A note on exploration of IoT generated big data using semantics

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ABSTRACT

Welcome to this special issue of the Future Generation Computer Systems (FGCS) journal. The special issue compiles seven technical contributions that significantly advance the state-of-the-art in exploration of Internet of Things (IoT) generated big data using semantic web techniques and technologies.

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1. Introduction

Recent studies have shown that we generate 2.5 quintillion ($2.5 \times 10^{18}$) bytes of data per day (Cisco and IBM) and this is set to explode to 40 yotta ($40 \times 10^{24}$) bytes by 2020 – this is 5,200 GB for every person on earth. Much of these data is and will be generated from IoT [1] devices such as sensors, RFIDs, remote sensing satellites, business transactions, actuators (such as machines/equipment fitted with sensors and deployed for mining, oil exploration, or manufacturing operations), lab instruments (e.g., high energy physics synchrotron), and smart consumer appliances (TV, phone, etc.), but also social media and clickstreams. This vision has recently given rise to the notion of IoT Big Data Applications (IoTBDAs) in domains such as Healthcare, Smart Cities, Smart Manufacturing, and Smart Energy Grids. These IoTBDAs are required to have novel capability (currently non-existent) of analyzing large number of dynamic data streams [2], tens of years of historical data, and static knowledge about the physical world (i.e. city map, road network map, utility network map, etc.) to support real-time and/or near real-time decision making.

The decision making process involving such big data applications often involves exploration for meaningful patterns and connections. Despite the rapid evolution of IoTBDAs; current generation of Cloud Computing and Big Data Processing techniques/frameworks (e.g., batch processing, stream processing, and NoSQL) lack the following very important abilities to support effective exploration: Several novel interfaces and interaction means for exploration of big data are being proposed, for example, exploratory search systems, data browsers, visualisation environments and knowledge graph-based search engines. Although on the rise, the current solutions are still maturing and can benefit from computational models that aid intuitiveness and improve the effectiveness of exploration tasks. The Semantic Web and its derivatives in the form of Linked data and Web of data can play a crucial role in addressing various big data exploration challenges.

The ability to discover semantic context [3–5] is one of the primary requirements as in regards to exploring and managing big data. Further, enriching data exploration techniques with semantic context information has been proven useful in inferring knowledge about what is exactly happening in the physical environment [6], which is being monitored and/or controlled, by IoT sensors and/or actuators. For example, identifying a malfunctioning IoT sensor by comparing data from nearby functioning sensor is critical, so the data exploration engine can ignore the data items captured by the malfunctioning sensors. Semantic context data can provide information about data quality, which can also have a direct impact on the final analytics results. Moreover, semantic context information can be used to develop efficient and effective data collection plans specially, when multiple sensors available nearby offer similar information.

The main goal of this Special Issue is to explore new directions and approaches about key research topics needed to leverage innovative research aimed at tackling big data exploration challenges in IoTBDAs, based on semantic technologies [7]. We encouraged the submission of work with important theoretical and practical results, as well as case studies on existing use of semantic technologies for big data exploration.

2. Summary of contributions

In this section, we present the summary of the papers that were accepted for publication in this special issue.

Large and complex spatial data can be leveraged for different purposes and in different IoTBDAs, however, traditional processing and analytical methods may not be fit-for-purpose. Such methods
generally use mathematical causal analysis techniques, which seek
to find causes and effects of everything. In spatial big data, how-
ever, users only wish to obtain all possible related resources and
data rather than why or how these correlations occur or the under-
lying classical theories. There are also many unknowns between
cause and effect. Therefore, imprecise and non-classical methods
have been used to realize similar and fuzzy retrieval of spatial
big data based on semantics. Associative retrieval, on the other
hand, has been identified as a potential technique for big data. In
the paper titled “Associative retrieval in spatial big data based on
spreading activation with semantic ontology (http://dx.doi.org/10.
1016/j.future.2016.10.018)”, Sun et al. integrate the spreading acti-
vation (SA) algorithm and the ontology model in order to promote
the associative retrieval of big data. In their approach, constraints
based on variant weights of semantic links are considered with the
aim of improving the spreading-activation process and ensuring
the accuracy of search results. Semantic inference rules are also
introduced to the SA algorithm to find latent spreading path and
help obtain results, which are more relevant. Their theoretical and
experimental analysis demonstrate the utility of this approach.

With the development of mobile technology, the users brows-
ing habits are gradually shifting from information retrieval to
recommendation. The classification-mapping algorithm between
a user’s interests and web contents has become more and more
difficult with the volume and variety of web pages. Some big
news portal sites and social media companies hire more editors
to label these new concepts and words, and use the computing
servers with larger memory to deal with the massive document
classification, based on traditional supervised or semi-supervised
machine learning methods. Li et al. in the paper titled “An optimized
approach for massive web page classification using entity similarity
based on semantic network (http://dx.doi.org/10.1016/j.future.
2017.03.003)”; provide an optimized classification algorithm for
massive web page classification using semantics networks, such as
Wikipedia, WordNet. In this paper, they used Wikipedia dataset
and initialized few category words as class words. A weight estima-
tion algorithm based on the depth and breadth of the Wikipedia
network is used to calculate the class weight of all Wikipedia
words. A kinship-relation association based on content similarity
is proposed to optimize the unbalance problem when a category
node inherited the probability from multiple fathersons. The keywords
of web page are extracted from the title and main text using an
N-gram with Wikipedia words, and a Bayesian classifier is used
to estimate the page class probability. Experimental results shows
that the proposed method has very good scalability, robustness and
reliability for massive web pages.

Multimedia big data is difficult to handle because of its enor-
mous amount and the elusive property of underlying information.
To study how to explore valuable information among multimedia
big data with low complexity, in the paper titled “Object detec-
tion among multimedia big data in the compressive measurement
domain under mobile distributed architecture (http://dx.doi.org/10.
1016/j.future.2017.03.004)”, Guo et al. propose an object detection
method of big data, which is in the compressive measurement
domain under a mobile distributed computing architecture. It in-
cludes the sparse representation and object detection processes.
Considering the unbalanced computation capacity between a mo-
 bile center cloud and mobile edge sites, they shift large storage
burden into the cloud, while performing the dictionary learning
by using compressive measurements in the mobile edge sites.
Specifically, after getting the measurements at the edge sites, they
perform dictionary learning to obtain the sparse representation in
the pixel domain, then select significant images and their feature
vectors to be stored in the center cloud. In addition, they also ana-
lyze the trained dictionary in the measurement domain employing
measurements. In order to reveal the two kinds of dictionaries’
relationship, they conduct a formulation process into each of them
and find that the relationship depends on the uniqueness relation
between the original signal and the sparse coefficient in the mea-
surement domain. At the same time, they keep coefficients for a
certain time period at the mobile edge sites in order to realize
real-time object detection, taking advantage of low latency of the
mobile edge computing ends. Since the sparse coefficients and
the original signal have a one-to-one correspondence relationship,
they can just search for the matched coefficients of the image block
for detecting object. Experimental results show that Hadamard
measurement matrix can better preserve the characteristics of the
original signal than Gaussian matrix and that the proposed method
can achieve a favorable detection performance. Meanwhile, the
computation cost and storage cost of the proposed detection pro-
cess can be significantly reduced compared with traditional meth-
ods, which is suitable for the multimedia big data.

It is very difficult to process large amount of structured and
unstructured big data generated by IoTBDAs with traditional se-
quential programming methods. To this end, the paper titled “A
MapReduce-based Scalable Discovery and Indexing of Structured Big
Data (http://dx.doi.org/10.1016/j.future.2017.03.028)”, by Singh
et al., proposes a parallel B-Tree index and its implementation
in the MapReduce framework for improving efficiency of ran-
don reads over the existing approaches. The benefit of using
the MapReduce framework is that it encapsulates the complexity
of implementing parallelism and fault tolerance from users and
presents these in a user friendly way. The proposed index reduces
the number of data accesses for range queries and thus improves
efficiency. The B-Tree index on MapReduce is implemented in a
chained-MapReduce process that reduces intermediate data access
time between successive map and reduce functions, and improves
efficiency. Finally, five performance metrics have been used to
validate the performance of the proposed index for range search
query in MapReduce, such as, varying cluster size and, size of range
search query coverage on execution time, the number of map tasks
and size of Input/Output (I/O) data. The effect of varying Hadoop
Distributed File System (HDFS) block size and, analysis of the size
of heap memory and intermediate data generated during map and
reduce functions also shows the superiority of the proposed index.
It is observed through experimental results that the parallel B-Tree
index along with a chained MapReduce environment performs
better than the default non-indexed dataset of the Hadoop and B-
Tree like Global Index in MapReduce.

The representation, management and application of continu-
ously increasing amounts of heterogeneous data generated by
IoTBDAs remains an open research challenge specially in context
of smart home application. To this end, Tao et al. in their pa-
per “Ontology-based data semantic management and application in
IoT- and cloud-enabled smart homes (http://dx.doi.org/10.1016/j.
future.2016.11.012)”, propose a scheme for ontology-based data
semantic management and application. Based on the smart home
system model abstracted from the perspective of implementing
users’ household operations, a general domain ontology model is
designed by defining the correlative concepts, and a logical data
semantic fusion model is designed accordingly. Subsequently, to
achieve high-efficiency ontology data queries and updates in the
implementation of the data semantic fusion model, a relational-
database-based ontology data decomposition storage method is
developed by thoroughly investigating existing storage modes,
and the performance is demonstrated using a group of elaborated
ontology data query and update operations. The work attempts
to provide accurate and personalized home services, and the ef-
ciency is demonstrated through experiments conducted on the
developed testing system for user behavior reasoning.

Just like other web-based information systems, IoTBDAs must
also deal with the plethora of Cyber Security and Privacy threats
that currently disrupt organisations and can potentially hold the data of entire industries and even countries for ransom. To realise its full potential, IoTBDAs must deal effectively with such threats and ensure the security and privacy of the information collected and distilled from IoT devices. However, IoT presents several unique challenges that make the application of existing security and privacy techniques difficult. This is because IoTBDAs encompass a variety of security and privacy solutions for protecting such IoT data on the move and in stores at the device layer, the IoT infrastructure/platform layer, and the IoT application layer. Therefore, ensuring end-to-end privacy across these three IoT layers is a grand challenge in IoT. In the paper titled “Privacy preserving Internet of Things: From privacy techniques to a blueprint architecture and efficient implementation” (http://dx.doi.org/10.1016/j.future.2017.03.001”), Jayaraman et al. tackle the IoT privacy preservation problem. In particular, they propose innovative techniques for privacy preservation of IoT data, introduce a privacy preserving IoT architecture, and also describe the implementation of an efficient proof of concept system that utilises all these to ensure that IoT data remains private. The proposed privacy preservation techniques utilize multiple IoT cloud data stores to protect the privacy of data collected from IoT. The proposed privacy preserving IoT architecture and proof of concept implementation are based on extensions of OpenIoT – a widely used open platform service for IoT application development. Experimental evaluations are also provided to validate the efficiency and performance outcomes of the proposed privacy preserving techniques and architecture.

How to obtain personalized quality of services from IoTBDAs and assist users selecting appropriate application instance has become a pressing issue with the explosion of different types of IoTBDAs applications (e.g., smart home monitoring to remote healthcare monitoring) on the Internet. Collaborative QoS prediction is recently proposed addressing this issue by borrowing ideas from recommender systems. Going down this principle, Wu et al. in their paper “Deviation-based neighborhood model for context-aware QoS prediction of cloud and IoT services” (http://dx.doi.org/10.1016/j.future.2016.10.015”), propose novel deviation-based neighborhood models for QoS prediction by taking advantages of crowd intelligence. Different from existing works, their models are under a two-tier formal framework that allows an efficient global optimization of the model parameters. The first component gives a baseline estimate for QoS prediction using deviations of the services and the users. The second component is founded on the principle of neighborhood-based collaborative filtering and contributes fine-grained adjustments of the predictions. Also, contextual information is used in the neighborhood component to strengthen the predicting ability of the proposed models. Experimental results, on a large-scale QoS-specific dataset, demonstrate that deviation-based neighborhood models can overcome existing difficulties of heuristic collaborative filtering methods and achieve superior performance than the state-of-the-art prediction methods. Also, the proposed models can naturally exploit location information to ensure more accurate prediction results.

With the growing popularity of IoTBDAs and sensors deployment, more and more cities are leaning towards smart city solutions that can leverage this rich source of streaming data to gather knowledge that can be used to solve domain-specific problems. A key challenge that needs to be faced in this respect is the ability to automatically (i.e., context aware) discover and integrate heterogeneous sensor data streams on the fly for applications to use them. To provide a domain-independent platform and take full benefits from semantic technologies, the paper titled “Automated discovery and integration of semantic urban data streams: The ACEIS middleware” (http://dx.doi.org/10.1016/j.future.2017.03.002”), Gao et al. present an Automated Complex Event Implementation System (ACEIS), which serves as a middleware between sensor data streams and smart city applications. ACEIS not only automatically discovers and composes IoT streams in urban infrastructures for users’ requirements expressed as complex event requests, but also automatically generates stream queries in order to detect the requested complex events, bridging the gap between high-level application users and low-level information sources. The paper also demonstrates the use of ACEIS in a smart travel planner scenario using real-world sensor devices and datasets.

Besides the abundant potential for the IoTBDAs, there are also challenges to security due to complexity and unpredictability of the Internet, clouds, and big data. One of the challenges is information and data exchange, for example, identifying untrustworthy cloud users and analyzing abnormal user behavior during information exchange. Hence in the paper titled “A game-theoretic model and analysis of data exchange protocols for Internet of Things in clouds” (http://dx.doi.org/10.1016/j.future.2016.12.030”), Tao et al. address exchange mechanism, which is a useful theoretical basis to make secure electronic commerce and electronic business transactions possible. To ensure and verify the property of fairness, a crucial property of exchange mechanism, this paper proposes a specific model for behavior analysis based on the extensive game with imperfect information. Rationality and fairness properties are built in the corresponding game and the game tree. To verify the properties, a tree analysis method is proposed, and a linear time algorithm is given. As a case study, some flaws of the ASW protocol are found.

We hope that the readers will find the articles of this special issue to be informative and useful.

References


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