Requirements for domain-specific data access of long-term interaction data in smart environments*

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I. Introduction

In recent years research on artificial cognitive and intelligent systems in interactive environments expanded further to more complex applications that support long-term scenarios [1]. With the increasing amount of sensors and actuators, these applications lead to the production of vast amounts of extracted data from various modalities (e.g. speech, dialog, persons, or situations) at rapid time scales. The issue of how to support storage and access to large amounts of data as generated in sensor-intensive environments over longer periods of time has not received sufficient attention so far. Many existing approaches have a robot-centric approach and thus data storage and access focuses primarily on aspects impacting the robot actions and behaviours. We hence argue that storage and access to data about the human robot interaction (HRI) domain needs to be simplified and extended for developers. Among central research questions are the accessibility of HRI related concepts, the possibility for online query evaluation, and the incorporation of machine learning in data storage and retrieval. Addressing these gaps, we consider a new approach that targets to improve storage and access of interaction related knowledge over long periods of time, focusing on capturing relevant data and concepts whilst making it online queryable. We thus propose the development of an appropriate abstraction for a domain-specific data access that encapsulates and simplifies the retrieval of such data for developers of interaction relevant components. In the following, we want to analyse the domain further and extract first requirements for data structures, representations, storage, granularity, storage policies, etc. to facilitate such functionality.

II. Related Work

Previous research has shown that there is a need for effective and intuitive querying of world knowledge in robotics [2]. Dietrich et al. recently presented their approach called *SelectScript* to aid querying of discrete robotic world knowledge. They provide a small declarative language stub, inspired by the SQL syntax, to facilitate query operations on a world model along the paradigm of language-oriented programming. Queries with temporal constrains are restricted to the executing component runtime horizon. Humans, their interaction among each other, and interactions with the robot are not considered.

Other researchers have developed complex frameworks to equip robots with knowledge and reasoning capabilities (cf. KnowRob [3]). They created a knowledge representation ontology using Prolog and the Web Ontology Language (OWL), which can be inspected via programmed query predicates. Reasoners allow to deduct knowledge from data extracted from robot sensors or information on the web. The emerging ontology is equipped with a query interface to enable robots with the required knowledge to perform manipulation tasks from human description. Their approach focuses on the knowledge needed for task completion and excludes the representation of human interaction. As already discussed by the authors, this approach is difficult to combine with machine learning algorithms and requires carefully designed and optimised queries to avoid very long query times.

Other approaches also target the creation of ontologies, such as OUR-K [4] or the Open Robot Ontology [5]. In the latter, Lemaignan et al. focus on maintaining a consistent knowledge representation by continuously updating and checking for inconsistencies. Though information is mainly gathered by the robot via natural human interaction (i.e. speech or textual input), only knowledge about objects and their location is stored. Querying of the knowledge base is possible via the use of RDF triples.

Lastly, few approaches target the storage of stream sensor data in an either large-scale global or small-scale local setup [6] [7]. Aspects related to interaction domain relevant data, long-term storage, or improved data access are not considered in these.

III. A Robot Enabled Cognitive Environment

We are currently building an exemplary laboratory setup consisting of an intelligent apartment, featuring a multitude of various sensors. Within this apartment a mobile autonomous robot is envisioned to operate and interact with guests. Therefore, to determine the general domain-specific key requirements $\mathbf{R}_n$ for this domain, we want to outline a general use case: a robot enabled cognitive environment, which is represented by a general cognitive environment accompanied by a mobile and autonomous service robot. Humans interact with the robot, the environment, and other objects of the environment over a long period of time. The targets of interactions are the artificial agents, objects within the

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environment, and other humans. The data about these long-term interactions are collected, stored in a database and made available for retrieval. Interviews with component developers for HRI scenarios in our laboratory environment lead to an understanding of what information is when relevant to them for the design of intuitive interactions. Summed up, we constitute three exemplary queries to derive further requirements from:

(Q1) Has a detected user U **been seen before** and **what were interaction partners** P and topics T of these interactions?

(Q2) Which set of objects O **was visible to** the agent A **when interacting with** user U at time t_x?

(Q3) Which objects O did the user U **refer to** within the time interval t_x and t_y?

In the following we want to shortly present and described the derived requirements for the above described use case.

$\mathbf{R}_1$ - *Storage of interaction related data*: As knowledge about these long-term interactions in this domain is necessary for an intuitive HRI, we consider efficient storage of interaction related data over long time spans as our first requirement.

$\mathbf{R}_2$ - *Forgetting strategy*: From the available sensors in our described exemplary setup, (multiple depth sensors, cameras, etc.), we calculated an estimate of at least 1362 MiB per second, or 112 TiB per day. General households have rather low and varying computational resources available and infinite storage of streaming data at this scale is infeasible. Hence, suitable forgetting strategies following certain policies to reduce the granularity of data over time are required (in the database domain known as retention or downsampeling).

$\mathbf{R}_3$ - *Data structures for varying granularity*: Considering this we further derive the requirement to provide adequate data representations that allow to represent data at different levels of granularity.

$\mathbf{R}_4$ - *Online querying*: Developers ideally require queries such as Q1, Q2 and Q3 to be answered in a timely manner (less than 500ms) so that interaction is not hindered. However, the query duration depends strongly on the actual content and timespan queried. A domain-specific query language can be exploited here to give developers feedback about expected query duration at query design time. Additionally, one could define fallback strategies so that even a maximum query time assurance can be possible.

$\mathbf{R}_5$ - *Query based online storage optimisation*: Taking this idea further, optimisations within the underlying database structures can be applied on the basis of designed queries (e.g. specialised index generation or adaptive data structure generation). Though this is a basic database feature, it is to the best of our knowledge not yet applied by complete state of the art frameworks in this domain.

$\mathbf{R}_6$ - *Temporal queries*: The various temporal constrains of each query displays another important element. We think that allowing this kind of queries in the interaction domain is a non-trivial aspect and forms an important requirement, a missing functionality of current approaches (cf. [2]).

$\mathbf{R}_7$ - *Interaction specific predicates*: Each example query also features highly interaction domain-specific concepts as query predicates (see Q1-Q3, bold parts). These are to be addressed within the domain-specific query language and will allow easy design, extendibility and transferability of predicates. Though existing approaches also allow the cumbersome definition of own predicates (cf. Proglog predicates in [3]), their integration in a domain-specific query language will further facilitate new predicate design, allow consistency checks and at the same time ensure all other requirements.

IV. Conclusion & Future Work

In this abstract we presented our current work on a domain-specific data access approach for querying interaction related data in robotics and smart environments. Therefore, we described a use case along with three exemplary queries that cover core elements encountered in this domain. Using state of the art solutions it is either entirely impossible or very laborious to formulate queries targeting this type of knowledge in the interaction domain. Core issues are the missing knowledge about interactions, the inability to reference interaction related concepts, the conceptual lock-ins of large frameworks, the inability for temporal queries, and lastly no query time guarantees. We determined 7 core requirements, which we think are most important for this domain and hence need special consideration. As this represents work in progress, we plan on implementing a prototype in order to further extend and finally meet our identified requirements and provide developers with necessary tools. With the type of data to be represented, we chose NoSQL databases as a good fit to support the requirements best. We plan to exploit the database's special features, such as graph traversals algorithms and others, to efficiently determine interaction related information and relationships.

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