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Space-time cube analysis of animal behaviour

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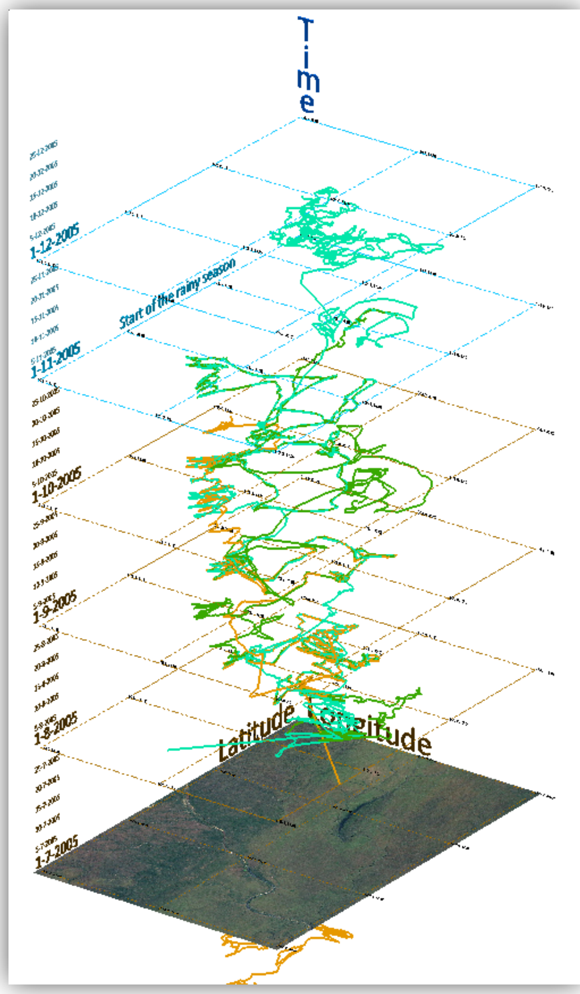

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Foreword

For this thesis I wanted to combine my interest in ecology with my interest in geo-information science. The visualization of spatiotemporal patterns in ecological GPS data has been an interesting topic to do so. Combining two fields of science has proven to be a challenge. The realization of this thesis was therefore not possible without the help of ecologists. I would like to thank Dr. Frank van Langevelde for advising me about resource ecology research. I would like to thank Shan Li BSc, Michiel Faber MSc., Dr. Fred de Boer and Ing. Jeroen Spitzen for participating in this research and having a look to the space-time cube. Their time, effort and insights are greatly appreciated.

I would like to thank my supervisor Dr. Ir. Ron van Lammeren for his patience, insights and enthusiasm. When I got stranded, his inputs and energy got me going again. I would like to thank my parents for their support. And last but not least I would like to thank you, the reader, for taking your time to read this thesis.

Abstract

In 1970 Hägerstrand developed the three-dimensional space-time cube. With this method spatiotemporal patterns can be visualized and analysed. Due to this ability the space-time cube is mentioned as potential method for exploratory analyses of animal time-tracking data in ecology. However, this has never been tested. Therefore a space-time cube was created visualizing a GPS-dataset of African buffalo *(Syncerus caffer).* No similar space-time cube has been found in literature. The possibility of adding additional attributes in the form of Orellana's (2012) interactions was investigated. Eventually, one additional attribute was added, namely "distance to water source".

A usability test was created in which the visualization operators described by Koua et al. (2006) were tested. Next to the visualization operators the ease-of-use of the visualization was tested among resource ecologists.

Preferably, a little practice time is given before the use of the space-time cube, for after a while its use becomes easier. For some visualization operators statistical alternatives were deemed favourable over the space-time cube. The space-time cube's unique ability to visualize space-time paths resulted in an advantage. Spatiotemporal patterns are easily recognized within a space-time cube. Half of the respondents regarded the space-time cube as a useful tool for explorative data analyses. However, respondents had difficulties to keep their orientation, but this problem might be overcome with dynamic axis, labels and basemaps. There is no easy method to create a space-time cube yet and with the tools currently available it is a struggle to create one. As a result the space-time cube probably remains a nice concept for analysing animal tracking data instead of a used method for explorative data analyses.

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1 – Introduction

1.1 – The arise of data

Major improvements in information technology has made a transformation in GIS possible, from separate initiatives during its emergence in the 1960s (Coppock and Rhind, 1991) to the industry it is now. Storing capacity within personal computers grew from several kilobytes to several terabytes within two decades. This increased storage capacity is used to automatically store huge amounts of data inserted by users. According to the popular website Mashable.com (2011), the global amount of data is doubling every two years. Social media users share locations, pictures and activities, satellites sense data from all kind of sensors and companies register lots of business activities. Animation techniques improved on a scale which resulted in a situation in which 3d animated movies are competing with traditional Hollywood movies. These developments create opportunities for the GIS industry.

Cartographers are no longer limited by two spatial dimensions to visualize data. Where cartographers are used to two spatial dimensions, the third dimension does not necessarily have to be used to represent elevation. Everything has a place in space and time, and many spatial datasets therefore contain a time factor. These datasets can have coordinates with multiple values, in other words the primary key of this dataset consists of a combination of the spatial and the temporal factor, therefore the dataset is spatiotemporal. Goodchild et al. (2007) present the geo-atom as basis of a general theory for geographical representation. This geo-atom is a tuple <x, Z, z(x)> consisting of a point in space-time (x), with a property (Z) and its value on point x (z(x)). With this concept not only a theoretic simplification of GIS is made, but the concept also includes time in its core, acknowledging all spatial data as spatiotemporal.

Working with spatiotemporal datasets makes it necessary to not only think spatially but also temporally (Andrienko et al., 2010). Spatial datasets are capable of answering two questions: *what is where* or *where is what*. In addition, spatiotemporal datasets add *when* to *what* and *where* which increases the amount of answerable questions to three (Li, 2005): *where was what at when*; *what was where at when; when was what at where*. An example of a spatiotemporal dataset can be found in a dataset about traffic jams within a certain area. Because most users want to know the current situation on the roads, a real-life visualization will do for most users. But what if users are more interested in the history of traffic jams, for example a logistic planner? One could highlight the bottlenecks, or create a map where the likelihood on a traffic jam is visualized. This might work for this example because the spatial aspect is only limited to highways and roads, but the time aspect is still not visualized and only used for calculating the likelihood of a traffic jam to occur. Among the fields of science in which spatiotemporal datasets form a core part are human geography, time geography and resource ecology. Research on intra-actions and interactions of populations is what these fields of science have in common. The difficulty of this research is that every population consists of individuals and all these individuals have their own patterns, activities and relations (Kwan and Lee, 2003). To find patterns statistics can be used, but with improved visualization techniques new possibilities arise.

One type of visualization which contains both the spatial and temporal dimension and which is static in use is the space-time cube. The space-time cube was introduced by Hägerstrand in 1970 and it uses the third dimension to visualize time. The combination of the 2D map and time on the z-axis create a cube in which paths can be visualized. In this way spatiotemporal data is visualized without animations but with time fully integrated, where both discrete and continuous time can be visualized (Li, 2005). As a result spatiotemporal patterns become visible. Figure 1 shows a time geography example of the space-time cube from Vrotsou et al. (2010). The idea of the conceptual framework of time geography is that every population consists of *"socially and geographically interrelated individuals and not as indivisible masses"* (Vrotsou et al., 2010, p. 264). The space-time cube was born out of this concept and is useful for visualizing individuals' space-time paths. Once the space-time paths are visualized within the space-time cube the data can be explored and one can discover bundles or meetings among individuals like in figure 1. The characteristics of the space-time cube to visualize spatiotemporal patterns and bundles suggest the suitability of the space-time cube method for explorative analyses of spatiotemporal data.

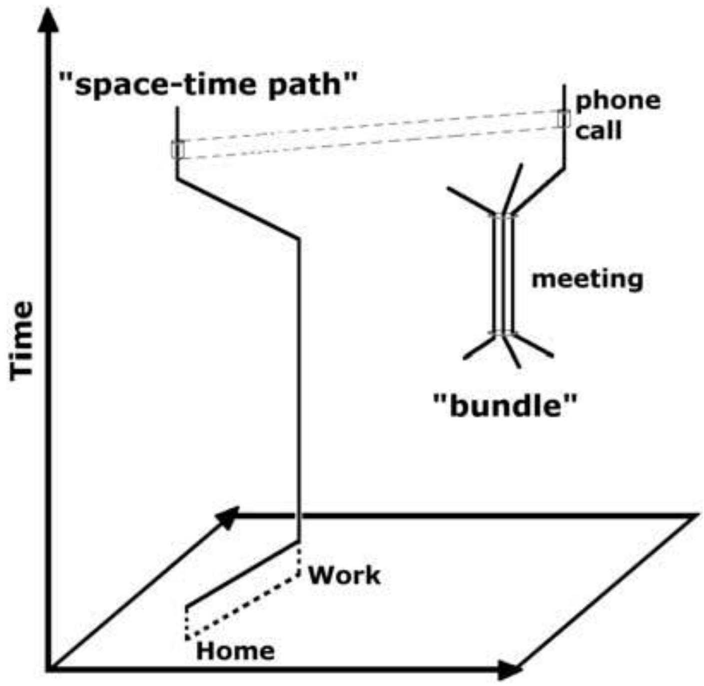

Figure 1: Example of a space-time cube (Vrotsou et al., 2010)

1.2 – Resource ecology and the space-time cube

Resource ecology can be defined as: *"The ecology of trophic interactions between consumers and their resources"* (Van Langevelde and Prins, 2008, pp: 1). The main question in this field of science is: why are organisms distributed like they are? A rather spatial question, so not surprisingly GIS technology found its way towards resource ecologists. In the 1960s grizzly bears and elks were the first animals to wear radio collars, put on them by the Craighead brothers (Hebblewhite and Haydon, 2010). Now, 50 years later, radio and Global Navigation Satellite System (GNSS) collars are an integral part of ecological research, resulting in large datasets containing the tracks of individuals (Hebblewhite and Haydon, 2010). During this research these datasets will be regarded as animal tracking datasets. Animal tracking datasets proved to be suitable for research on wide range species, effects of conservation and habitat modelling amongst others (Hebblewhite and Haydon, 2010). Although GNNS technology facilitates resource ecologists with more and improved spatiotemporal data, the datasets are still primarily used for calculating a species distribution while more information is hidden in these datasets. This information can be found by exploring the data for interesting patterns or relations. However, to make this explorative analysis possible, the patterns should be made visible by means of a suitable visualization. In their paper, Mansmann et al. (2011) describe their experiences with animal tracking data, Mansmann et al. (2011) mention three difficulties: the messiness of raw data which makes pre-processing necessary, the visualization tool should be flexible to make analyzing data easier and it is important to combine the data with several other datasets. This is necessary to calculate the environmental interactions and these are important to analyze what triggered the changes in movement. Was it the weather;

human presence or a track the animal picked. The more datasets you have the bigger the change that the cause of change can be found within them. The availability of these vast amounts of data and more detailed data requires good databases and therefore ecologists need database management skills (Cagnacci et al., 2012). While lots of effort and investment is put in obtaining the data, the use is still limited.

A reason why these datasets are not used to their full potential is that resource ecologists are not geo-information experts and geo-information experts are not resource ecologists. Where the ecologists do not know which tools and analyses are available, geo-information experts do not know which questions there are to be answered in the field of resource ecology. So, on one side we have the field of resource ecology not making full advantage of their animal tracking datasets and on the other side we have the space-time cube approach which started this millennium with new interest due to the increased amount of data and the technical improvements (Kraak, 2003). Theoretically, the space-time cube seems suitable for the field of resource ecology and that is where our current knowledge stops for its potential in this field of science has never been tested.

1.3 – Research objective en questions:

The main objective of this research is to investigate the possibilities for the space-time cube within resource ecology, especially in studies dealing with animal tracking datasets.

Based on the objective three research questions have to be answered:

1. What are advantages of the space-time cube for explorative analysis of animal tracking datasets?
2. How to create a space-time cube of an animal tracking dataset?
3. Do resource ecologist see the space-time cube as a useful tool for explorative analysis animal tracking datasets?

1.4 – Guidance

The subsequent chapters are structured as followed. Chapter two describes the conceptual framework which resulted from a literature study. The conceptual framework contains the answer to research question 1. In chapter 3 the methodology regarding answering the second and third research question is explained. For research question 2 the dataset is introduced plus an explanation of the requirements the space-time cube should fit. For research question 3 the test is introduced together with the choices made. The survey itself is available by Appendix 1. In chapter 4 the results are presented. Research question 2 will be answered by means of several versions of the space-time cube ending with the final version. The several versions of the space-time cube will help the reader understand the choices made. The test results for research question 3 will also be presented in chapter 4 including the judgment of the test-respondents. The discussion and conclusion can be found in chapter 5 together with recommendations for future space-time cubes.

2 – Conceptual framework

2.1 – Literature research on the space-time cube in resource ecology

If a researcher wants his input to be a valuable addition to a scientific discussion, he needs to know which questions have been answered already, which questions are recently asked and are there issues or opportunities overlooked by the other participants of the discussion. The theoretical background of this research covers two fields of science. Within geo-information science literature the concept of the space-time cube and the issues concerned it are discussed and in resource ecology literature the advantages of and the problems with animal tracking data are discussed. These discussions are separated from each other. For this research both discussions are combined. Firstly, literature about the space-time cube and other spatiotemporal visualizations was read to find out what the pros, cons and alternatives are of the space-time cube concept. When these questions are answered one needs to find out what questions resource ecologists are dealing with and how they use their animal tracking datasets. For this resource ecology literature is necessary. In this chapter these questions are answered by means of literature research.

2.2 – Time is a factor

Only the last 50 years of the last century the fundamental plate tectonics theory got widely accepted among geologists (Nitecki et al., 1978). Not only did the theory gave an explanation for the marine fossils high up in the alps or the tropical leave fossils found in Svalbard, it also made clear that everything on earth is temporal even the continents themselves. This makes the term spatiotemporal data a pleonasm, for if data is spatial it is temporal. In their paper Goodchild et al. (2007) introduce a new general theory of geographical information based on geo-atoms. They define a geo-atom *“as an association between a point location in space-time and a property”* (Goodchild et al., 2007, p 243). Literally by definition, time is included in this new general theory. However, time is not necessarily of interest and therefore not necessarily visualized. As long as *what* is relatively static the *what is where* and *where is what* questions are perfectly answerable by means of the traditional maps. But lots of the objects we are interested in are not static, whether it is the weather, traffic, people or in the case of resource ecology animals they are dynamic and therefore time is a factor. But how to visualize time?

2.3 – About animations, time-travel maps, timelines and the space-time cube

One of the most obvious methods to include the time aspect within a visualization is by means of an animation. Animations are obvious to use because it is a natural way to visualize time and animations are widely used outside the scientific world. However, the use of animations has its downside. The human eye is inclined to focus on moving, or in this case changing objects. These kind of subconscious circumstances make it impossible to give each animated object the same attention (Tversky et al., 2002). Therefore animations are not per se more suitable for exploring and analysing data at once. By replaying the animation over and over and pause it in between some trends could be noticed, but there are better ways to solve this problem. One way is pausing the visualization after certain durations or after important events programmed by the creator of the animation. An example can be found on the history website of the British Broadcasting Corporation (BBC History, 2011). This example shows the progression on the western front during World War I. The BBC talks about an animated map, but other examples of self-called animated maps (The Map as History, 2011) work differently. The example from the BBC uses turns to move along the time axis, the user can advance to the next turn by pressing the next-button. An advantage over a normal animation is that the maker of the animation can decide whether a period is important enough to cover several turns, so the time scale is not necessarily continuous. This is nice for the maker of the animation but it does not make the animation more useful for explorative analysing. The maps of “The Map as History” also pauses during the animation to zoom in on important events, but there is no such thing as a next-button, instead there is a voice-over which guides you through the animation. A voice-over is a nice tool for presenting data and conclusions, but it is not useful for exploratory analysing. A guide can show a speleologist its way through the caves, but when the speleologist starts his analytic work within the cave the guide can take a break.

In the computer game industry one distinguishes the use of time in turn-based and real-time (Juul, 2004). Real-time comes down to a time factor which is fluently continuous, regardless the acts of the player. In turn-based games the player determines the next turn, most board games are turn-based in which the turns describe time. The World War I map of the BBC is a turn-based animation in which the user initiates the next step. In both real-time as in turn-based animations time is a pre-processed factor. Maybe time is less unrelenting in turn-based maps in comparison with real life maps, but it still is limiting the explorative analyser.

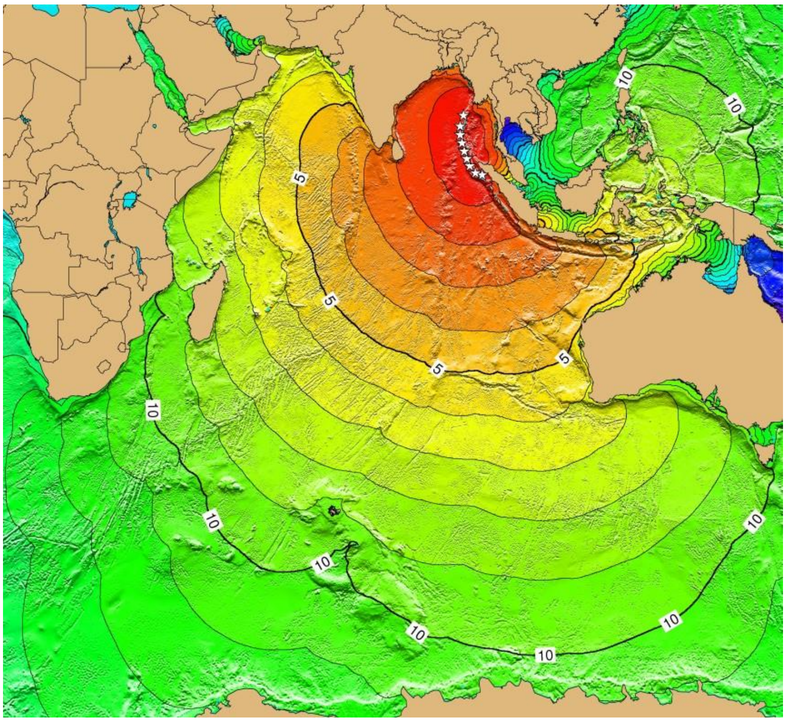

Figure 2: Tsunami Travel Time map of December 2004's tsunami (NGDC, 2011)

A visualization of a spatiotemporal dataset does not intrinsically contain animations. Time can be visualized as an object. This might sound unnatural, but moving objects leave tracks. Species of snakes find their prey on heat tracks (Gracheva et al., 2010). We are used to visualize infrared data, the weaker or colder the signal, the older the track. By visualizing time as an object, time can be visualized on a two-dimensional maps. However, the amount of information one can converse is limited. Travel time maps show time in a ratio scale and show the reader how much time it takes to travel from a certain place for a traveller, or as in *figure 2* a tsunami. It works nicely, but one could only visualize a time-travel-map for one spot on the map. The *what* question is replaced by *when* and *what* became the subject of the entire map, so only one spot or tsunami in this case can be visualized at once.

Another way of including time within a two-dimensional map is by adding time-charts at the corresponding spot on the map. Research by Andrienko et al. (2006) gives an example. However, point-data is not represented by a point but as a time-chart which takes more space, therefore the spatial resolution of the map is the limiting factor concerning the amount of data one could visualize. Instead of time-charts a ring-map can be used. A ring-map visualizes the time at which an activity is being executed in a certain area. Zhao et al. (2008) describe a ring-map where the visualized activity is ringed around a circle which represents time, the height of the ring at a certain time shows the amount of activity. Zhao et al. (2008) are using a 3D visualization but this is not necessary, Huang et al. (2008) created a 2D ring-map for ESRI. Both Zhoa et al. (2008) and Huang et al. (2008) use ring-maps in the same way as Andrienko et al. (2006) used time-charts. Both ring maps and time-charts do not have a spatial aspect but are dropped on a map, time is therefore not included in a ratio scale or in another dimension but more as an additional object.

A two-dimensional visualisation which visualizes time in a ratio scale is the timeline. A timeline shows events in a chronological order and is used to teach history but is also used in project management. Although it includes time is does not include space. A static spatial visualization which includes time in a ratio scale requires a combination of a spatial map and a timeline and therefore it requires three dimensions. This makes the space-time cube one of the few candidates. A much discussed candidate, for 30 years after its introduction the space-time cube started the new millennium with new interest. Due to the increased amount of personal data and improved technological possibilities the space-time cube concept received new impulse (Kraak, 2003).

2.4 – Pros and cons of the space-time cube

A well-constructed visualization can make analysing easier and could create new hypotheses out of already existing datasets (Andrienko et al., 2006). This means that datasets become more useful and therefore more valuable. The space-time cube is more useful for finding spatiotemporal patterns than a map in which the time factor is not visualized. However, Li (2005) also mentioned three disadvantages of the space-time cube. The first one Li mentions is that the space-time cube limits the amount of representable items to five. Multivariable data or higher level information is difficult to represent in space as well as height and gradient, which is the third disadvantage mentioned by Li (2005). The new scientific interest for the space-time cube, left Kristensson et al. (2009) wondering what the true advantages are of this method in comparison with the more traditional 2D representation. The space-time cube needs some practice before use, "*for simple and direct queries the space-time cube results in a higher error rate than a baseline 2D representation"* (Kristensson et al., 2009: p702). However, for more complex queries concerning spatiotemporal patterns, the space-time cube results in a lower response time (Kristensson et al., 2009).

Research on the usability of the space-time cube as tool is done in different fields. Gatalsky et al. (2004) investigated the usability of the space-time cube for event data, like traffic accidents and natural disasters. Li et al. (2010) and Kraak (2007) investigated the use of the space-time cube for eye-movement data respectively epidemiological research. Hägerstrand (1970) initially created the space-time cube concurrently with time-geography which describes the science of human behaviour within time and space. Since humans are part of the animal kingdom, it is a small step from time-geography to ecology. This, together with the complex nature of animal tracking datasets insinuates that the space-time cube has potential in ecology. Especially because animal tracking devices become more and more advanced. However, little or no research is done concerning the use of the space-time cube in ecology. Mostly, research is limited to the concept of the space-time cube.

Many papers have been written about the possibilities of the space-time cube, but only little research has been conducted to the efficiency and the limits of the space-time cube. Kristensson et al. (2009) and Li (2005) both conducted a usability study about this three-dimensional visualization. Its big advantage in comparison with animations is that it shows all the spatiotemporal information in one static 3D image. Of course, the space-time cube also has limitations. The amount of space-time paths which can be visualized in a clarifying way is limited to 5 paths (Li, 2005). Dealing with spatiotemporal data is not something natural for GIS. During its evolution from the first map 15.000 years ago until the industry it is now, the two dimensionality has rooted deep into GIS basics and combining space and time is still problematic (Peuquet, 2001).

Table 1: Space-time cube in scientific literature

Literature	Subject	Number of objects	Time span	Area
Kraak, 2003	Figure 1: the Author's travel through Enschede	1	14 hours	The city of Enschede
	Figure 2: Napoleon's March into Russia (1812)	1	7 months	1000x500 km
	Figure 4: A run in a nature conservation area near Enschede	1	< 1 hour	1x2 km
Kwan and Lee, 2003	African and Asian Americans working in downtown Portland	>10	Time reference is missing	Portland, Oregon (50x50 km)
	Figure 9: Licensed driver movement	216	6 days	Lexington, Kentucky (30x40 km)
Petrovic, 2004	The movement of the Italian and Austrian army during the 11th battle of Isonzo	2	1 day	Not mentioned in Literature.
Kristensson, 2009	Human walking movement	4	<1 day	A Swedish Campus
Demšar and Virrantaus, 2010	Maritime transport in the gulf of Finland	>10	1 day	Gulf of Finland
Biadgilgn et al., 2011	Fictitious dataset of people walking through a city	4	4 hours	No spatial reference

Most of the space-time cubes presented in literature have a small space-timespan. Table 1 shows a list of the space-time cube examples one can find in scientific literature. Like figure 1, there are lots of papers which contain images which clarify the concept of the space-time cube, but only a few examples based on data are presented. And most of these space-time cubes cover a far smaller space-time span than that of an average animal tracking dataset. The space-time cube presented by Kraak (2003) about Napoleon's march into Russia covers 7 months and a large area, but only shows one space-time path of historical event which has been analysed before. The other space-time cubes presented by Kraak (2003) are visualising personal data are used to explain the concept. Biadgilgn et al. (2011) use a fictitious dataset to explain the concept. Kwan and Lee (2003) use their space-time cube to analyse a real dataset, namely for analysing differences between African and Asian Americans. However, this space-time cube is based on diaries written by the subjects and not on raw GNSS data. Kwan and Lee (2003) describe the space-time cube as a good method for exploratory analyses of data, but also encountered some problems. The space-time cube with a good rendering speed is a demanding visualization in terms of computer requirements and users can lose their orientation (Kwan and Lee, 2003). Demšar and Virrantaus (2010) use the space-time paths of the maritime vessels to calculate vessel density on the Gulf of Finland. A space-time cube covering a time span of 7 months is not been used before. This new scale will bring its own challenges regarding visualizing the data. Comparing the subjects of the space-time cubes in table 1, one striking similarity is that all of them are bounded to roads or in the case of the vessels to certain waterways. The big advantage of this restriction to roads is that the location higher up in the space-time cube does not have to be derivable on a precise level, because one can assume the subject is on a road. Animals are not constrained to follow roads or paths, although they might tend to follow the same routes. So, for the space-time cube to work in resource ecology it should overcome this challenge. To summarize, the disadvantages of the space-time cube are:

- The space-time cube limits the amount of representable items to five.
- Only a limited amount of variables can be visualized.
- Elevation and gradient are hard to visualize.
- The space-time cube needs some practice before use.
- For simple spatial queries a higher error rate can be expected.
- The space-time cube is demanding in terms of computer requirements.

- Users can lose their orientation.

The advantages of the space-time cube are:
- Time is visualized in a ratio scale, which makes it suitable for explorative spatiotemporal analyses.
- A low response time for spatiotemporal queries.
- Speed and direction are directly visualized.

2.5 – Resource ecology and spatiotemporal data

The use of a GNSS-collar results in a dataset consisting of geo-atoms <x, Z, z(x)>, where x is the location in space-time and Z is the attribute 'animal ID' with its nominal value z(x). By connecting the geo-atoms in chronological order, a raw GNSS dataset can be processed from geo-atoms into spatiotemporal paths, which makes pattern based analyses possible. Study of patterns in animal behaviour serves multiple goals. Ranging from conservation studies to exotic invasion studies. Space-time patterns are suitable for habitat analysis which is traditionally based on *"comparing the habitat characteristics of a large number of statistically independent utilized locations with a large number of available or not utilized locations with compositional analysis or linear models, such as logistic regression*" (Cushman, 2010, p. 132). Cushman (2010) structures the traditional method for habitat analysing in such a way one is deemed to think the method is outdated, vague and complicated. Not surprisingly, Cushman (2010) proposes the use of pattern based methods rather than the traditional point-based methods. Webb et al. (2011) use a path-based approach to study the effects of human activity on elk. Data obtained with GPS-collars are processed into time paths and then combined with a map of human activity (Webb et al., 2011). The elks are grouped in three classes, these classes are compared and by this analysis the human effects are calculated and visualized in graphs.

The use of space-time cubes is helping social scientists to analyse their data since Hägerstrand (1970) came up with it. However the space-time cube has not found its way to resource ecology yet. One example forms a study on Swedish brown bears (*Ursus arctos*) by Bjarnvall and Sandegren (1987). Due to their size and notoriousness this species is often investigated, also by use of sensors, started from 1987 when Bjarvall and Sandegren were the first to attach a radio sensor on a Swedish brown bear. The data retrieved from the sensors is presented in a two-dimensional map (Bjarvall and Sandegren, 1987). More recent studies also constrain themselves with two-dimensional maps, where space-time cube technology is available (Edwards et al., 2011). A research conducted on populations of Japanese black bears (*Ursus thibetanus japonicas*) near Mt. Fuji analyses a spatiotemporal dataset to find factors splitting up the ecological network needed to combine separated populations (Doko et al., 2011). Though time was available within the dataset it was not used by Doko et al. (2011) as a variable. Moe et al. (2006) did research on day-round brown bear behaviour and the habitat selection during the day. Ordiz et al. (2011) studied the effects of human activity and hunting on brown bear behaviour, but next to GNSS-collars, additional measurements are used for their statistical analysis and eventually the results are presented in graphs and tables. The space-time cube seems perfectly suitable for this type of research especially when the temporal aspect is important within a research. A land cover map is available in combination with GPS radio-telemetry data, but instead of explorative analysis through the use of a space-time cube, statistics are used to find patterns (Moe et al., 2006).

2.6 – The African buffalo *(Syncerus caffer)* as a test species

The African buffalo makes a good test species for it is a wide spread species with suitable social activities. The fact that it is a large herbivore is an advantage, because this sub-group of animals is regarded as model species for the emerging field of spatial ecology (Van Langevelde and Prins, 2008). The main reasons for their status given by Van Langevelde and Prins (2008) are the impact large herbivores have on the resources exploited; their ability to memorize resources in space and time; the time they spent foraging and their mobility. Like many other large herbivores the African buffalo lives in fission-fusion societies (Cross et al. 2005). In a fission-fusion society herds are dynamic which makes them not only more interesting but also more difficult to analyse. In the case of the African buffalo a wide variety of questions can be thought of within the context of resource ecology. Large ruminants like the African buffalo spent most of their time foraging (Van Langevelde and Prins, 2008), constantly considering the quality of the resources and the effort needed to utilize them. Since African buffalo live aside other herbivores and congeners, a buffalo is also subject to interspecific and intraspecific competition. Depending on size, large herbivores are utilized themselves as resources by organisms of higher trophic levels (Hopcraft et al., 2012). Lions (*Panthera Leo*), in case of the African buffalo. Next to foraging and avoiding lions a buffalo needs water and buffalo will try to mate during the mating season. Summarizing, the spatial distribution of buffalo depends on the spatial distribution of high quality resources, water, interspecific and intraspecific competition, predation risk and potential mates. All of these factors are changing through time and space. The dynamics of the herd can partly be explained with the collective interactions of Orellana's method (Orellana, 2012), but a dataset with a high temporal resolution is necessary. In statistical analyses these dynamics were calculated by adding "group-member" parameter to each sensored individual (Cross et al., 2005). Within a space-time prism groups can be labelled as such as soon as the group-members are at a certain distance of each other and following the same distance. In this way a "one-night stand" with another herd will not go unnoticed.

Another advantage of the African buffalo as a test species is that it is one of the "big five" species. Notorious for its strength and ranging throughout sub-Saharan Africa the species is regarded as one of most dangerous species in Africa. Large mammals are economically interesting, because they attract visitors (Lindsey et al., 2007). The African buffalo is not the most popular of the big mammals, but they are popular among experienced wildlife spotters and African wildlife spotters (Lindsey et al., 2007). This, in combination with the impact they have on ecosystems and the large distribution of the species makes it an interesting test species for this research.

2.7 – Patterns to be found in animal tracking data

Tracking data retrieved from collars is used for many different purposes and each purpose or every research objective determines which patterns are interesting. Haberkorn (2011) explored the spatiotemporal concepts available in order to extract behavioural information out of spatiotemporal datasets. Haberkorn (2011) slightly adapted three levels of behavioural patterns defined by Dodge et al. (2008), in which he differentiates co-incidence in time, space and both space and time. Orellana (2012) introduced the interactions which can be combined with the space-time cube. Orellana (2012) created a method to explore GPS data from pedestrians. His method consists of a classification of movement patterns or interactions. Orellana and Renso (2010) describe different types of interactions: pair-wise interactions (approaching, guiding-following), environmental interactions (route choosing, visiting) and collective interactions (flocking, aggregation). Although the examples of Orellana and Renso (2010) do not cover all aspects of animal life, they provide a method to describe interactions. Firstly, an interaction is categorized by type. Secondly, the associated movement pattern is described together with the contextual parameters and finally a definition is given. In this way, interactions are described in a technically clarifying way and suitable to explore GNSS data. Since these interactions are described as spatiotemporal data, a space-time cube is suitable to visual them (Orellana and Renso, 2010).

Table 2 shows interactions of Orellana and Renso (2010) compiled with specific animal interactions. Because the classification is made for exploratory analyses and to prevent an unclear classification only a limited amount of interactions should be used in a possible classification. Another big difference in comparison with Dutch hikers is that African buffalo are not restricted to paths. And this restriction to paths, but also the restriction in time, resulted in many interactions. What potential interactions can be distinguished in the case of African buffalo?

<u>Drinking/ cooling down (*environmental*)</u>
African Buffalo have to drink nearly every day and therefore water is of essential to them (Prins, 1996). Combining water locations with the space-time path of buffalo is the basic idea of calculating this class. However, in the climate of Kruger National Park water levels will fluctuate throughout the year. For this study we assume it does not. Another point of interest is that not every buffalo near or in water is drinking, buffalo also like to bathe to regulate body temperature, therefore the class is called drinking/ cooling down. Being an environmental interaction, the interaction cannot be calculated without environmental data, in this case spatial data of the location of water. Waterways in Kruger NP differ the year round and show the importance of time in maps. Although most people on earth live in a climate which knows a dry and wet season, maps generally show rivers and lakes as a stable object, while they are dynamic throughout the year, on the long term rivers and lakes are even more dynamic due to climate change. Therefore research by Venter and Gertenbach (1986) might be slightly outdated, but it shows two important characteristics of climate in Kruger NP. Spatially, climate differs significantly and the National Park knows a rainy season (November to March) and a dry summer. The herbivores of Kruger NP, especially the elephants, also effect the vegetation and therefore the local climate (Asner and Levick, 2012).

<u>Foraging (*environmental*)</u>
Although African buffalo might forage in the water we will assume a buffalo is foraging if it moves slowly through the landscape. Since *S. caffer* is a ruminant, foraging is probably taking most of its time. Therefore the class-name ‘foraging’ is a sufficient one.

<u>Running (*environmental*)</u>
With a top speed of 15.8 m/s (57 km/h) the African buffalo is not the fastest bovine on the savannah (Blanco et al., 2003). They will run if being attacked, but that is not their only defence, the speed in combination with their weight and horns will not leave him changeless while facing the predator. So a buffalo will not simply run away, there might be interesting patterns to be found in the visualization. Because there is no class between running and foraging the speed from which a buffalo is classed as running will be the speed up which a buffalo is going too fast to forage.

<u>Forming a herd (*collective*)</u>
Cross et al. (2005) define two buffalo in the same herd if they are within one kilometre of one each other.

Table 2: Animal interactions

Interaction	Interaction type	Associated movement pattern	Contextual parameters	Data needed
Encounter*	Pair-wise interactions	Spatio-temporal conincidence	Constriction level, spatio-temporal threshold	Space-time Paths of several individuals, preferably a large percentage of the individuals.
Buffer Space-Time paths, overlap buffers = encounter				
Approaching*	Pair-wise interactions	Spatio-temporal conincidence with relaxed temporal threshold	Constriction level, spatio-temporal threshold	Space-time Paths of several individuals, preferably a large percentage of the individuals.
Buffer Space-Time paths, overlap buffers = Approaching. *The difference compared with an encounter is the buffer parameter.*				
Guiding – following*	Pair-wise interactions	Spatial coincidence with temporal delay	Constriction level, spatio-temporal threshold	Space-time Paths of several individuals, preferably a large percentage of the individuals.
Guiding-Following is an encounter over a longer period of time, where spatial parameters do change.				
Visiting*	Environmental interaction	Stopping	Attractiveness level, spatial proximity	Space-time path of one individual. Places which are suitable to visit.
What are suitable places for an animal to visit. Drinking pools, foraging opportunities, shelters and so forth.				
Route choosing*	Environmental interaction	Short stops	Constriction level, temporal duration	Space-time path of one individual. Crossings, splits, roads.
A short stop before a change in direction.				
Attraction*	Environmental interaction	High density / movement suspension	Attractiveness level	Space-time path of one individual. Places which are suitable to visit.
More suitable for human interactions.				
Trail formation*	Environmental interaction	Linear movement clusters	Constriction level.	Space-time Paths of several individuals, preferably a large percentage of the individuals.
Space paths which are used (have been used) regularly by the subjects.				
Flocking*	Collective interaction	Collective coordination of relative motion parameters	Constriction level, temporal threshold	Space-time Paths of several individuals, preferably a large percentage of the individuals.
Buffer the paths. Two or more subjects who are "guiding-following".				
Aggregation*	Collective interaction	Concentration (High-density pattern)	Constriction level	Space-time Paths of several individuals, preferably a large percentage of the individuals.
More or less the same as aggregation.				
Resting	Environmental interaction	Long stops	Spatial proximity	Space-time path of one individual.
Space-time path which does not change in space.				
Foraging	Environmental interaction	Short stops	Constriction level, temporal duration	Space-time path of one individual. In case of predator: Space-time paths of several prey-individuals, preferably a large percentage of the individuals. In case of herbivore: NDVI levels, vegetation information.
In case of predator: encounter prey and predator animals. Herbivores: Space-time paths, which move slow on suitable vegetation levels.				
Drinking	Environmental interaction	Stop near water	Spatial proximity near water body.	Space-time path of one individual. Water sources.
See visiting.				

*Interaction from Orellana and Renso (2010)

Summing up, the basic environmental interactions of African buffalo are drinking/cooling down, foraging and running. There are a lot of pair-wise interactions one can think of while studying buffalo behaviour: two bulls fighting; two buffalo approaching each other; one buffalo guiding another buffalo; etc. However, the limited amount of individuals used in animal tracking datasets or more specifically the big amount of individuals outside the datasets the pair-wise interactions classified can be combined with the collective interaction of forming a herd. This interaction in combination with running offers a second collective interaction: running amok.

2.8 – Visualizing a classification of interactions

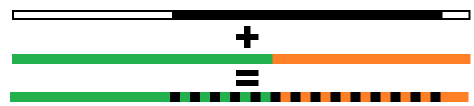

Figure 3: combining the classifications

By combining these interactions a classification is made. Like other spatial data, a classification of a spatial dataset can be visualized. Although the classification itself can be made without visualising the dataset, its main purpose is for a better understandable visualization for analysing and communication purposes. Due to its capability to visualize time and space continuously in the same visualization the space-time cube seems the only applicant for the job. But can the interaction classifications be visualized with the space-time cube? The base of the space-time cube visualises two-dimensional spatial data, like any other geo-information systems it can contain multiple layers, like land use, vegetation cover and so forth. To use multiple layers a toggle-menu should be available with which the user can select the wanted layer. The third dimension is used for time. Within the three dimensions the classified interaction may be visualized. The visualization of the classified interactions may overlap. For that reason the different classes cannot be seen together. To overcome this issue, the visualization can be adapted. One can use dotted lines to visualize two classes at once as is shown in figure 3. The additional details could make the visualization harder to understand and less suitable for analysing. The visualisation should be easy to use and easily understood, a badly designed user interface might scare possible users away despite the possibilities. The alternative strategy would be to reduce the amount of classes visualized within the cube. Although the information retrievable from the visualization will be reduced, the information still visualized is easier to retrieve.

2.9 – Not a fully classified space-time cube

Although Orellana (2012) offers a new method to deal with tracking data based on interactions, a visualization of a fully classified dataset is not always better than a visualization of a partly classified dataset, especially in the case of the space-time cube. Multiple space-time paths within a space-time cube tend to result in a box filled with spaghetti in which it is hard to follow one path, therefore the number of paths to be visualised are limited to five (Li, 2005). The space-time paths originate by chronologically combining the geo-atoms with the same value of attribute ‘animal ID’, so each path has its unique ‘animal ID’. This attribute can be visualized by giving each path a different colour, this helps the user to distinguish the different space-time paths. Orellana’s interactions can overlap and although this can be solved as shown in figure 3, it does not leave space for the ‘animal ID’-attribute. Therefore choices have to be made, for not all type of interactions can be visualized. The advantage of the space-time cube is that the pair-wise and the collective interactions are theoretically visible within the space-time cube. It should be visible, for example, to see two animals encounter each other or to see several animals merge into a herd. Another characteristic in which the space-time cube is difficult to beat is the way in which one can find patterns by using it. Patterns like, the repeated use of certain paths, two animals joining each other for a while, animals going the same direction during the same period. All these patterns have the same variables as a movement. An object movement can vary in direction and speed. Direction is a function of (x,y) and speed a function of ((x,y), z). Where the space-time cube directly shows spatiotemporal patterns, multivariable statistics are needed to find these patterns without the A disadvantage is that calculating the interactions described by Orellana and Renso (2010) requires a dataset with a high temporal resolution and multiple subjects. The buffalo dataset does not meet these requirements

A lot has been written about the space-time cube, but only a few examples of space-time cubes exist (table 1). As a result the question can be raised whether it is useful to investigate the benefits of a classified space-time cube in resource ecology over the more standard space-time cube in which the only attribute visualized is an ID attribute. Given that the space-time cube has never been used in this field of science and that there is no space-time cube which covers such a large space-timespan, the first question to ask is whether the use of the space-time cube in resource ecology is beneficial at all.

2.10 – The conceptual framework

Although the space-time cube can only be used to visualize a limited amount of items and attributes (Li, 2005), its unique characteristics of representing time in a ratio scale and directly visualizing speed and direction makes it, theoretically, a usable tool for explorative data analyses of animal tracking data. However, the space-time cubes presented in literature were not used to visualize animal tracking data nor data of the same space-timespan. The ecological research presented in the literature read, was based on animal tracking data. However the data was analysed by using statistical methods and as a result most results were presented in graphs.

The next step would be to find out whether it is possible to make a space-time cube which covers the space-time span of a real animal tracking dataset. Which problems do arise while trying and how to overcome these challenges? And is the resulting space-time cube deemed usable for explorative analyses by ecologists? The ecological literature read, mostly described statistical analyses of animal tracking data. One can ask why ecologists tend to stick to the statistical methods. Are these the most suitable or are the alternatives not known?

3 – Methodology

3.1 – Methodology introduction

The previous chapter concluded that the space-time cube might be a suitable tool for exploratory analysis of animal tracking data in resource ecology, due to its characteristic to visualise time in a ratio scale which has the result that directions and speed are directly visualised. To test this assumption an example of a space-time cube is needed which can be used as a testing environment. This space-time cube demo is based on literature and personal experiences and to value it, the demo's usability should be tested. Do ecologists think the demo can be used for exploratory analyses of the visualized animal tracking dataset? Exploratory analyses can be done after the pre-processing of the data. The aim is to explore the dataset to see whether patterns can be found. These patterns can be solely spatial or temporal but also spatiotemporal. Once patterns are distinguished, the search for explanations of these patterns can be started. Exploratory analyses can therefore be defined as distinguishing patterns within the data. Usability can be defined as "*The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"* (ISO/IEC, 1998). Roughly we can say that the product in this case is the space-time cube demo, the specified users are resource ecologists and the goal is exploratory data analyses. But all these will be further specified in this chapter in which the methodology is explained. But first the dataset is introduced followed by the making of our testing environment or demo cube.

3.2 – Case study: The African buffalo datasets

In chapter 2.6 the African buffalo (*Syncerus caffer)* was introduced as a suitable test species. Its reputation, its impact on the landscape and the social structure of the herds are among the main reasons why this species, as a large herbivore, is regarded as a model species in resource ecology (Van Langevelde and Prins, 2008). Figure 4 shows two datasets containing animal tracking data from African buffalo. The datasets are made available on movebank.org and consists of a dataset of African buffalo in Kruger National Park. Both datasets share the same attributes but differ in source. For one dataset GPS based collars were used to obtain the data where for the other dataset Very High Frequency (VHF) radio collars were used. As a result both datasets show different statistics (table 3). The equality in attributes makes it possible to use both datasets to study the effects of these differences. Firstly, I started with the GPS dataset for the spatiotemporal point density is much higher. To truly understand animal movement not only the amount of points is important but regularity of the points taken might be even more important (Breed et al., 2011). When the GPS collars were active they took a point every hour. This means that one hour is the maximum temporal resolution.

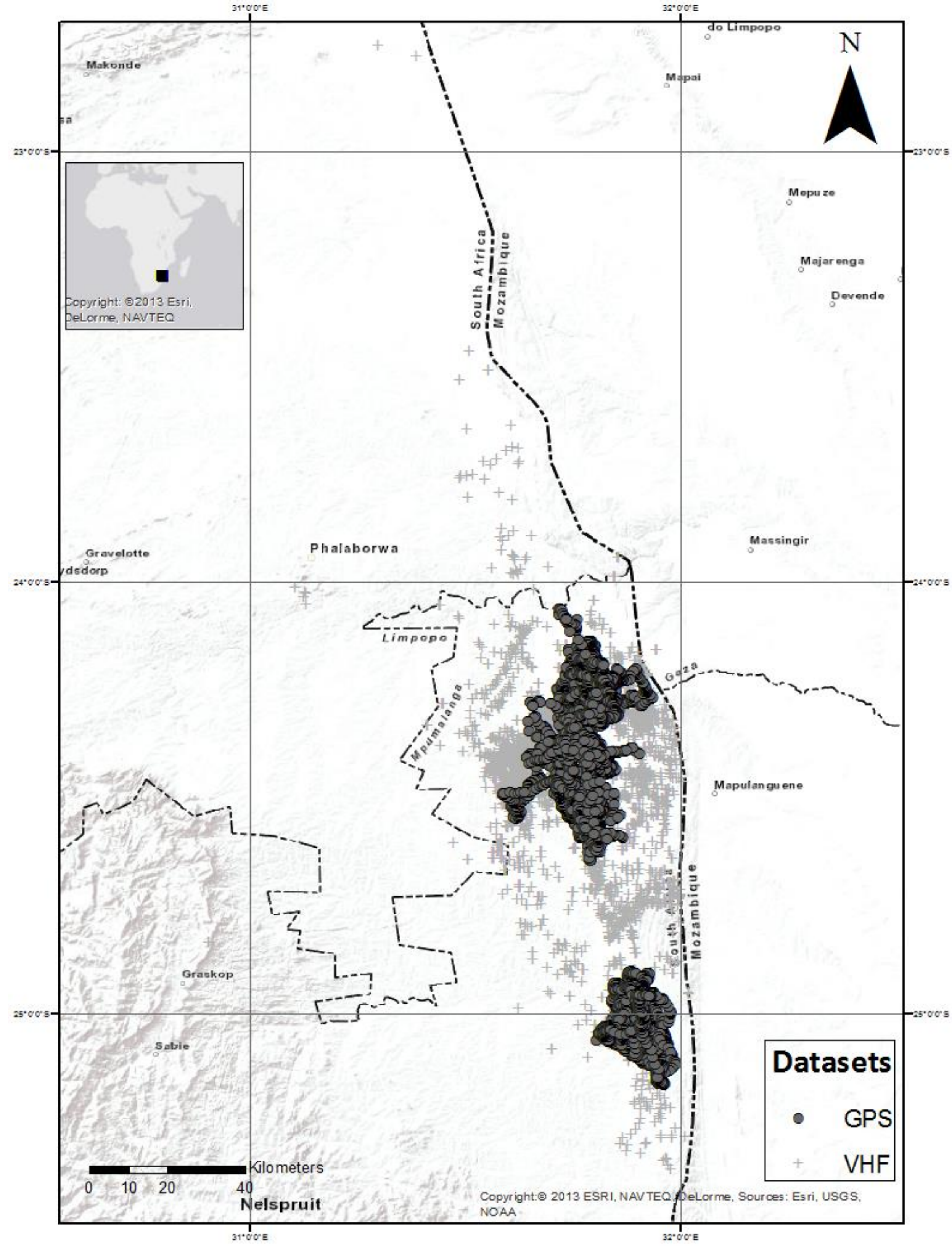

Figure 4: The original dataset (source: http://www.movebank.org/panel_embedded_movebank_webapp)

Differences in speed or direction which occur within an hour are not measured. This is a limitation, because short runs are not visible. Because not all individuals are wearing a working collar during the full study time the average is lower than a point per hour. Each GPS-collar-wearing individual has on average nearly 6 spatiotemporal points a day. Although the dataset only contains six individuals it can be backed-up with VHF dataset which may come in handy to study the collective interactions. In figure 4 one can observe that the GPS dataset is separated in two parts. Both parts consist of three animals.

Table 3 Dataset statistics

	VHF dataset	**GPS dataset**
Number of points	2660	24656
Individuals studied	165	6
Points per individual (average)	16.1	4109
Starting date	2000-11-14	2005-02-17
End date	2006-11-21	2006-12-31
Study time (days)	2199	683

3.3 – The making of the space-time cube

3.3.1 – The space-time cube's requirements

The aim of this research is to test the assumption that the space-time cube is suitable for exploratory analyses of animal tracking datasets in resource ecology. To test this assumption a demo space-time cube is necessary. The demo-cube needs to fulfil certain requirements before it can be labelled a suitable test environment. Mansmann et al. (2011) mention messiness as one of the difficulties of working with a raw animal tracking dataset. Therefore, the space-time cube should visualize a realistic dataset in which realistic patterns are to be found. In this way the patterns are found which are expected but are not visualized due to the limitations of the method. The easiest and obvious way of achieving this realistic effect is to use a real animal tracking dataset. Another advantage is that potential nuisances of the creation process can pop up. In this way one will also find out whether it is possible at all to create a space-time cube of animal tracking datasets. The demo-cube should also fulfil quality requirements. But what are these quality requirements? A visualization serves certain objectives, without these objectives one cannot determine whether the quality is good enough or not. The objective for the space-time cube is to visualize space-time paths in order to find patterns or other potential interesting information. Therefore, the space-time paths should be easily distinguishable from each other. To achieve this the space-time paths should differ in colour or shape, one could also chose to give each path a different size but this might make the user think the data is ordinal. Another necessity to make the different space-time paths distinguishable is a high enough resolution, both spatially and temporally. If the spatial resolution is not high enough, distance covered and differences in direction are hard to see, if the temporal resolution is not high enough differences in speed are hard to see. If interesting events are spotted in the space-time cube one probably wants to read the location and time of these events. Therefore some reference is necessary, again both spatial and temporal. Furthermore, the amount of paths visualized should be limited. Animal tracking datasets' visualizations should be flexible to make analysing easier

(Mansmann et al., 2011). To increase the possibility of putting the found patterns in context, additional datasets are necessary (Mansman et al. (2011). Without these additional datasets certain changes in speed or direction cannot be explained. Al these requirements should prevent a resemblance of the space-time cube with a plate of spaghetti. Another requirement is a basemap. Although spatial reference is theoretically enough, a basemap is more convenient for it gives an idea about the landscape features which might declare some changes in direction. Ideally, the basemap can be moved over the z-axis. This is useful because the higher the path goes on the z-axis the more difficult it is to derive the location, especially on a 2 dimensional screen.

3.3.2 – Which software to use?

One of the reasons why the space-time cube received renewed interest are the technological improvements (Kraak, 2003). When Hägerstrandt introduced the space-time cube in 1970, GIS was still in its pioneers phase (Coppock and Rhind, 1991) and the first microprocessor was still in development (Noyce and Hoff, 1981). Where the microprocessor conquered the world, the space-time cube did not yet breakthrough and specialized space-time cube software is not available. However, working with the third dimension becomes more common. For example, ESRI's ArcDesktop 10.1 contains some new 3D functions. This and personal experience with ArcDesktop were the main reasons to choose ArcDesktop to make the space-time cube in. The most obvious use of the third dimension is to visualize elevation and most 3D functions are created with this purpose in mind. In the original buffalo datasets time is stored as a string, where elevation values are often stored as integer, double or float data type. To use the time factor on the z-axis it has to be converted to a ratio-data type. By use of algorithm 1 the dates were converted into "days after 1-1-2000" and as a result an attribute "time" was created ranging till 2558 days after 1-1-2000.

Algorithm 1:

```
((float(str( !timestamp! )[:4])-2000)*365.25) + ((float(str( !timestamp! )[5:7])-1)*30.4375) + ((float(str( !timestamp! )[8:10]))) + ((float(str( !timestamp! )[11:13]))/24) + ((float(str( !timestamp! )[14:16]))/1440)
```

With the new "time" attribute it is possible to plot time on the z-axis.

3.4 – Test setup

3.4.1 – The features included in the test and visualization operators.

The definition of usability is: *"The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"* (ISO/IEC, 1998).The product is space-time cube approach fulfilling the requirements described in chapter 3.3.1. The specified users are resource ecologists and the specified goal is exploratory analyses of animal tracking datasets. But how do you test whether the space-time cube approach is suitable for effective, efficient and satisfying exploratory analyses of animal tracking datasets?

Koua et al. (2006) present an overview on which points a visualization should be tested, this overview is presented in table 4. Koua et al. (2006) list the visualization operators and describe their operational tasks. In the third column of table 4 a corresponding example of a test question specific to this study is presented. Whether the visualization operators are successfully executed by the test group indicates the effectiveness of the space-time cube. To test the efficiency one needs to compare the results with a norm or the alternative methods. In the case of this research one should conduct several usability tests of different methods of exploratory analyses. This is not done in this research. However, alternative methods are asked and respondents can suggest or recommend different methods for different visualization operators. One can imagine that for the operator 'compare' alternative methods can be found in statistics. The experiences in the sense of difficulty of the respondents indicates whether the method is satisfactory or not.

Table 4: first two columns from Koua et al. (2006)

Conceptual goals/ visualization operators	Operational visualization task	Specific task explored in the study
Locate	Indicate data items of a certain range of value	Locate buffalo 1
Identify	Identify relationships between attributes	When do buffalo 1 and 2 meet?
Distinguish	Distinguish how a target value measured at one particular spatial location, or at various neighboring locations, varies for different attributes (e.g. different values of the same attribute at different spatial locations, and the value of different attributes at a specific spatial location)	Do the buffalo seem to be more often near water at the end of the dry season?
Categorize	Define all the regions on the display, and draw boundaries. Indicate spatial positioning of elements of interest and spatial proximity among the different elements	Which buffalo is the most water-needing animal.
Cluster	Find gaps in the data on the display	Locate a gap in the data for buffalo 3
Distribution	Describe the overall pattern (overview)	Can you notice repeated movements?
Rank	Indicate the best and worst cases in the display for an attribute	Which buffalo has been followed the longest time
Compare	Compare values at different spatial locations and the order of importance of objects (data items) accordingly	Which buffalo makes the most kilometers a month
Associate	Form relationships between data items in the display. Identify relationships between data items (within clusters and between different clusters)	Which buffalo are near water in September?
Correlate	Discern which data items share similar attributes	Which buffalo have similar patterns

Kristensson et al. (2009) were the first to put the space-time cube to the test to see whether it has any advantages. They did it as *"as an important contribution toward changing some parts of the information visualization field into a "hard" science"* (Kristensson et al., 2009, p.696). Since the space-time cube is generally not used in ecology we can assume that most ecologists are novice users of the space-time cube. This together with the cubes unintuitiveness makes it is important to inform ecologists on forehand about the concept of the space-time cube. This will be done with a short introduction.

Since the space-time cube is made in Esri's ArcScene it is not possible to send it to the test group and, preferably, testing has to take place in a room with pc's which have Esri's ArcDesktop installed. A fringe benefit is that upcoming questions can be answered immediately by the author present. Another way to present the space-time cube to possible users is by means of animations. The advantage is that one is not limited by the availability of ArcDesktop, the disadvantage is that you are not presenting the visualization but a visualization of the visualization.

Koua et al. (2006) presented a checklist for visualization testing, but what specific questions come with the space-time cube? Theoretically, the advantage of the space-time cube is that it adds *when* to *what* and *where*. Therefore the questions asked should emphasize on the *when*, within *when* was *what where, where* was *what when* and *what* was *where when.* During the users test of the cubes the ecologists are asked to answer both specific questions about the data as well as questions about the concept. First question would be for which purpose they normally use animal tracking data. And how is the data normally analyzed. Do the testers think the cubes are easy to navigate through and do they see certain patterns while exploring the data? Since the space-time cubes are mostly discussed among GIS experts, it would be interesting to ask for suggestions.

In Appendix I, the survey is presented. Firstly, personal questions need to be answered by the responder. Is he a professional or a student? What is his experience with GIS and is he open to new methods or does he tend to stick to the old ways?

The second part of the survey will consist of seven specific space-time cube related questions. Unlike questions from the other parts of the survey, these questions can be answered wrongly. The seven questions are from different conceptual goals according to Koua et al. (2006) and the correct answers are highlighted in yellow in Appendix 1. The purpose of these questions is to test whether the responders can retrieve data from the visualization. The patterns are there, but will they be recognized by the ecologists?

Finally, in part 3, seven questions are asked which focus on the concept of the space-time cube. This covers the general use of animal tracking data in resource ecology and the ease-of-use of the visualization. The ease-of-use is addressed in two questions. How did the respondents experience finding answers of the questions in part 2 and did it became easier after some use as in Kristensson et al.'s (2009) research? Do ecologist see the space-time cube as a good tool for exploratory analyses of animal tracking data?

The space-time cube is often discussed as an alternative for exploratory analyses for animal tracking data, the word alternative means that there is choice to be made. So, what is GNSS data used for within the field of ecology, how is the data normally analysed and what additional data is used? Furthermore, how did responders experience the questions of part 2 and the navigation through the space-time cube? Most of the question are multiple-choice questions which makes it possible to group the responders and it opens the door for quantitative analyses if enough respondents can be found. The two open questions are about recommendations and one concluding question.

3.4.2 – Test group

To find out whether resource ecologists regard the space-time cube method as a usable approach for exploratory data analysis, the test should be brought to them. Finding out their opinion on space-time cubes requires a significant amount of participative resource ecologists. Finding out the major usability issues requires fewer resource ecologists. Nielsen and Landauer (1993) created a mathematical model to calculate the number of test-users needed to reveal the usability problems of a visualization. 75 per cent of the usability problems can be found with four participants (Nielsen and Landauer, 1993). The participants were recruited by e-mail, next to the request to participate the e-mail also contained a short description of the research.

4 - Results

4.1 Results introduction

This chapter describes the results of this research. The results consist of the created space-time cubes and the test results. The different space-time cubes resulting from the creation progress are named chronologically by means of numbers and decimals. The very first one, for example, is named space-time cube 1.0. After slight adjustments the decimal will increase, if radical adjustments are made the number of the name will change.

The results will be presented chronologically, so the different space-time cubes are described before the test results. The test results are divided in four sub-chapters, the first one describing the test-group. The second chapter describes the test results of the visualization operators (Koua et al., 2006) of the space-time cube. In the third and the fourth chapter, the test results of the space-time cube as a concept and the judgement and recommendations of the space-time cube are described, respectively.

4.2 –Space-time cubes 1.0 and 2.0

The first space-time cube was not deemed useful for exploratory analyses. With the “time”-factor calculated from algorithm 1, space-time cube 1.0 was made in ArcScene and presented in google earth as is visible in figure 5. As one can see in figure 5 there were some problems while transforming the cube from one program to the other. The difficulties with the spatial and temporal resolution became clear. The GPS dataset only uses two years of the entire temporal range which makes the spatiotemporal path not steep enough to follow. By using the entire z-axis for the two years the paths become steeper and easier to read. The ratio between the (x-, y-) axes and the z-axis is not ideal for having an overview of the dataset. Figure 6 shows space-time cube 2.0, where the first adaptations were implemented. Although the situation improved it is not ideal yet. Ideally the z-axis would be higher in the situation of figure 6.

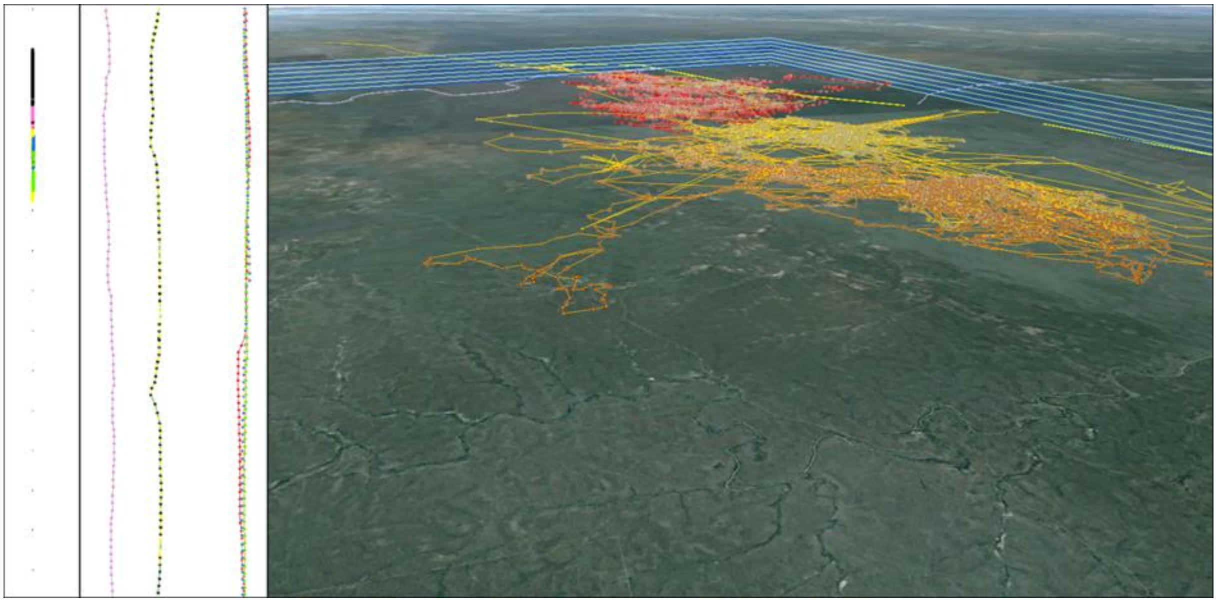

Figure 5: Space-time cube 1.0. The two pictures on the left show the dataset with time on the z-axis in ArcScene, where the middle picture is a zoom. The image on the right shows the scene exported to google

The first space-time cube version, space-time cube 1.0, lacks reference. The lack of axis and labels makes it difficult to navigate through the spatiotemporal dataset. The space-time cubes in literature did cover smaller areas and shorter periods of time. Most larger species cover areas of several tens of square kilometres, so showing axis only on the edges of the space-time cube is not sufficient. On maps and globes graticules are used to visualize the geo-reference. Especially for larger maps these are necessary. By adding the third dimension to these graticules a three-dimensional grid emerges which partly copes with the navigational problem, the space-time grid. However, it also adds additional lines which makes it harder to focus on the space-time paths. Because time on the z-axis is not intuitive, labels are necessary. Especially if the time span covered is larger. In the second version of the space-time cube, space-time cube 2.0, the space-time grid is implemented, this is visible in figure 7.

The space-time grid has the same function as graticules in two-dimensional maps. Figure 6 shows two empty maps and two empty space-time cubes. The map on the left site has no graticules, which makes it harder to estimate or read the value of a certain point on the map, for example the black point in figure 6. The same point is visualized in the space-time cubes, but a space-time grid is added to the space-time cube on the right. The space-time grid in picture 6 consists of three additional levels of graticules plus additional lines which run parallel to the z-axis (t) forming vertical graticules on the four sides of the space-time cube.

Figure 6 shows the necessity of navigation while using the space-time cube. For reading the (x,y,t)-location of the black point in figure 6 the space-time grid is insufficient. Only due to the two-dimensional maps given in figure 6 it is possible to read the location. A static image of the space-time cube has one dimension too little to actually get some information out of it. To achieve this idea of three-dimensions one needs to navigate through the cube.

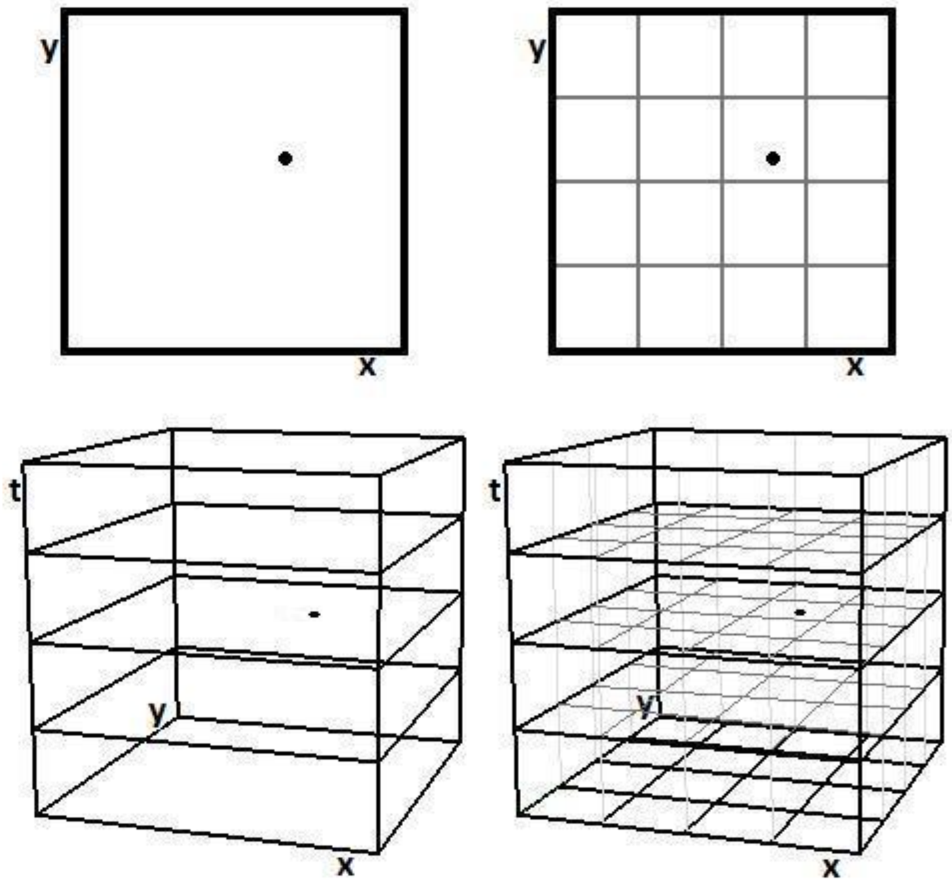

Figure 6

The labelled space-time grid visible in figure 7 is a big improvement but is still far from ideal. In the lower part its limits become visible. Only the bottom part is usable, but after that the space-time grid and the space-time paths combine into some kind of colourful spaghetti. But some patterns can already be seen and navigating through the cube one can follow each path to find a clearer image further on.

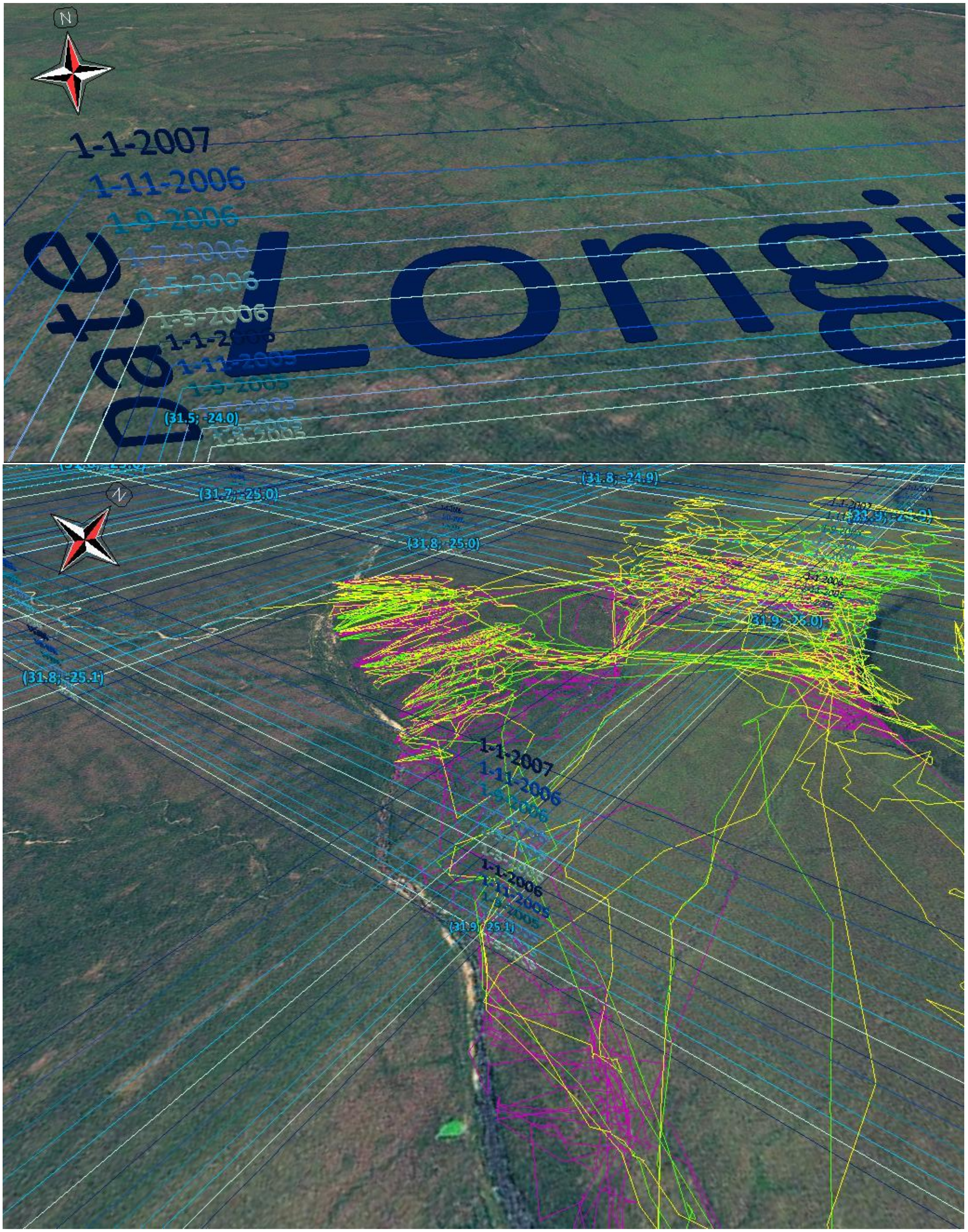

Figure 7: Space-time cube 2.0 including the space-time grid.

4.3 – The space-time cube 3.0

4.3.1 – Introducing Space-Time cube 3.0

Space-time cube 1.0 and space-time cube 2.0 were made in respectively Google Earth and ArcGlobe. But as a result of the maximum in elevation the cube's space-time cube could not be made high enough and therefore the temporal resolution remained limited. Eventually, it was decided that the final space-time cube was constructed in ArcScene. Another difference was made in the number of animals included in the space-time cube. Figure 4 shows the entire dataset and one can see that within the GPS dataset two groups are distinguishable, both consisting of three buffalo. Since there are no interactions between animals from the different groups, including both groups in one cube does not add extra information in comparison with two separate cubes. Therefore, the decision is made to select one of the groups for visualization, namely the south-eastern group. As a result the area covered by the visualization is decreased to a tenth of the complete GPS dataset. The visualization will still contain 40 per cent of the total GPS points, effectively increasing the amount of points per area by four. The time span is decreased from 683 days to 255 days, 37 per cent of the total time span. So the South-Eastern group only covers 3.73 per cent of the total space-time span of the complete GPS dataset (table 5), giving it a larger density in points and therefore a bigger change of interactions and interesting patterns.

Table 5: Point density Complete GPS dataset vs GPS dataset of South-Eastern group (SE group)

	Total points	N	Area	Point/area	Area*time		Point/Area*time		
GPS complete	24656		100	246.56	100		246.56		
GPS SE group					9762	10	976.2	3.73	2617.16

In figure 7 the final version of the space-time cube, without additional attributes is presented: space-time cube 3.0. As in the other space-time cubes each line represents the space-time path of a different animal. The paths are given orange, cyan dark green colours. These colours were chosen because they match each other and are somewhat natural which fits the theme of the cube. The colours are not too intensive, in that way the cube is less overwhelming. Space-time cube 1.0 and space-time cube 2.0 were created in Google Earth and ArcGlobe, respectively. Both programs present a digital globe covered with aerial and satellite imagery. These images automatically formed a basemap both space-time cubes. ArcScene does not have a basemap function and therefore other satellite imagery was geo-referenced to fit ArcScene decreasing the quality of it. The space-time grid of space-time cube 2.0 returned but due to the higher z-axis it has a smaller impact on the visibility of the space-time paths. Another advantage of the higher z-axis is that not only the months were labelled but every five days were labelled. The coordinates are present on every corner of the space-time grid. One buffalo's data was recording earlier than the others. It was chosen to start the cube in the month all three buffalo's collars were recording locations. As a result the orange line crosses the basemap.

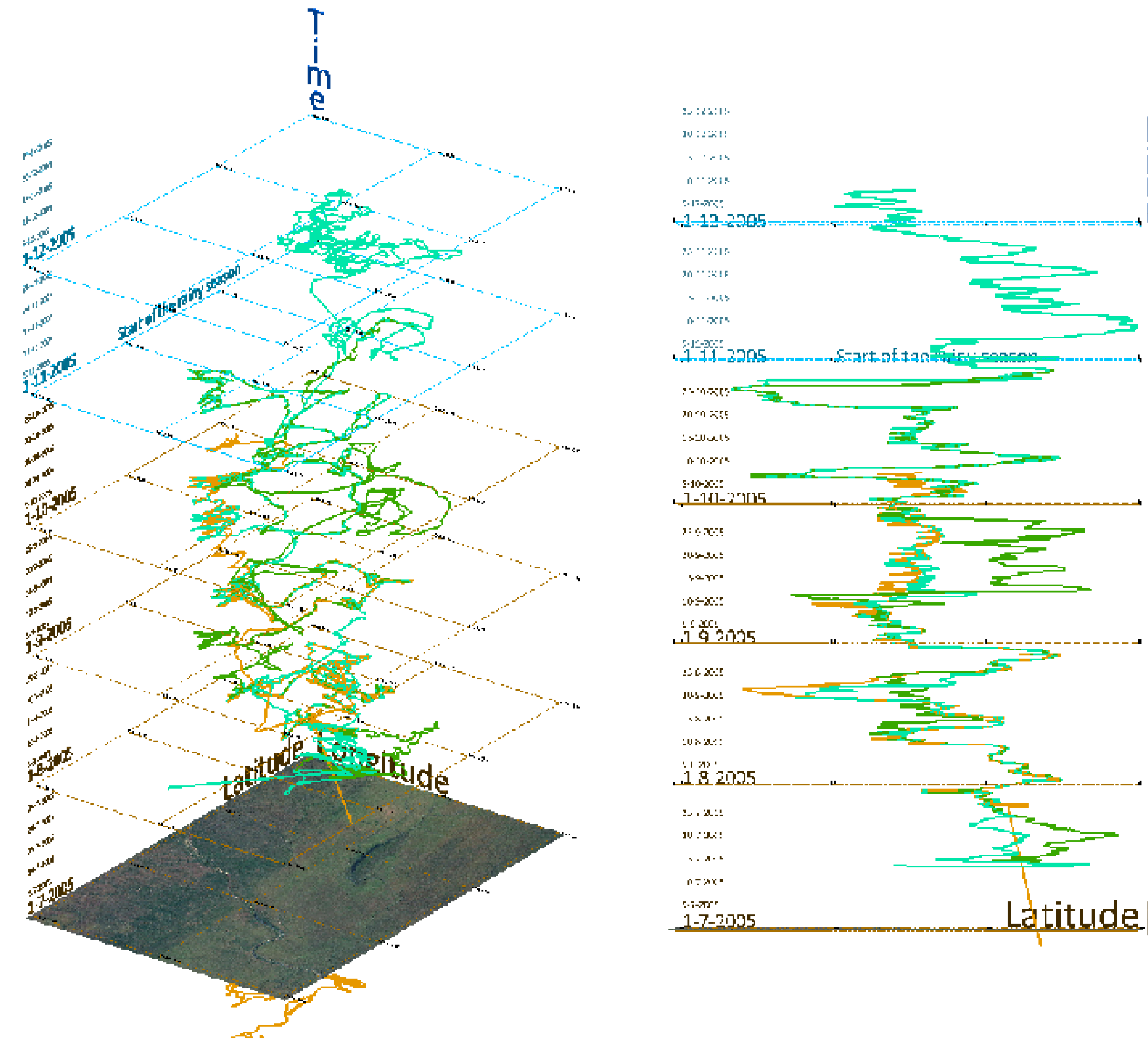

Figure 8: Space-time cube 3.0 from two perspectives.

4.3.2 – Additional attributes

Additional information presented in a visualization can, if implemented correctly, add new insights to the exploratory analyser. Although the dataset was not suitable for most interactions described by Orellana and Renso (2010) some attributed might be suitable to add. In figure 8 the climatic start of the rainy season is an example of additional information. In Kruger National Park the rainy season starts in November (Venter and Gertenbach, 1986), therefore the labels and the space-time grid were given a blue lay-out instead of the more brownish lay-out used for the dry season. This information comes from a climatic description from the area, so this implication only shows the possibility of adding additional information. Actual weather data would be more valuable and could show the user some direct effects.

Speed is visible by the steepness of the paths but one could make this more easily visible by overlaying the lines with a speed-attribute. A dotted line overlapping the original line could represent speed (figure 3). One could also chose to classify speed. Since African buffalo probably do not forage and run at the same time, one can assume they exclude each other as interactions and can be used as the different classes. Despite of their top speed well over 10 m/s, the maximum top speed calculated from the dataset was 5.5 m/s. These were the first points of one buffalo, who probably fled after receiving its GPS collar. Figure 8 shows the boxplots of the buffalo's speed. Everything above 0.5 m/s is seen as an outlier. This has to do with the time interval between two points which averages around one hour. Due to these statistics speed was not added as an additional attribute to the space time-cube.

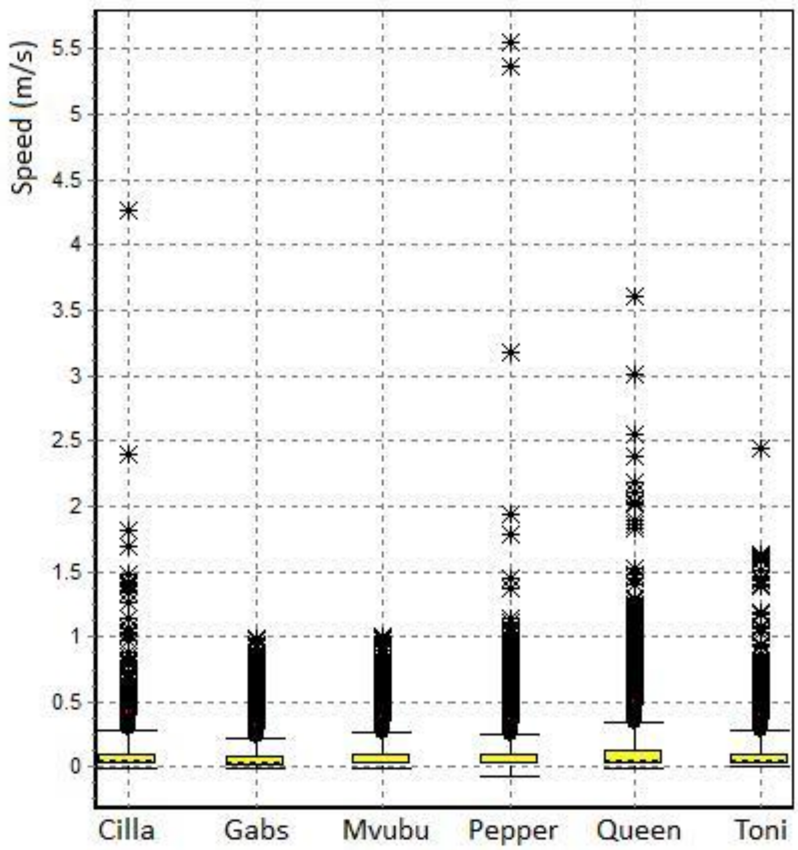

Figure 9: : boxplot of the bufallo's speed (m/s)

Since the basemap lost some of its quality during the geo-referencing of the aerial and satellite imagery and due to its stativity, some environmental attributes were regarded useful. The only environmental data available were the aerial and satellite images from Bing maps. By creating polygons from the waterways by hand some calculations could be done and an attribute named 'distance to water' could be created. This method is not accurate for small waterways may have been overseen, but due to the dynamic nature of the waterways and the non-temporal water dataset this inaccuracy is inevitable. Since the area has a rainy season one can expect the rivers and waterways to differ significantly through the year. However some expectations have come through. One could expect that during the rainy season more temporary waterholes are available and that grasses are growing throughout Kruger NP. In the dry season water is more constrained to the bigger waterways. Figure 10 shows the normalized distribution of the buffalo during the rainy season (November to March) and during the dry season (April to October). Figure 11 shows space-time cube 3.1 which includes the new attribute. The points or spheres have an impact on the visibility of the space-time paths, therefore they are only visible once the user stops navigating through the cube.

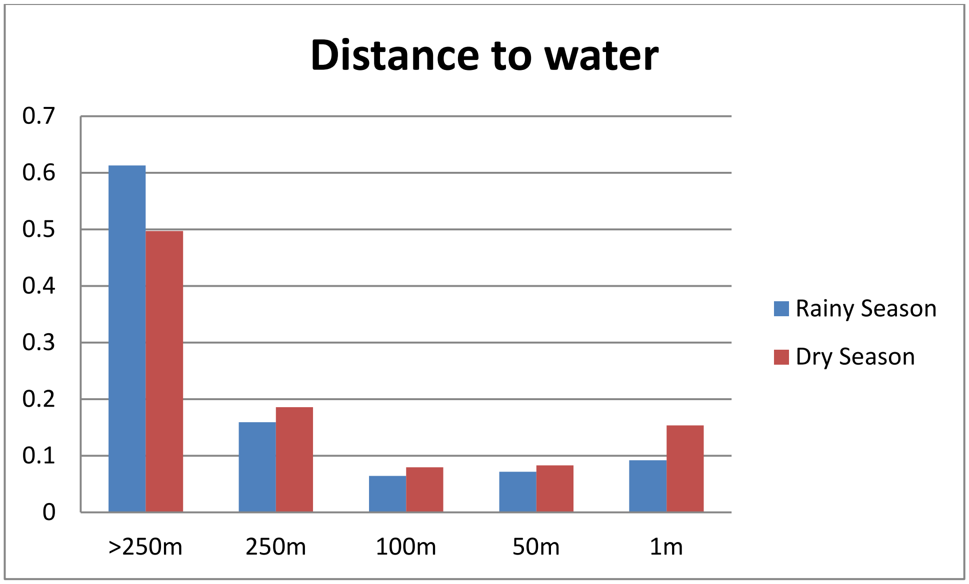

Figure 10: The statistics of the attribute 'distance to water'.

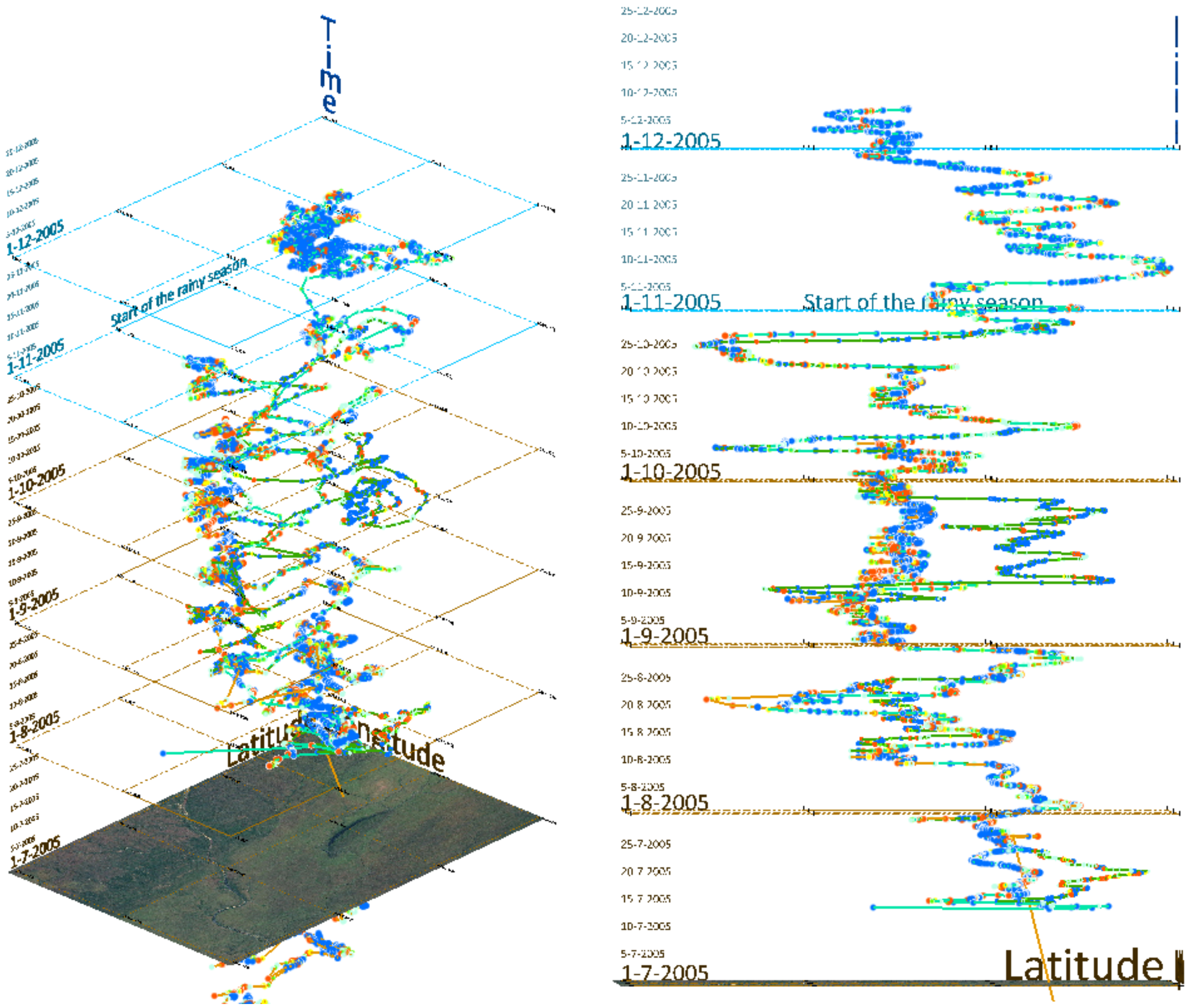

Figure 11: The space-time cube 3.1 which includes the 'distance to water'-attribute.

4.3.3 – A preview of space-time cube 3.1

Originating from the raw geo-atoms of the GPS-dataset plus the aerial photo, space-time paths emerge with two attributes: 'animal ID' and 'distance to water'. In comparison with the GPS-dataset mapped on the same basemap, more information can be distinguished from the space-time cube. Purely due to the time-factor which is included now. Patterns which are difficult to calculate with statistics can be found relatively easy. For example, one can have a look at figure 11. This image provides four views of the space-time paths from September 2005.

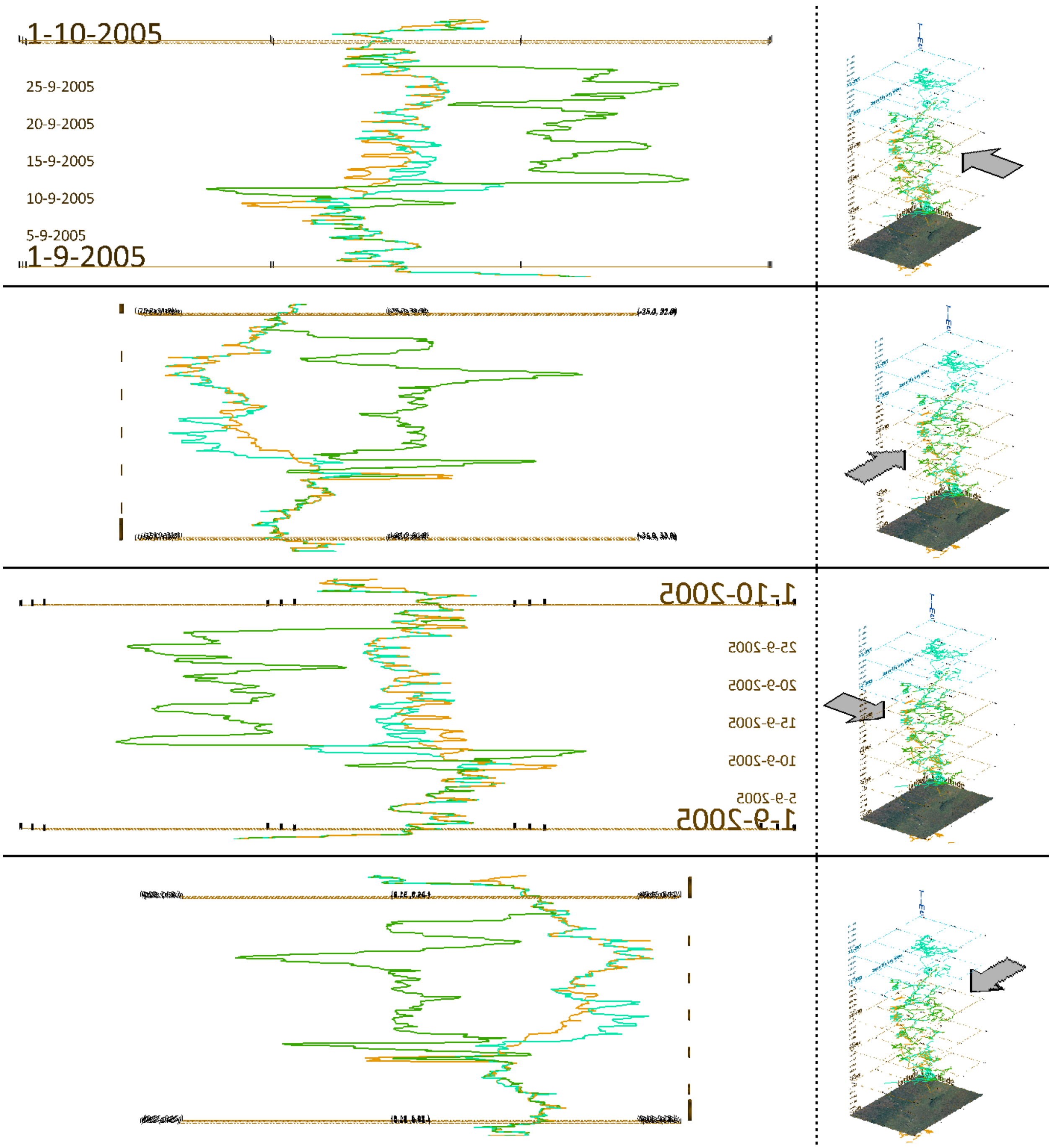

Figure 12: The month September seen from four different perspectives

Although no information from the basemap is visible in figure 11 and even though navigation is not possible still patterns can be noticed. The first ten days the three buffalo are together, but then one buffalo (dark green) decides to leave the group. Between 12 and 17 September the two remaining buffalo repeat a daily pattern. However, the daily patterns differ from each other. Moreover, the pattern of one buffalo (orange) is limited to one spatial dimension and resumes the pattern of a lawn mower. The 27th of September the three buffalo join each other again.

4.3.4 – An overview of the space-time cubes

Table 6 shows an overview of the progress of the space-time cubes. The heuristic process of creating the space-cube eventually resulted in space-time cube 3.1 which will be used in the test.

Table 6: An overview of the space-time cubes versions

Version	Software	Major issues	Improvements/additions
1.0	Google Earth	Lack of spatiotemporal reference; temporal resolution too coarse	
2.0	ESRI's ArcGlobe	Temporal resolution too coarse	Space-time grid introduced; temporal resolution increased.
3.0	ESRI's ArcScene	Basemap quality decreased, no additional attributes visualized	Temporal resolution increased; only the "SE"-group was visualized, reducing the area covered by the cube
3.1	ESRI's ArcScene	Static basemap and static spatiotemporal reference	New attribute "distance to water" introduced

4.4 – Test results

4.4.1 – Test group

Finding participants for the research proofed difficult. Eventually an online survey was used to make participating easier[1]. The online review is basically a digitalization of the review attached in appendix 1. The visualization or at least the survey does not have an appeal to most ecologists, 13 potential respondents had a look at the survey, but only three ecologists completed the survey. Another respondent completed the survey by means of the visualization running in ArcScene. The test group consisted of two professionals, one PhD-student and a MSc-student from the field of resource ecology. Two participants used GIS once or twice, where one respondent was an experienced GIS user and for the other respondent GIS was his second field of science. Half of the participants is open to new methods and will try them before most of their colleagues, the other half starts using new methods once they have been recommended to them. Four respondents is not enough to determine ecologists opinion on the space-time

[1] *Link to The online version of the test*: http://survey.websurveycreator.com/s.aspx?s=faa9d70a-da83-48f4-ba88-dc4cb80c0736

cube, but the test group is theoretically enough to find 75 per cent of the usability problems (Nielsen and Landauer, 1993). The mix in GIS experience helps to identify the difficulty of the use of the space-time cube.

4.4.2 – Testing the cubes visualization operators

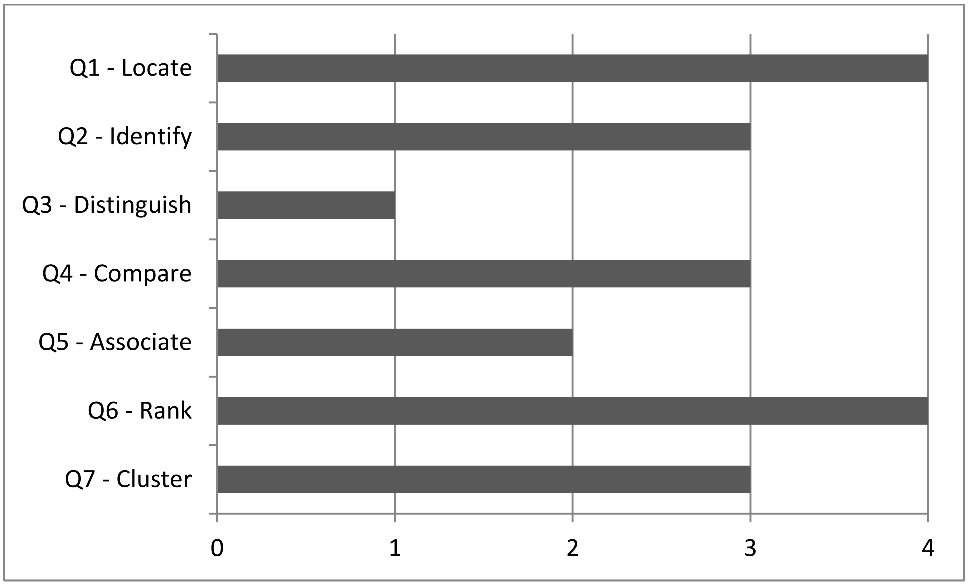

Figure 13: Correct answers per visualization operator

Figure 13 shows a graph which shows the amount of correct answers per question and the corresponding visualization operator from Koua et al. (2006). Overall 20 out of 28 questions were answered successful. So, of the total of implemented visualization operators, 71% were implemented successfully. The first question of the survey was designed to see whether users were able to locate a point in space-time, in this case the first location of one particular buffalo. All respondents identified the correct coordinates and the correct date. To test how suitable the visualization is for identifying relationships between attributes question 2 was created. During the timespan covered by the space-time cube the three buffalo are together several times. Question 2 asks for the date of the last time the three are together, three out of four ecologists gave the correct answer. Question 3 was to see whether the respondents managed to distinguish a difference between the nearest water source during the dry season and the rainy season. One participant managed to notice a difference and the other three could not tell a difference from this visualization. The fourth question was about the month September of figure 11. The respondents were asked to compare the area the three buffalo covered in that month. Three out of four answered correctly.

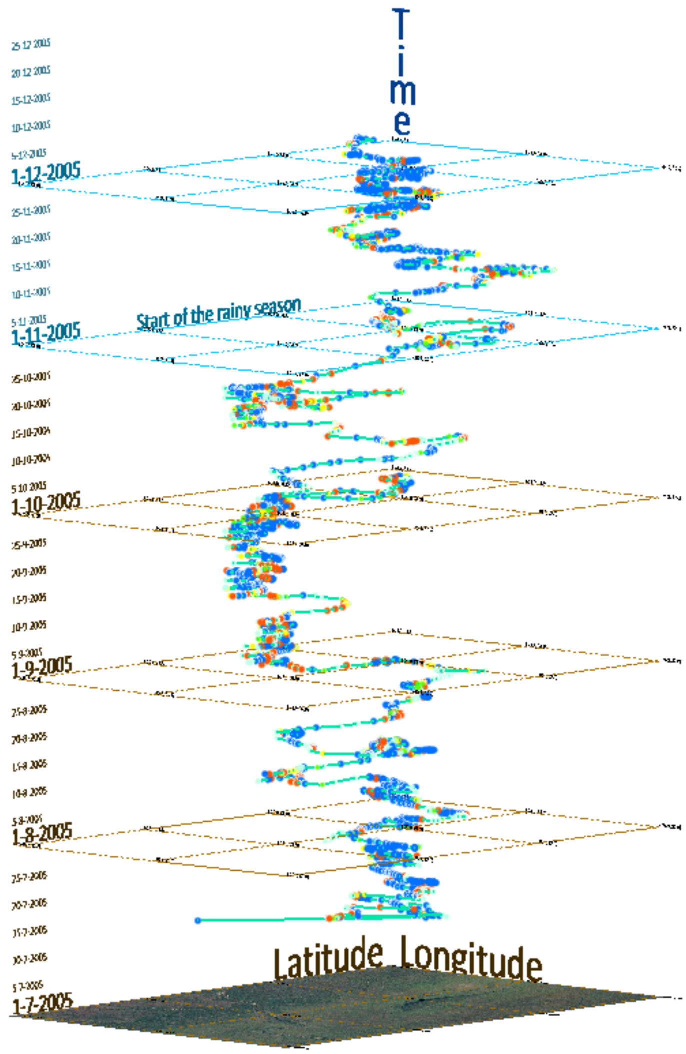

Figure 14: The space-time path of the buffalo which collar is still measuring locations during the rainy season.

Question 5 was about the same animal as question 3, its space-time path is visible in figure 13. A lot of ground is covered between the first two points of the path. The question was what the associate this with either animal behaviour or a gap within the data. A relative flat line within a space-time cube suggests that the animal was going really fast for a while. Probably, the animal was stressed from receiving a collar. Half of the respondents gave the correct answer where the other half associated the phenomenon with a gap in the data. Question 6 was a ranking question. The participants were asked for the most popular location amongst the buffalo. Although this question is answerable with a map of the GPS-dataset, it should also be answerable with the space-time cube. For example, by having a top down view like in figure 14. The space-time grid divides the area in six parts and all the participants chose the most popular part as the answer.

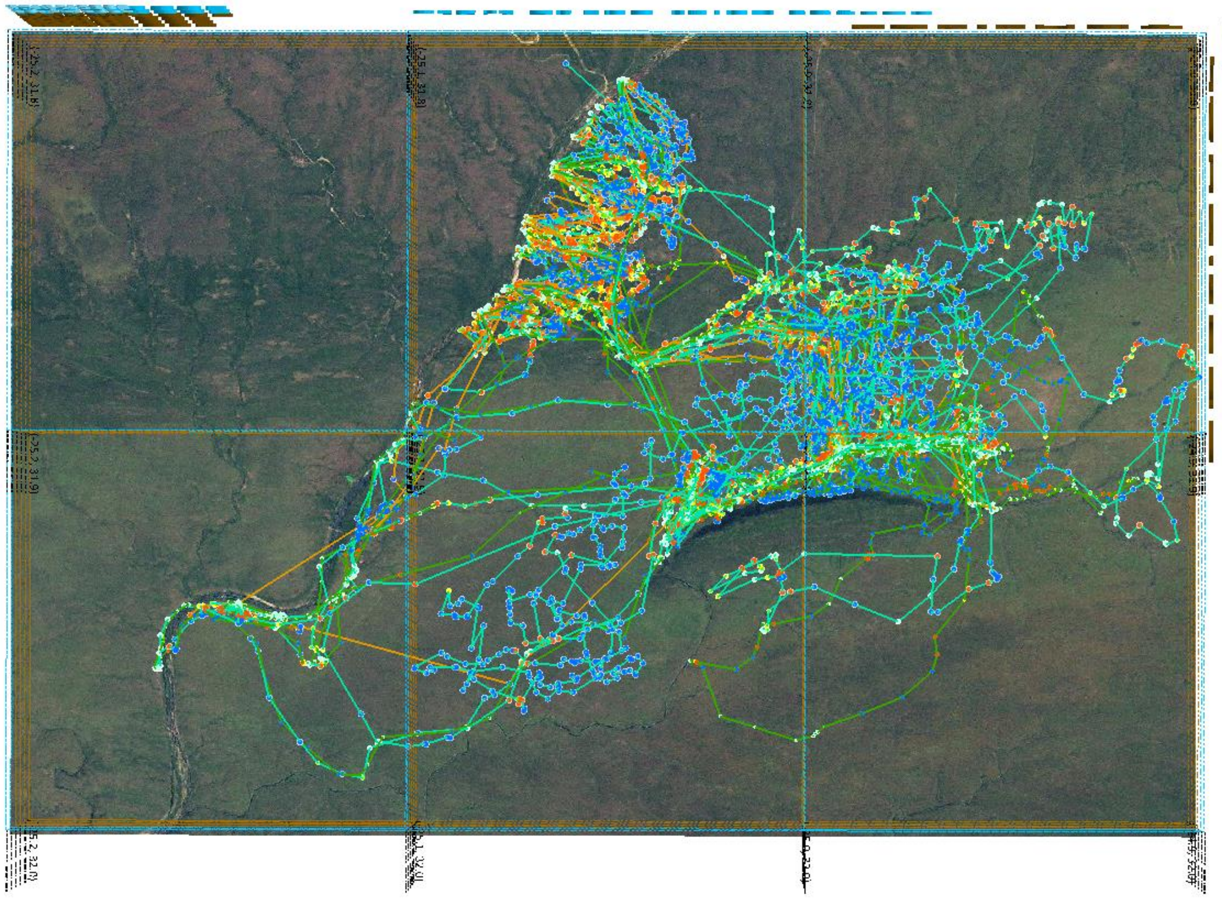

Figure 15: a top down view of the space-time cube.

Question 7 was an open question and the subject was the gap in the data of one buffalo. The participants were asked to give the end of the gap. The collar started giving signals again at 27-7-2005. One participant answered the correct date, two others answered the 26th and the 28th of July. Taking the temporal resolution in mind these answers were regarded as correct. The answer of the fourth participant was invalid for he already knew the answer.

4.4.3 – The space-time cube as a concept and its ease-of-use

The third part of the questionnaire attended to the space-time cube as a concept. The respondents were asked how they normally use GPS data or similar geo-atoms retrieved with other techniques. One respondent uses GPS data to calculate the average speed of the subject and the distances covered by it. Another participant uses GPS data for other purposes, which were not defined. One of the respondents is entomologist who studies the resource ecology of malaria mosquitos. He uses spatiotemporal data to investigate the effect of human activity on wildlife, to study the role of high quality resources in a species diet choice and to calculate the distance covered by and the average speed of the mosquito. The hypothesis from the literature study was that most ecologists tend to use statistics as main tool for analyses and that as a result the results are presented in graphs. Therefore question 2 was added to part 3 of the survey (Appendix 1). The multiple-choice question offers four answers which were all picked once. Of course a significant answer is impossible with the four responses, but it seems that the hypothesis is an exaggeration.

Because commonly most spatiotemporal datasets are used in combination with other datasets the participants were asked to indicates the different datasets they normally use in combination with the spatiotemporal data. The answers given were: Normalized Different Vegetation Index (NDVI), water sources, weather data and land use-data.

Another question asked was how the participants experienced the difficulty of the questions in part 2. What was the ease-of-use of the space-time cube? Nobody thought it was easy. One respondent thought it was moderately easy, two thought it was moderately difficult and another thought it just was difficult. Kristensson et al. (2009) discovered that users experienced working with the space-time cube more easier after a while. This was also the case with three out of four respondents. One participant thought it was difficult and still thinks it is difficult.

4.4.4 – Judgment and recommendations from the ecologists

The final questions asked to the participants were essentially research question 3 and whether they have recommendations or improvements. One respondent named the space-time cube: *"Great for first exploration of data!"*. Another defined the cube as: "*Nice Visualization of spatial movement over time, very nice."* The respondent with the most GIS-experience was less enthusiastic. He stated: *Within a space-time cube you lose the overall picture because while navigating through time (vertically) the basemap is not visible. It is still unclear where the animal is. While navigating horizontally you do not see the time labels and that is basically what one wants to achieve by using this method".* In other words the goals one wants to achieve by means of a space-time cube are not achieved due to the loss of the overall picture while navigating.

The participants came with some concrete suggestions and recommendations for the space-time cube. Two respondents thought it was hard to read the time labels on the z-axis, one participant suggested to keep rasters and axis while navigating and zooming in. Or in other words dynamic axis which adjust themselves while the user is navigating. Another recommendation given was that while the buffalo are together their space-time paths should merge into a herd space-time path. This would reduce the messiness of the space-time cube. The last recommendations was an interactive tool which would give the distance and average speed of a selection of the space-time path. Logically, this would also require a selection tool.

The respondent who did not deem the space-time cube as suitable for spatiotemporal data analyses mentioned two alternatives. The first he mentioned was a map of the space-time paths in which time was visualized by means of colour, this would be more intuitive. The second alternative he came with was an animation. By using an animation one can directly see when animals meet each other.

5 – Conclusion, discussion and recommendations

5.1 – Conclusion

Time can be hard to grasp in real life, visualizing it can be even more challenging. Over the years many methods emerged ranging from 2D maps of time-tracks, ringmaps, animations, time-travel maps and of course Hägerstrandt's space-time cube. Several aspects of the space-time cube makes it standing out from the rest. It is three-dimensional, time is fully integrated on a ratio scale and complicated space-time patterns can be found by analysing the space-time cube.

The creation process of the space-time cube was a heuristic one. A version was created, inspected and improved four times. One could describe the process as trial and error as well. At least it was a bit of struggle to create a space-time cube which covers the space-timespan as the one presented. The space-time grid was introduced in the second version of the cube. But initially these extra lines made the space-time cube more messy due to the limited height of the z-axis. Eventually after switching to ArcScene, a space-time cube was deemed suitable for testing. The possibility of adding additional attributes based on Orellana and Renso (2010) was investigated. Their method of calculating interactions without additional information has a great potential for spatiotemporal datasets. However, the dataset visualized in the dataset was temporally too coarse and consisted of too few subjects to use this method. But the future datasets will be more detailed temporally and more and more animals can wear a GPS-collar since GPS-collars become better and cheaper. The amount of attributes visualizable in a space-time cube are limited (Li, 2005). The interactions do not necessarily have to be visualized by means of a space-time cube, the algorithms to calculate the interactions are interesting enough for animal tracking datasets.

Concluding, is the space-time cube method usable for exploratory data analyses of animal tracking datasets? Two participants see the concept of the space-time cube as a useful tool for exploratory data analyses. For the truly spatiotemporal queries, the questions in which both space and time played a part, the space-time cube managed to communicate the information. The remaining question is whether the alternative methods would also be capable of doing so. The question in which the additional attribute was used statistics were suggested as a more convenient alternative. The questions in part 2 were in 71% of the cases answered correctly, but still some mistakes have been made while answering the questions. Kristensson et al. (2009) concluded that the space-time cube takes some practice before using. The results of this research suggest the same. About the ease-of-use we conclude that it is not an easy tool to use, but practice helps. The respondent who named GIS his second field of science lost the overview while using the space-time cube. While reading the location of the animal you cannot read the time and vice versa, and as a result the theoretical advantage is neutralized. Some theoretical advantages of the space-time cube were acknowledged by the participants. However, the space-time cube was presented to them. A straightforward tool to create a space-time cube is missing. Therefore, improvisation is essential and the creation process can be described as heuristic or trial and error. We can conclude that the space-time cube is suitable for spatiotemporal exploratory data analyses of animal tracking data, but if the query is not truly spatiotemporal one can better use alternatives.

Does the space-time cube method have a future in resource ecology? The cube originates from a total different field of science, namely time geography. And although resource ecologists are interested in complicated space-time patterns, their main interest is to find out why organisms are distributed as they are. Additional datasets including food availability or resource quality, water sources, human activity and weather data are used to answer the question of organisms' spatiotemporal distribution. Other more statistical methods are used to combine the several datasets. When a question was asked in which the additional environmental attribute was needed, the respondents did not deemed the space-time cube suitable. A well-constructed space-time cube can help ecologists exploring their animal tracking data. Currently, the question can be raised whether the advantages of a space-time cube weigh up to disadvantages, the difficulties and the improvisation necessary to create a space-time cube.

5.2 – Discussion and recommendations

The literature consulted for this research suggested that the space-time cube was suitable for resource ecology and that it has never been implemented in that field of science before. However, it could be that is has been implemented but that the literature about has been overlooked. So some uncertainty remains whether the space-time cube method has not been used in resource ecology or that the literature study was not extensive enough.

The space-time cube created in this research is not perfect. Real animal tracking data was used to run into real problems. The timespan of the three buffalo did overlap, but only for three months. Furthermore no additional datasets were used, where they would result in new opportunities and additional attributes. A dataset of the local actual weather conditions from the timespan visualized would be more useful than a general starting date of the rainy season. This was also mentioned by a participant. The climate of Kruger National Park knows a dry and a rainy season as a result the waterways and water sources differ throughout the year. A dataset which includes these differences would be necessary to truly use water sources as an additional attribute. The use of Normalized Different Vegetation Index (NDVI) would come in handy for investigating the role of resource quality on the animals distribution. Another useful dataset to add would be a land use dataset which contains roads, villages and other human activity. If one would like to investigate the competition and predation pressure one would like to add datasets from different animal species. One limitation of the space-time cube is the amount of objects one can visualize with it (Li, 2005). New research has been done in methods to cluster patterns in pedestrian movement (McArdle et al., 2013). This method is suitable for constrained as well as free-range movement (McArdle et al., 2013) which makes it suitable for animal tracking data.

New research on the space-time cube method have been conducted in different fields of science and does not only cover point-based data. Starek et al. (2013) used the space-time cube to visualize stream bank evolution.

The creation of the space-time cube was a bit of struggle. Mainly because all the 3D functions were created with elevation in mind. The space time cube really needs its own environment to work and should not be taken for a separate data processing step but as a whole new template for spatiotemporal data. The same algorithms as the original 3D functions can be used. If the 3D functions improve, for example 3D buffering, the space-time cube will get a new impulse, for with these functions new attributes can be calculated. Dynamic basemaps, labels and axis would be really helpful for space-time cube users. If the points representing the “distance to water”-attribute would be flexible in size one could increase as such that the density of the animals can be visualized. The space-time cube used for this research had a static basemap and static label and axis, but this caused loss in orientation for some users. The messiness of the space-time cube can be reduced by merging multiple space-time paths into a herd’s space-time path once animals are near each other. By doing this the number of space-time paths one can visualize will increase. A big difference from space-time cubes in literature is that animals are not bounded to roads or waterways, this makes the basemap more important for you cannot estimate on which the animal is.

Unfortunately only four participants joined the test. Partly this can be explained by the effort it takes to understand the visualization. This might have scared off potential respondents. Eventually an internet survey was created, which reduced the quality of the survey, for the participants could not navigate through the cube themselves.

For further research the use of better more detailed dataset is recommended. The more detailed the dataset the more interactions can be calculated by means of Orellana’s (2012) method. It is also recommended to do a larger usability test with a bigger test group, because a lot of uncertainties remain. Additional research needs to be done in the visualization of different attributes in the space-time cube. None of the space-time cubes in literature visualized any additional attributes.

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Appendices

Appendix 1 - Dear participant,

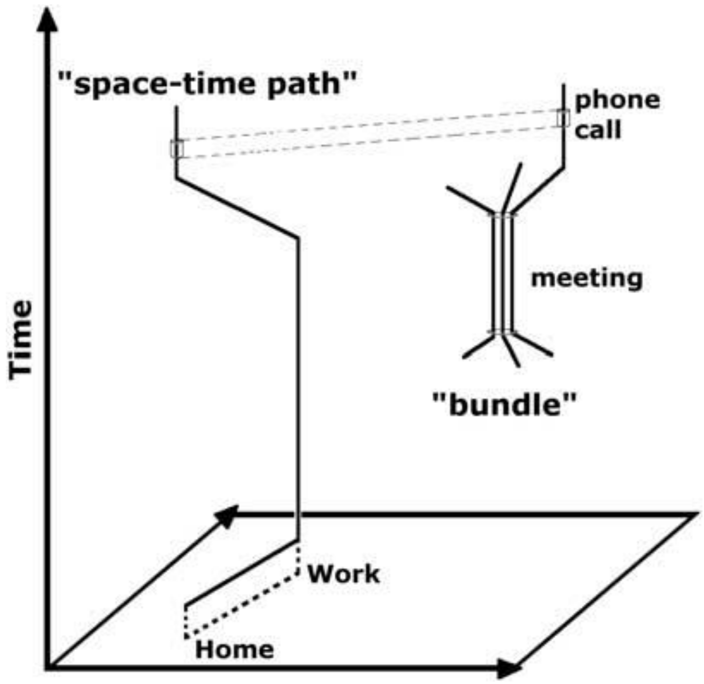

Figure 1: Example of a space-time cube (Vrotsou et al., 2010)

Thank you in advance for your cooperation. The purpose of this survey is to test a visualization type which is much discussed in literature as a potential suitable visualization for animal tracking data analyses: the space-time cube. The space-time cube was introduced by Hägerstrand in 1970 and it uses the third dimension to visualize time. The combination of the 2D map and time on the z-axis create a cube in which paths can be visualized. In this way spatiotemporal data is visualized without animations but with time fully integrated, where both discrete and continuous time can be visualized (Li, 2005). *Figure 1* shows a time geography example of the space-time cube from Vrotsou et al. (2010). The idea of the conceptual framework of time geography is that every population consists of *"socially and geographically interrelated individuals and not as indivisible masses"* (Vrotsou et al., 2010, p. 264). The space-time cube was born out of this concept and is useful for visualizing individuals' space-time paths. By combining multiple space-time paths within a cube one can discover bundles or meetings among individuals (figure 1) and by doing so study human behaviour. Since humans are part of the animal kingdom, it is a small step from time-geography to ecology. This, together with the complex nature of time-track datasets insinuates that the space-time cube has potential in ecology. Especially because animal tracking devices become more and more advanced. However, little or no research is done concerning the use of the space-time cube in ecology. Up till now...

Three African buffalo (*Syncerus caffer)* living in Kruger NP

Hereby I like to present a space-time cube of three African buffalo in Kruger NP. Each animal's space-time path is represented with a different colour. The small points do not only represent how far the nearest water source is, but also indicate each time the GPS -collar saved every location. The survey consists out of three parts. Firstly, three personal questions are asked. In the second part seven specific questions about this particular cube are asked and finally seven general questions about the space-time cube as a concept are asked. Additional suggestions and comments are appreciated. The test will take 20 minutes.

Question 1 – What's your current situation?

A – I am a professional in the field of resource ecology
B – I am a student in the field of resource ecology
B – I am a PhD student in ecology
D – Other,...

Question 2 – What is your relation with Geo-Information Science?

A – I have no experience whatsoever with GIS
B – I worked with GIS before, but only once or twice
C – I am familiar with GIS
D – GIS is my second field of science.

Question 3 – Are you open to new methods?

A – I immediately embrace them
B – I will try them, often before colleagues do
C – If it is recommended to me, I will try
D – I'd rather stick to the old ways

Part 2 – specific questions

Question 1 – What is the date + location of the first signal of buffalo 3 (Mvubu)?

A – 25-7-2005 (-24.92, 31.86)
B – 17-7-2005 (-24.91, 31,88)
C – 15-7-2005, (-24.96, 31.90)
D – 14-7-2005, (-24.99, 31.84)

Question 2 – The three buffalos are observed together multiple times, the last time the three split buffalo 1 (Gabs) leaves buffalo 2 and 3. When did this happen?

A – 2-10-2005
B – 25-9-2005
C – 15-10-2005
D – 28-9-2005

Question 3 – Since buffalo 2 (Cilla) is the only buffalo still wearing a working GPS collar during the rainy season, the following question is specifically about this animal. Can you notice a difference between the nearest water source during the rainy season and the dry season?

A – The buffalo seems to be more bounded to water in the rainy season
B – The buffalo seems to be lees bounded to water in the rainy season
C – There are no significant differences
D – I cannot tell from this visualization

Question 4 – What buffalo covers the largest area in September

A – Buffalo 1 (Gabs)
B – Buffalo 2 (Cilla)
C – Buffalo 3 (Mvubu)

Question 5 – A lot of ground seems to be covered between the first two point of buffalo 2. How come?

A – There is a gap in the data
B – The animal is resting for a while
C – The animal is going very fast for a while.

Question 6 – According to this visualization, which location is the most popular among the three buffalo?

A – The area around point (-25.15, 31.95) or the right lower corner
B – The area around point (-24.95, 31.85) or the left upper corner
C – The area around point (-25.05, 31.85) or the left in the middle
D – The area around point (-25.05, 31,95) or right in the middle

Question 7 – There is a big gap in the data of buffalo 1 (Gabs). Can you give the end date of this gap?
End date: 27-7-2005

Part 3 – Space-time cube as a concept

Question 1 – For what purpose do you normally use GPS data (multiple answers possible)?
A – Estimation of a species distribution
B – Investigating habitat selection of a species
C – Distinguishing populations of species
D – Investigating the effect of human activity on wildlife
E – Investigating the predator-prey relations
F – Investigate the role of high quality resources in a species diet choice
G – To calculate average speed and distance covered
H – I normally do not use GPS data
I – Other, …

Question 2 – How do you normally analyse a GPS dataset[2]?

A – I use statistics to analyse the data and therefore results are often presented in graphs
B – Firstly, I plot the data in a map to explore the data, but for the analyses I use statistics and results are therefore often presented in charts
C – I use GIS to analyse the data and results are often presented in maps
D – I use a combination of GIS and statistics to analyse the data

Question 3 – What data do you add to a GPS dataset for analysing (multiple answers possible)?

A – Normalized Different Vegetation Index (NDVI)
B – Water sources
C – Weather conditions
D – Additional GPS data of animals of different trophic levels
E – Landuse data (roads, agriculture)

Question 4 – How did you experience finding the answers of the questions in part 2?

[2] Of course, the analyses depends on the research questions, but we are interested in the most common approach.

A – Easy
B – Moderately easy
C – Moderately difficult
D – Difficult

Question 5 – Time on the z-axis is one way to fully integrate time in a visualization, but is thought of as being unintuitive. What do you think of navigating through the space-time cube?

A – I immediately got the hang of it
B – After a while it became easy
D – I thought navigating was difficult at the start and I still think it is difficult

Question 6 – What improvements would you suggest for the space-time cube?

Question 7 – Overall, do you think the space-time cube is a good tool for exploratory data analysis for GNSS data?

Comments and suggestions:

Thank you very much for participating!

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Appendix 2

This thesis was delivered with a DVD.

This is the table of content of the DVD

- Report (Word, PDF)
- Presentation (PPT)
- Animations of space-time cube 3.1
- Figures of the space-time cubes
- Datasets used
- Space-time cube 2.0
- Space-time cube 3.1
- Questionnaires (in case of)
- Literature (PDFs of used articles)
- Other (additional sources)