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Understanding the Relationship between Behaviours using Semantic Technologies

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Abstract. While a growing number of studies report on relationships between behaviours (e.g. alcohol consumption, political behaviours, sleep, recycling), there is a need for a shared understanding of behaviour (e.g. how to characterise and differentiate between behaviours) and the ability to integrate insights on the relations between behaviours. Semantic technologies and ontologies can help in formalising the behaviour domain in a structured approach to support sharing, reuse and interoperability in a manner that can allow future researchers to build on activities in this space. In this work-in-progress paper, we describe the semantic technologies (ontology, data capture tool and visualisations) that are currently being developed by the TURBBO (Tools for Understanding the Relationship between Behaviours using Ontologies) project to support researchers in understanding relations between behaviours and reason upon the existent data. In this paper, we also describe our future plans to evaluate the technologies being developed as a part of the project.

Keywords: ontologies, behavioural studies, data visualisation, semantic technologies

1 Introduction

Everyday life is characterised by a range of behaviours such as eating, sleeping, walking etc. Psychologists and behavioural scientists often study these behaviours in isolation, seeking to, for example, improve sleep or increase levels of physical activity. Sometimes, these studies will consider the extent to which changes in one behaviour impact another (e.g. increasing physical activity may increase consumption of calories). These analyses are typically only limited to a small number of behaviours, usually within the same domain. There is a growing interest in studying multiple behaviours simultaneously, or how behavioural interventions can impact other behaviours over a range of domains. Much of the evidence needed to understand these relationships already exists in the literature - studies measuring behaviours and reporting correlations between them can be used to estimate relations between the behaviours.

Despite the presence of a large body of research on behaviour correlations, the community currently lacks a shared understanding of behaviour (how we can describe and characterize behaviours, how can we differentiate between them etc.) and the ability to integrate insights on the relations between behaviours across existent data. The TURBBO (Tools for Understanding the Relationship between Behaviours using Ontologies) project aims to address this gap by developing a set of semantic technologies to help behavioural scientists study correlations between behaviours. As a first step in achieving this goal, the project aims to develop a 'collaboratively edited ontology' that user communities can contribute to, beyond the project lifetime.

Ontologies are formal descriptions of concepts, including their attributes and relationships, of which domain experts share a common understanding [1]. Logical rules and constraints [2] are further defined which enable software to reason about the knowledge represented by the ontology, and discover new knowledge [3]. Ontologies provide a standardized representation of the semantics of a domain and so can be used to exchange data and models, encouraging re-use, communication, collaboration and integration [1]. In the TURBBO project, we used a co-design methodology to co-create our ontology with user communities [4], which included researchers, academics and practitioners. In this work-in-progress paper, we provide a brief overview of the ontology, a data capture tool and a set of visualisations that are currently being evaluated with user communities.

The paper is organized as follows: we first discuss some of the ontologies developed for the behavioural science domain, and then discuss various visualizations for studying behaviour correlations (Section 2). We then present a high-level overview of our ontology and some of the tools developed in the TURBBO project (Section 3). We conclude the paper with some discussions around future research in the project (Section 4).

2 Related Work

We discuss related work from two perspectives – (i) an initial discussion presents some of the previous efforts in developing ontologies that are relevant to studying human behaviour, and (ii) a discussion on different approaches taken in visualizing behavioural data. Understanding previous efforts in developing ontologies is important as one of the key considerations to be made is how existing ontologies could be re-used, refined or extended, to avoid duplication and promote interoperability [5]. In the TURBBO project, we conducted a systematic review of the literature using existing databases (Bioportal, Ontology Lookup Service, OBO Foundry) to identify 70 ontologies that could be relevant for our research. While over half of these ontologies considered health behaviours (physical activity, substance use, food consumption appearing most frequently), there is a lack of ontologies that explore the field of behavioural studies and human behaviour more holistically. We also identified domain specific ontologies such as Legal APA ontology [6] (criminal and antisocial behaviours), Education Cluster ontology [7] (learning and education), International Classification for Nursing Practice [8] (behaviours related to religious practices like praying), Physical Activity Ontology [9] (a range of activities), and Neuro Behaviour Ontology [10] (learning, sleeping, substance use). Our review also included a range of taxonomies that have been developed to classify human behaviours into different hierarchies and categories such as [11,12]. Given the need for capturing existing studies reporting on the correlations between behaviours, we were also interested in understanding existing ontologies that are used to measure empirical data. As such, the Consumer Wearable Devices Ontology [13], Intervention Setting Ontology [14] are ontologies that we identified as relevant to our ontology. Finally, the need to capture details about existing research makes it important to identify ontologies that can capture scholarly and scientific activities such as Documents Components Ontology, ScholOnto[15], Core Information about Scientific Papers [16], Semantic Web Conference Ontology and Core Scientific Concepts [17]. There are also existing generic ontologies which are helpful vocabularies for describing documents, individuals and organisations such as Friend of a Friend (FOAF), Dublin Core Metadata Terms, and SIOC. A longer, separate paper detailing the systematic review of existing ontologies and taxonomies is currently being prepared by the project team.

Given the range and typologies of human behaviour, the need to conduct meta-analysis in order to give greater weight to correlations from studies with larger samples when estimating relations between behaviours, our data involves complex data structures. Furthermore, the interpretation of these data relies on evaluation and integration of a range of statistical information and provokes the need for application of data visualization tools [18]. Beyond the behavioural studies domain, a range of visualisations exist that can represent relationship data. These are predominantly network visualisations, employing different types of configurations and layouts such as force-directed, circular, or hierarchical visualisations, applied within other domains such as social network analysis [e.g. 19], transport and mobility [e.g. 20], bibliometrics [e.g. 21] and so on. Other visualisations such as scatterplot, correlation matrix or even treemaps can provide insights on the strength of relationships between different behaviours. A range of applications exist that allows the creation of network visualisations such as Cytoscape [22], Gephi, and TreeNetViz [23]. Closer to behavioural studies, Rethomics [24] is a framework for the analysis of high-throughput behavioural data, particularly to study circadian and sleep data. ViSiElse [25] can be used to visualize raw behavioral data over time extracted from visually recorded sessions of experimental observations. More specific to the application of visualisations for meta-analysis, a range of visualisations have been proposed, such as the Vitruvian plot [26], forest plot, funnel plot and meta-regression plots [27], or a combination of multiple visualisations such as forest plots, radial plot, network visualisations and so on [28]. The literature highlights a range of possible visualisations that are relevant for studying the relationships between behaviours, and our user studies highlighted existing practices within the user community.

3 Development of Semantic Technologies

As described previously, our starting point for the project was to co-design an ontology that could be used and curated by the community. We conducted a systematic review of ontologies, which identified a set of ontologies that we could extend and re-use. Together with this activity, we organized a set of six workshops, that involved 22 participants in total (academics, practitioners, businesses and charities interested in behaviour). The workshops involved providing a brief overview of what we mean by ontologies and how they are helpful. The sessions then involved the use of Miro, an online whiteboarding software that offers interactive features such as collaborative mind mapping, voting, building workflows, user stories and so on. Participants provided their views on what concepts would be important for describing and modelling behaviour, through a series of tasks. The participants were invited to indicate how the concepts can be potentially connected and describe the type of relationship that exists between the concepts.

A subsequent desk-based activity by the research team then brought together the concepts and relationships identified by the participants in the workshops. This required understanding which concepts were most commonly highlighted as important, identifying similar concepts and how the concepts could be hierarchically arranged. Over several iterations, the team developed the Relationship Between Behaviours Ontology (RBBO). The ontology consists of three independent modules which can be combined to form a complete schema. The TURBBO_Behaviours module provides a hierarchical organization of different behaviours (moving, self-care behaviours, communication etc.) and we re-used the IC-Behaviour taxonomy [11] as a starting point. The TURBBO_Properties_of_behaviour module describes classes of behaviour characteristics (e.g motivation, effectiveness, goal etc) and other properties represented as data properties (e.g., whether a behaviour is habitual or not, opportunistic or not etc). The TURBBO_Properties_of_studies_measuring_behaviour module consists of concepts for describing studies that report on behaviours (e.g., methodological design, participants, context). Figure 1 presents a high-level conceptual view of the main concepts and relationships within the three modules in RBBO.

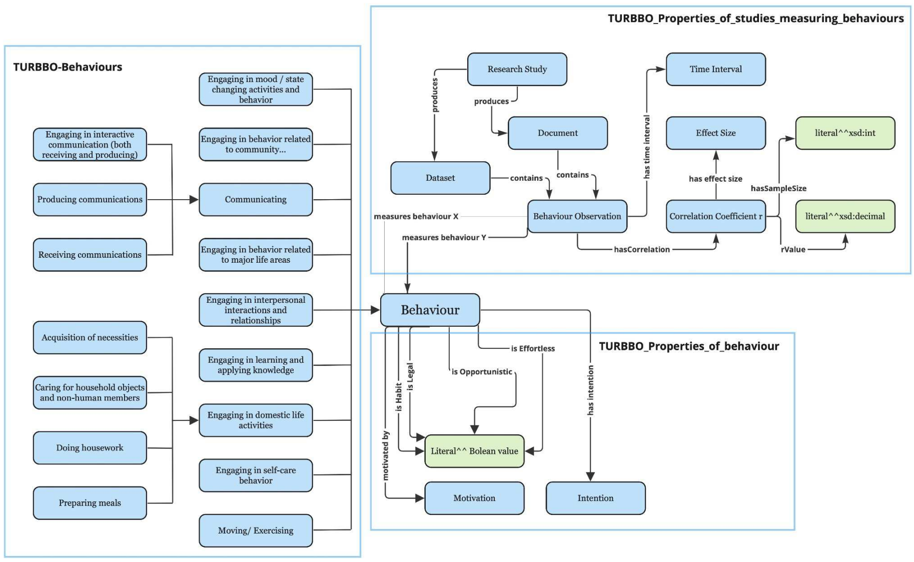

Figure 1: A fragment of RBBO showing some concepts from the TURBBO_Behaviours, TURBBO_Properties_of_behaviour and TURBBO_Properties_of_studies_measuring_behaviours modules.

Following the development of the ontology, we created a knowledge base that can be populated by the behavioural research community to capture data about studies reporting on relations between behaviours. This is, for the time being, a manual task, where researchers in our project team identify a relevant paper and enter the details of the experiments, findings and behaviours reported in the study through an online interface, as can be seen in Figure 2 (left). The elements in the data collection system directly align with the ontology and therefore, all data inputted from the system gets stored in a knowledge repository, accessible through an API. In the TURBBO project, we are currently evaluating the data collection application with user communities, using a task-based approach. The project is also in the process of developing tools to analyse and visualize the knowledge base. While this is a work in progress, early prototypes are presented in Figure 2 (right).

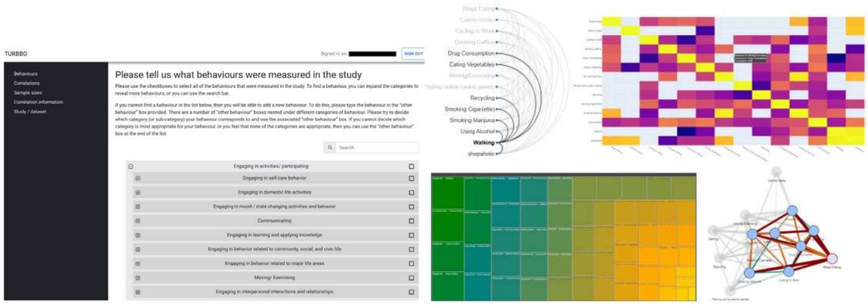

Figure 2: (left) Data collection application for recording behaviour correlation and associated data. (right) a composite of visualisations (based on synthetic data) currently being developed to support researchers study behaviour correlations

The Figure 2 (right) presents some example visualisations that the TURBBO project is implementing and is currently work in progress, using a synthetic dataset created for the purpose of testing our tools. The aim of this activity is to develop a dashboard that can incorporate multiple visualisations and help researchers answer questions about the relationship between behaviours. In the figure, the top left image presents an arc diagram which enables users to hover over a specific behaviour to find other behaviours that arecorrelated with the behaviour of interest. The image in the top right presents a colour-coded correlation matrix, while the image in the bottom left presents a treemap that presents colour-coded pairs of behaviours. The colour-coding is based on the strength of the correlations, which is calculated as a combination of correlation values reported from multiple studies. The right image presents a force-directed network that allows users to select a specific behaviour to highlight connections with other behaviours.

4 Discussions and Conclusions

The TURBBO project seeks to use semantic web technologies and ontologies to help researchers to understand the relationship between behaviours. Ontologies enable user communities to develop an agreed description and formalization of a given domain, and, in this case, an ontology has been developed to represent (human) behaviours, their properties and the studies that describe the correlations between different behaviours. We have developed a data collection interface that enables users to manually enter the details of previous research findings to populate a growing knowledge base of existing studies. This will then be used by the research community to understand relationships between behaviours from a holistic perspective, using a variety of visualization tools, currently being developed. As the ontology, data collection tool, and the associated visualisations use open source libraries, and will be made available to the user community, we expect the knowledge base to grow in the future, with the contribution of users. As discussed earlier, future work will involve conducting user studies with the data collection tool. Future work will also involve developing a visualization dashboard and conducting user studies to understand how they can support users in exploring the knowledge base using simulated scenarios and a task-based approach.

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