Towards "Executable Reality”: Business Intelligence on Top of Linked Data

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Abstract—**Tight competition within mobile technology domain resulted to quite advanced applications and services for the users. Among them there are mobile (augmented and mixed) realities as an effort to enhance real-world observation by bridging it with virtual worlds of relevant data and services. At the same time, due to emerging Semantic Technology, the Web content moves rapidly towards Linked Data. The layer of machine-processable semantics allows automated processing of the content by Web-based Business Intelligence (BI) applications and services. Real-time analytics related to various real-life objects provided to the users of Mixed Reality by online BI services would be a nice enhancement of the technology. In this paper we propose “Executable Reality” as an enhancement of the “Mixed Reality” concept within two dimensions (utilization of Linked Data and BI on top of it). We present “Executable Knowledge” as a tool to enable Linked Reality and “Executable Focus” to control it by a user. Executable knowledge in addition to subject-predicate-object semantic triplet model (in ontological terms) contains also subject-predicate-query triplets. Actual value for the properties based on a new triplet will be computed “on-the-fly” (based on user request navigated by executable focus) by some online BI service or other computational capability provider at a right time and place according to the dynamic user context.**

Keywords- Business Intelligence; Linked Data; Mixed Reality; Executable Reality; Executable Knowledge

I. INTRODUCTION

Business intelligence (BI) can be considered as a set of methods, techniques and tools utilized on top of business data to compute (acquire, discover) additional (implicit) analytics out of it and to present it in a form suitable for decision-making, diagnostics and predictions related to business. Taking into account that “business data” is becoming highly heterogeneous, globally distributed (not only in the Internet space but also in time), huge and complex, extremely context sensitive and sometimes subjective, the ways the BI is utilized have to be qualitatively changed. Semantic (Web) Technology [1, 2, 3] is known to be a suitable approach to enable more automation within BI-related data processing. The vision of BI 2.0 [4] includes also issues related to SOA, mobile access, context handling, social media, etc. All these issues will also definitely benefit from adding semantics [5, 6]. It is however a known fact that there is not much semantically annotated data available for BI. We have to live with data sets created independently, according to different schemas or even data model types. The realistic role of Semantic Technology for such data would be linking related “pieces” of it with some semantic connections and by doing this transforming the original data into Linked Data.

There are no doubts that such semantically interlinked “islands” of data have a lot of hidden (implicit) and potentially interesting information that none of separate data sets has alone. Now the challenge would be how to utilize BI on top Linked Data to be able to get all the benefits from semantic enhancement of the data.

Another trend is related to fast development of technology, tools and devices for better delivery and visualization of information to a user. Among those there are technologies like Augmented Reality [11], Mixed Reality [14] and mobile versions of both [12, 13, 15]. These technologies are based on automated interlinking of various Web-based digital data collections with the real-time data from sensors about physical world and presenting it in a useful form for a user. An interesting topic would be considering these technologies in the context of business data or even BI-provided analytics. This may inspire more professional use of Augmented and Mixed Reality in addition to public use of it.

In this paper we propose “Executable Reality” as an enhancement of the “Mixed Reality” concept within two dimensions (utilization of Linked Data and BI on top of it). We present “Executable Knowledge” as a tool to enable Linked Reality and “Executable Focus” to control it by a user. Executable knowledge in addition to subject-predicate-object semantic triplet model (in ontological terms) contains also subject-predicate-query triplets. Actual value for the properties based on a new triplet will be computed “on-the-fly” (based on user request navigated by executable focus) by some online BI service or other computational capability provider in a right time and place and according to dynamic user context.

The rest of the paper is organized as follows: in Section II we discuss Linked Data issues and its enhancement by context-sensitive similarity links; in Section III we present (Mobile) Augmented and Mixed Reality technology and challenges; In Section IV we show how these technologies can be further developed towards “Executable Reality” on top of enhanced Linked Data and BI services (there we also present concept of “Executable Knowledge”); we discuss Related Work in Section V; and we conclude in Section VI.

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II. Linked Data and Semantic similarity

Linked Data is a concept closely related to the Semantic Web yet providing some specific facet into it. According to Tim Berners-Lee "The Semantic Web is not just about putting data on the web. It is about making links, so that a person or machine can explore the web of data. With linked data, when you have some of it, you can find other, related, data" (http://www.w3.org/DesignIssues/LinkedData.html). The so called "5 stars" advice from Tim Berners-Lee to enable Linked Data includes: making data available on the web (whatever non-proprietary format) as machine-readable structured data, utilizing open standards from W3C (RDF and SPARQL) to identify things and finally linking the data to other people's data to provide context.

According to Kingsley Idehen (OpenLink Software CEO), due to development of Semantic Technology, *meshing* (or natural data linking) will replace *mashing* (brute-force data linking) and therefore mesh-ups can be considered as a next step comparably to the mash-ups in the sense to merge and integrate different data sources and processing devices to provide new information services.

Linked Data can be considered as an outcome of the technology, which semantically interconnects heterogeneous data "islands" (e.g., as shown in Figure 1). Even if the original sources of data are highly heterogeneous (not just only different schema of data within the same data model type but also different data model types), still it is possible to build some "bridges" between entities from these data sources utilizing semantic technology. The traditional Semantic Web approach would be: (a) creating semantic model of the domain (ontology), (b) replacing original data from each source with full semantic (RDF) representation of its resources in terms of the ontology. Of course such approach enables seamless integration of the original data and simplifies the usage of it. However with distributed and dynamic sources of data, which are managed and constantly updated independently, it would be difficult to provide such "semantic synchronization" (updating metadata and mapping it to the ontology) in real time. Therefore Linked Data would be less ambitious and more practical approach: data sources are managed independently as they used to be; semantic connections between appropriate resources from different sources will be either automatically discovered or manually created whenever appropriate. Usage experience and usability performance for each separate data source will be preserved. The usability of such "virtually integrated" data storages will increase with the increase of the amount of the semantic "bridges".

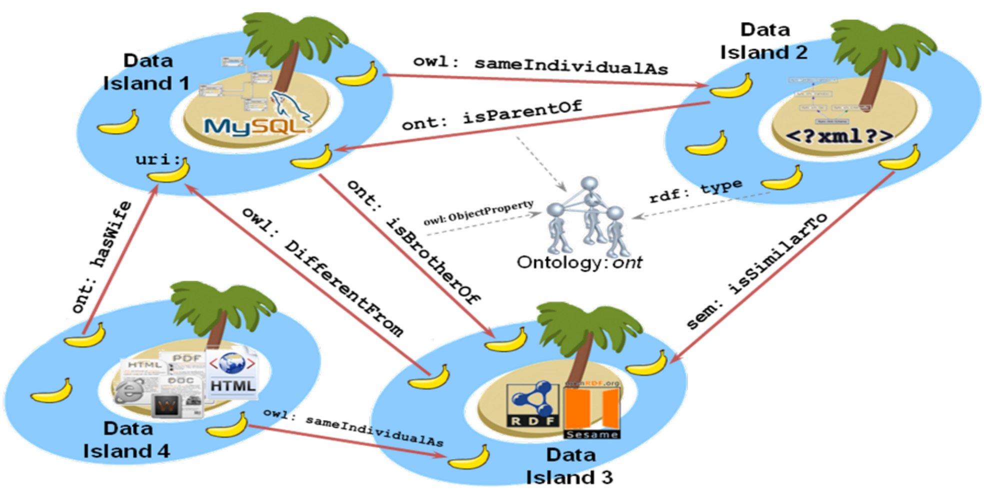

Figure 1. Linked Data: "bridges" between heterogeneous "islands" of data

According to [7] there are three important types of RDF links within Linked Data: (a) "relationship links" that point at related things in other data sources (like "object properties" in terms of OWL: *owl: ObjectProperty*); (b) "identity links" that point at URI aliases used by other data sources to identify the same real-world object or abstract concept (e.g., *owl: sameIndividualAs*, *owl: equivalentClass*); (c) vocabulary links that point from data to the definitions of the vocabulary terms that are used to represent the data (like "datatype properties" in terms of OWL: *owl: DatatypeProperty*).

We think it would be reasonable to extend traditional explicit semantic links within Linked Data with the implicit ones, e.g., those, which could be automatically derived by various reasoners. Among those special attention should be paid to the "semantic similarity" links. Usually, when one queries a data, she looks for the resource(s), which are "the same" as the one specified in the query. However often there are none of such found. In many cases there is a sense to find "similar" to a target one resources. Similarity search was always a big issue within many disciplines and it is especially important for the Linked Data. The reason is related to the fact that actually same resources in different "islands" of data may have different URIs and often quite extensive work should be done to recognize same resources. Usually first we see that some resources look similar and therefore in practice could be the same ones and then we perform some check on the identity of the resources. Another use of similarity measure is when one is looking for a capability providing resource (e.g., a service), cannot find exactly the one she wants but still will be satisfied by finding a resource with similar functionality. Therefore explicit similarity links between data entities would be reasonable to have as a result of appropriate similarity search procedures. The two major challenges here are: (a) a resource within one data "island" may have very different model of description when compared to some resource within another data "island" (e.g., a human documented in a relational database will not be easily compared with a human from some XML storage or from some html document); (b) some resources being very different in one particular context could be considered as similar ones in some other context.

We consider three types (sub-properties in terms of OWL) of semantic similarity based on common ternary object property relation named *isSimilarGivenContext* and they are: (1) *isSimilarGivenQuery*; (2) *isSimilarGivenRole*; and (3) *isSimilarGivenGoal*. The first type of similarity assumes that two resources can be considered as similar ones (in the context of some semantic query, e.g., SPARQL query) if this query, being applied over the locations of these two resources, returns both of them as a result. For example, resources "Mikhail S. Gorbachev" and "George W. Bush" will be considered as similar ones, given query "Former president, male with at least one daughter". The second type of similarity assumes that two resources will be used as similar ones if they both can fill some slot in a business process with the specified role. For example, some instance of class "Lamp" can be considered similar to some instance of class "Candle", given role "Lightening". The third type of similarity applies to the resources which can be replaced with each other as input parameters needed to perform some function (action) or utilize some external capability (service) without affecting expected outcome. For example, a "Bottle of vodka" would be a similar resource to e.g., "Pack of beer" as an "input" ("natural payment") to a ferry service somewhere in Siberia countryside, given goal "To cross the river". More information about our approach for defining context in various practical applications and semantic similarity search within context can be found in [8, 9, 10].

The major challenge is how to provide support for automated utilization of Linked Data, which in fact remains heterogeneous, and how to get added value of additional semantic connections between data components. Anyway we claim that providing similarity links, in addition to traditional types of RDF links described in [7], can be very helpful for practical utilization of Linked Data and we will try to show this in the following sections of the paper.

III. Augmented and Mixed Reality

Augmented Reality (AR) [11] is a technology aimed to enhance the traditional perception of a reality (real-world environment), which elements are augmented by computer-generated sensory input (e.g., data, sound or graphics). AR enriches real world for the user rather than replaces it. By contrast, *virtual reality* replaces the real-world with a simulated one. Emerging development of mobile computing has naturally resulted to growing interest towards Mobile AR [12] and also to Ubiquitous Mobile AR [13] for successfully bridging the physical world and the digital domain for mobile users. The AR concept has been further developed to Mixed Reality [14], which means merging of real and virtual worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in real time. In June 2009, Nokia Research Center announced the vision [15] of Mobile Mixed Reality, according to which a phone becomes a "magic lens" (smart and context-aware), which lets users look through the mobile display at a world that has been supplemented with information about the objects that it sees. The users simply point their phone's camera, and look "through" the display. Objects of interest visible in the current view will be gathered from existing Point-Of-Interest databases or created by the user and will be highlighted. They can be associated with physical objects or featureless spaces like squares and parks. Once selected, objects provide access to additional information from the Internet and hyperlinks to other related objects, data, applications and services. Context-awareness is guaranteed by various rich sensors that are being incorporated into new phones (GPS location, wireless sensitivity, compass direction, accelerometer movement, sound and image recognition, etc.). Therefore the new technology is going to actively utilize acquired dynamic context to better filter and select relevant information about surrounding real-world objects for a user.

In the following section we further develop the concept of (mobile) mixed reality within two dimensions: the first one is related to Linked Data utilization and the second one will be related with the utilization of Business Intelligence through "Executable Knowledge".

IV. Towards "Executable" Reality

The concept of "Executable Reality" and associated technology, which we are offering, should be considered as an extension of the (Mobile) Mixed Reality concept and the technology. If the traditional technology assumes that the explicitly available relevant data about some real-world object will be taken from some database and delivered to the user on demand (based on her attention focus pointed to this object), the Executable Reality in addition is able to provide online BI computation on similar demand (we call it "Executable Focus") and present to the user results of computed analytics adapted for the current context. Two use-case scenarios for the Executable Reality are shown in Figure 2 (a, b). In the first one, the user (maintenance engineer of the power network company) is putting the executable focus (smart phone camera) into direction of the power line and by doing this makes implicit request for the last 24 hours performance statistics of this power line. The query will go further to server; appropriate BI service will be selected and automatically invoked; resulting page with numbers, graphics (and sounds if appropriate) will be generated and delivered back to the terminal and shown in appropriate window of the screen as shown in Figure 2 (a).

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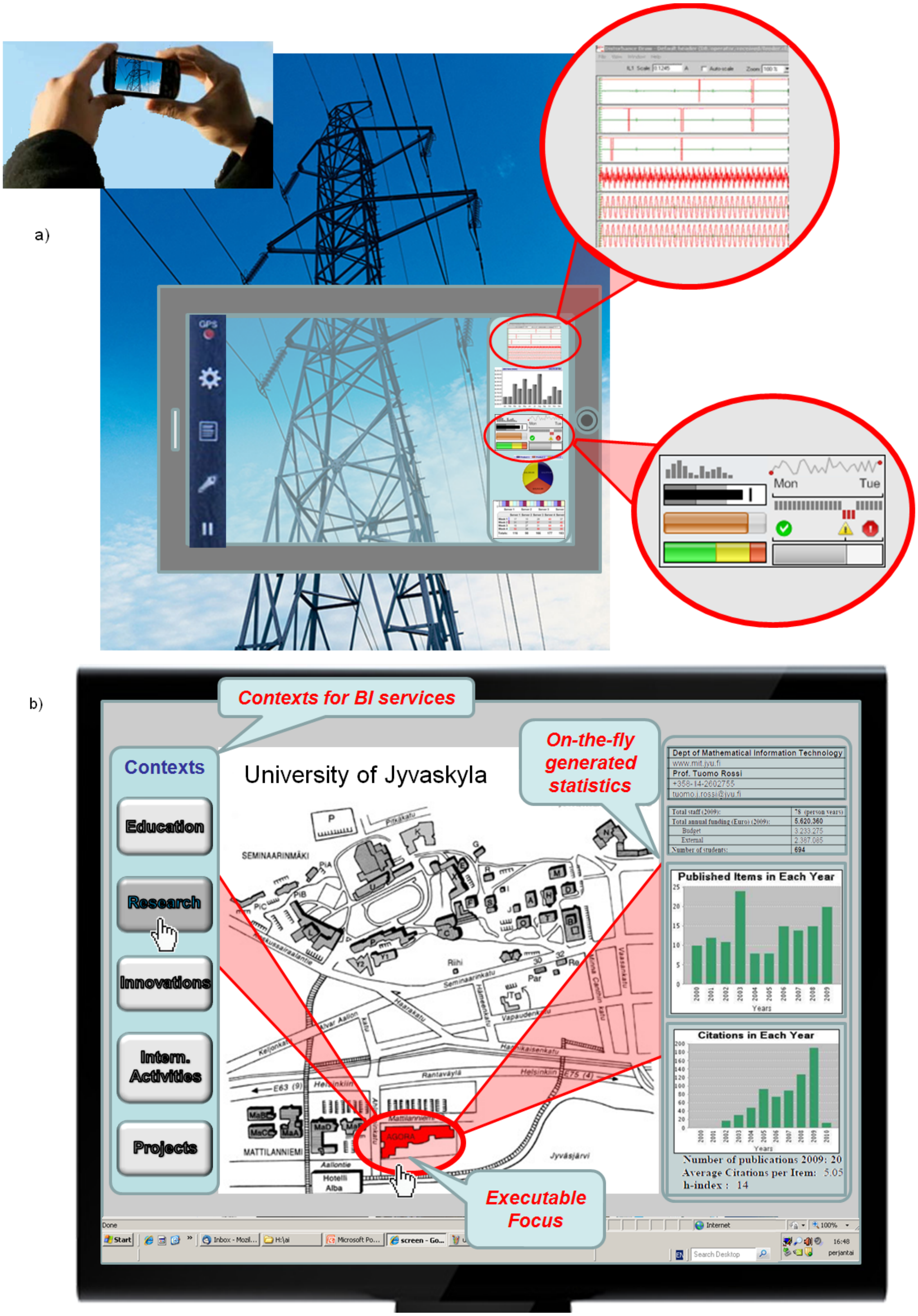

Figure 2. Executable Reality use case examples: (a) on-the-fly computed statistics about power line performance is delivered to mobile terminal of the maintenance engineer on implicit demand; (b) research performance statistics is delivered to the user based on chosen unit (click on the building where the university department is located and selecting context "research" for filtering appropriate data from the unit needed for research performance calculations)

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Another scenario in Figure 2 (b) shows that a user observes the campus map of some university and selects the building where a particular department is located. The user also selects the context in which she wants to get performance statistics of the unit, e.g., "research". Chosen object and the context together form the executable focus, which will automatically generate the query for the required computation. Then the process goes in a similar way as with previous scenario and the user will get "fresh" statistics concerning research performance of the department chosen.

To enable Executable Reality we have to find effective way to utilize Linked Data, which is natural source for online BI computations, and also to enable BI functionality as semantically annotated Web services. We propose to organize Linked Data in form of "Executable Knowledge".

Executable Knowledge can be considered as distributed (or organized as a cloud) set of heterogeneous data storages and computational services (e.g., BI) interconnected with semantic (RDF) links. The major feature here is that, in addition to the traditional ("subject-predicate-object" or "resource-property-value") triplet-based semantics of an RDF link (either "datatype" property, where "value" is a literal; or "object" property, where "value" is another resource), the new model will have new property type named "executable property" with the structure: "subject-predicate-query". It is supposed that reasoners, engines, etc. working with such knowledge will execute query within target triplet and treat obtained result as a value for the property. Two immediate advantages of this extension are: (a) triplet will always implicitly keep knowledge about most recent value for the property because query to some data storage or to some BI function will be executed only on demand when needed and the latest information will be delivered; (b) query may be written according to different standards, data representation types, models and schemas so that heterogeneity of original sources of data and capabilities will not be a problem. Therefore distributed data collections can be maintained independently (autonomously) and "queried" in real time by executable RDF links.

Consider simple example in Figure 3. Here the executable statement in RDF (N3 syntax) actually means: "If you want to know with whom John is currently in love, execute the query Q1". The query Q1 (prefix "exe:" points to Executable Knowledge ontology of various query types and indicates that the RDF statement is executable) in this case is semantically described as SPARQL query to the RDF data storage and it means: "Select the girl from the current database of staff, who is colleague of John, has red hair and is 25 years old". When the SPARQL query engine executes the query and finds that "Mary" fits it, the executable RDF statement is transformed into the traditional one (reference to the query "exe:Q1" is replaced with actual value "Mary"). Notice that, if the same knowledge will be explored after 1 year, then the same executable statement will be transformed into: "John is in love with Anna", because staff data (separate source) will be autonomously updated (Anna becomes 25 years old) and RDF connections (semantic layer of Linked Data) on top will be updated when executed.

Consider similar example in Figure 4 and notice that here we have an SQL query to some relational database as implicit value of executable RDF statement. The query Q2 means request for computing average journal papers' publication performance of young (< 30) PhD students. The original executable RDF statement means: "If you want to know average performance of young doctoral students in AI Department, execute query Q2". When the query returns computed value the executable RDF statement is transformed into the traditional one (reference to query "exe:Q2" is replaced with actual value "7", which means that "executable" RDF property is replaced with "datatype" one).

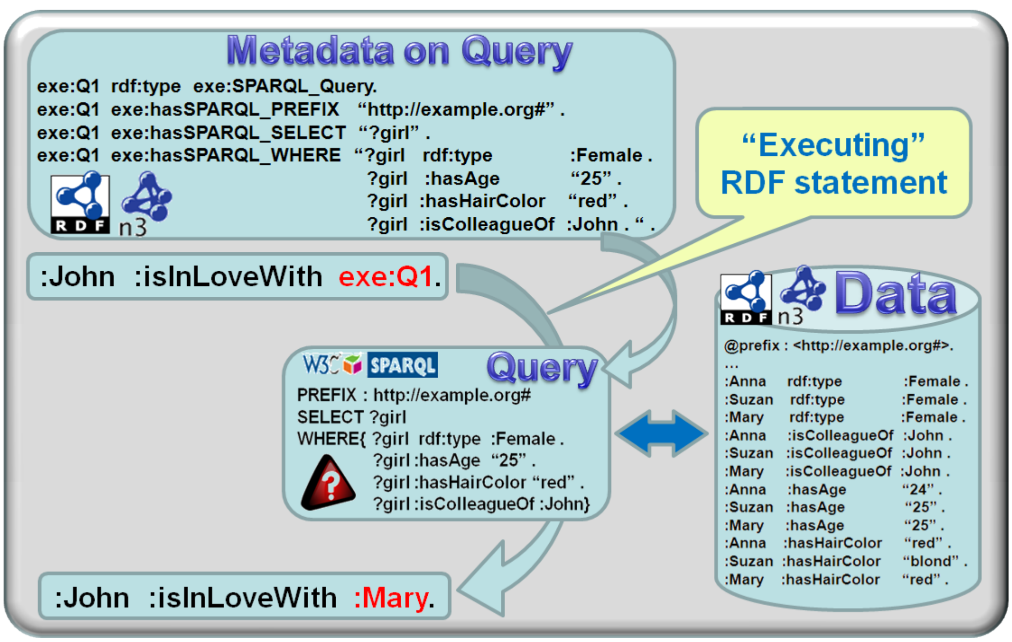

Figure 3. Example of processing executable RDF statement, which contains implicit value as SPARQL query to RDF storage

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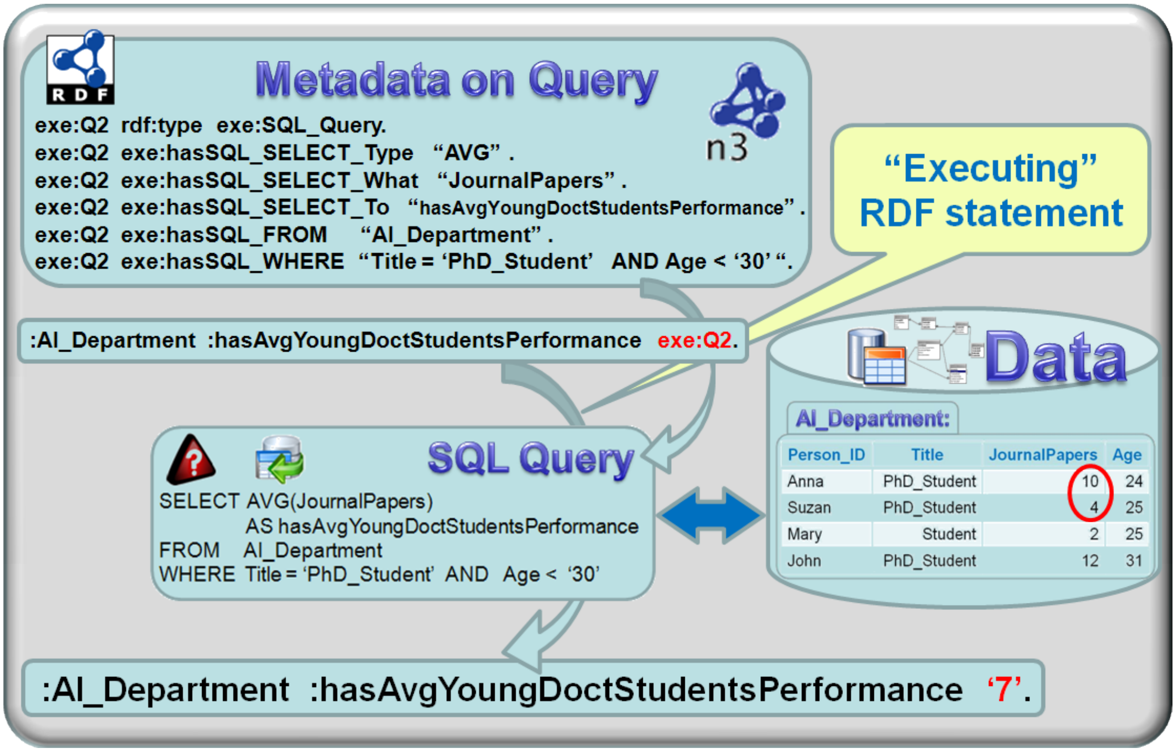

Figure 4. Example of processing executable RDF statement, which contains implicit value as SQL query to a relational database

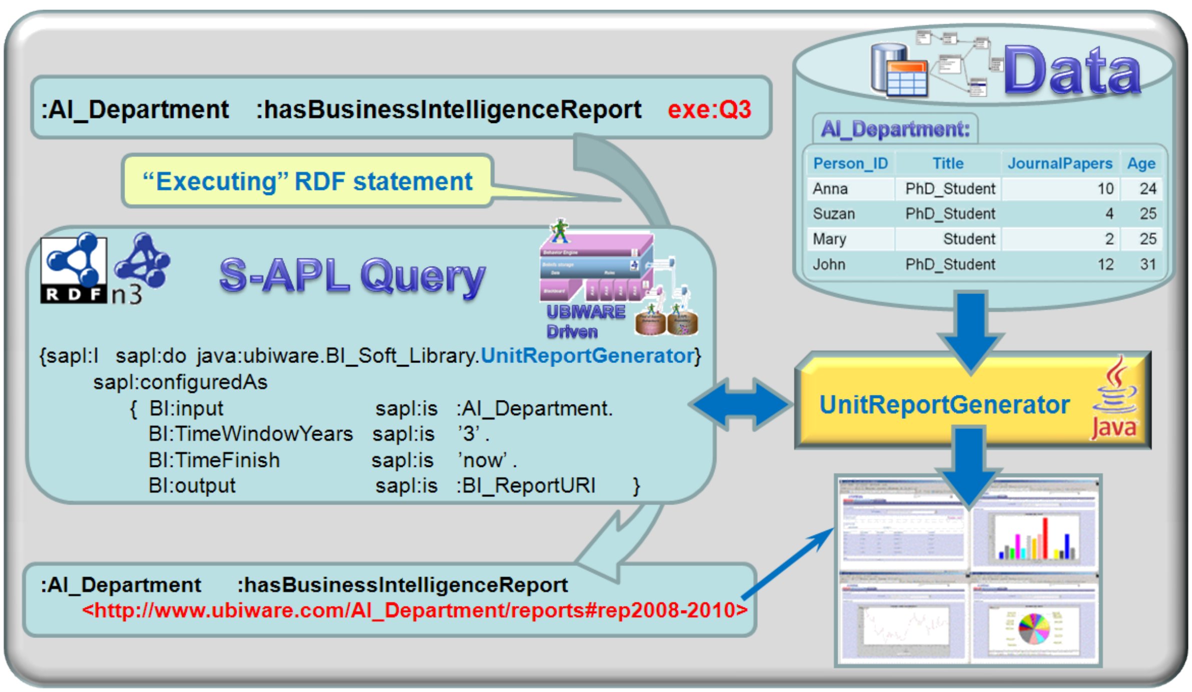

Figure 5. Example of processing executable RDF statement, which contains implicit value as S-APL query to BI software as a service

Consider example in Figure 5. Here we have executable RDF statement that can be interpreted like: "If you want to get basic BI-statistics report for the AI Department for last 3 years, execute query Q3". Behind this query there is a Java software module "UnitReportGenerator" provided as-a-service from online software library. The query itself is written in S-APL (Semantic Agent Programming Language [16]) used for UBIWARE-based applications [17]. S-APL is

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RDF-based language for multi agent systems, in which both data and actions are described semantically. UBIWARE [18] ("Smart Semantic Middleware for Ubiquitous Computing") has been developed by Industrial Ontologies Group (http://www.cs.jyu.fi/ai/OntoGroup). It as a software technology and a tool to support design and installation, autonomic operation and interoperability among complex, heterogeneous, dynamic and self-configurable distributed systems, and to provide coordination, collaboration, interoperability, data and process integration service. UBIWARE platform is used actually to deal with "Executable Knowledge" and its utilization for "Executable Reality" services. In the example, when the BI software is executed, it generates the html page where all analytics is visually presented with different BI widgets. The URI for this page will replace the implicit "exe:Q3" value from the original RDF statement and creates traditional RDF statement with object property connecting two resources (AI Department URI and BI statistics Report URI).

There is also a possibility to compute semantic similarity between resources from different data storages and automatically create appropriate RDF connections for similar (same) instances. As it was shown in Section II, some instances can be considered as similar ones in one context and can be considered otherwise in other context. Therefore, similarly to the examples above, the "Executable Knowledge" supports also RDF statements with implicit similarity search queries, in which needed query parameters are automatically taken from the current context. Change of context can be considered as implicit query (if appropriate setup is made) to re-compute similarity links, which makes RDF graph on top of Linked Data very dynamic. Our approach for context-sensitive semantic similarity computing and its implementation is discussed in [10].

Mixed Reality is just one possible way to utilize Executable Knowledge concept. There should be definitely other application areas for it. Generally many industrial applications, which require dynamic self-configurable solutions, applications and architectures, will benefit from the flexible Executable Knowledge, as our experience with UBIWARE industrial cases demonstrates [18].

V. Related Work

Concepts of "virtual", "augmented", "mixed", etc., realities discussed in Section 1 are being actively developed into various services for public. There are many other relevant concepts and activities, which have many common features with the above, having however some specifics. One such abstraction is so-called "Mirror World" [19], which is a representation of the real world in digital form mapped in a geographically accurate way. Mirror worlds are can be seen as an autonomous manifestation of digitalized reality including virtual elements. Other relevant concept is "Metaverse" (http://metaverseroadmap.org), which is the convergence of virtually-enhanced physical reality and physically persistent virtual space being a fusion of both. The "Second Life" (http://secondlife.com/) is a 3D virtual world enhanced by social networks and communication capabilities. "Lifelogging" [20] is continuous capturing from a human and sharing through the Web various data, events and activities collected by various devices, sensors, cameras, etc. Other slightly different concept is "Lifeblog" [http://europe.nokia.com/support/product-support/nokia-photos], which is also known as popular service for collecting and putting into a timeline (mobile) user activities and creating data in the form of complex multimedia diary.

Our intension was to find out reasonable services out of these concepts suitable not just for public use but mostly for professionals. For that we explored the possibility to utilize Business Intelligence as an additional capability. Preliminary information on the interesting relevant effort named "Augmented Business Intelligence" has appeared in the Web [21] just a couple of months ago. Augmented BI is considered in [21] as a process of using a mobile device to scan an image or a barcode and overlaying metrics and or charts onto the image. This supposes to facilitate the process of a store manager moving around a retail store and would like more information about that products sales performance. See Figure 6, which demonstrates possible use case for the Augmented BI. There are some evident similarities with our use-cases shown in Figure 2, however our implementation benefits from the Linked Data utilization and allows context-sensitive view to the BI-enhanced reality.

Figure 6. Demonstration of possible Augmented Business Intelligence utilization scenario [21].

Our solution related to BI-enhanced mixed reality (or Executable Reality) is based on Executable Knowledge concept. The Executable Knowledge inherits some features from a Dynamic Knowledge (see, e.g., [22]), which is actually dynamically changing knowledge and according to (www.imaginatik.com) providing on-demand, in-context, timely, and relevant information. Issues related to such knowledge include power and expressive tools and languages (as, e.g., LUPS [23]) for representing such knowledge and proper handling of conflicting updates as addressed in [22]. Given an initial knowledge base (as a logic program) LUPS provides a way for sequentially updating it.

Since executable knowledge is definitely a kind of dynamic knowledge, other issue would be whether it is declarative or procedural knowledge. A procedural knowledge (or knowledge on how to do something) is known to be a knowledge focused on obtaining a result and exercised in the accomplishment of a task, unlike declarative knowledge (propositional knowledge or knowledge about something) [24]. Procedural knowledge is usually represented as finite-state machine, computer program or a plan. It is often a tacit knowledge, which means that it is difficult to verbalize it and transfer to another person or an agent. The opposite of tacit knowledge is explicit knowledge.

The concept of executable knowledge can be actually considered as a kind of hybrid of declarative and procedural knowledge. As it can be seen from the examples in Section 4, by "executing" knowledge one actually transforms tacit (procedural) knowledge into explicit (declarative one). Therefore an executable knowledge contains explicit procedural (meta-) knowledge on *how to acquire* (or compute) declarative knowledge. Such capability means that the executable knowledge is naturally self-configurable knowledge (or more generally – self-managed knowledge). We use S-APL (Semantic Agent Programming Language [16]) for its representation, which is based on RDF (N3) syntax and which is equally suitable to manage declarative and procedural knowledge.

Our implementation of the executable knowledge on top of UBIWARE [17,18] agent-driven platform allows UBIWARE agents autonomously "execute" knowledge by following explicit procedural instructions for BI services execution and therefore updating (or making explicit) appropriate declarative beliefs.

VI. Conclusions

In this paper, we presented one way on how Linked Data (from heterogeneous sources) can be automatically processed by various BI services; and also how the results of BI processing can be shown through the (Mobile) Mixed Reality technology. Data heterogeneity problem is handled by the "Executable Knowledge" approach, according to which semantic (RDF) links include explicit queries to data or to (BI) services and other capabilities based on various possible data models and the context.

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