Big Data Knowledge Service Framework based on Knowledge Fusion*

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Abstract: In big data environments, knowledge fusion is the necessary prerequisite and effective approach to implement knowledge service. This paper firstly analyses the requirements of big data knowledge service and the contents of knowledge fusion, constructs a multi-level architecture of knowledge service based on knowledge fusion. Then, this paper presents a design of a knowledge fusion process model and analyses its implementation patterns. Finally, a system framework of big data knowledge service is proposed based on knowledge fusion processes, in which processes of both knowledge fusion and knowledge service are organically combined together to provide an effective solution to achieve personalized, multi-level and innovative knowledge service.

1 INTRODUCTION

Knowledge is awareness and understanding about people or things in the objective world, which is generated by feeling, communicating and logic reasoning activities in the course of practice and education and maybe facts, information or skills. With the development of data creating, releasing, storing and processing technologies, data is showing a rapid growth trend in all society areas. Of all the data available to the human civilization, 90% were produced in the past two years (Meng and Chi, 2013). Big data gives rise to the emergence of large scale knowledge bases. Famous knowledge base research projects, e.g. DBpedia, KnowItAll, NELL and YAGO, use information extraction techniques acquiring knowledge from high quality network data sources (e.g. Wikipedia), and automatically realize its construction and management (Suchanek and Weikum, 2014). Facts in knowledge bases, including entity names, semantic classes and their relationships, are derived from textual data in Web.

Meanwhile, big data brings about information overload and pollution too, in which knowledge also presents characteristics of heterogeneity, diversity and independence. In the era of data, with rapidly increasing of information and knowledge, knowledge discovery has become the research focus in various disciplines, including data science and information science(Ye and Ma, 2015). Therefore, in order to improve the efficiency and quality of knowledge service, issues of analysing and utilizing knowledge existing in big data, eliminating the inconsistency between different sources, and extracting, discovering and inducing the potential valuable connotations, have become important in knowledge management researches.

Knowledge Service (KS) is to meet user needs, by analysing the knowledge requirements in the domain, and applying knowledge acquisition, analysis, reorganization and implementation processes via service procedures helping users to find and form solutions (Zhang, 2000). In big data environments, KS is no longer limited to traditional literature and information services, but turns its perspective into massive fragmented information, user behaviors and relationships, and the resulting real-time, unstructured and machine data (Qin et al., 2013). Features of multi-source, heterogeneous, real-time and low value density data have brought unprecedented challenges to KS.

Knowledge Fusion (KF) is to acquire and utilize knowledge aiming at the KS problems. Operated by KF activities, implicate and undiscovered valuable knowledge is mined from various distributed and heterogeneous data sources. KF converts autonomous knowledge into a new one with higher levels of intension and reliability, while KS helps users to find potential associations between knowledge and fact,

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improve decision-making levels by making more efficient, objective and scientific judgments. KF becomes a new growth point for KS (Tang and Wei, 2015).

2 RELATED WORK

2.1 Processes of KF

KF is a new concept developed on *Information Fusion*. There are many intersections between the two research areas. The early definition of KF is given by Preece in the KRAFT project (Preece et al., 2001), refers to a process locating and extracting knowledge from multiple, heterogeneous on-line sources, and transforming it so that the union of the knowledge can be applied in problem-solving. Smirnov studies on patterns for context-based KF in decision support system (Smirnov et al., 2015), provides several KF patterns including *Simple*, *Flat*, *Extension*, *Configured*, *Instantiated*, *Historical* and *Adaptation* fusion, specifically for decision-making demands.

Hou (Hou et al., 2006) and Xu (Xu et al., 2010) believe that KF is to acquire new knowledge via intelligently processing distributed databases, knowledge bases and data warehouses by transforming, integrating and fusing knowledge. Xu gives a KF framework based on ontology to reduce the fused knowledge scale and improve its validity and accuracy. The framework is composed by functional modules such as constructing meta-knowledge set, determining knowledge measure indicators, designing fusion algorithms and handling post-fusion knowledge.

Gou (Gou and Wu, 2006) proposes a method to share and integrate distributed knowledge sources by using the fusion process to map knowledge objects into the ontology base and construct the knowledge set, in which KF algorithms based on Genetic Algorithm and Semantic Rule are used, and a feedback mechanism is considered to optimize the fusion process and knowledge space.

Qiu (Qiu and Yu, 2015) and Guo (Guo et al., 2012) review and evaluate research trends and theoretical developments of KF, point out that, there is not yet a general framework for KF systems, as well as directly applicable KF algorithms and standardized procedures. Existing researches mainly focus on specific KF frameworks, algorithms, and practical theories.

2.2 Framework of Big Data KS

Big data KS is produced in processes of acquiring, storing, organizing and analysing data for decision-making, which is a new model of information service used to solve demands of handling structured, semi-structured and unstructured data multi-dimensionally. It has features of intelligent services oriented, autonomy demands, uncertainty and customer driven, and is based on processes of sharing knowledge, ability and resources (Qin et al., 2013). Kawtrakul indicates that intelligently applying KS promotes the demand of innovative and service-oriented economy, and the key function of innovative service is to provide personalized KS (Kawtrakul, 2010). Research on big data KS management needs to solve several key issues such as representable, treatable, combinable and reliable abilities of big data.

In terms of research on KS framework, Gao (Gao et al., 2016) studies a library KS model based on associated data, divides the KS process into three levels: publishing resource, integrating resource and applying resource. Zhou (Zhou, 2008) provides a framework of personalized KS based on SOA, considering generation and acquisition mechanisms of the framework and its implementation methods, and realizing personalized KS according to user feedback information and different requirements. Zhu (Zhu et al., 2010) proposes a distributed KS framework based on cloud-shadow model, which is supposed to be applied in knowledge management systems.

Guan (Guan, 2015) provides a factor-relationship model of big data KS based on the knowledge supply chain, "acquisition-processing-storage-service-transfer". It uses knowledge bases to store contents required by KS processes, which is limited in terms of massive data migration and dynamic knowledge updating. Li (Li et al., 2013) analyses an architecture of big data KS platform by partitioning it into several hierarchical layers, systematically expounds the key technologies required to build the platform. However, without analysing module relationships and logical structures in layers, it lacks method analysis for KS realization.

As discussed above, there is no uniform definition of KF concepts and research categories, and a general KF framework oriented to KS requirements has not yet formed. It is necessary to carry out research on a general applicable KF process model, and propose a system framework of KS based on KF processes.

3 REQUIREMENT ANALYSIS ON BIG DATA KS

In big data environments, data represents information assets characterized by such a high volume, velocity, variety and veracity to require specific technologies and analytical methods for transforming it into value, which brings new challenges to KS activities such as knowledge acquisition, analysis and storage. The 4Vs of big data puts forward new requirements of KS realization such as heterogeneous, multi-source, implicit, dynamic and verifiability demands.

KF is a process of applying knowledge extraction, analysis, reorganization and integration activities over multiple heterogeneous knowledge sources, mining the implied valuable knowledge and information, and forming new knowledge oriented to user needs. This section discusses the KF contents oriented to the KS requirements, and proposes a multi-level architecture of KS based on KF processes.

3.1 KF Contents for KS Requirements

3.1.1 Heterogeneous Demand for KS

The accessing methods and querying results of heterogeneous knowledge sources are different from each other, and so do its structures and contents. Implementing KS over heterogeneous knowledge sources, first of all, needs to access, define and describe the required contents. Knowledge objects from different sources may be defined in different ways, which needs to be transformed via a unified description method to carry out structural comparison and content analysis among them. Then, subsequent KF activities can be applied to discover and correct inconsistency among the knowledge objects, to eliminate redundant or repeated ones. Thus, oriented to KS demand of heterogeneity, KF requires activities of knowledge extraction, knowledge representation, knowledge trans-formation and knowledge cleansing.

Knowledge extraction is built for extracting embedded contents from sources to form knowledge objects, through activities of identification, comprehension, selection and induction. Knowledge representation is a process of defining and describing organizational structures, association rules and content-handling mechanisms of knowledge objects. Knowledge transformation transfers heterogeneous knowledge into homogeneous one with uniform structure represented in the same method, which is the key issue solving the heterogeneity problem. Knowledge cleansing is a process of reviewing and checking knowledge objects, removing duplicate contents and correcting errors, providing a unified and accurate knowledge source for following KS activities, which ensures correctness and consistency of the source.

3.1.2 Multi-source Demand for KS

Knowledge existing in multiple sources might be homogeneous on its structures and contents, but also results in the multi-source demand of KS, which needs to select, aggregate and reorganize fragmented knowledge, and so called *knowledge integration*. The concepts of knowledge integration and knowledge fusion have overlaps in term of dealing with multi-sources and multi-structures knowledge objects, both of them have connections and differences.

Literally, integration is the process of aggregating multiple individual objects to form a whole one, while fusion is the process of recombining multiple individual objects, and splitting and dismantling it into a complete one. Integration emphasizes aggregation and combination, while fusion is more emphasis on merging and reorganizing. After fusion processes, knowledge objects should have new emerging features relative to the original ones. Therefore, this paper argues that KF is the advanced stage of knowledge integration. KF applies fusion algorithms and matching rules over the result of knowledge integration to implement deduction, discovery and innovation of knowledge.

Furthermore, KF is also different from knowledge aggregation, in which KF has no need to keep and remain all knowledge concepts, relationships and instances from the original sources, but need to construct the required objects meeting KS demands.

3.1.3 Implicit Demand for KS

The implicit demand refers to identifying effective, novel, potentially valuable knowledge objects and associations in services. Knowledge mining is a process of finding and discovering implicit knowledge objects from knowledge collections, linking the objects within a more explicit and effective way, and resulting in new knowledge objects and associations.

In KF processes, knowledge mining can not be completed individually by itself, but work with knowledge integration together in manners of complementary, interdependent, mutually supportive and iterative. Knowledge integration constructs foundation sources to support knowledge mining, and the derivative knowledge generated by knowledge mining is further used to support recombining and reorganizing knowledge as well as eliminating redundancies, by which the result of knowledge integration is optimized and refined progressively. The two processes, carrying out alternately, help users to obtain solutions efficiently from massive, low value and complicated data sources, to meet the implicit demand.

3.1.4 Dynamic Demand for KS

In big data environments, rapidly growing and continuously updating data involves the dynamic demand

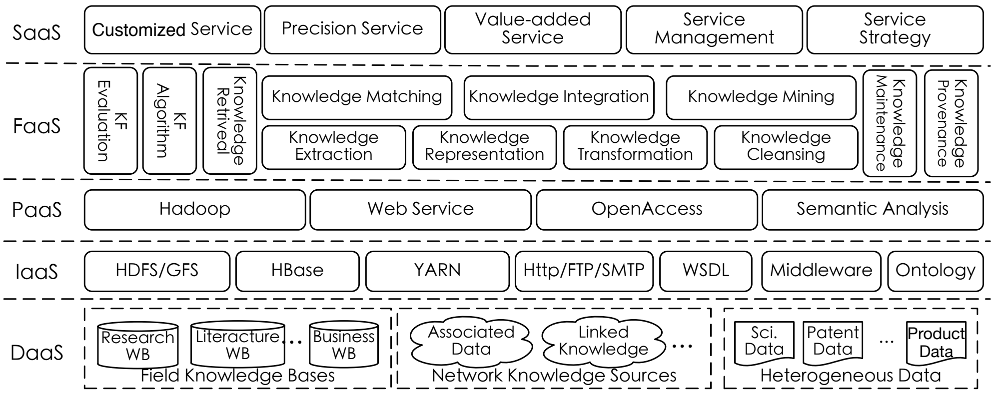

Figure 1: Muti-Level Architecture of Big Data Knowledge Service based on Knowledge Fusion.

of KS, i.e. the result of KS is constantly changing with the updates of the knowledge sources. Knowledge maintenance is the activity used to solve the dynamic demand. When the source content is modified and changed, the fused knowledge needs to be updated as well to ensure the consistency, reliability and real-time abilities.

According to specific requirements of users, maintenance strategies might be either periodically or immediately. In addition, due to the high cost of migrating large data, incremental maintenance is a feasible approach to implement knowledge maintenance. Namely, only the changes of the knowledge sources are captured and used to compute the updates of fused knowledge, i.e. the fused knowledge is refreshed with the updates rather than recomputed from scratch.

3.1.5 Verifiability Demand for KS

The verifiability demand is used to guarantee the correctness and validity of KS results. Both processes generating results and source references for making decisions, need to be traceable and verifiable. Knowledge provenance is a process of finding and tracing the lineages and the producing procedures of fused knowledge, which results in either metadata recording and annotating knowledge migration, conversion, cleansing and integration procedures, or the original information and initial data content of a specific fused knowledge object, in the knowledge sources.

In addition to knowledge provenance, knowledge evaluation is required for evaluating KF activities and results, in terms of measuring the standardization, effectiveness and logicality of the activities, and appraising the correctness, accuracy and completeness of the results. Knowledge provenance can be used to evaluate correctness and accuracy, to meet the verifiability demand of KS.

3.2 Multi-level Architecture of KS

As discussed above, KF is the necessary prerequisite and effective means to implement big data KS. To meet KS requirements, KF contents include activities of knowledge extraction, representation, transformation, cleansing, integration, mining, maintenance, provenance and evaluation. Based on these KF activities, this paper proposes a multi-level architecture, as shown in Figure 1, constructing the KS implementation procedure within five levels: Data-as-a-Service (DaaS), Infrastructure-as-a-Service (IssA), Platform-as-a-Service (PaaS), Fusion-as-a-Service (FaaS), and Software-as-a-Service (SaaS).

Knowledge is widely distributed in various heterogeneous knowledge sources in big data environments, the DaaS layer provides the underlying data sources for KS activities. The IaaS layer provides support for accessing data and extracting knowledge from the underlying sources, via protocols, middleware tools or APIs embedded within the big data infrastructure.

Parts of KF activities, such as knowledge extraction, representation, retrieval, maintenance and provenance, need to access knowledge sources and handle the knowledge initially extracted from the sources. The PaaS layer is specifically designed to provide channels for these KF activities exchanging data with the IaaS interfaces. The Fusion-as-a-service (FaaS) layer, which is originally proposed in this paper, contains the core activities of KF process that is used for mainly solving demands of the upper KS activities.

The SaaS layer constitutes the business logic part of big data KS directly interacting with users to achieve the performance of personalized, multi-level and innovative services. Customized services produce personalized efforts to meet specific user demands in accordance with requirement expressions; Precision services produce different services for different users, according to user types, preferences and behavior

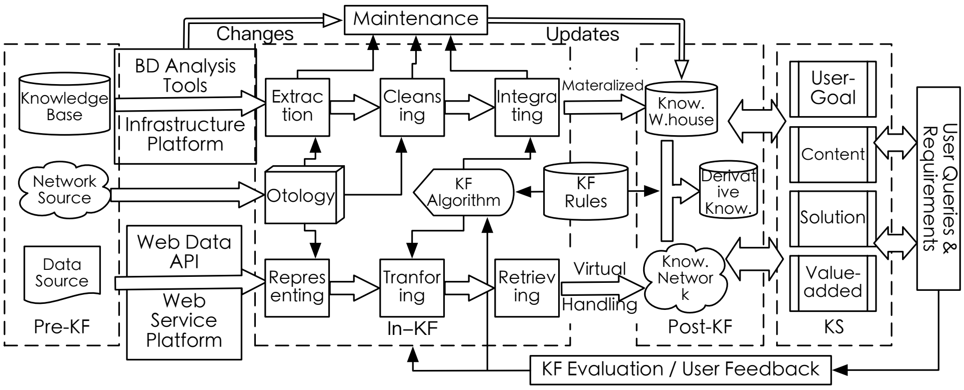

Figure 2: Process Model of Big Data Knowledge Fusion.

characteristics. Value-added services are going beyond regular service ranges, adopting unconventional methods to achieve valuable services, as a performance of service innovation.

Service management covers quality standards, security specifications, evaluation indicators, etc., to ensure KS qualities. Service strategy includes service optimization, distribution and identification, etc., to promote personalized and multi-level services.

4 PROCESSES OF BIG DATA KF

4.1 KF Process Model

KF activities can be treated as functional modules that transform inputs into outputs, and used for composing the KF process model. We roughly split the KF process into three stages: Pre-KF, In-KF and Post-KF, shown in Figure 2, in which the wide-white-line arrows represent flows of data and knowledge, and the fine-line ones represent flows of control information.

In Pre-KF stage, massive knowledge exists in the initial state, and is widely located in distributed knowledge bases and network sources. The big data infrastructure and Web service platforms provide supports for accessing the Pre-KF knowledge.

The In-KF stage contains the main activities of KF, either migrating knowledge objects from the sources and storing it in the knowledge base though knowledge extraction, cleansing and integration activities, or generating knowledge networks to define knowledge structures and associates though knowledge representation, transformation and retrieval activities. Knowledge networks aggregate and reorganize knowledge definitions, structures and associates from the source. Meanwhile, the In-KF stage includes the part of constructing domain ontology, designing fusion algorithms and rules according to user requirements and its problem definitions, which can be revised and validated by accepting user feedbacks. Also, it is necessary to establish a measurement mechanism for evaluating KF activities and it results, in order to measure the efficiency and effectiveness and provide a basis for optimizing and improving KS.

KF is a necessary prerequisite and effective means for the realization of big data KS. From literature service to information service and knowledge service, which is a gradually deepening and developing process. Based on the fused and derivative knowledge, KS activities are divided into four types: user-goal oriented, knowledge-content oriented, problem-solution oriented and value-added oriented.

The user-goal oriented KS is a target driven service, which is focusing on “whether or not did the service solve users problems?”, but not “does the service provide the information users need?”. The knowledge-content oriented KS is based on logic acquisition, through information acquisition and integration to form knowledge products in line with the needs of users. The problem-solution oriented KS is committed to helping users find or form a comprehensive solution through the continuous inquiry, analysis and reorganization of information and knowledge. The value-added KS is concerned with reprocessing the existing services, realizing service values by improving the efficiency of applying and innovating knowledge, so as to form new service products with unique value.

4.2 KF Implementation Pattern

KS is supported both by knowledge that is relatively stable, verified and frequently accessed, such as the pathogenesis of a disease, clinical manifestation, characteristic index, commonly used drugs, treatment and pathological knowledge in chronic disease management situations; and by knowledge that is widely existing in the network, real-time updated, usually changing and unfrequently visited, such as the diagnosis treatment cases of the same disease type, and its related research works, news reports, and so on.

Costs of big data accession, migration and storage are very high. It is infeasible for realizing KS by organizing and storing all source knowledge into a single knowledge warehouse. Thus, this paper distinguishes KF implementation patterns into three types: oriented to materialized knowledge warehouse, oriented to virtual knowledge network, and based on the mixed models.

4.2.1 Oriented to Materialized Knowledge Warehouse

The KF implementation pattern oriented to materialized knowledge warehouse is to prepare knowledge that is relatively stable and need to be frequently visited by KS activities, in terms of providing a local organization and storage mode.

Knowledge warehouse is an integrated collection facing topics, non volatile and changeable, which is used to decision-support for knowledge service and management processes. The so-called materialized is to acquire the knowledge objects required by KS in advance, and physically preserve it in warehouses, in order to avoid repeatedly visiting and computing operations over the sources.

Under this pattern, data analysing and processing tools provided by the big data infrastructure are used to support knowledge extraction activities. Appropriate knowledge objects are migrated and stored in the warehouse by steps of knowledge cleansing, integrating and loading. During the procedure, not only knowledge objects, but also knowledge structures and associates are handled to establish knowledge sharing and reusing mechanisms. There is also implicit knowledge in the warehouse needing to be excavated and discovered, according to the types of user requirements, to form types of derivative knowledge.

4.2.2 Oriented to Virtual Knowledge Network

The KF implementation pattern oriented to virtual knowledge network is used for handling knowledge widely existing in the network and providing access to methods for KS activities.

Knowledge networks might be divided into three types: *subject-subject*, *subject-knowledge* and *knowledge-knowledge*. In this paper, we refer to knowledge-knowledge networks defining knowledge structures, associates and constraints among knowledge objects. Virtual knowledge networks contain the knowledge definitions, but do not contain specific knowledge units and instances. The time of executing conventional data query and analysis technologies will increase to be unacceptable for handling big data, and the pattern oriented to virtual network is mainly used for dealing with this high-costs.

In addition to containing definitions of structures, associates and constraints of fused knowledge objects, virtual knowledge networks use metadata, i.e. the query statements over the data sources, to describe procedures generating the fused objects. When KS users need to access specific knowledge contents and instances of virtual knowledge networks, user queries are decomposed, step by step, into various specific sub-queries over data sources. Based on Web service platforms and its data processing API, knowledge retrieval module acquires query results from the source in manners of stream or batch processing. Knowledge representation, transformation and integration activities further use the results to produce fused and derivative knowledge to meet the user requirements.

4.2.3 Based on Mixed Models

The KF implementation pattern based on the mixed modes comprehensively handle knowledge types required for KS activities, in which both materialized warehouses and virtual networks are considered. Since linked knowledge will change along with the changes of network, it is necessary to apply dynamic selection of data sources and evaluate its knowledge quality, and design adaptable strategies for choosing, maintaining and updating the fused knowledge materialized in the warehouse.

5 SYSTEM FRAMEWORK OF BIG DATA KS

5.1 KS Framework Model

As discussed above, KF processes either gather and transform various, distributed and heterogeneous knowledge into a materialized warehouse, or use virtual network to link massive remote knowledge sources. Both of them feasibly provide available knowledge sources for following-up KS activities.

In order to achieve personalized, multi-level and innovative services, this paper further analyses the KS process, decomposes its activities, and constructs a system framework based on the KF process model, as shown in Figure 3, to meet the KS requirements.

Personalized and multi-levels demands for precision services require to analyse user requirements and decompose complex problems into smaller, more

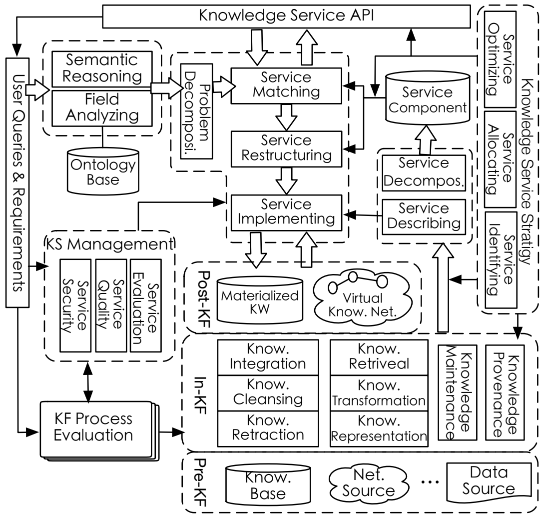

Figure 3: System Framework of Big Data KS based on KF.

manageable and tractable sub-problems. Then, the service components needed to solve sub-problems are compared with the ones provided by the KS system. Through service matching and restructuring activities, KS solutions for the entire problem are formed, and finally implemented with the support of KF processes.

In the framework, the KS API is the interface interacting with users. User queries and requirements are analysed and resolved by semantic reasoning and domain analysis activities based on domain ontology. Then, activities of problem decomposition, service matching, service restructuring and service implementation are used to realize the requirements.

Semantic reasoning focuses on knowledge concepts and their relevance in semantic levels, and domain analysis is an analytical activity of the concept objects in a particular field, such as domain definition, commonality abstraction, characteristic description, concept description, relationship identification, and so on. Semantic reasoning and domain analysis are necessary manners to decompose user requirements, and generally require the participation of domain experts for completion.

Service matching is a process of retrieving and finding the service component satisfying user requirements from the base storing various service components and specifications. Service matching may use the Universal Description, Discovery, and Integration (UDDI) standards to establish norms to complete service releasing and discovering processes. Service restructuring is to test and verify the service components found in service matching, remove redundancies, and reassemble them into a feasible service solution. After service restructuring, the service solution is converted to access requests over the fused knowledge, and executed by service implementation activities, mainly including processes of request analysing and decomposing, request rewriting and executing, result assembling and integrating, etc.

Service description and service decomposition apply granularity analyses on services provided by KF processes and its results, i.e. fused knowledge, resulting in fine-grained service components and specifications, which are used for matching with the decomposed fine-grained user requirements, and reconstructing service solutions further accurately and specifically satisfying the user requirements.

The KS framework presented here reveals corresponding relationships and influence mechanisms among KS activities and KF processes, and provides a systematic solution for implementing personalized, multi-level and innovative services for KS users.

5.2 KS Strategy

The KS strategy is concerned with the processes of service identification, allocation and optimization. Service identification is to abstract applicable and functionalized service components from complex business flows, which is carrying out standardized management on the service interfaces. The KF process, as the basis of KS, includes knowledge representation, extraction, cleansing, transformation and integration modules. Different modules combined together form different KF implementation patterns oriented to either materialized warehouses or virtual networks. Service identification is mainly to standardize the interface definition and component functionality of the services provided by KF processes, and enable them to be feasible and accessible for KS activities.

Service allocation is the process of assigning the identified service to appropriate users and problem domains according to the requirements, so as to realize precision services. Among user requirements and service components with different granularity, there might be one-to-one, one-to-many or many-to-many mapping associations. Based on analysing and classifying these associations, allocation principles and mechanisms are developed to supply references for service matching and restructuring.

In specific situations, one requirement might correspond with a variety of service allocation strategies. Different strategies produce different service matching and restructuring schemes, so that service solutions and implementation results are varied. Service optimization is to analyse affecting effects of service allocation strategies, adjust service matching and restructuring schemes, and optimize KF process results, so as to ensure the realization of innovative KS.

5.3 KS Management

KS management is essential to improve the quality of service (QoS) of the framework, in terms of standardizing and administrating security measures, quality standards and evaluation indicators of KS. Security measures include mechanisms of user authentication, role administration and privilege management, generally working along with the service allocation strategies, to assign appropriate KS solutions for various types and levels of users, in which both the security and the precision of the services are considered.

Quality standards and evaluation indicators are interdependent and complementary. Combined with the evaluation module of KF process, quality standards are used to determine and classify the correspondence relationships between KF results and KS requirements in various degrees and levels, which is also the standard of satisfaction for KS demands, while evaluation indicators are used to assess the QoS in perspectives of user cognition and sensation, to indicate the differences between user expectation and user perception, between expected service results and experienced service results, and between desired service qualities and perceived service qualities.

6 CONCLUSIONS

KF is a new research topic rising to the challenges of KS. The emergence of massive, various and heterogeneous knowledge in big data environments implies new demands on both KF and KS implementations. This paper reviews current research on KF processes and KS frameworks, and analyses big data KS requirements in terms of KF contents. Then this paper constructs the KF process model and implementation patterns, proposes a multi-level architecture and a system framework of big data KS, organically combining with KF processes together, to meet demands of personalized, multi-level and innovative services.

In future work, we will consider to apply the KF process model for empirical analysis in a specific domain, i.e. chronic diseases knowledge management.

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