A Service-Oriented Framework for Big Data-Driven Knowledge Management Systems

Thang Le Dinh[1(✉)], Thuong-Cang Phan[1], Trung Bui[2], and Manh Chien Vu[1]

[1] Research and Intervention Laboratory on Business Development in Developing Countries, Université du Québec à Trois-Rivières, C.P 500, Trois-Rivières, QC G9A 5H7, Canada
{Thang.Ledinh, Thuong-Cang.Phan, Manh.Chien.Vu}@uqtr.ca
[2] Adobe Research, Adobe Systems Incorporated, San Jose, CA 95110-2704, USA
Bui@adobe.com

Abstract. Enterprises nowadays are intensifying their efforts to create value through big data initiatives as well as knowledge management systems to outperform their competitors. Big data is considered as a revolution that transforms traditional enterprises into Data-Driven Organizations (DDOs) in which knowledge discovered from big data will be integrated into traditional organizational knowledge to improve decision-making and to facilitate organizational learning. This paper proposes a service-oriented framework for designing a new generation of big data-driven knowledge management systems to help enterprises to promote knowledge development and to obtain more business value from big data. The key artefacts of the framework are presented based on design science research, including constructs, model, and method. The objective of the framework is to promote both knowledge exploration and knowledge exploitation that need to take place simultaneously in DDOs.

Keywords: Big data analytics · Knowledge management system · Service-oriented · Design science research

1 Introduction

In the knowledge-based economy, the use of Information and Communication Technologies (ICT) for creation, management, dissemination and exploitation of organizational knowledge is extremely critical because knowledge is a vital factor for managers in modern and networked organizations [1].

Big data is a popular term used to describe the exponential growth and availability of data, both structured and unstructured from traditional and new digital sources inside and outside enterprises [8]. In order to transform big data into organizational knowledge, a new generation of knowledge management systems (KMSs) is required to enable insight discovery and to promote organizational learning [9]. Big data is considered as a revolution that drifts toward data-driven discovery and decision-making [10]. This revolution transforms traditional enterprises into a new generation of

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knowledge-intensive enterprises: *Data-Driven Organizations* (DDOs) in which managers can translate knowledge discovered from big data into organizational knowledge to improve decision-making and enterprise performance [11].

This paper proposes a service-oriented framework for designing a new generation of big data-driven KMSs to help enterprises to promote knowledge development and to obtain more business value from big data. The paper is organized as follows. Section 2 describes the theoretical background and the related work. Section 3 introduces the research design. Section 4 proposes the fundamental of the framework based on design science research, including the constructs, model, and method. Section 5 presents an illustrative example of the framework. Section 6 ends the paper with the conclusions and future work.

2 Background

Knowledge is defined as 'information possessed in the mind of individuals related to facts, procedures, concepts, interpretations, ideas, observations, and judgments' [2]. Based on the knowledge-component classification, there are different types of *knowledge components* such as know-what (declarative), know-how (procedural), know-why (causal), and know-who (possessive) [3, 4].

Knowledge Management is considered as "…the art of performing knowledge actions such as organizing, blocking, filtering, storing, gathering, sharing, disseminating, and using knowledge objects…" [5]. *Organizational Knowledge* is the capability of members of an organization that have developed to draw distinctions in the process of carrying out their work, in particular, and concrete contexts, by enacting sets of generalizations whose application depends on historically evolved collective understandings [6]. Enterprises require having an effective knowledge management system that renders them more competitive [2]. Knowledge-intensive enterprises offer to the market the use of sophisticated knowledge or knowledge-based products and services [7]. DDOs are a specific type of knowledge-intensive enterprises in which knowledge captured from big data needs to be integrated with traditional knowledge to promote both knowledge exploration as well as knowledge exploitation.

Through *Knowledge Management Systems* (KMSs), enterprises are not only collecting and storing large amounts of knowledge, but also they are using it to develop intellectual capital, to improve customers' experiences, and to make better business decisions [2]. KMSs nowadays are being confronted with a variety and unprecedented amount of data, resulting from different business and ICT-based services, called "*big data*". Big data, which is high volume, velocity, or variety information assets or all, provides a new source of knowledge about the business environment. Therefore, big data is considered a challenge but also an opportunity for enterprises. In order to integrate knowledge extracted from big data into organizational knowledge, there are several studies that separately concentrated on specific aspects such as knowledge management, business intelligence and business analytics [11], data mining and knowledge discovery [12, 13]. However, most enterprises spend more time, money and effort to build and manage their big data infrastructure than to create applications that solve their own business problems [9]. In other words, current applications of big data concentrate on knowledge exploration, but have not been fully supported knowledge exploitation yet.

In addition, the emerge of service science has directed KMSs research towards service-based knowledge management systems [14–17]. In our observation, there is still a little effort to study both the trends in service orientation and in big data in order to promote the whole process of organizational knowledge management, including knowledge exploration and knowledge exploitation [18].

Consequently, we propose a novel service-oriented framework for designing big data-driven KMSs. The new generation of KMSs forms the knowledge infrastructure [5] of a DDO that supports different activities in the knowledge development process in order to provide a unified way of working, learning and innovating in the big data era. This framework is fundamental for DDOs, in which both knowledge exploration and exploitation need to take place simultaneously [18]. The framework helps DDOs to create more business value by discovering more knowledge, obtaining more customer/user experience, and making more accurate business decisions.

3 Research Design

The main research question of this study is *"How to design a service-oriented knowledge management system for a data-driven organization?"*.

In order to respond to this question, we propose a framework that has two main objectives. Firstly, the framework presents a new viewpoint on knowledge management research by introducing the service orientation as an architectural approach for managing organizational knowledge. Secondly, the framework allows DDOs to capture knowledge discovered from big data and to integrate it with traditional organizational knowledge. Therefore, the proposed framework addresses two major challenges: *Service orientation for organizational knowledge management* [18] and *Unification of organizational knowledge discovered from diverse data sources, including big data*.

The service-oriented framework for designing big data-driven KMSs, hereafter called the SO-KMS (service-oriented knowledge management system) framework, aims at providing a knowledge infrastructure to support the knowledge development process in a data-driven organization. The specification of the framework (Table 1) is based on the principles of design science research, including artefacts such as constructs, model, method, and instantiations [19].

Table 1. Artefacts of the SO-KMS framework.

Artefact	Description
Constructs	Different types of concepts related to knowledge objects in a data-driven organization and its business environment.
Model	A set of statements expressing the relationships between knowledge objects at different levels in the knowledge base.
Method	A set of activities that supports the process of knowledge development.
Instantiations	Best practices related to the operationalization of the framework.

4 Service-Oriented Framework for Designing Big Data-Driven KMSs

This section presents the key artefacts of the framework, including the constructs, model and method. The instantiations will be developed in our future work based the validation and experimentation of the framework with real-world applications [25].

4.1 Framework Constructs

The *constructs* of the framework are based on the existing typologies of knowledge for knowledge creation [20] and knowledge components for knowledge organization [3, 4]. The knowledge infrastructure for a DDO is composed of different knowledge components that are used to represent knowledge objects and to form the semantic context of knowledge creation.

In our approach, knowledge is constituted from objects, called *knowledge objects*. These knowledge objects are classified based on their level of development such as data, information, knowledge or wisdom [48]. In addition, the knowledge development process covers organizational activities in an organization that promotes the learning process and develops the intellectual capital. The main activities of this process are knowledge capture, knowledge organization, knowledge transfer and knowledge application [4].

Concerning the development view, a knowledge object is a highly structured, interrelated set of data, information, knowledge, and wisdom (Fig. 1). In our approach, we prefer the term “understanding” instead of “wisdom” [18] because our research just focuses on the first level of understanding. At this level, enterprises understand how to create or increase values by using their knowledge and knowing [26]. A knowledge object may concern some organizational, management or leadership situation and provides a viable approach for dealing with that situation [48]. Concerning the structure view, a knowledge object is constructed based on a set of knowledge components such as know-what, know-how, know-who and know-why. Organizational knowledge could be explicit knowledge or tacit knowledge, individual or collective [18]. Systems and people can use and share organizational knowledge of knowledge objects by using different knowledge conversion processes such as socialization, externalization, combination and internalization [20].

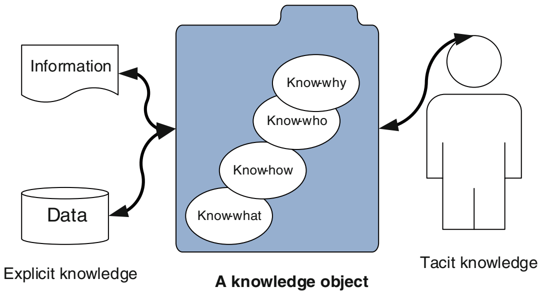

Fig. 1. A knowledge object.

Knowledge development process supports both knowledge exploration and knowledge exploitation. The *knowledge exploration* creates and stores knowledge through individual's cognitive processes (tacit knowledge) or collaboration processes (explicit knowledge) [2, 20]. The *knowledge exploitation* enhances the intellectual capital of an enterprise with existing knowledge in the knowledge base [23]. The process of knowledge exploration, including *knowledge capture* and *knowledge organization*, concerns the capture and organization of different knowledge (tacit and explicit) in the organization memory. The process of knowledge exploitation, including *knowledge sharing* and *knowledge application*, concerns the transfer and application of classified and organized explicit knowledge in the knowledge base.

4.2 Framework Model

The *model* of the framework is based on four aspects of knowledge that forms the knowledge structure of a DDO: structure, transition, possession, and governance [4]. The structure of knowledge is represented by know-what that describes knowledge artefacts known and related to a phenomenon of interest [3]. The transition of knowledge is represented by know-how that describes the understanding of the generative processes constituting phenomena [3]. The possession of knowledge is represented by know-who that refers to individuals, groups, or organizations that work on knowledge objects [4]. The governance of knowledge is represented by know-why that describes the understanding of principles of the underlying phenomena [3].

Recently, we have witnessed a rapid progress in a paradigm shift from the object-oriented computing paradigm to the service-oriented paradigm, which aims at structuring enterprises around services [27–29]. Consequently, the model of the framework (Fig. 2), which determines the knowledge infrastructure for a DDO, includes four levels: service-oriented computing (know-what), service-oriented architecture (know-how), service-oriented enterprise (know-who), and service-oriented paradigm (know-why).

Service-Oriented Computing (SOC) is a computing paradigm that utilizes services to process data as the basic constructs to support the rapid and low-cost development of distributed applications in heterogeneous environments [28]. *Service-Oriented Architecture* (SOA) is a design framework for the construction of information systems by "combination of services" to transform data into useful information. *Service-Oriented Enterprise* (SOE) aims at transforming information into organizational knowledge by combining business processes in a horizontal fashion [30, 31]. *Service-Oriented Paradigm* (SOP) aims at improving business services by applying organizational knowledge that is based on the principles of service science, including Service management, Service science, and Service engineering [26, 32].

In addition, the framework model should also match the requirements of the new-generation of KMSs as mentioned before, such as the support of the service-oriented activities, and the unification of knowledge derived from diverse (big) data sources in a DDO. Designing the framework based on service orientation leads to more shareable, reusable, efficient and flexible KMSs. Besides, one of the most

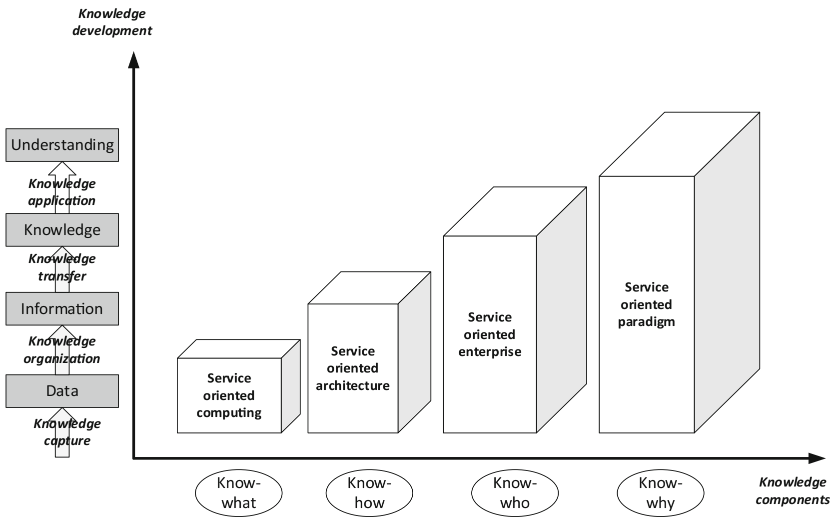

Fig. 2. Framework model.

important characteristics of those KMSs is *big data-driven* that leverages all available data to gain a competitive advantage in the big data era.

An overall architecture of the SO-KMS based KMSs includes four layers: Data Services, Information Services, Knowledge Services, and Business Process layers (Fig. 3).

Business layer, corresponding to the SOP, includes the process representation and provides the structure for aggregating knowledge-intensive services to form a knowledge-intensive process that is aligned with a subset of business goals [7, 26]. A business is now constructed by a flow of knowledge-intensive processes realized by corresponding services. The flow contains the logic for the sequence in which the services need to be invoked and executed. To access a capability provided by a service, a process needs to be aware of the existence of the service. This requirement is generally achieved by executing queries on the service registry or by using other means of service discovery. The business layer finally allows users to develop their service-oriented way of working through supplying a workflow of processes and associating each process with corresponding services in different layers.

Knowledge layer, corresponding to the SOE, provides knowledge services to support processes that are also called *Knowledge-as-a-Service* (KaaS). This layer is a conceptual bridge between *Business layer* and *Information layer*. Its primary work is to transfer the information from *Information layer* into the knowledge based on their semantic contexts. The organizational knowledge of this layer is delivered on request by using different services such as knowledge-based, collaboration, discovery and decision-making services. *Knowledge base service* is a high-level composite service realized by the data migration and analytics services. *Collaboration service* allows the creation, sharing and application of the knowledge from the knowledge base service. *Discovery service* provides functions such as search, retrieval, mining, mapping,

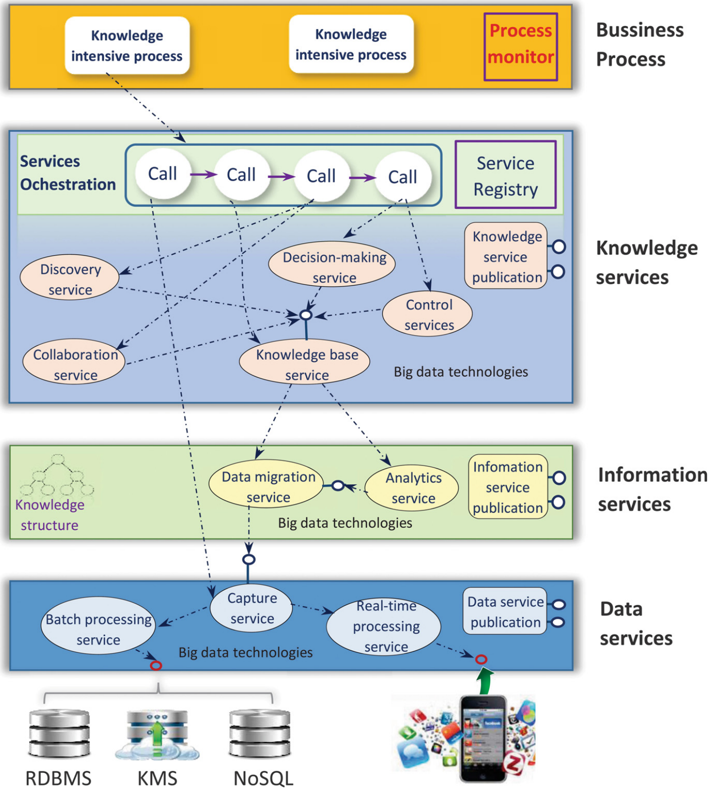

Fig. 3. A service-oriented framework for big data-driven KMSs.

navigation, and presentation of the knowledge from the knowledge base service. *Decision-making service* devises an increased understanding about a business situation, and provides a guideline to make the most effective and strategic business decision. *Control services* ensure the high-quality performance for business processes and their corresponding services. These services are published thanks to a *knowledge service publication*. In addition to the services listed above, a service orchestration enables the layer to support different processes by orchestrating existing services. Some of those services are the services of the organization and others of which may be provided by external organizations. A service registry function stores information and specification about all the available services (e.g. service artifacts, description, configuration and policies) to advertise for service clients.

Information layer, corresponding to the SOA, contains information services that carry out isolated business functions, which are also known as *Information-as-a-Service* (IaaS). These services provide a bridge between the higher-level layers and the data layer. They structure and analyze the disorder, disparate and obscure data from data layer into linked, integrated, and organized information. Thus, this information is delivered on demand as a service throughout the organization. The information services consist of *Data migration service* and *Analytics service*. The data migration service manages the data structure and implements the unification of data; meanwhile, the analytics service performs analytics on the data.

Data layer, corresponding to the SOC, includes data services that work directly with diverse big data sources. After collecting the data, the layer publishes the available *Data-as-a-Service* (DaaS) to higher-level layers. Its main service is *Capture service* that is a composite service of two individual services: *Batch processing service* and *Real-time processing service*. Those services capture batch data and real-time streaming data. The batch data is data of existing applications that is collected, processed, and stored in databases. The real-time data is data delivered immediately after the collection from continuous inputs in a short time period or near real time.

Thanks to loose coupling between the services, the layers can be adapted to specific requirements of a DDO by updating the existing services or adding some new ones. All these new services should be disseminated to consumers by registering to the service registry and be easily discovered and published using standard interfaces.

4.3 Framework Method

In this section, the framework method is presented according to its main activities: knowledge capture, organization, transfer and application. The *framework method* is based on the process of knowledge development and organizational learning for knowledge organization [2, 21]. It is also referred to the governance model enhanced from the coordination theory for knowledge transfer [22] as well as to the organizational learning and service innovation for knowledge application [23, 24].

Knowledge capture invokes and executes *capture service* that is realized by the batch and real-time processing services in the data layer. The data processing services then call user-defined functions to collect data from the diverse data sources such as big data, existing KMSs, and traditional information systems. It notes that both the data sources and volume of data collected have exploded for the time being, especially the case of social network data. These sources lead to the formation of new useful information that can be mined to glean insights into organizations, products, services and customers. In contrast, there would be great challenges in capturing, analysing and processing them.

Knowledge organization calls *data migration service* and *analytics service* to receive, unify and analyze the data from *capture service* and then transforms it into semantic information stored in a large-scale distributed knowledge base. In detail, the *data migration service* maps the batch and real-time data from the *capture service* into semantic information stored in the knowledge base, which is organized based on the knowledge structure. Meanwhile, the *analytics service* creates more knowledge for decision-making thanks to analytic tools and techniques used by data scientists, predictive modelers and other analytics professionals. In addition, cluster analysis is used to segment the information into groups based on similar attributes. Once these groups are discovered, organizations can fulfill targeted actions. These capabilities as mentioned above have been untapped by conventional KMSs.

Knowledge transfer invokes and executes the *discovery and collaboration services* to retrieve, transform and infer the semantic information into knowledge that is stored in the knowledge base. The actual knowledge structure is designed once (under the supervision and revision of the designer) and must be updated when the data schema is changed. In contrast, knowledge views in the knowledge base are built on demand. The *discovery service* can incorporate rules and the knowledge views in the design of updatable knowledge views that represent inferred knowledge. The collaboration service provides functions such as discussion, feedback, personal note, comment, and rating to facilitate the collaboration in a DDO.

Knowledge application uses *decision-making services* to create a new application of the knowledge. Moreover, the activity may also communicate the services of external application systems through standard service interfaces. The services of this activity can query the knowledge views, and represent the result in several ways, such as virtual personalized file system views in the form of folder hierarchy, graph views, and array views. Finally, users can use tools to visualize and analyze their query result. Besides, the result can be published on the desktop of the end-user through a knowledge explorer or a web browser.

5 Illustrative Example

The SO-KMS framework is built based on the service orientation that supports loosely coupled services to enable business flexibility in an interoperable and technology-agnostic manner. From the technical perspective, the framework is an application architecture wherein services are defined using a description language with callable interfaces. Those services are implemented in different programming languages to support various knowledge-intensive processes in a DDO.

In order to demonstrate the applicability of the framework, we present an illustrative example based on our on-going project that builds a Customer Knowledge Management System (CKMS) for SMEs (small-and-medium-sized enterprises). The purpose of this application is to construct and leverage a knowledge structure as an ontology to organize information assets efficiently so that they can be used and shared to facilitate the decision-making and organizational learning. We are developing an open-source software prototype based on the current open-source tools and systems for developing big data applications. This prototype can assist DDOs, especially SMEs, to take the benefits of exploring and exploiting business value from their data as well as big data.

At first, Web service technology has been chosen for implementing CKMS because it is the most popular and well-known technology for implementing SOA, both in the industry and academia [33]. The main triad of Web services standards is [34]: WSDL (Web Service Definition Language) for defining the interfaces of the services, SOAP (Simple Object Access Protocol) for invoking the services, and UDDI (Universal Description, Discovery, and Integration) for publishing and querying the registry of services. To specify a knowledge structure, OWL (Web Ontology Language), which is the most powerful of the ontology languages [35], adds a semantic layer to the descriptions of Web services.

The semi-structured and unstructured data sources are not often processed in traditional KMSs and enterprise systems, which are generally based on relational databases. Furthermore, these existing KMSs are not able to handle on sets of big data that are updated frequently or even continuously. In Table 2, we, therefore, investigate emerging open-source big data technologies used for this application to overcome these challenges.

Table 2. List of emerging open-source big data software tools.

Name	Description	Implementation
Apache Hadoop [36]	A large-scale parallel data processing framework across clusters traditionally, used to run MapReduce jobs. It has become dominant in the area of big data processing with large infrastructures being deployed and used in manifold application fields [37, 38].	Capture service, Batch processing service, Data migration service, and analytics service.
Apache Spark [39]	A cluster-computing framework for big data processing. Spark has emerged as the next-generation big data processing engine. It is faster, easier to program, and better to support a variety of computing-intensive tasks [40, 41].	Capture service, Real-time processing service, Data migration service, Analytics service, Knowledge base service, Discovery service, Decision-making service, Control service, and Collaboration service.
Apache Jena Elephas [42]	A set of libraries that provide various basic building blocks to write Hadoop based applications, which work with RDF or OWL data. Jena is a leading Semantic Web programmers' toolkit [43, 44].	All the services of the information and knowledge layers
Apache Hive [45]	A data warehouse software facilitates querying and managing large datasets residing in distributed storage assembled on top of Hadoop. It is widely used for data warehouse systems with Hadoop, and big data analytics applications [46].	Capture service, Data migration service, Analytics service, and Knowledge base service.
Apache Axis2/Java [47]	A Web Services/SOAP/WSDL engine, the successor to the widely used Apache Axis SOAP stack.	All the services of the framework

6 Conclusion

We presented a novel service-oriented framework, called the SO-KMS framework, for designing big data-driven knowledge management systems (KMSs) that aims at providing a knowledge infrastructure to support the knowledge development process in a data-driven organization. The purpose of this approach is to add more business value from big data and to facilitate the whole knowledge development process. According to our knowledge, our approach is one of the first that focuses on unifying big data with knowledge management systems based on the perspective of knowledge structure [18]. Besides, applying the principles of service orientation and big data to knowledge management, we can achieve more agile and flexible KMSs and make knowledge more available, consistent and trustworthy. The approach also enables access to complex, heterogeneous data within organizations and deployment of that information as reusable services. As a result, the framework focuses not only on providing a loosely coupled infrastructure for service enablement, but also effectively designing and managing loosely coupled business processes, which are aggregations of knowledge-intensive services.

With regard to practical and theoretical implications, our approach helps enterprises to unify big data and KMSs to gain a competitive advantage in the big data era. By proving the different categories of knowledge components, the artefacts of our framework can be adapted to some real-world scenarios of innovation and decision-making in which each category of knowledge components could be more or less important. Unifying big data within KMSs following our framework helps practitioners to make better use of their data in traditional information systems and new information assets, and to accumulate organizational knowledge. When an enterprise intends to build its own knowledge infrastructure that covers big data applications and KMSs, the framework provides a starting point for capturing, classifying, integrating and organizing knowledge, and for sharing them within and among organizations through services.

Concerning the future work, the suggested framework could be applied and refined by researchers to improve its generalizability and to broaden its scope. We have stressed on validating the framework in practice, especially to manage knowledge related to customers and the business environment. The open-source customer KMS is currently being built to support customer knowledge management in digital marketing. Furthermore, we continue to complete the instantiations of the framework. Besides, process optimization problems of the framework should also be thoroughly considered.

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