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To cite this version:

David Noël, Marlène Villanova-Oliver, Jérôme Gensel, Pierre Le Quéau. Modeling semantic trajectories including multiple viewpoints and explanatory factors: application to life trajectories. ACM SIGSPATIAL International Workshop on Smart Cities and Urban Analytics (UrbanGIS) 2015, ACM SIGSPATIAL, Nov 2015, Seattle, United States. hal-01212903

HAL Id: hal-01212903

https://hal.science/hal-01212903v1

Submitted on 7 Oct 2015

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Modeling semantic trajectories including multiple viewpoints and explanatory factors: application to life trajectories.

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ABSTRACT
In this paper, we propose a semantic trajectory model handling complex trajectories. We consider that a trajectory is composed of multiple aspects which are all different viewpoints from which it can be observed. This model also allows for the representation of explanatory factors that influenced the episodes that compose a trajectory. We here deal with a particular type of trajectory: the life trajectories of individuals or citizens. The residential aspect in life trajectories is particularly relevant for decision makers and urban planning experts who try to understand the residential choices of inhabitants in order to adjust their decisions. Those choices depend on factors related to the home (type, size...), and to the surroundings (accessibility, amenities ...) but they can only be fully apprehended by taking into account the life circumstances of the individuals, along their family, or professional or even spare-time activities viewpoints.

Keywords

Semantic trajectories, Residential trajectories, Geospatial lifelines, Individual lifeline

1. INTRODUCTION
Urban planning experts and decision makers face many challenges related to residential choices of inhabitants of metropolitan areas. These choices are strongly influenced by the various phases individuals go through in their personal lives. Thus, in general, couples with children prefer to live away from the metropolitan centers while those latter, in general, attract a higher proportion of both newly independent and retired people [7]. This illustrates some of the most important problems that major cities have to solve. This exodus of working couples with (young) children to peri-urban areas makes it difficult for the cities of the peripheries to provide the necessary amenities (for instance, nurseries and schools), but also increases the time workers need to commute from home to work, which generates pollution and traffic congestion. Similarly, in city centers, one witnesses the emergence of problems of cohabitation between two age categories with sometimes different lifestyles. The diversification of the population of city centers and the periphery of these cities is an important issue and it is essential for decision makers and urban planning experts to acquire a better knowledge of residential dynamics. In particular, in order to make their decision, they try to better understand what is at stake for an individual or a household in the process of choosing a residence.

Reasons for residential choice can be provided from a comprehensive approach to life trajectories of individuals that takes into account many decisive aspects of their lives: familial, professional... The living conditions, especially what is related to the characteristics of the residence and its neighborhood, the lifestyle preference [23], as well as other elements linked to the economic conditions must also be considered [10]. In this work, we specifically aim to take into account how individuals feel impacted by these elements. Then, in order to study the residential trajectory of an individual (the succession of its residential choices in time and space), it should be considered as an integrated part of a broader vision of her/his life trajectory. This part is one of the multiple and interconnected viewpoints (already demonstrated in computer sciences by Thériault [18]) from which the life trajectory of an individual can be observed.

Our goal is to provide a generic model able to support this complexity related to the multi-dimensional nature of a life trajectory and to explanatory factors that each viewpoint may encompass to explain its evolution or the evolution observed in another viewpoint. For example, in the case of life trajectories, a move (from the residential viewpoint), may be explained by a change from a professional viewpoint (career development, job loss, etc.). Beyond this trivial example, one issue is the

representation of the combination of several explanatory factors of various kinds (a change of job may have imposed a move, the beginning of a sense of insecurity may initiated it). Finally, another issue is the opportunity to represent, beyond the observed *true* facts (*e.g.* an observed *true* move), projects that contribute to an ideal of residential trajectory (*e.g.* a desire to settle down in a particular place, or in a particular type of home, *etc.*). In this work, we therefore provide a model handling the complexity and variety of trajectories by combining the concept of viewpoint with a time structuration relying on *episodes* and *events*. Our model includes also explanatory factors as they may be reported by individuals. This work uses life trajectories as an application case for the modeling and analytics of human mobility in the urban context.

The rest of the paper is organized as follows: we introduce in section 2, the notion of life trajectory. We present in section 3 a brief state of the art on semantic trajectory modeling and life trajectory modeling. Then we propose in section 4 our semantic life trajectory model which integrates multiple viewpoints and explanatory factors. Section 5 describes how this model can be exploited. Finally, we conclude and give directions for future work in section 6.

2. REPRESENTING AND STUDYING LIFE TRAJECTORIES

Figure 1 (adapted from Thériault [18]) shows a part of the life trajectory of an individual. The life trajectory is represented here as a succession of states which are characterized by values of different *statuses* or attributes describing this individual. These attributes can be grouped according to the different aspects of the life of a person (such as residential, family, work, hobbies, etc.). These different groups of attributes can therefore be considered as different trajectories targeting a particular theme. Therefore, our representation of life trajectory is multidimensional, each dimension corresponding to a "thematic" focus. Thus, for example, the residential trajectory is represented by statuses *is owner*, *rent/loan*, *housing type* and *city* (see Figure 1). Any status, and consequently any trajectory is intrinsically temporal, as related to a timeline that ordered its different states.

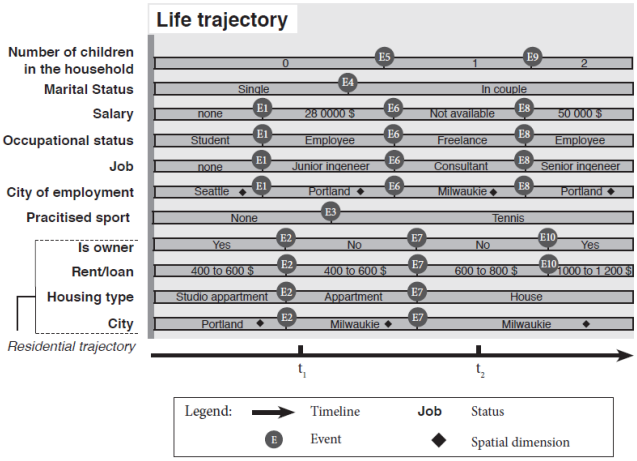

Figure 1: A part of a life trajectory (Adapted from Thériault [18])

In Thériault's work (see Figure 1), the residential and the professional trajectories are spatiotemporal trajectories since they each contain an attribute describing spatial information: the *city* of residence, and the *city of employment*. Such an information could be considered at another spatial scale, such as a neighborhood for the residential trajectory or as x, y coordinates. Other aspects of the life of the individual may also contain a spatial component, and be useful for the study of residential trajectories, for example the location where a hobby is practiced.

As underlined by the French sociologists Yves Grafmeyer and Jean-Yves Authier [14], the term "residential trajectory" "tends to suggest that successive positions in a given set is not simply by chance, but rather are linked together by an intelligible order." As a matter of fact a residential trajectory is not just a series of spatiotemporal positions.

Part of our objective is to make it possible to understand the meaning of residential trajectories by bringing to light the underlying reasons why individuals move in a given space, at a specific moment of their lives. The degree of control of an individual on her/his trajectory differs, and it seems to be appropriate to highlight the conditions under which each individual makes her/his own choices. More broadly, we want to elicit the explanatory factors or combinations of factors that have shaped a given trajectory. Thus, somehow what we seek to bring out here is close to the notion of *career* such as it has been defined by Howard Becker [6]. This concept "refers to the sequence of movements from one position to another" and includes "both objective facts of social structure and changes in the viewpoints, motivations, and desires of the individual". In the case of a residential trajectory, these factors are first to be found in the context surrounding the life trajectory of an individual. There are of course some internal factors which are directly linked to the specific characteristics of one or more viewpoints of this life trajectory. But, there are also some explanatory factors which can be external and so exogenous to the considered life trajectory. Among such external factors are, for instance, the housing market or change in the surroundings of the housing, *etc*... These external factors have nevertheless to be considered in correlation with the life trajectory. For instance, the fact that housing market prices are rising may have an impact depending on the salary of the individual/household and thus on her/his professional trajectory. In this work, we are particularly interested in those external factors which may be considered as plausible explanations, whether they are explicitly mentioned by the individuals or not.

Representing life trajectory is complex because it is composed of many descriptive attributes which may refer to different aspects of the individual life. The structuration using viewpoints aims to facilitate the overall comprehension and to offer a better readability of some salient characteristics attached to a particular thematic focus. The representation of a life trajectory is highly dependent on the domain of the study and on its purpose. For a study in urban development, the focus is on the attributes describing the residential trajectory, but explanatory factors can potentially be found in other foci. The study of life trajectories requires the use of suitable referential for considering the various parts of the trajectory separately but also in their interrelationships. Thus, a relevant modeling will enable the integration of explanatory factors of the trajectory, whether internal or external.

3. RELATED WORK

3.1 Modeling semantic trajectories

Many semantic trajectory models have been proposed in recent years, offering different solutions to enrich space-time trajectories. Most of these semantic trajectory models are based on different kinds of segmentation proposed for spatio-temporal trajectories. Indeed, following Hägerstraand and the "time-geography" [15], researchers have modelled the spatio-temporal trajectories through periods of trips and periods of activities [24], or through moves and stops [17]. These structures are then used to add information about the trajectory, like the transportation mode during a trip, or the nature of an activity. Such information can, for example, be related to the nature of the moving object, the nature of the mode of transportation, or the visited places. These authors propose especially solutions to enrich raw GPS data indicating the path of a moving object, which result in trajectories encompassing useful information in their description (see Figure 2).

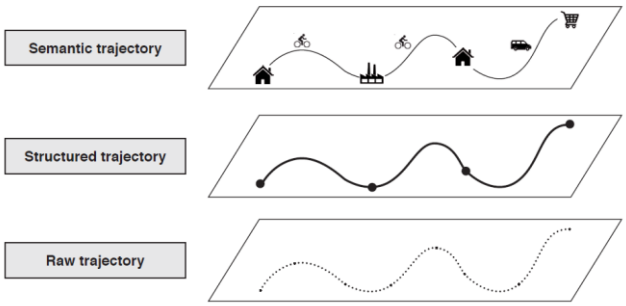

Figure 2 : From raw data to semantic trajectory (From Yan and Spaccapietra [21])

Depending on the scale level of the trajectory, raw data are not necessarily a series of GPS points. Indeed, in the case of life trajectories and when focusing on the residential aspect (or residential trajectory), the essential spatial component is the location of residence, which can be considered at different scales (address, district or, as in our example, the city). This, therefore, implies to consider a sequence of points or areas, indicating the successive residences of a person. When considering the structuration proposed by Spaccapietra [17], the positions of such places of residence, which persist over time, can be considered as "stops" in the life trajectory of an individual.

In Figure 2, the moving object is a person (individual, citizen) whose travels and moves are examined at the scale of the day. We understand thanks to some semantics (annotations) added to the trajectory that this person went to work on a bike, and after being back home she drove to the supermarket, information that was not contained in the raw trajectory. More broadly, any information which would make sense or help to describe or explain a trajectory more deeply than raw date (usually a series of triplets (latitude, longitude, time)), should be included in a semantic trajectory model [4].

3.2 Modeling life trajectories

The work conducted by Marius Thériault is a reference in the field of the life trajectory modeling. The space-time model for the analysis of life trajectories [18] is based on three different trajectories - residential, family and professional. Each of these trajectories is conceptually modeled by *episodes* - stable statutes during a time interval - and *events* altering one or more of these statutes. The conceptual model is based on a relational approach. Later, the model has been modified in order to determine the likelihood of an event occurring under certain conditions in a life trajectory [19]. The conditions of the residential choices are also addressed by [22] with a strong emphasis on the role of job changes occurring in the professional life of individuals. The models proposed in these works are centered on the temporal aspect of residential choices: the focus is more on *why* people have moved at some place (depending on their life circumstances) than on *why they have chosen* the place where they have moved to.

The aforementioned approaches have clearly laid the conceptual foundations on which we rely for the representation of life trajectories. Our work, however, aim to enrich this representation by a model of semantic trajectories that handles multiple semantic viewpoints and integrates explanatory factors about trajectories, whether these trajectories belong to a single project of life in the minds of individuals, or are drawn from proved observations.

4. A SEMANTIC TRAJECTORY MODEL

4.1 Modeling semantic trajectories

In order to address the issue of the different viewpoints from which a trajectory is observed, we rely on the concept of point of view[1] (see [20]). A viewpoint is a perception among many that an observer has of a studied entity. The point of view consists of a subset of the attributes describing the entity that includes the key attribute – or the set of attributes - which form (s) its identifier as well as a subset of some other attributes. The identifier of the entity is always present in a point of view (or seen from this point of view). Any other attribute can be part of several points of view. According to the most common design of point of view (corresponding to the notion of views in DataBase Management Systems), we consider that the entity, whose trajectory is studied, is unique. The union of the points of view forms a complete picture (all attributes are represented) and coherent (all the attributes have the same value in every point of view) of the entity.

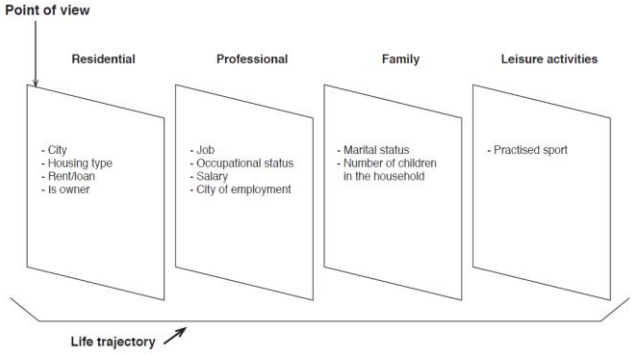

Figure 3 : Illustration of the notion of point of view

Figure 3 shows an example of four viewpoints from which the trajectory of a person can be observed. These viewpoints are adaptable to each person and/or over time, either by adding a new

[1] Viewpoint and point of view are considered as synonyms in this work.

attribute in a viewpoint, or by adding a new viewpoint. In our case study, the three viewpoints "residential, "family" and "professional" are essential because they are aspects of life that must absolutely be taken into account to find the explanatory factors behind residential trajectory. Other viewpoints may appear, however depending on the interests of the studied individual, such as leisure activities, which may indeed also influence residential choices. In the following sections, we define the key concepts of our proposal.

4.2 The life trajectory structuration

In this work, we combine the approaches of Leibniz and Newton. While the former considers time as a succession of events, the second considers it as a flow measurable in absolute terms [9]. Indeed, we consider the evolution of time as a succession of events, but without renouncing to measure it, using available units (year, day, hour ...). Our approach incorporates considerations carried out by Claramunt and Theriault [9] [8] in their work on time management in geographic information systems.

The first problem is to define the temporal granularity adapted to the modeling of life trajectories. According to [12], a *chronon* is a minimum amount of time, the smallest time stamp unit for an event. In the case of a life trajectory, a relevant *chronon* may be the day since this unit allows to locate important events in time with a precision that makes sense for an individual (such as the date of her wedding, the birth of a child, etc.). However, at the scale of life it is useful to use a chronon of other granularity, such as month or year, to locate an event for which accuracy in terms of day is impossible (for instance, when the precise date has been forgotten) or not required (for instance, when day accuracy is useless). The model must therefore supports varying degrees of temporal accuracy.

Our life trajectory model is composed of *episodes* which describe the *stable state* of a person when observed or considered from a given viewpoint. The state of a point of view is considered *stable* when the values of all its attributes remain unchanged. This modelling choice requires to choose carefully the information to represent (*i.e.* the relevant attributes), but also to determine the relevant degrees of precision. For instance, regarding the rent of some accommodation, the precise amount might be less relevant than a range of values. This allows to categorize and discretize information (low rent, high rent, etc.) and it has also the advantage of ensuring a certain stability for the value of the involved attributes. It might be indeed pointless for the overall objective (better understand the residential trajectories) to record a new episode simply because the rent has slightly increased.

The model is also composed of *events* that correspond to things that happen and that can be observed according to [1]. The event usually marks the transition from one stable state to another in one point of view (start and end of episodes).

Definition of an episode. An episode is the stable state of a person seen from a certain point of view during a time interval. The episode duration corresponds to a time interval between two instants t_s and t_e (as $t_s < t_e$). Each of these two instants may correspond to an event in the trajectory.

Let *Epi* be an episode of the life trajectory of a person *P* observed from a point of view *i*. It is composed of the k_P identifier of *P* and of attributes $a_j, \ldots, a_k$, and is valid over a time interval $[t_s, t_e]$. We note:

$$P.i.Epi(k_P, a_j, \ldots, a_k)\ [t_s, t_e]$$

In the example of Figure 1 showing the life trajectory of a person called Leo, an episode valid from 05/20/2000 to 06/30/2004 is noted as follows:

Leo.residential.Epi (k_P = 123, City="Seattle", Housing_type="Apartment", Rent=[400; 600]) [05/20/2000, 06/30/2004]

A non-strict order relation can be established between episodes using algebra of Allen (Allen, 1983).

Definition of an event. An event is related to a point of view *i* for an individual *P*. It has an identifier k_{Evt}, a name *evt_name*, and is associated with a chronon *t* relevant to the observed phenomenon (allowing to locate the event temporally). We note:

P. i.Evt (kEvt, evt_name) t

For example an event *move* occurred on 06/30/2004 in the trajectory of Leo and is noted in the residential point of view:

Leo.residential.Evt (K_{Evt} = 1, evt_name = "move") 06/30/2004

The evt_name attribute is selected from a controlled vocabulary and describes the nature of the event. An ontology structuring all of the vocabulary specific to each point of view is being defined.

Definition of a trajectory. The life trajectory *T* of a person *P* consists of the union of the points of view *i*, each being defined by a set of events and episodes. We note:

$$P.T = \{U\ P.i\}\ for\ i \in \{Residential, Professional, Family, \ldots\}$$

A simplified trajectory observed from a single point of view *i* composed of two events and two episodes with the one still ongoing can thus be noted as follows:

$$P.T.i = \{P.i.Evt(k_{Evt,}, evt_name)t_1\ ;\ P.i.Epi\ (k_P, a_j, \ldots, a_k)\ [t_1, t_2]\ ;\ P.i.Evt(k_{Evt,}, evt_name)t_2\ ;\ P.i.Epi\ (k_P, a_j, \ldots, a_k)\ [t_2, today]\}$$

With $t_1 < t_2$, $t_2 <$ *tod and tod= today's date. At least one value among the attributes* $(a_j, \ldots, a_k)$ *is different between* $P.i.Epi\ (k_P, a_j, \ldots, a_k)\ [t_1, t_2]$ *and* $P.i.Epi\ (k_P, a_j, \ldots, a_k)\ [t_2, tod]$. *(this means a new episode occured).*

4.3 Integrating explanatory factors

Considering that the life trajectory of a person includes events which modify its state under a given viewpoint, it is essential to model the explanatory factors which can be associated with these events.

The explanatory factors can be internal or external, which means that they can either be related to life circumstances of the individual or dependent on factors that are not directly related to these circumstances. For example, internal factors may be related to the birth of a child or to professional situation changes. It therefore appears that in our model, the events themselves may be explanatory factors. Thus, the event "job change" may be an explanatory factor behind the "move event. The explanatory factors of the residential trajectory of the individual can also be

found in environmental conditions (economic, social, *etc.*) within which the individual evolves. This is for example the case of the price of the real estate market that may limit acquisition or rental into a given neighborhood. However, we only want to model these external factors if they have some impact on individuals, and specifically if these factors are explicitly mentioned by them. In this case, an event related to a feeling expressed by the individual is added to the trajectory. Thus, the event "Feeling of insecurity" is an example[2].

An explanatory factor *F* is associated with the event it explains. Each event can be explained by several factors. The above definition for an event is extended and we note:

$$P.i.Evt(k_{Evt}, evt_name, \{F_1, \ldots, F_n\})t$$

$$\text{with } F_j\ (k_{Exp}, description)$$

Each explanatory factor *Fj* combines the identifier k_{Exp} of an event (the explanation) and a *description* attribute used to specify the influence of the event for the view *i* to which belongs the explained event k_{Exp}.

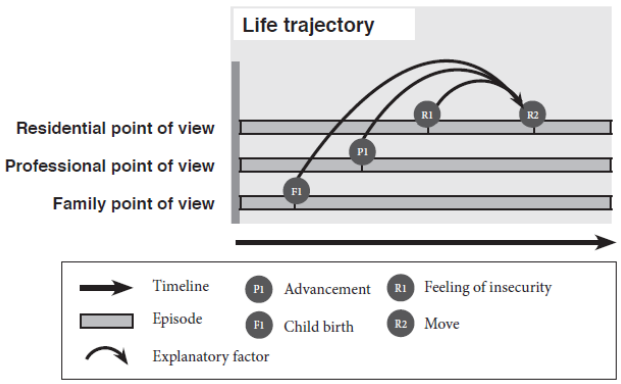

Figure 4 : The explanatory factors of an event. The values correspond to events identifiers.

In the example of Figure 4, an excerpt of the life trajectory of a person called Mila, there are three factors that explain the event R2 *Move*

$$Mila.residential.Evt\ (k_{Evt} = R2,\ evt_name="Move",\ \{F_1, F_2, F_3\})\ 05/10/2014$$

and they can be modeled as follows :

F_1 *(R1, "*The break-ins in my neighborhood in March 2015 made me move *")*

F_2 *(P1, "*The increase in my salary allows me more rent*")*

F_3 *(F1, "*We needed more room*")*

[2] In accordance with the definitions given above, this creates a new episode due to the change in value of an attribute dedicated to the feeling of insecurity.

Note that the explanatory factors can be inter-point of view or intra-point of view: they may depend on events occurring within the same point of view that the event they explain, or on events occurring in another point of view (see Figure 4).

5. EXPLOITATION OF THE MODEL

In this section, we present how the proposed model can be exploited. First we show how the concepts defined so far (episodes, events and explanatory factors) can be used in order to enrich the representation of life trajectories by modeling the expectations of an individual. Then, we illustrate with a few examples the possibilities of knowledge exploitation allowing by the model.

5.1 Observed trajectory and expectations

The explanatory factors of residential choices, whether they are linked to known facts or to feelings of the individual are not always sufficient to explain its trajectory. Individual projects, or more broadly, their desires or aspirations must be considered and therefore modeled. The concepts presented above (episodes, events and explanatory factors) can be exploited for this purpose. We can represent either the observed trajectory of individuals or the plans they have made or are making for the future.

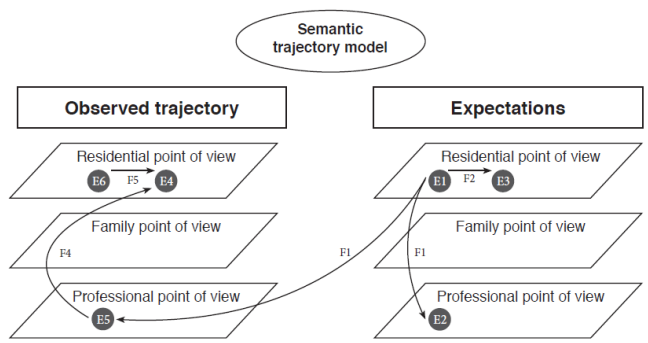

Figure 5 : Observed trajectory and expectations (representation of events and explanatory factors).

Thus, it is possible to represent residential or professional projects that Leo has made in the past while he was living in Portland, and the reasons for these choices (the events and the explanatory factors are shown in Figure 5):

Leo.residential_project.Epi (k_P*=35, City="Redmond", Housing="Apartment") [2000, 2005]*

Leo.professionnal_project.Epi (k_P*=35, City_of_employment="Seattle", Occupational_status="Student") [2000, 2005]*

Leo.residential_project.Evt(K_{Evt}*=E1, evt_name="Offer") april2000*

Leo.professional_project.Evt(K_{Evt}*=E2, evt_name="JoinSchool", F1) april2000*

Leo.projet_résidentiel.Evt(K_{Evt}*=E3, evt_name="Move", F2) august2000*

F1 (e1, "My aunt had an apartment in Redmond and she proposed me to live in it. The choice of school in Seattle was thus a viable option")

F2 (e1, "The apartment in Redmond was available from August")

This would mean that Leo had planned in April 2000 to join a school in Seattle (event E2) because he could live in the apartment of his aunt for free (event E1) (and not the reverse, he has not considered moving in Redmond because he was joining this school). The move (event E3) was possible in August 2000.

However, although Leo has joined the School of Seattle (event E5) at the beginning of September 2000, it turned out that his aunt had sold her apartment in June 2000, leaving him with no housing solution (event E6). He had therefore to find an alternative accommodation (event E4) near the city of Seattle.

Leo.residential.Epi (k_P=35, City="Renton", Housing_type="Studio Apartment") [2000, 2001]

Leo.professional.Epi (k_P=35, City_of_employment="Seattle", Occupational_status="Student") [2000, 2005]

Leo.residential.Evt(K_{Evt}=E4, evt_name="Move", F4, F5) sept2000

Léo.professional.Evt(K_{Evt}=E5, evt_name="Join School", F1) sept2000

Léo.residential.Evt(K_{Evt}=E6, evt_name="No housing solution") juin2000

F4 (E5, "I joined the school in Portland")

F5 (E6, "My aunt sold her apartment.")

This example illustrates that it is possible to use the model to represent two types of trajectories, the observed (*i.e.* where and when individuals have actually lived), and one that could have existed or to which the individual aspires. Both can be compared to measure and analyze differences. In particular, interesting cases can occur, such as the one related to *e1* event, expressed originally in a planned trajectory but which finally impacts the observed trajectory.

5.2 Model querying

The model can be operated with temporal spatial and / or thematic inputs through the use of a query language suitable for the formalism of implementation of the model. Concerning the time dimension, it can for example be used to get the status of one or more individuals at a time *t* or during a time interval [t1, t2]. For example, we could get the residential situation of Leo (given on figure 1 by the attributes *city*, *housing type*, *is owner* and *rent/loan*) between two dates. Spatially, it is possible to know which locations (according to the granularity chosen for the spatial attributes of the model) are part of the trajectory of individuals. Such requests may involve the location of residences or places of work and their possible neighborhood. Naturally, applications are also possible on spatio-temporal or thematic aspects.

The model allows also to learn about the underlying factors related to residential mobility for a particular individual or group of individuals. It is for instance possible to focus on a specific event in the trajectory and to look for its causes.

Similarly, queries combining temporal or spatial dimensions with explanatory factors are possible. For the residential point of view, it is possible to know for a given move at what date the first explanatory factor emerged. It is thus possible to define a latency period, which corresponds to a time interval during which an individual is likely planning to move.

6. CONCLUSION

We have proposed an original model for semantic trajectories integrating multiple viewpoints and explanatory factors. We have demonstrated the utility of these two concepts in order to model life trajectories. The use of the concept of viewpoint allows high adaptability depending on studied informations, besides a classification both in time and between individuals. In addition, the integration model of explanatory factors allows us to better understand the reasons why and circumstances in which people are moving, whether they depend on external or on internal factors to their trajectories.

The implementation of our proposal is in progress and relies on the principles of the TROPES model [16]. This approach is particularly interesting because it includes a classification mechanism of instances within each viewpoint.

A data collection will be first performed through a survey led with a representative panel of about fifty people in order to assess the model itself. In a second step, data will be provided by the individuals themselves through an *ad hoc* online application, before we try to harvest (part of) trajectory data from social networks.

We also work on an algebra and algorithms dedicated to the model exploitation. Besides querying the model, inference techniques will be propose to build some knowledge about trajectories We particularly focus on the possibility of identifying key explanatory factors underlying the reasons of changes observed in a given trajectory, specially residential one.

7. ACKNOWLEDGMENTS

We would like to thank the Rhône-Alpes Region Council for his support to our work.

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