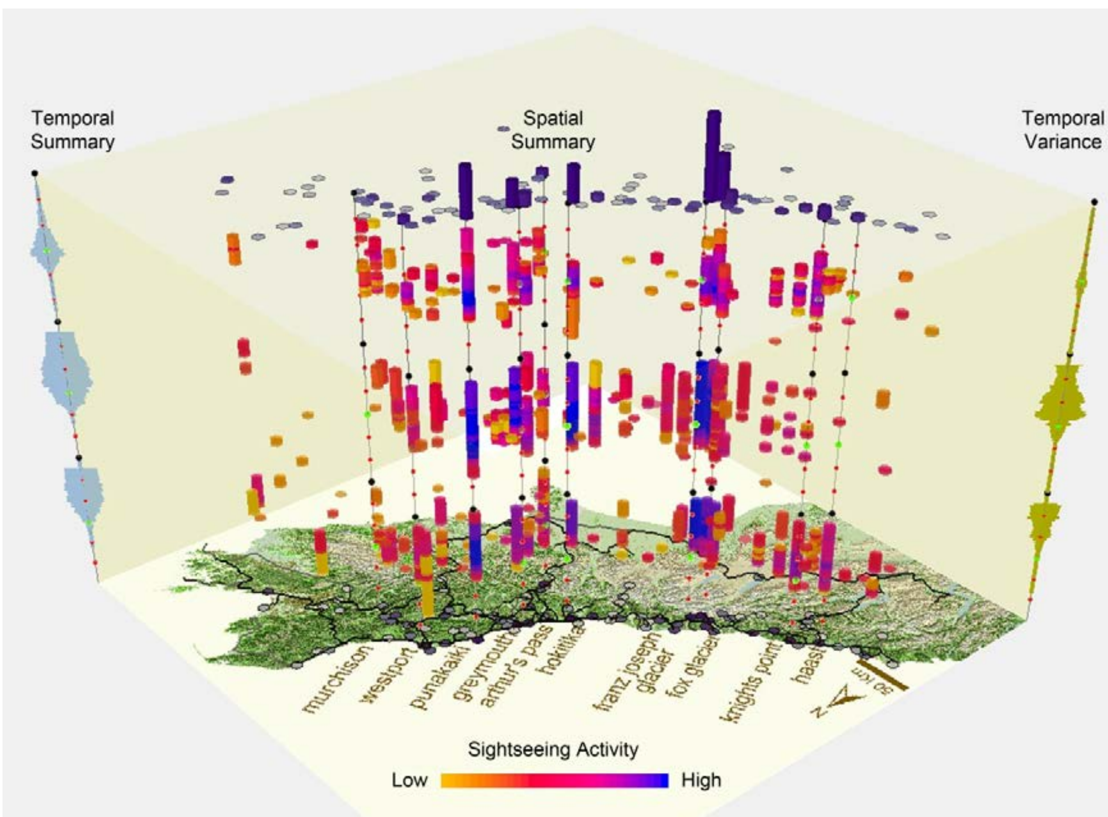


Figure 3: Horizontal views show sightseeing activity for tourists on the West Coast of New Zealand over space and time, with spatial and temporal summary statistics. The sightseeing activity is aggregated into 5 km radius hexagonal grids over 3 days with 15 minute intervals. The blue rod on the left hand side displays temporal summary statistics and the olive green rod on the right hand side indicates temporal variance. The dark blue histogram at the top of the view displays a spatial summary of the activity. The two rods and 10 main attractions have a marker every 4 hours with the larger light green and black makers indicating 12 noon and midnight respectively.

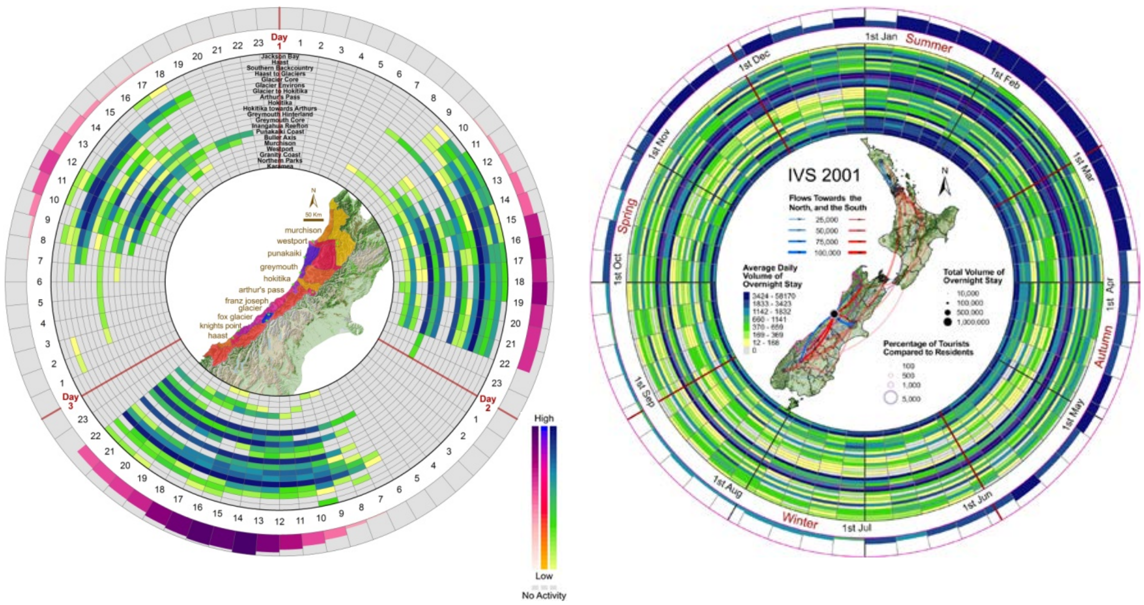


Figure 4: Vertical views. The left views show a spatial ringmap of tourists' sightseeing patterns on the West Coast of New Zealand over three days. Each ring represents a sub-regional zone ordered from north to south working outwards. Each sector represents one hour, starting from zero o'clock of the first day. The colours of the ringmaps show the volume of the sightseeing activity over corresponding sub-regional zones. The colours and heights of the outer ring-histograms show the overall volume of the sightseeing activity for each time period. The colours of the inset 2D maps display the overall volume of the sightseeing activity in the sub-regional zones. The green stars in the left inset map depict the locations of the top ten attractions on the West Coast. The right views show a spatial ringmap of annual patterns of the average daily volume of international tourist stays in New Zealand in 2001. Each ring represents a Regional Tourism Organisation (RTO) ordered from north to south working outwards. Each sector represents one week starting from 1st of January 2001. The inset flow map shows aggregated tourist movements between RTOs in two directions: towards the north (in blue) and the south (in red), where only volumes of flow greater than 25,000 tourists are shown for clarity. The black and the purple circles indicate the overall volume of tourist stays, and the proportion of tourist stays compared to the local population, respectively. The black and red radial lines indicate months and seasons respectively, while the grey radial lines indicate weeks. In order to facilitate the linkage with the left views, the ring that represents the West Coast RTO is highlighted in pink and its relative volume information is enlarged and displayed using a ring-histogram in the outermost ring and 'washing out' information for RTOs that do not have a direct link with the West Coast RTO in the inset as context.

Coordination strategies applied to multiple view visualisations of (s,t,a) tourist movement data

Visual exploration of complex and multidimensional data usually focuses on isolating and extracting relationships within and between dimensions. Linking and relating the information in one representation to that in another can effectively help users to rapidly explore rich information. Information displayed in one view may enhance the understanding of associated views and may provide additional insights into the underlying information. Multiple views support a precise expression of heterogeneous multidimensional queries using simple interactions (Roberts, 2005; Weaver, 2009) so it is important to construct coordinated relationships between multiple views (Carr, 1999). Coordination between multiple views allows us to simultaneously interact with and link disconnected information into a coherent whole so that we can sense relationships and gain insights (Andrienko and Andrienko 2006, Boukhelifa et al 2003). In this research, the main strategies for coordination are linked filtering, linked selecting and linked switching.

Linked filtering thins activity information of interest by its properties of space and time. Examples include simultaneously filtering information between multiple views by spatial zone, entry portal or time interval (see Figure 5). The application of this technique results in the filtered information being displayed clearly on top of overall patterns, which can be 'washed out' where appropriate (e.g. in a ringmap format) or placed underneath to provide contextual information. This technique greatly enhances the power of multiple view visualisations.

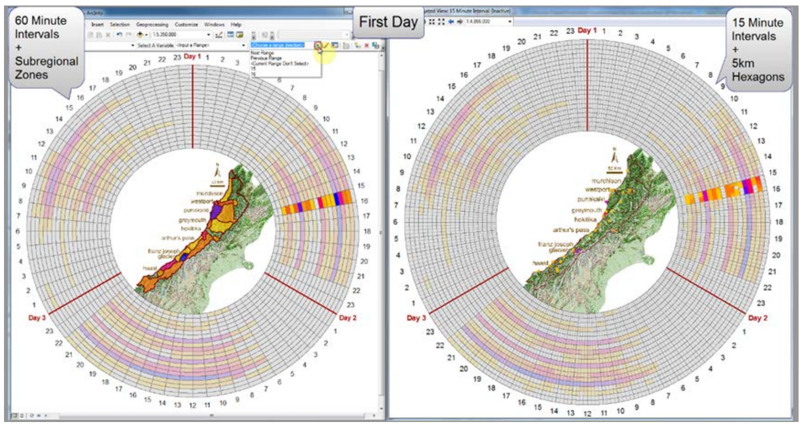
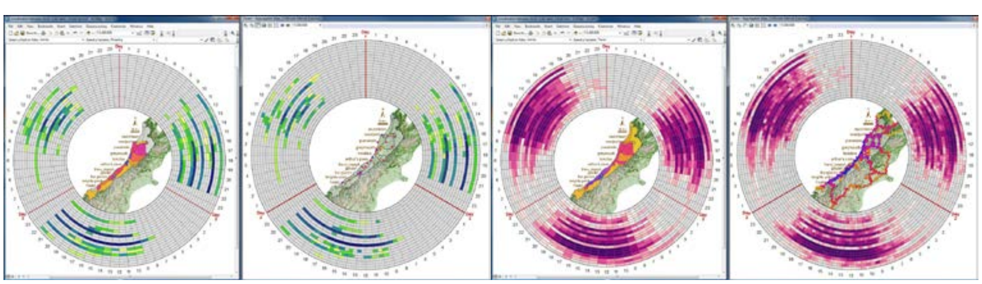


Figure 5: Cross scale linked filtering by time interval

Linked selecting highlights activity information of interest by its properties of space and time. This technique can be applied on top of filtered information to further narrow the focus. Linked selecting allows one to see overall information as well as information of interest as highlights. However, colour schema classifications can be difficult to distinguish when the data are densely mapped. In this case, the 'details outside' technique may be employed to make the selected information more evident (e.g. Figure 4).

Linked switching simultaneously changes activity across views to enable visualisation of many different activities occurring in the same space and time at an aggregated level (Figure 6). This technique allows interactive comparison between activities, which may facilitate the detection of relationships between activities.



a b

Figure 6: Coordinated switching activities from 'shopping' (a) to 'travel' (b) for tourists on the West Coast of New Zealand.

Conclusions

This paper explored various representation and visualisation options for communicating the complexity of space, time and activity in tourist movement. It demonstrated the significant value of the purposeful, integrated visualisation of the space, time and activity dimensions of the movement of tourists to enhance understanding of tourist movements and to gain knowledge and insights. Using a prototype CMV visualisation toolset that was developed by the first author, the space, time and activity components of the tourist movement data were co-ordinately visualised in a unified fashion and at different scales. The visualisation tools have generated many powerful and meaningful visualisations that unpacked patterns of tourist movements in a regional context and enhanced understanding. In addition to this deployment , this visualisation toolset has also been used on two other conceptually similar but contextually different data sets, the movements of citizens in the city of Halifax (Zhao et al., 2008) and possum movement on a periurban farm in Auckland (Zhao et al., in press). These suggest that the tools are reasonably generic. An insight-based domain expert evaluation proved that CMV visualisations that show integrated patterns of space, time and activity of sentient movement data encourage deeper insights (Zhao, 2012). Sentient beings are uniquely engaged in motivated activities over space and time, and they react to and interact with their environment, so it should prove even more fruitful to involve environmental contexts to a greater degree in the representation and visualisation of sentient movement in the future.

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