Visual exploration of large animal trajectories

Elodie Buard, Mickaël Brasebin

Keywords: trajectory, 3D, visualization, attractive areas, pressure, station, corridor

1-Context and objectives

The aim of our research is to analyze the interactions between animal population and space dynamics. On the one hand, animals, and in particular herbivores, move in relation to the availability of natural resources (water and vegetation), that varies naturally in the year according to seasons (Valeix et al. 2007). On the other hand, when animals gather at specific places in depleting local resources, they influence space dynamics (Chamaillé-James et al. 2007). One major issue is to evaluate the impact caused by flows of individuals on space, what we call pressure due to animals on space. To begin, trajectories of individuals are drawn, enabling to visualize non only habitats but also movements. The aim of this contribution is to provide visual methods to identify attractive areas, where flows of individuals converge. Thus, from one or several trajectories, places are identified as undergoing pressure due to animals, in different ways. Indeed this pressure stems from different reasons that can be combined: a particular activity done in this place (such as eating, drinking or resting), the number of animals that are gathering or the temporal recurrence of this activity.

In order to study animal movements, GPS collars are attached to animals. Such GPS devices collect a set of positions at a pre-determined time interval. The collected positions can be used to identify movements, meaning their spatial changes through time: from points, we display trajectories. We define a trajectory as a "set of positions and movements that an individual takes" (Chardonnel 2001), both in space and in time. For Time-Geography (Hägerstrand 1970, Langran 1988), which has studied, among other things, human trajectories in cities, trajectories are chosen by an individual in relation to its activities (Peuquet, 1994) and its environment. To characterize a place where individuals accomplish activities during certain duration, Time-Geography uses the term of "stations". We use this notion to describe places of stops in animal movements.

The animals we study are African large herbivores of the Hwange National Park, in Zimbabwe, mainly elephants, buffaloes and zebras. As herbivores live and move in groups, only a single representative individual in the group wears the GPS collar (also because, though GPS devices have become affordable, one cannot afford to have a collar for all 200 members of the group). Therefore, with every GPS track, we study the movements of a group, considered as a whole. Figure 1 illustrates a space-time path of an individual that is showing the "trajectory of an individual's movements in physical space over time" (Hägerstrand 1970). This path is linking the stations, which are the portions of space where the individual stops during a given period of time (vertical lines with a given height). On Figure 1, there are three stations. Moreover, note that the more horizontal the line is, the faster the animal goes.

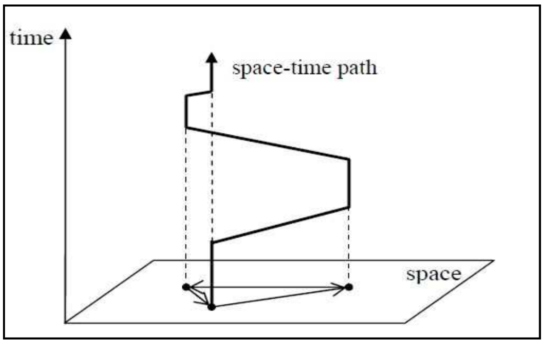

Figure 1: A space-time path from (Hägerstrand 1970)

Many approaches exist in Geovisualization to analyze trajectories in visualizing them in 3D space (Kraak 2006; Kraak 2003, Li 2010a). Often timestamps in the trajectories are converted into Z coordinates (Li 2010b) following conversion rules between time and space, for example 10 hours equivalent to 1 meter in Z in the visualization space. In that way, single trajectories of two groups of zebras are visualized in Figure 2.

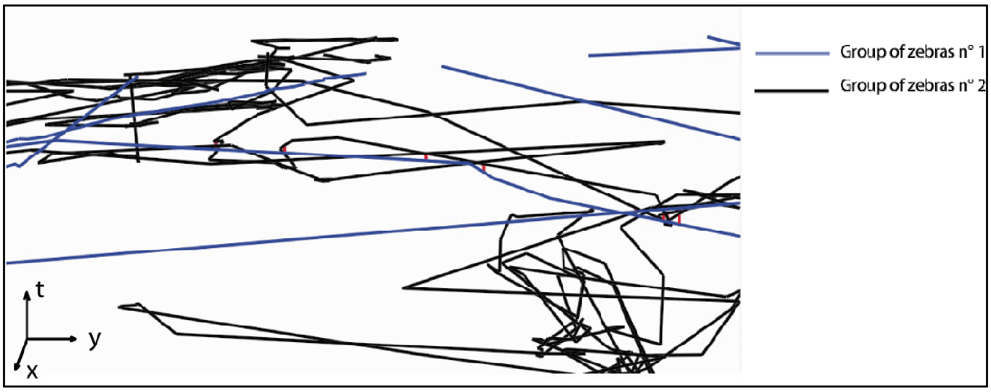

Figure 2: Two paths of two groups of zebras

Analysis of animal trajectories is complex because they regularly do micro movements themselves included in larger movements: for instance, daily small movements integrated in migrations (Nathan 2008). In Figure 2 micro movements disrupt good reading and interpretation of data because regularities in movements and places are not perceived. The eyes only perceive random movements. Thus, we think that 3D representation is adapted for large and repetitive movements localized in specific and precise places as people moving from house to office, but not for movements with high variability. Indeed, for an animal, the notion of stop is not a total end of movement as animals always move. In addition, the habitation of most of animals is not constrained by spatially bounded objects like houses for human. We define a stop as a time period when animals move a little, doing micro movements in a small area, these movements being inferior to a certain speed threshold. The interest of defining stops and paths for animals is to evaluate their resource needs and their temporal access to these resources.

In order to improve animal trajectory visualization, we propose to segment the trajectories in movements and stops (section 2). This step enables to identify flows and activities on attractive areas to quantify the pressure on these areas. Then we provide a 3D tool to help the interpretation of trajectories to emphasis temporal recurrence of movements (section 3). They have been implemented on GeOxygene, the open source GIS development platform developed in the COGIT laboratory at IGN-France (Badard et al. 2003; Bucher et al. 2009). Section 4 is a discussion. Finally, conclusion and further works are presented in section 5.

2-Automatic extraction of activities of individual trajectories

We describe here a first tool that extracts attractive areas, where animals converge, and activities, based on Time-Geography (Peuquet 1994; Langran 1988). As it turns out, these attractive areas double-matter because (1) animal occupancy there testifies resources quality and quantity and (2) these resources are likely to be fast damaged as a consequence of pressure due to animals. We distinguish three main types of attractive areas corresponding to different notions of convergence and different types of pressure: station area, corridor and crossroad. A station is an area where an individual stops or does micro movements. Usually individuals stop to do activities. An area where stations are dense is called a station area. A corridor is an elongated-shaped area where several trajectories pass through, so the individuals are moving along corridors. A crossroad is an area where several trajectories cross. The automatic extraction of attractive areas is a three steps process, each step refining the results of the previous one. First, stations are extracted, then attractive areas are identified and, finally, after computations, activities are allocated to stations and attractive areas.

The first step of this method consists in segmenting individual in movements, when animals effectively move with a non-null speed, and stops, as shown in Figure 3. The stops in the trajectories determine the stations, areas where individuals stop to accomplish a certain activity during a certain time (Hägerstrand 1985). For us, stations are identified when successive points are localized in a close area, as animals still do small movements. The distance threshold between points defines the maximum acceptable distance of small movements. In other words, Station = function (Number of points, Maximum distance between points). This threshold depends on the species. For experimental studies on large herbivores, we fix the threshold distances to 100m for 2 hours stop, 200m for 3 hours stop, 400m for 4 hours stops etc, according to expert knowledge. Figure 3 illustrates this step.

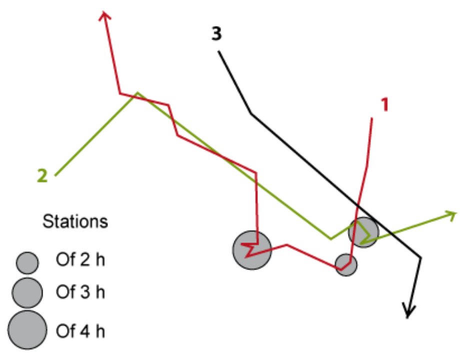

Figure 3: Extraction of stations having different durations on three trajectories.

Once stations have been extracted, in a second step, other attractive areas can be analyzed from several trajectories. Attractive areas are places where one group or several groups of animals gather or come back. The identification of such areas depends both on the trajectory's shape of a species (in particular if the trajectory is cyclic, it comes back to attractive areas at a certain frequency) and the number of tracks in this portion of space. In this last case, by observing several trajectories, we identify and construct different shapes of attractive areas: station areas, corridors and crossroads. Station areas are places where individual stations previously determined are dense. Corridors, which are elongated-shaped areas where animals pass several times, are determined in intersecting buffers around trajectories and whose size is to fix and depends on the species. For experimentation, we fix the buffer size to 50m. Crossroads are areas where several trajectories cross, the clustering distance needing to be fixed. For our study, this distance is set at 50m. An example of these particular places is presented in Figure 4.

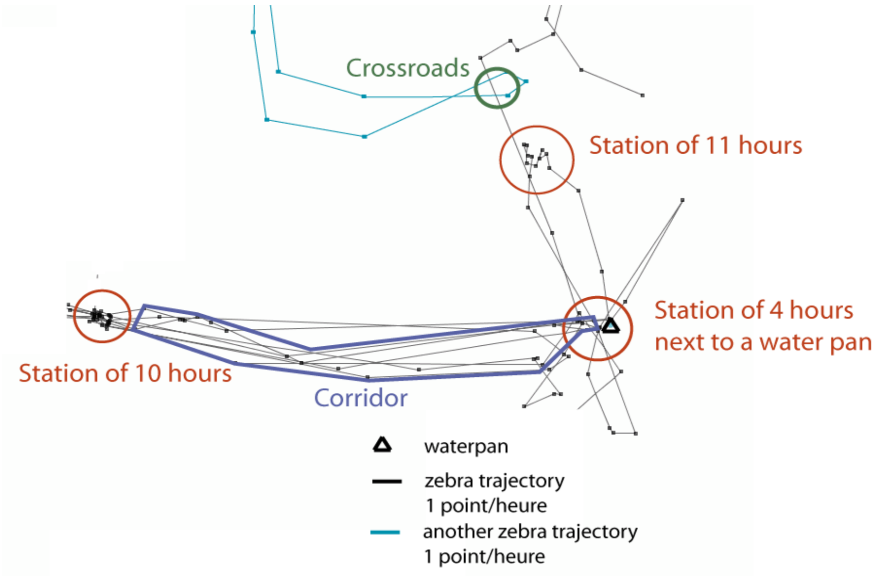

Figure 4: Extraction of attractive areas of two trajectories (the "blue" and the "black").

According to the duration of stations and the species, the activities can finally be analyzed (third and last step of the extraction process). The determined activity is chosen among eating, drinking or sleeping. This simple classification of activities is adapted to our aims of analyzing the pressure due to animals on space. The decision process used here involves 2 thresholds t1 and t2 defining three time intervals such that I1 = [0, t1[, I2 = [t1, t2[, I3 = [t2, +∞[. If the duration of the stop belongs to I3, the activity is assigned to sleeping (Rauske et al. 2010). The assignment of the activities for intervals I1 and I2 might differ from one species to the other. This assignment, as well as the values for thresholds t1 and t2, can be defined by ecologist either using prior knowledge or by testing different hypotheses and visualizing the result in the proposed tool (trial and error). Figure 5 presents an example of such results for one group of zebras, two maps of identified stations using a parameter of respectively 2 hours and 4 hours. This extraction enables to better perceive same activities of individuals, which depends on the duration of the station. We note that short stops are in greater number than long stops. A study to correlate station location to resources location is ongoing (Jolivet et al. 2011).

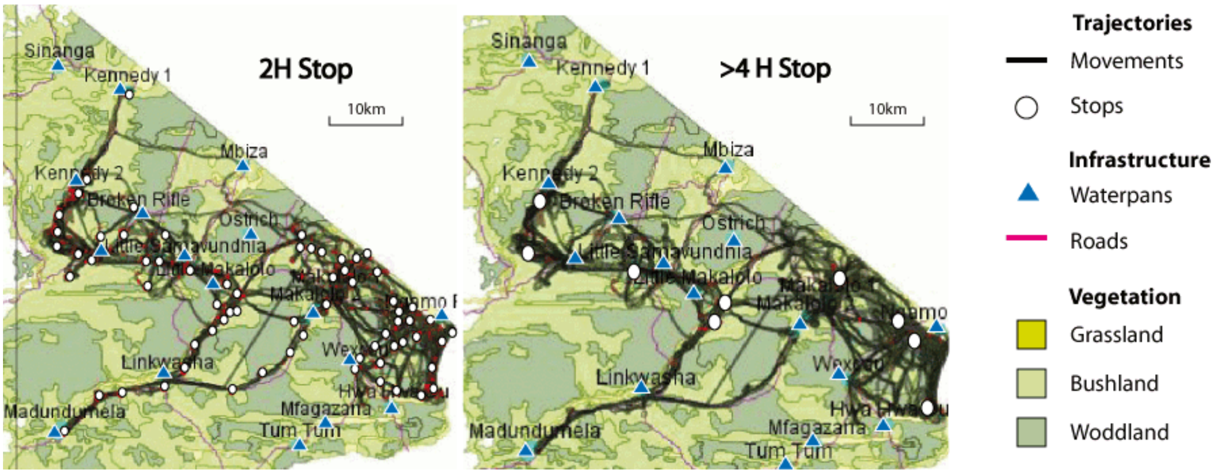

Figure 5: Stations patterns of different durations.

To sum up this section, the presented tool treats large datasets to extract places of convergence for several trajectories and assign activities to them. However we cannot follow the temporal frequency and temporal recurrence of attractive areas, in case animals come back several times in a place using the same path. To answer this issue, a 3D representation with time as the Z coordinate is proposed in section 3. For that, we focus on two types attractive areas: stations and corridors.

3- 3D representation of animal trajectories

To visualize our data in 3D, we use GeOxygene 3D (Brasebin 2009), a plateform developed at the COGIT laboratory. The rough 3D representation of an animal path, as presented in Figure 1, is unreadable for animal trajectory analysis. Nevertheless, this kind of representation becomes very useful if some visual clues are added in order to facilitate analysis on movements. Some applications use 3D representation to visualize animal trajectories in doing a generalization of trajectory rhythms (Andrienko et al. 2003). Our application for 3D path visualization is focused on the use of a well-adapted representation of the different points of interest to convey useful information for experts. In case of animal movements, useful information concern location of attractive areas (stations and corridors), durations of stations, number of animals stopping in these area and at different periods of time for movements to evaluate different species behaviors and in particular their activities. Again, these attributes define the pressure on space due to animals.

The first step is to integrate the stations of a trajectory in a 3D view, enlightening the duration and the environment. The trajectory of a group of animals is displayed as a 3D colored-line with a specific color (pink area on Figure 6).

From the phase of extraction of activities (section 2), stations are known and we choose to represent them as cylinders centered on the centroid of all locations in the station and whose

1. Filling color correspond to station duration. White corresponds to a short duration station (2h), then yellow to a 3h station, then orange a 4 h station and finally red for a more than 4 h station. In other words, the redder the station is, the higher the pressure is;
2. Radius corresponds to the size of the resting area (from the center of the cylinder). The thinner the cylinder is, the less the group of animals moves. It defines the compactness;
3. Border color identifies the animal (and is the same as the path color).

The choices of representation 1- and 2- precise the attributes of the stations in order to later affect activities to stations.

The filling color of the cylinder is chosen in a color shade. As an example, on Figure 6, white is for a 2-hour stop, yellow is for a 3-hour stop, orange for a 4-hour stop and red for a stop longer than 5 hours. This choice of colors is customizable. In addition, cubes are added on the cylinders to convey information about the local environment using image icons: a water drop represents a presence of waterhole and vegetation icons represent presence of vegetation. This vegetation has been classified by an expert according to three levels of density: tree, bush or grass. On this Figure, you can see the presence of trees in the station thanks to the acacia tree icon. Last information is added in representing corridors, which are detected from the extraction of attractive areas (section 2). If a path is inside a corridor, the 3D representation of the path is highlighted with red. It can be seen on the path on the right of Figure 6.

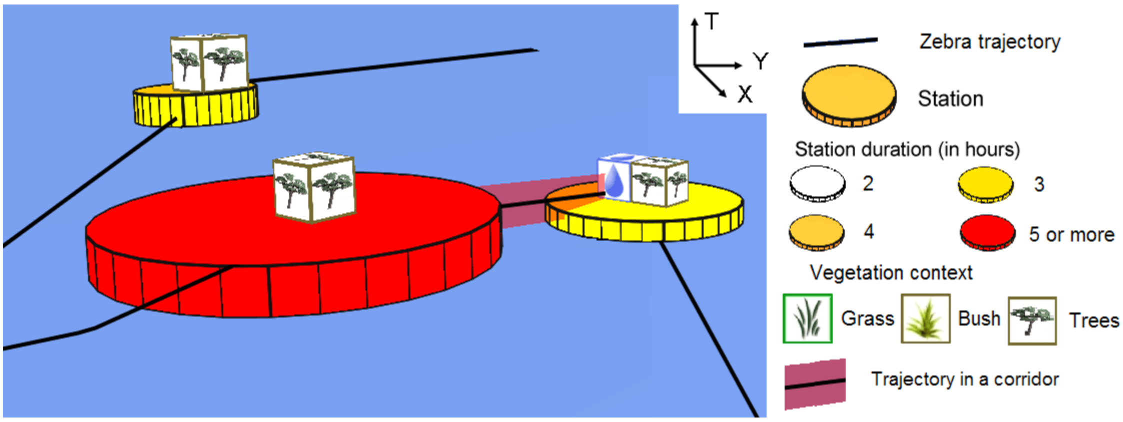

Figure 6: Focus on a part of a view representing stations of a zebra group.

This proposal for representing stations in 3D by varying size of cylinders can distort the perspective: a small station seems to be bigger if it is in front of the view. However icons on the top of the cylinders could help adjust this perception drawback. This 3D visualization of stations duration is designed as a tool for a 3D analysis of activities. Thus the idea is to connect station duration; station extent and the context to a particular activity among {drink, eat and sleep}. If it is easy to assume that the activity of drinking takes place next to a water hole (in Figure 6: the yellow station on the right), the two others activities are more difficult to distinguish with the context. One hypothesis is that if the station area is very thin, the activity is probably sleeping. In that way, in Figure 6, the big red station would be a station for eating whereas the thin yellow station in the background would be a place for sleep. This analysis is ongoing and is undertaken with experts.

The second represented information aims to distinguish periods of time, according to the relevant time intervals. In that way, we have a visual access to the temporal context of movement. The first temporal interval is the season, as resources and animal behaviors may change according to the season. The two seasons (wet and dry) are visually differentiated by hollowed colored cubes (blue for wet seasons and orange for dry seasons) which surround the whole space. Thus, the background color of a local view indicates the season. In Figure 7 following this principle, it can be seen that a group of zebras seems is slightly more mobile during the wet season than during the dry one. This view also enables to partition the quantity of information to ease readability.

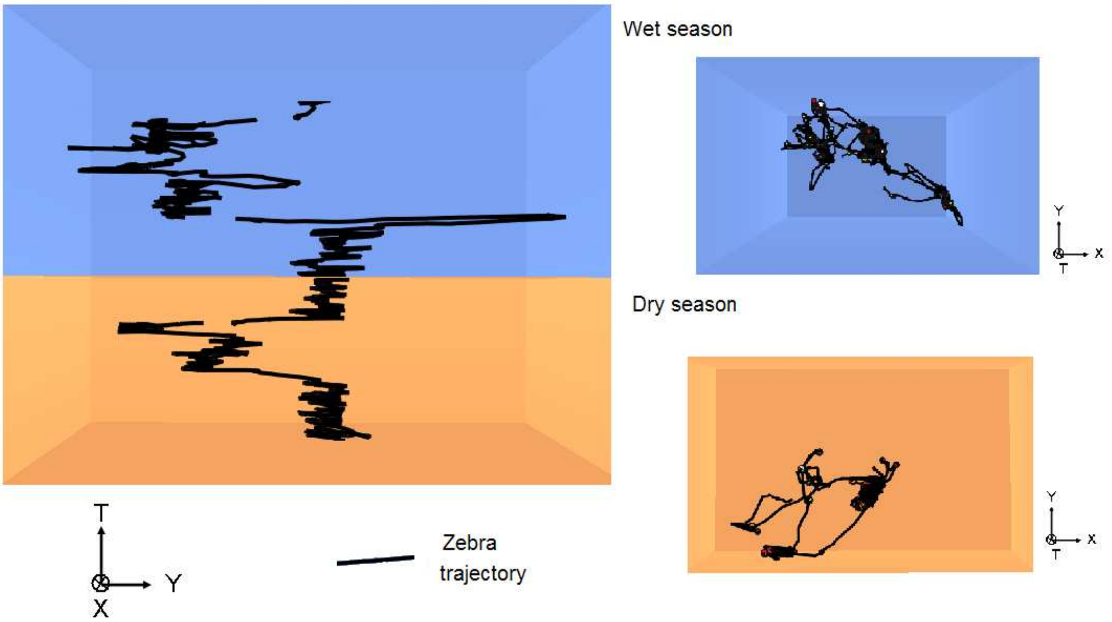

Figure 7: Global views of the trajectory of a group of zebras across two seasons (views in front and above the cube).

The second possible temporal interval distinguishes day and night periods, represented on the background on the 3D space as in Figure 8. Day is colored in yellow, night in dark blue. This Figure combines duration of station and temporal context in day or night. We can notice that one station is done per day and these stations are reached mainly at the beginning of the day after a night movement.

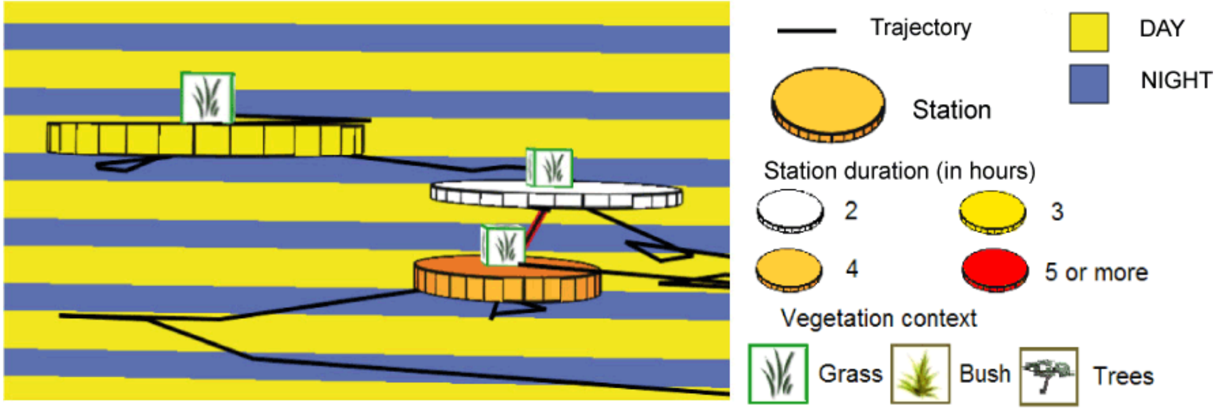

Figure 8: View of the trajectory of a zebra group by day and by night and station duration.

These representations of time periods are useful for a big time interval (seasonal difference for instance) but are more difficult to read in a small time interval. Indeed colors are localized in the background of the cube and because of the perspective, precise location of cylinders in the temporal zone is not ensured. Thus coloring time periods offers a new visual analytical capacity.

4- Discussion

4.1- Interest of automatic activities detection

Having activities and places of activities for several trajectories enables a place-oriented analysis of movements at a global scale.

To refine the analysis of attractive areas, the trajectories can be aggregated according to different criteria:

1) Time periods (the season, the day or others) to determine when the place is visited;
2) Species diversity: is it the same group, the same species or distinct species? We need to know if the resources of the place are specific to one species or common;
3) Spatial scale of the movements (are they large or small?) to identify the local or the global attractions;

Moreover, attractive areas bear quantitative information. Thus we define the pressure on space as a function of intensities of concentration ("How many animals come?") and frequency ("How often?"). These data are known on each area respectively by counting the number of tracks entering it and identifying temporal recurrences. Figure 9 shows the intensities of concentration of the previous attractive areas. Note that in 2D, these intensities are directly seen, as a superposition of different tracks. However in 2D, it is quite difficult to visualize temporal recurrence.

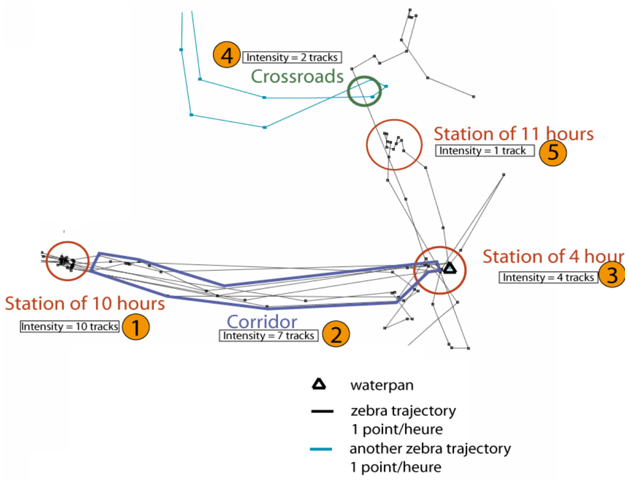

Figure 9: Intensities of concentration of attractive areas in trajectories. The area number 1 is the most intense, the number 5 the less.

The pressure on the vegetation is higher in these areas than in other areas of the park. Hence, in the attractive areas the animals should have the highest impact on the vegetation (Boulanger 2010), that is to say areas where the vegetation changes the most. We assume that when animals stop on stations consuming resources, the vegetation might be damaged according to the size of a station place (Loucougaray 2003). In the same way, in a corridor with much pressure due to animals, the vegetation might be damaged in a linear form. This work on pressure consequences is still ongoing.

4.2- Interest of 3D visualization for analyzing movements

In this section, we illustrate through two examples the interest of using the 3D visualization.

4.2.1- Time pattern

To study temporal recurrences in 2D, individual analysis and indicators are needed. 3D visualization facilitates this study by direct representation of time. Thus it is possible to perceive what happens in time in particular in areas where GPS tracks are dense. Moreover the application makes it possible to calculate time gaps between two features during 3D navigation: time to go from one station to another that is far away in case of back and forth movement (in Figure 10: stations among A and among B) or time gaps between stations that are spatially close (in Figure 10: stations among A only), called spatio-temporal collocation of stations, and represented by red large lines between concerned stations. For example, Figure 10 shows the temporal visualization and analysis of a back and forth movement of a zebra group during the wet season (background= blue) between a waterhole (icon= drop) and a station area in a bushy vegetation (icon= bush). Figure 11 shows the same data, in the same area but in 2D. 3D visualization enables to focus on a short period, to count the frequency of movements, to perceive the durations of stations and speed of movements, to visualize directly the context of stations and to detect possible comebacks.

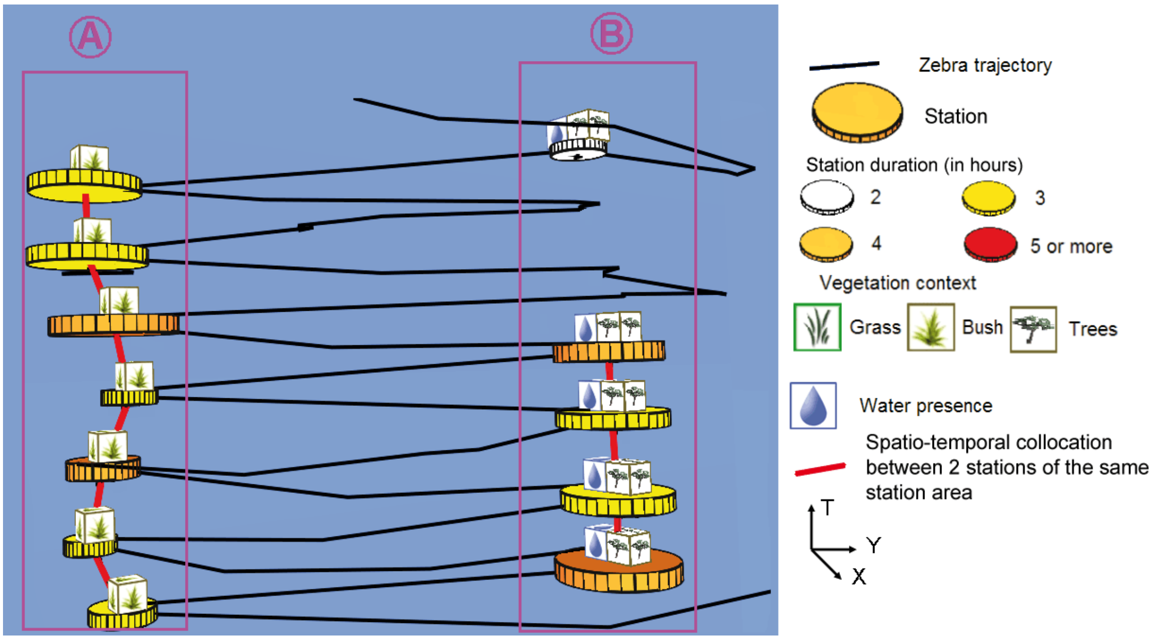

Figure 10: Temporal pattern of zebra trajectory.

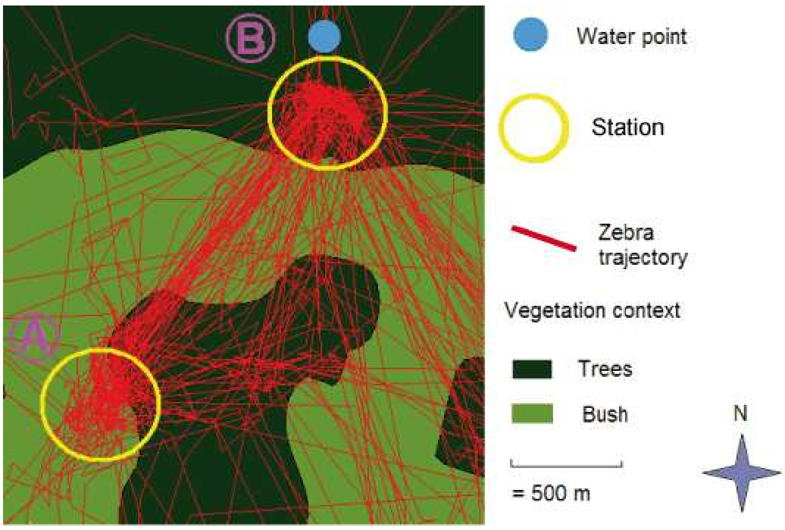

Figure 11: The same trajectory visualized in 2D with environment information (water points and vegetation).

In Figure 11, we see that 3D visualization is relevant to focus on temporal individual analysis. However aggregation analysis and attractive areas are better seen in 2D. In addition, context information is only localized on stations in 3D so the context information on movements, between stations, is lost in 3D. On the contrary, the continuous representation in 2D of the environment enables to make hypothesis on the movement. Therefore we believe that a join 2D-3D representation of movements is necessary in order to study spatial and temporal recurrences.

4.2.1- Interaction of individuals

A 3D viewer is also convenient for visualizing interactions between two different individuals. It enables to detect the possible influence of simultaneous presence of animals.

Different cases are possible: one avoiding the other (for example: prey/predator), sharing a place or one following the other. Figure 12 presents an extract of a scene with two groups of zebras, the green and the black groups. Each group stops at its own stations, the green and the black stations. However these stations are almost is the same place at the same time. There are three common station areas, where interactions take place, from the first in time to the last:

- Area 1 (bottom): the green group stops in a grassy station for a long time, 5 hours and more. Then the black group arrives and stops for a shorter time. The green group leaves before the black group.
- Area 2 (middle): the black group arrives first in a bushy area and leaves the last. This station lasts 4 hours. The green group takes a 2 hours station. Note that they take the same trajectory between the station areas 1 and 2 but this trajectory is hidden by the cylinders of the area 2.
- Area 3 (top): both groups leave this place at the same time. However the station extent of the black group is bigger, totally hiding the green station.

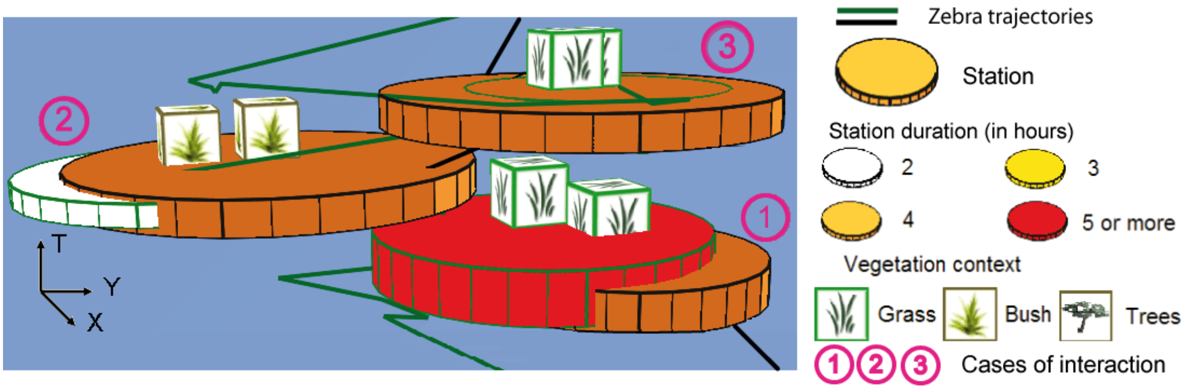

Figure 12: Interaction between two groups of zebras.

Figure 12 associates two trajectories together. The stations are represented separately. However to facilitate the reading, we should aggregate the icons together (one context icon for two trajectories) and improve the superposition of stations.

5- Conclusion and perspectives

In this paper, we explore animal trajectories in connecting together the environment and the movements. The first tool automatically detects attractive areas, especially stations and corridors, according to certain parameters (section 2). The second tool uses the previous results and integrates them in 3D: stations are represented as cylinders and corridors as red lines (section 3). It is particularly useful to see the interactions (1) between one path and the environment, since context information is added to the stations, and (2) between two paths (section 4).

As shown in this paper, a 3D view is interesting in order to follow individual paths in time, to detect time gaps and detect recurrences or interactions between individuals. The main issue with this kind of visualization is that it is quite disturbing for people not accustomed to 3D navigation. The activities extraction and 2D visualization enables to detect attractive areas and intensity of attraction. We think that 2D and 3D navigations are complementary, as they show different properties of trajectories.

To go further, good 3D representations for other concepts such as crossroads or centrality areas still have to be proposed. Concerning collocation, the different forms of mutual presence have to be studied. Indeed, this could appear not only on the stations but also on a corridor or on a crossroad (shunning, following, etc.). Finally, future work will also address the impact of pressure due to animals on the vegetation and water availability.

Acknowledgement. I express my gratitude to the HERD (Hwange Environmental Research for Development) project for its movement data and its expertise. Thanks also Anne Ruas and Lena Sanders for their helpful comments and suggestions.

6- References

Andrienko N., Andrienko G., Gatalsky P., 2003, Exploratory spatio-temporal visualization: an analytical review, Journal of Visual Languages and Computing, n° 14(6), pp 503-541

Badard T., Braun A., 2003, OXYGENE: An open framework for the deployment of geographic web services. In proceedings of the 21st International Cartographic Conference (ACI/ICA), Durban, South Africa, pp 994-1004

Baker RR, “The Evolutionnary Ecology of Animal Ligration”, 1978, Hodder and Stoughton, London.

Boulanger V., “Pression d’herbivorie et évolution des communautés végétales : influence à court et moyen termes des populations de cervidés sur la diversité végétale en milieu forestier ”, Université de Nancy, Ecole Doctorale RP2E, soutenue le 27 avril 2010.

Brasebin M., 2009, GeOxygene: An Open 3D Framework for the Development of Geographic Applications, 12th International Conference on Geographic Information Science (AGILE'09), 2-5 June, Hanovre (Germany)

Bucher B., Brasebin M., Buard E., Grosso E. and Mustière S., 2009, GeOxygene: built on top of the expertness of the French NMA to host and share advanced GI Science research results. *Proceedings of International Opensource Geospatial Research Symposium 2009* (OGRS'09), 8-10 July, Nantes (France).

Chamaillé-James S., Fritz H., Murindagomo F., 2007, “Climate-driven fluctuations in surface-water availability and the buffering role of artificial pumping in an African savanna: Potential implication for herbivore dynamics”, *Austral Ecology* 32, n°. 7, pp 740–748.

Chardonnel S., “La time-geography : les individus dans le temps et dans l’espace ”, *Modèles en analyse spatiale*, sous la direction de Léna Sanders, Chapitre 4, 2001, Traité IGAT, Editions Hermès, pp 129-156.

Hägerstrand T., “Time-Geography : focus on the corporeality of man, society and environment”, *The Science of Praxis of Complexity,* The United Nations University, 1985, pp 193-216.

Hägerstrand, T., “What about people in regional science?”, *Papers of the Regional Science Association*, **24**, 1970, 1-12.

Homburger W.S., Kell J.H., Perkins D.D., 1992, Fundamentals of Traffic Engineering, Institute of Transportation Studies, University of California at Berkeley, 13th edition.

Jolivet L., Cohen M., Ruas A., 2011, Characterizing geographical space to analyze fauna movement, accepted to ICC’11, July, Paris, France.

Kraak M.J, 2003, The space-time cube revisited from a geovisualization perspective, *Proceedings of the 21st International Cartographic Conference (ICC)*, pp. 1988-1996.

Kraak M.J, 2006, Playing with maps Explore, discover, learn, categorize, model, analyse, explain, present geographic and non-geographic data. IV, pp 291-296.

Kwan M.P. , Lee J.,”Geovisualization of Human Activity Patterns Using 3D GIS: A Time-Geographic Approach”, *Spatially Integrated Social Science*, 2003.

Loucougaray G., “Régimes de pâturage et hétérogénéité de la structure et du fonctionnement de la végétation prairiale (Marais Poitevin),” Décembre 18, 2003.

Langran G., “A Framework for Temporal Geographic Information”, *Cartographica*, vol 25, n°3, 1988, pp 1-14.

Lenntorp, B, “A time geographic simulation model of individual activity programmes”, In T. Carlstein, D.N. Parkes, and N.J. Thrift (eds.), *Human Activity and Time Geography*, London: Edward Arnold, 1978, pp 162-180.

Li X., Çöltekin A., Kraak M.-J., 2010, Visual Exploration of Eye Movement Data Using the Space-Time-Cube. GIScience 2010: 295-309- a.

Li X., Kraak M.-J., 2010, A temporal visualization concept: A new theoretical analytical approach for the visualization of multivariable spatio-temporal data. Geoinformatics 2010: 1-6- b.

MacEachren A.M, Kraak M.J., Research challenges in Geovisualization, Cartography and Geographic Information Systelms, N°1, 2001, pp.3-12.

Nathan R., “A movement ecology paradigm for unifying organismal movement research,” *Proceedings of the National Academy of Sciences* 105, 2008, n°. 49: 19052.

Peuquet D.J., 1994, “It’s about time: A conceptual framework for the representation of temporal dynamics in geographic information systems”, *Annals of the Association of the American Geographers*, vol 84, n°3, pp 441-461.

Rauske P.L., Chi Z., Dave A.S., Margoliash D., 2010, “Neuronal Stability and Drift across Periods of Sleep: Premotor Activity Patterns in a Vocal Control Nucleus of Adult Zebra Finches”, *The Journal of Neuroscience,* February 17, vol 30, n°7, pp 2783-2794.

Valeix M., Chamaillé-Jammes S., Fritz H., 2007, “Interference competition and temporal niche shifts: elephants and herbivore communities at waterholes,” *Oecologia* 153, n°. 3 (6), pp 739-748.