Towards a WHAT-WHY-HOW Taxonomy of Trajectories in Visualization Research

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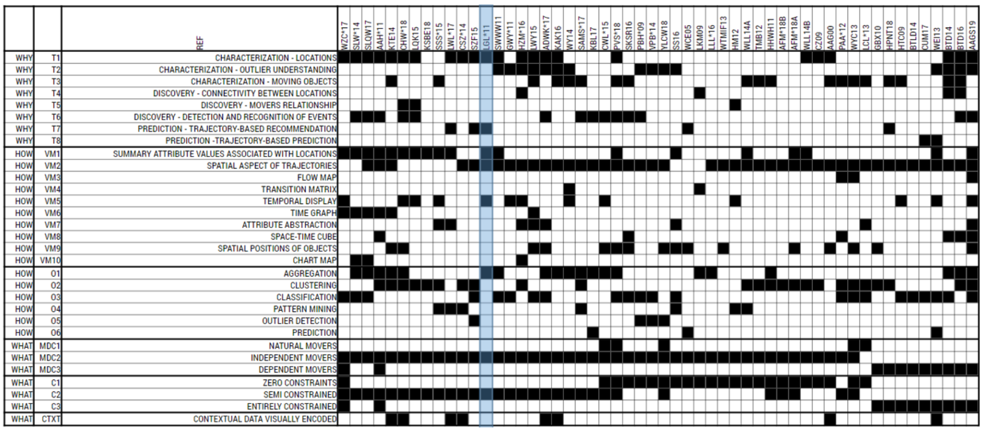

Figure 1: *Our WHAT-WHY-HOW taxonomy of trajectories visualization research illustrated using the Bertifier technique [PDF14]. The documents are ordered through Bertifier's visual similarity algorithm that makes patterns easier to discern. Find the data here:* `https://bit.ly/2vyoSoQ`*. The blue column indicates a document discussed as a populating example here:*`https://bit.ly/3047x5l`

Abstract

Effective analysis of movement often requires a comprehensive approach where computational and visual methods are combined to address a wide variety of tasks involving movers with diverse characteristics. In order to help the process of designing effective methods for a wide range of movement analysis cases, we develop a provisional taxonomy that links what Brehmer et al. [BM13] term statements of WHY-WHAT-HOW with tasks, types of movers, context and methods used to compute or visualize data. Within this document we present the origin of this taxonomy, the process we followed to populate it, discuss the novel categories within it, and finally use it to explore relationships between elements of trajectory analysis. Our main contribution is to provide a new means of connecting elements of WHY-WHAT-HOW when analysing trajectories.

1. Introduction

As capacity to collect data records of movements has increased, many methods and tools have been developed in an effort to analyse movement [AA13]. Brehmer et al. [BM13] introduced a typology that links WHY-WHAT-HOW for the analysis of a field. This model can be used to identify the data, tasks and idioms being employed. It provides "*a scaffold to think systematically about design space*" [BM13] and enables us to develop a taxonomy that may help us learn about current practice, guide analysts and designers and identify gaps for research and design. This document uses the model developed by Brehmer et al. [BM13] to link WHAT-WHY-HOW for the analysis of movement. The result is a taxonomy presented in Figure 1, with 54 documents populating it. Two existing works are relevant to our proposed taxonomy: the conceptual framework by Andrienko et al. [AAB*11] that presents a series of approaches to analyse spatio-temporal data by linking low-level analysis tasks and visualisation methods (WHY-HOW); and the taxonomy developed by Mazimpaka et al. [MT16] that details the types of operations that can be applied to support certain higher-level tasks, provides suggestions for mining methods, and to a lesser extent, visualisation methods (WHY-HOW). Both those papers link tasks and methods to analyse movement and discuss different movers through examples but none attempt to identify mappings between tasks, methods and movers. Their work provides the baseline taxonomy that we build upon. Our scope for movers is the same as theirs, i.e. a mover with a single position, sized at a "human scale", e.g. natural phenomena, animal, urban, naval and aerial mover. In an effort to understand how types of movers and context impact trajectory analysis, we enlarged the scope of the baseline taxonomy by adding attributes of elements belonging to the WHAT aspect of our taxonomy. We first produced a taxonomy populated by papers selected following a convenience sampling [EMA16] approach in order to find categories which needed modifications. The convenience sample was useful to indicate issues with the categories of the taxonomy, but was neither systematic nor reproducible, thus we restarted populating the taxonomy, following this approach: **(1)** Search on Scopus for all conference papers and journals articles that discuss "trajector(y/ies)","visuali(s/z)ation" and exclude keywords that were representative of notions that fell out of our scope, e.g. "trajectories of eye movement". **(2)** Remove posters, short papers and VAST challenges to ensure contributions at a full paper level. **(3)** Remove the papers outside of our scope and use the remaining ones to populate the taxonomy. The categories WHY and HOW within this taxonomy are not described in detail within this work due to their lack of novelty, but further information can be found here: https://bit.ly/2V7iUWt. In this document we discuss the elements composing WHAT, reflect upon the resulting taxonomy, and conclude and discuss potential future work.

2. WHAT-WHY-HOW Taxonomy & Reflections

Analysis of visualisation is influenced by knowledge the user possesses about the elements being part of it [MGM19]. Our motivation to develop the attributes composing the elements of WHAT was based on documents mentioning their importance during the analysis of trajectories. One case is Bonham et al. [BNTW18] discussing explanations of vessels trajectories that appear counter-intuitive unless rules they have to abide to and whether they are the ones deciding the trajectories undertaken are known. Another case is Andrienko et el. [AAGS19a] who discuss flight variability and underlines the importance of context such as weather. Brehmer et al. [BM13] acknowledge that "WHAT" comprises a visualisation isn't agreed upon within the literature and advocate for a "*bring your own what*" mentality. Building upon our baseline taxonomy, we designed the following categories of WHAT:

Mover's decision capabilities (MDC): The mover's decision capabilities is a category that indicates whether the mover is the one deciding for the trajectory they follow. The mover's decision capability is useful to assess if a trajectory is an error, if the mover possessed the ability to take another trajectory, or the existence of potential interactions in between several movers.

MDC1 - Natural movers: this category describes objects where the movement will not undergo modifications due to the will or action of a sentient being, e.g. storms or glaciers. - *MDC2 - Independent movers*: Independent movers are responsible for deciding their own movement, e.g. a pedestrian or a car being driven by an occupant. - *MDC3 - Dependent movers*: Dependent movers are not making the decisions for the movement they are undergoing, e.g. a plane following direction given by an agent outside.

Levels of constraints (C): This section presents categories that define how constrained a mover is, i.e. how many rules the mover has to abide to. This notion is a continuum rather than a series of precisely defined ordered categories, and this notion can also change depending on the context, e.g. a car is semi-constrained, limited normally by legal constraints, but has access to a range of velocities and several directions. It can however be forced into a deviation in various ways: when being towed, or when under instruction by an external person, making it entirely constrained exceptionally.

C1 - Zero constraints: whereby the mover is able to go in any direction within its physical capability so to reach its destination. - *C2 - Semi constrained*: whereby the mover has sets of possibilities for trajectories, but is not free to take all of them. - *C3 - Entirely constrained*: whereby movers are unable to move in ways other than those predefined, e.g. trains are forced to move on rail roads, and are unable to deviate from the planned routes.

Contextual data (CTXT): This category is used to label documents which display contextual data different to movement, e.g. display of metadata of points of interest that can help to understand the reason behind the time a mover stops at a specific location.

Reflecting on the results: Through the development of the taxonomy we made a number of observations, some of which can be seen in the taxonomy table as well, and we reflect on some here. Tasks '*Characterisation of locations (T1)*' and '*Characterisation of moving objects (T3)*' are mainly discussed while using the visualisation method '*Spatial aspect of trajectories (Vm2)*', and most movers are '*Independent movers (MDC2)*', but there is more variety on level of constraints with the task '*Characterisation of moving objects (T3)*' which might indicate this task being researched within more domains, implying more types of movers. Additionally, most cases of '*Context (CTXT)*' are in documents discussing *(T1)*, indicating the usefulness of displaying contextual data for providing richer semantic context. Still, the over-representation of '*(MDC2)*' could indicate a lack of diversity in our population, making the emergence of strong links less likely. Furthermore, all cases of '*Entirely constrained (C3)*' are linked to '*Dependent movers (MDC3)*', potentially indicating combinations of our WHAT elements which are not separable, and thus flaws in our structure.

3. Conclusion

In this poster we introduce a taxonomy that links particular components of WHAT to a WHY-HOW structure of trajectory analysis. The taxonomy is populated with academic papers that involve the visualization of trajectories, and draws links to help navigate the design space in trajectory analysis. In the current form of the taxonomy these links are limited, likely due to particular elements of WHAT being inseparable. Our taxonomy is an in-progress framework that is open for changes to incorporate alternative WHAT structures. Potential modifications could be merging *(MDC)* and *(C)* into one dimension. This dimension would indicate how likely a mover is to follow a trajectory that appears illogical or difficult to interpret, unless provided with information about its intentions or rules it's abiding to. Additional categories could be physical characteristics of trajectories, e.g. sinuosity, granularity, and attributes of locations, and whether those are constant, e.g. elevation of area, or time-dependent, e.g. precipitation.

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