Representing Habits as Streams of Situational Contexts

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Abstract. The increasing use of smart devices allows us to extract massive streams of data, e.g., sensor streams, questionnaires, answers, annotations, etc. This information is crucial for the recognition of people's behaviours and habits. The main challenge is how to represent and organize such large scale, complex and heterogeneous data streams. This representation should allow for the management of all possible and unpredictable personal situations. The main goal of this paper is to propose a formalization of the personal situational context, showing how it can model real-life situations. The intuition is that, by collecting data from different people, we can populate the model and enhance the knowledge about those people by learning different aspects of their life habits. We start defining the abstract notions of the personal situational context and habits. Then, we provide an informal representation of such notions. Finally, we generate a universal ontological model of the situation context and habits, formally represented with an Entity Type Graph.

Keywords: Representing Habits · Situational Context · Data Streams

1 Introduction

Habits[1] are "behavioral patterns acquired by frequent repetition or physiologic exposure that show themselves in regularity or increased facility of performance." A habit is regular, predictable, learned by practice and is performed almost automatically [1]. Knowing about habits can help predict people's activities, thus supporting them in everyday life. But how to learn about them? Smart devices can collect a large amount of personal data, e.g., answers to questionnaires, annotations, and sensors. For instance, a study used smartphone data (call records, Bluetooth logs, and others) to study students' social networks and daily activities [2]. The StudentLife project [3] employs smartphone sensors and answers to questionnaires to infer students' mental health, academic performance, and

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[1] https://www.merriam-webster.com/dictionary/habit.

so on. These are examples of studies that used smart devices streams to study partial aspects of people's habits, but the challenge of formalizing a universal ontological model still remains.

Context is a theory that describes the world from an individual's perspective [4, 5]. Situational contexts are very powerful means for modeling the user's life, as understood by the users themselves [6]. As such, they provide a powerful means for organizing a large amount of highly heterogeneous data streams that are needed to represent possible daily situations and, as a particular case, personal habits. Some work in this direction is described in [5], where contexts are used to provide a unified account of people, devices, the environment and services provided. Further, the work in [7] models the personal context and uses it to represent different dimensions, e.g., the spatial-temporal and the social dimension.

This paper improves on the previous work by extending our notion of situational context, by introducing the notion of habits, and by defining a general formal model in the form of an Entity Type Graph (ETG). This ETG allows us to organize and store large amounts of data streams. In the ETG, nodes are the entities of our model (e.g., Person, Location), and links represent the relations existing across entities (e.g., With relation between Object and Sub-event).

We will exemplify our notions, across the paper, via the following *motivating example*. Mary usually shops with her smartphone and Bob in the Sun market. They talk with each other in the shopping. Often, Mary studies in office A with her laptop. After that, Mary studies with her laptop on the balcony of her home and then has dinner with Bob in the kitchen. All the above activities are habits, happening at different frequencies. For instance, shopping at the Sun market happens every week, while Mary goes to work every weekday.

2 Modeling Life Sequences, Contexts and Habits

A situational context represents a real life scenario from the perspective of a person, that we call `me`, e.g., Mary in the example. We call the *Life sequence* a sequence of contexts during a certain period of time. We have the following:

$$S\left(me\right) = \langle C_1\left(me\right), \ldots, C_n\left(me\right)\rangle; \quad 1 \leq i \leq n \tag{1}$$

where $C_i(me)$ is the i_{th} situational context of `me`. We assume that `me` is involved in only one personal context at a time. In fact, at any given moment, a person can be in only one place. Hence, S is a sequence of contexts of `me` covering the full period under consideration, where contexts without overlapping. In turn, we model the situational context of `me` $C(me)$ by `me`'s views as follows:

$$C(me) = \langle L(C(me)), E(L(C(me)))\rangle \tag{2}$$

In the following, we simplify the notation by dropping the argument `me` when no ambiguity arises. $L(C)$ is the *Location* of `me`. The location defines the spatial boundaries inside which the current scenario evolves. $E(L(C))$ is the *Event* within which `me` is involved at the moment. The current event defines the temporal boundaries within which the current context evolves. An event is parameterized on the location as we may have different events occurring in the same location. Location and event are the priors of experience, defining the scenario that needs to be modeled. They univocally define the spatio-temporal coordinates of any person in the world. The change of context coincides with a change of the current location or of the current event. For Mary's shopping example, the location *Sun market* and the event *shopping* give an example of the (current) context at a certain moment in time.

Inside a certain context, `me` can be inside one or more locations, which change any time `me` moves from one place to another. For example, when at home, Mary may stay on the balcony or in the kitchen. We have the following:

$$L(C) = \langle L_1(C), \ldots, L_n(C) \rangle; \quad 1 \leq i \leq n \tag{3}$$

where $L_i(C)$ is a spatial part of $L(C)$. We say that $L_i(C)$ is a *sub-location* of $L(C)$. If `me` is in one location, we say that the current context is *static*, and we have that $L(C) = L_1(C) = \cdots = L_n(C)$. Otherwise, we say that the current context is *dynamic*. In the above example, Mary's home (i.e., $L(C)$) contains the balcony (i.e., $L_1(C)$) and the kitchen (i.e., $L_2(C)$). Depending on the level of detail at which we represent Mary's life, we may have a static context, i.e., Mary being at home, or a dynamic context, i.e., Mary being first on the balcony and then in the kitchen. The choice is part of the way Mary thinks of what she is doing, see, e.g., [8] for more details on the issue of the subjectivity of (the descriptions of) the situational contexts. Within contexts, events behave as contexts within life sequences. We have the following:

$$E(L(C)) = \langle E_1(L(C)), \ldots, E_n(L(C)) \rangle; \quad 1 \leq i \leq n \tag{4}$$

with $E_i(L(C))$ part of $E(L(C))$. Similarly to the above, we say that any $E_i(L(C))$ is a *sub-event* of $E(L(C))$. Sub-events may be parallel or sequential or mixed. We may again have that $E(L(C)) = E(L_1(C)) = \cdots = E(L_n(C))$. In fact, with static contexts, events are distinct (while occurring within the same location), while in dynamic contexts we may have, but not necessarily, the same event occurring in different locations. Thus, for instance, at home, Mary will usually do different things, e.g., cooking and watching TV, while she might keep talking when moving from one place to another. In this case, we say that the current life sequence is *location-dynamic* but *event-static*. The case of *traveling* is of particular relevance. Assume, for instance, that Mary will be traveling from Trento to Rome and that she will be doing many different things while traveling. This real world event will be modeled as a static context if the location considered is Italy, or as a life sequence of length greater than one if the different locations touched by the trip, e.g., Trento, Rome, are explicitly represented.

The context defined by location and event will contain, within its spatio-temporal boundaries, various types of general objects interacting among them. It is required that `me` is one of them. We capture this intuition by defining the notion of *Context Part* $P(C)$ defined as follows:

$$P(C) = \langle me, \{P\}, \{O\}, \{A\} \rangle \tag{5}$$

where $\{P\}$, $\{O\}$ and $\{A\}$ are, respectively, a set of persons (e.g., Bob), a set of objects (e.g., a smartphone) and a set of actions involving them. As from Definition 5, even within the same location and the same event, the world evolves, because of actions. For instance, in the shopping scenario, the event *shopping* involves Mary's action "speak to Bob" and Bob's action "speak to Mary". We say that a context is a *static context* when there are no changes. Data streams in fact capture the instantaneous properties of static contexts. Given the above definitions, we define Habits H as follows:

$$H = \langle S_{a_1} : a_1, \ldots, S_{a_n} : a_n, F\rangle; \quad 1 \leq i \leq n \tag{6}$$

where S_i is a life sequence and a_i is an *activity* involving `me` involving any other element in the current context. Examples of a_i are: *being in a location*, *being involved in an event*, *being together with a person*, *using an object*, *performing an action*. F is the *Frequency* at which H occurs. There are various levels of flexibility which can be used in the definition of F, but this is out of the scope of this short paper. We have therefore five basic types of habits: spatial habits, temporal habits, social habits, material habits, and action habits. An example of habit is Mary's material habit of always carrying her smartphone and laptop.

3 Representing Life Sequences, Contexts and Habits

Figure 1 is an example of informal representation of life sequence (see Definition 1), as described in the motivating example. A life sequence is represented as

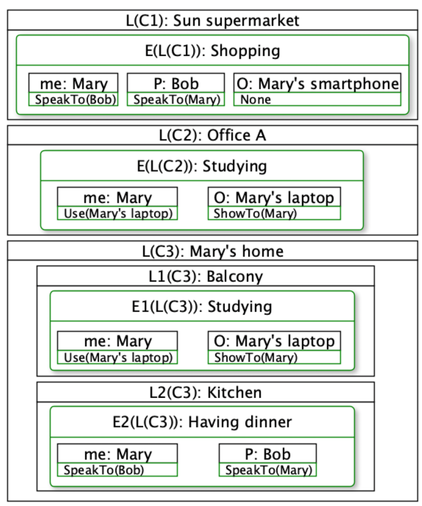

Fig. 1. The contexts of Mary.

a sequence of contexts, where, for each context, we draw location, event, `me`, person and object with boxes. Events and actions are drawn with green borders. For each context, the most external reference is the location container, which may contain multiple sub-locations. Multiple locations are ordered from the top to the bottom according to time. Each location contains an event, which may contain multiple sub-events. Multiple sub-events are ordered from the top to the end by their happening time. For example, in the bottom box of Fig. 1, the location is Mary's home, which contains the balcony and kitchen. At Mary's home, we have the default event *being at home*. An event box contains `me`, person and object boxes, e.g., Mary (`me`), Mary's smartphone box in the top box.

As from Definition 6, habits are just sequences of life sequences where specific activities have been selected annotated by the frequency at which they occur. This means that Figure 1 can be used to represent habits simply by selecting the relevant actions, as from Definition 6 (see the comment after Definition 6). Thus, for instance, the life sequence in Figure 1 can be used to define and represent the following spatial habit

$$H_S = \langle\langle \text{ C1 } \rangle : \text{Sun market, 1 week } \rangle$$

where we have assumed that ⟨ C1 ⟩ is a life sequence containing the single context C1 and that the habit H_S occurs every week.

The key observation, which allows for the representation life sequences of any length and representing any possible real world situation, is that contexts can be represented as ETGs where location and event define the spatio-temporal boundaries within which such models hold. Fig. 2 reports the corresponding ETG, where for simplicity, we have not represented actions. (They would be modeled as properties of entities.)

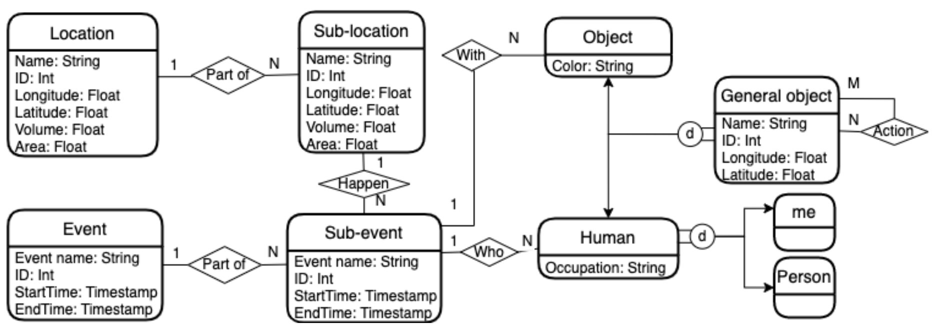

Fig. 2. The ETG modeling the situational context.

From the definition of $C_i(me)$, we represent five main entities. Based on this, we have the following entity types: `General Object`, `Object`, `Human` (`Person` and `me`), `Location`, and `Event`, drawn with nodes in ETG.

1. `General Object`: Represent any object in any context.
2. `Object`: Extend from General Object and represent the non-human objects in any context (e.g., Smartphone).
3. `Human`: Extend from General Object and represent humans (e.g., me, Person).
4. `Location`: Represent any Location. Sub-location is a `part of` Location.
5. `Event`: Represent any Event. Sub-event is a `part of` Event.

We add the properties with data types of entity types in nodes, e.g., `Name: String` in the `Location` node. We show relations among entity types with rhombuses. For example, we have two Relations: `With` and `Who`, the first linking events with objects, the second linking events with humans. These two relations implement Definition 5. There are inheritance relations among entity types. We use the "d" in a circle that connects the superclass with a double line and each subclass using a single line with an arrow. For example, the superclass `General object` has two subclasses `Object` and `Human`.

Our graph representations will allow us to create, read, update, and relate information as they are recognized. This model, in a preliminary version, has been validated by using it in a large scale data collection and study experiment in the SmartUniversity (SU) project. This project used the `iLog` app [9] to collect one hundred and eighty-four students' daily life data over a period of four weeks. We have two studies that used this data collection [8, 10]. Mapping data collections into our model opens the possibility of learning people's habits.

4 Conclusion

This paper proposes a general model of life sequences, situational contexts and habits. The (sequence of) ETG model(s) defined based on these definitions can be used to organize large scale data streams, as they can be collected by the sensors of smartphones and smartwatches.

References

1. Joan C Rogers. Habits: Do we practice what we preach? *The Occupational Therapy Journal of Research*, 20(1_suppl):119S–122S, 2000.
2. Nathan Eagle and Alex Sandy Pentland. Reality mining: sensing complex social systems. *Personal and ubiquitous computing*, 10(4):255–268, 2006.
3. Rui Wang, Fanglin Chen, Zhenyu Chen, Tianxing Li, Gabriella Harari, Stefanie Tignor, Xia Zhou, Dror Ben-Zeev, and Andrew T Campbell. Studentlife: assessing mental health, academic performance and behavioral trends of college students using smartphones. In *Proceedings of ACM - UBICOMP*, pages 3–14, 2014.
4. Fausto Giunchiglia, Enrico Bignotti, and Mattia Zeni. Personal context modelling and annotation. In *2017 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops)*, pages 117–122. IEEE, 2017.
5. Ramón Hervás, José Bravo, and Jesús Fontecha. A context model based on ontological languages: a proposal for information visualization. *J. University C.S.*, 16(12):1539–1555, 2010.
6. Paolo Bouquet, Enrico Giunchiglia, and Fausto Giunchiglia. Contexts, locality and generality. *Mathware & soft computing. 1996 Vol. 3 Núm. 1 [-2] p. 47-57*, 1996.
7. Fausto Giunchiglia, Marcelo Rodas Britez, Andrea Bontempelli, and Xiaoyue Li. Streaming and learning the personal context. In *Twelfth International Workshop Modelling and Reasoning in Context*, page 19, 2021.
8. Wanyi Zhang, Qiang Shen, Stefano Teso, Bruno Lepri, Andrea Passerini, Ivano Bison, and Fausto Giunchiglia. Putting human behavior predictability in context. *EPJ Data Science*, 10(1):42, 2021.
9. Mattia Zeni, Ilya Zaihrayeu, and Fausto Giunchiglia. Multi-device activity logging. In *Proceedings of ACM - UBICOMP: Adjunct Publication*, pages 299–302, 2014.
10. Mattia Zeni, Wanyi Zhang, Enrico Bignotti, Andrea Passerini, and Fausto Giunchiglia. Fixing mislabeling by human annotators leveraging conflict resolution and prior knowledge. *ACM UBICOMP*, 3(1):32, 2019.