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IEEE Standard for Framework of Knowledge Graphs

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IEEE Std 2807™-2022

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IEEE Standard for Framework of Knowledge Graphs

Developed by the

Standards Activities Board
of the
IEEE Computer Society

Approved 23 September 2022

IEEE SA Standards Board

Abstract: A framework of knowledge graphs is proposed in this standard. The knowledge graph conceptual model, construction and integration process of knowledge graphs, main activities in the processes, and stakeholders of knowledge graphs are described in detail. This standard can be applied in various organizations that plan, design, develop, implement, and apply knowledge and in organizations that develop support technologies, tools, and services to knowledge graphs.

Keywords: IEEE 2807™, knowledge graph, knowledge graph application, knowledge graph construction, knowledge graph integration, stakeholder

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When the IEEE SA Standards Board approved this standard on 23 September 2022, it had the following membership:

Introduction

This introduction is not part of IEEE Std 2807-2022, IEEE Standard for Framework of Knowledge Graphs.

Artificial intelligence (AI) applications, including machine translation, speech recognition, image classification, and information retrieval, have achieved remarkable success. AI applications are developing toward expertise AI, like medical diagnosis, autonomous vehicles with AI, and smart factories. Knowledge graphs can assist in linking machine learning experts with experts from different industries, for example, medical care and transportation, and further transform human knowledge into machine knowledge. Knowledge graphs provide a natural and efficient way to represent entities and their relationships in a format that is understandable by machines and humans.

However, the unified framework and key terms of knowledge graphs have not been established clearly. Thus, the IEEE Standard for Framework of Knowledge Graphs is proposed. This standard proposes the important terms related to knowledge graphs; describes the conceptual model, the involved activity types, and the corresponding stakeholders of knowledge graphs; and further proposes the construction and integration process of knowledge graphs in detail. This standard can promote communication and cooperation among the various stakeholders under a unified framework and terminology, as well as provide guidance to construction of knowledge graphs, development and maintenance of knowledge graph application systems, and quality management and control of related projects, tools, and systems.

Contents

IEEE Standard for Framework of Knowledge Graphs

1. Overview

1.1 Scope

This standard defines the framework of knowledge graphs (KGs). The framework describes the input requirement of KG; construction process of KG, that is, extraction, storage, fusion, and understanding; performance metrics; applications of KG; verticals; KG-related artificial intelligence (AI) technologies; and other required digital infrastructure.

1.2 Purpose

The purpose of this standard is to define the framework of KGs. This framework will help enterprises, especially small- and medium-sized enterprises and start-ups, which develop KG applications to follow a general KG construction method. In addition, the proposed framework will help digital infrastructure suppliers, such as cloud developers and IT security engineers, to understand the KG diagrams and provide more efficient tools to support KG. Vertical applications may extract more types of knowledge and generate more applications after applying the standardized framework.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).[1, 2]

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

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[1] The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

[2] The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

This standard does not contain any normative references.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[3]

attribute: Describable features.

NOTE—It can be expressed by string, numerical value, and other literals.[4]

entity: An object existed independently in the real world.

entity type: Abstract of a certain set of entities with the same attribute.

event: Changes of things or states comprised by one or more actions with the participation of one or more roles, which occurs at a specific point in time or within a specific geographical area or time period.

NOTE—An event can be expressed as a combination of entities and relations with the information of time.

knowledge: Facts, opinions, actions, or skills acquired through learning, practicing, or exploring.

knowledge acquisition: An activity that extracts knowledge from input data with different sources and structures.

NOTE—The data source can be classified into three categories by data organization: structured data, semistructured data, and nonstructured data (e.g., plain text, audio, and video data).

knowledge cell: A set of organized knowledge elements.

knowledge computing: An activity that discovers or acquires implicit knowledge by using constructed knowledge graphs and algorithms to provide knowledge services.

NOTE—Types of knowledge computing can be categorized into statistical analysis, knowledge inference, and so on. Statistical analysis refers to statistics and induction of knowledge structures and characteristics of knowledge graphs. Knowledge inference refers to discovery and mining of implicit knowledge from existing facts or relations.

knowledge element: Knowledge unit describing a certain object or concept that is independent and inseparable.

NOTE—Knowledge element is an umbrella name for the terms of an entity, concept (entity type), attribute, relation, relation type, event, or rule in this document.

[3]*IEEE Standards Dictionary Online* is available at: http://dictionary.ieee.org. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.
[4]Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

knowledge evolution: An activity that replenishes, updates, or reorganizes original knowledge by using new produced knowledge with changing of ontology models and data resources.

NOTE—Knowledge completion may trigger knowledge evolution.

knowledge fusion: An activity that integrates knowledge cell(s) to form a knowledge graph with global unified knowledge identifications.

knowledge graph: Assemblies of knowledge elements and their relations described in a structured form.

knowledge graph ecosystem partner: An organization that provides necessary information infrastructures, data, tools, methods, standards, and mechanisms for knowledge graph suppliers, integrators, and users to construct and apply knowledge graphs.

knowledge graph integrator: An organization that integrates knowledge graphs, information systems, or services to satisfy the demands of knowledge applications and provides knowledge graph application systems and services.

knowledge graph supplier: An organization that constructs knowledge graphs by using data and knowledge to satisfy specified demands and provides fundamental tools or services for knowledge graphs.

NOTE—A fundamental tool or service can be used to build complicated applications or system middleware.

knowledge graph user: An organization or an individual that applies knowledge graph application systems and services to satisfy their own demands.

NOTE—A knowledge graph user can output data or knowledge if necessary.

knowledge modeling: An activity that constructs ontology of a knowledge graph and its formal expressions.

NOTE—Knowledge modeling activity includes the definition of entity types, relation types, relations, and attributes.

knowledge provenance: An activity that tracks transformation from raw data to knowledge in knowledge graph lifecycle.

knowledge representation: An activity that describes knowledge acquired by humans while discovering or understanding the real world through machine interpretable symbols and methods.

knowledge storage: An activity that designs the storage architecture and conducts knowledge storing, querying, maintaining, and managing by using software and hardware infrastructures.

NOTE—Types of knowledge storage usually include, but are not limited to, storage based on relational database, graph database, and resource description framework (RDF) database.

ontology: A model to describe entity types, entity attributes, and relations among them.

NOTE—Ontology is also described as an “ontology model.”

relation: Connection between entities, entity types, combination of entities, or combination of entity types.

NOTE—Relation describes the connections between entities, entity types, or an entity and an entity type.

schema: Formalized expression of ontology models.

3.2 Acronyms and abbreviations

API	application programming interface
KG	knowledge graph
RDF	resource description framework
SDK	software development kit

4. General

4.1 Knowledge graph conceptual model

The conceptual model of a knowledge graph can be divided into the ontology layer and instance layer, as shown in Figure 1. The ontology layer is composed of ontology-related knowledge elements, such as entity types and their attributes, and relation types between entity types and rules. The instance layer, which is the instantiation of the ontology layer, is composed of entity-related knowledge elements, such as entities corresponding to the entity types and their attributes, and relations between entities.

The main part of a knowledge graph is entities and relations. Multiple entities and relationships can constitute a complex entity, such as an event constituted by time, persons, places and other elements, and a product constituted by different modules.

NOTE—Based on different levels of abstraction, the ontology layer is relative to the instance layer in Figure 1.

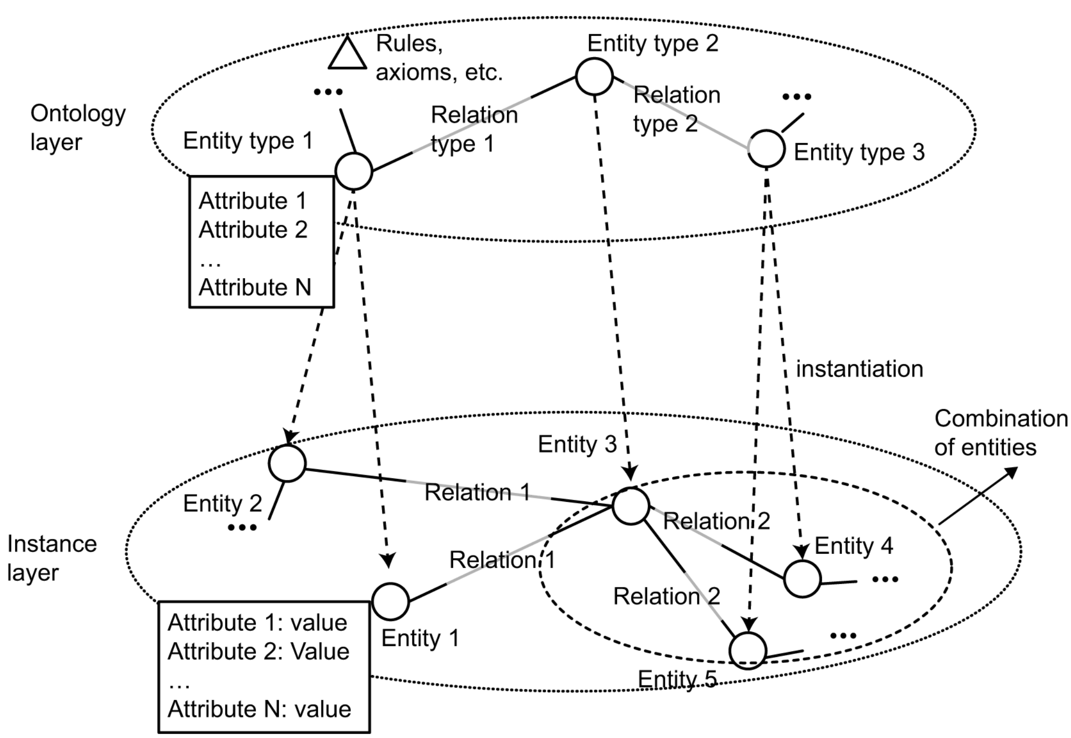

Figure 1—Knowledge graph concept model

4.2 Framework of knowledge graphs

Figure 2 shows the framework of knowledge graphs involving various technical activities, from construction of the knowledge graph to application of the knowledge graph. These activities can be summarized into the following four categories:

— Construction of knowledge graphs
— Development of knowledge graph-based products or services
— Application of knowledge graphs
— Auxiliary support for development and application of knowledge graphs

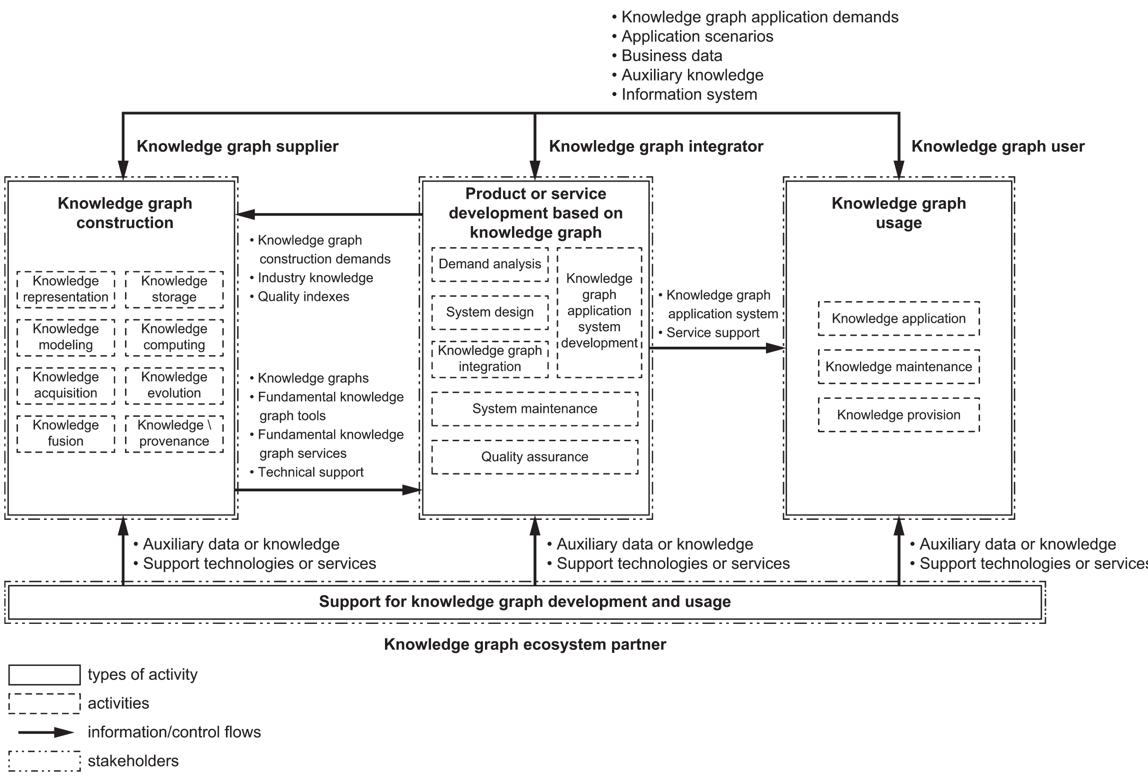

Figure 2—Framework of knowledge graphs

The four categories of knowledge graph activities shown in Figure 2 are briefly described as follows:

a) Construction of knowledge graphs: This group of activities mainly includes knowledge representation, knowledge modeling, knowledge acquisition, and others. The main purpose of this group is to construct the demanded knowledge graph and develop the corresponding basic tools or services. This group mainly refers to the application demands and quality requirements of the knowledge graph and should be supported by vertical knowledge, business data, and auxiliary knowledge.

b) Development of knowledge graph-based products or services: This group of activities mainly includes requirement analysis, system design, knowledge graph integration, and others. The purpose of this group is to complete development and integration of the knowledge graph application system or services based on the constructed knowledge graph through item a) and the knowledge application demands.

c) Application of knowledge graphs: This group of activities mainly includes knowledge applications, knowledge maintenance, knowledge provision, and others. Execution of these activities is based on the knowledge graph application system or services generated by the activities in item b). Through these activities, application and maintenance of knowledge can be completed, and necessary knowledge can be provided.

d) Auxiliary support for development and application of knowledge graphs: This group of activities mainly includes infrastructure provision, data provision, security assurance, consultation, and evaluation. The activities provide necessary supports for execution of the activities in item a) through item c), for example, providing auxiliary data or knowledge, technologies, or services.

The four categories of activities shall be carried out by the following four categories of logical stakeholders:

— Knowledge graph suppliers, which mainly carry out construction and provision of knowledge graphs
— Knowledge graph integrators, which mainly carry out development and integration of products or services based on knowledge graphs
— Knowledge graph users, which mainly carry out application of knowledge graphs
— Knowledge graph ecosystem partners, which mainly give supports for development and application of the knowledge graphs

NOTE—An actual participant, that is, enterprises related to knowledge graphs, may perform multiple stakeholders according to its business scope or concerns.

5. Knowledge graph supplier

5.1 Inputs of knowledge graph supplier

The inputs of a knowledge graph supplier shall include, but are not limited to, the following:

a) Knowledge graph application demands: Requirements of knowledge graph users for application of knowledge graphs, such as business demands, application constraints, and data status

b) Knowledge graph construction demands: Requirements of knowledge graph integrators for constructing a knowledge graph, such as knowledge scope, knowledge granularity, and knowledge graph scale

c) Business data: Basic data, industry data, and other necessary data required to construct a knowledge graph

d) Auxiliary knowledge: Common sense, industry knowledge, expert knowledge, and others that guide or support the construction of knowledge graphs

e) Supporting technologies and services: Technology and service support required to construct a knowledge graph, such as data preprocessing and data annotation tools

f) Quality indicators: Knowledge graph quality requirements and performance indicators proposed by knowledge graph users or knowledge graph integrators

5.2 Outputs of knowledge graph supplier

The outputs of a knowledge graph supplier shall include, but are not limited to, the following:

a) Knowledge graph

b) Fundamental knowledge graph tools, which undertake basic functions, such as knowledge acquisition, retrieval, relational reasoning, visualization, and maintenance

   NOTE—Some knowledge graph tools also have basic functions related to knowledge management.

c) Fundamental knowledge graph services, which provides knowledge query or invocation of calculation results based on the knowledge graph through interfaces or other forms

   NOTE—The knowledge graph supplier can provide basic knowledge graph services due to consideration on security, ownership of knowledge, and so on. A knowledge graph integrator can develop and integrate new products or services based on the basic services in some cases.

d) Technology support, which provides the required supports during integration of basic knowledge graph tools or services

5.3 Main activities of knowledge graph supplier

5.3.1 Activity process

The main activity process of a knowledge graph supplier is shown in Figure 3.

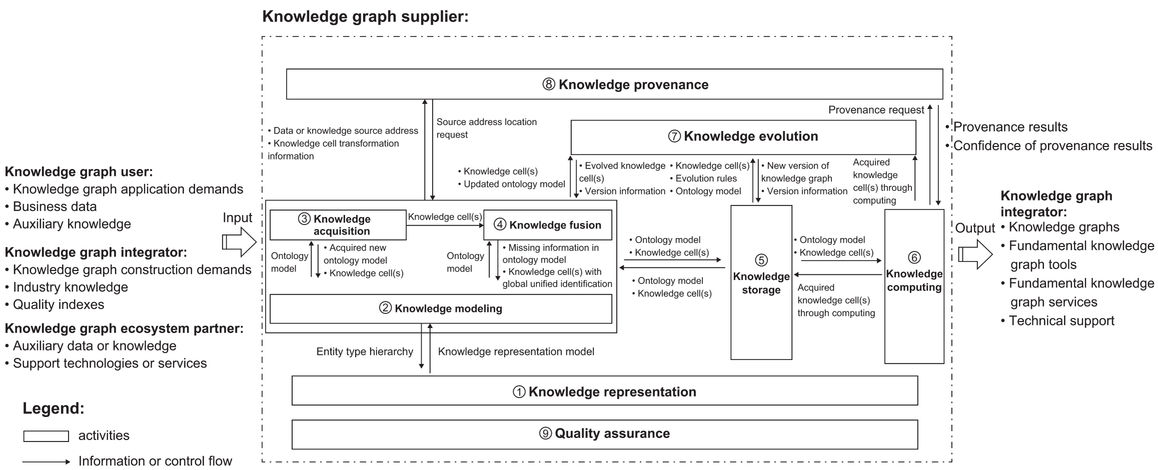

Figure 3—Main activity process of knowledge graph supplier

The main activity of the knowledge graph supplier shall include the following:

a) Knowledge representation
b) Knowledge modeling
c) Knowledge acquisition
d) Knowledge fusion
e) Knowledge storage
f) Knowledge computing
g) Knowledge provenance
h) Knowledge evolution
i) Quality assurance

Besides these activities, the knowledge graph supplier may provide knowledge exchange and knowledge governance. In knowledge exchange, the knowledge cell(s) from the ontology layer and the instance layer shown in Figure 1 should be exchanged based on a unified communication process and a unified communication message format among knowledge graphs, especially distributed knowledge graphs.

5.3.2 Knowledge representation

5.3.2.1 Inputs

The inputs of knowledge representation shall include, but are not limited to, the following:

a) Knowledge graph application demands, which are as follows:
   1) Business demands: Business problems to be solved, business goals to be achieved
   2) Application scenarios: Specific business scenarios to apply the knowledge graph
   3) Application constraints: Relevant requirements, standards, laws, and regulations that shall be followed during application of the knowledge graph
   4) Knowledge background: Subject, technical, and domain backgrounds of knowledge representation experts
   5) Application feedback: Suggestions on applying knowledge representation models to other activities of the knowledge supplier
b) Knowledge graph construction demands
c) Quality indicators
d) Hierarchy of entity types

5.3.2.2 Outputs

The outputs of knowledge representation shall include, but are not limited to, the following:

a) Knowledge representation model:
   1) Knowledge representation framework: Knowledge representation structure and concrete expression
   2) Knowledge representation elements: Elements used in knowledge representation and their meanings, such as entity type, entity, relation type, and inference rules
   3) Knowledge representation requirements: Rules and constraints that need to be complied with during knowledge representation
   4) Applicable scope of knowledge representation: Boundary, scope, and limitation of knowledge representation model
b) Evaluation hierarchy of knowledge representation model

NOTE—Knowledge representation models can usually be divided into knowledge representation based on discrete symbols and numerical knowledge representation based on continuous real-valued vectors.

5.3.2.3 Task composition

The task flow of knowledge representation is shown in Figure 4.

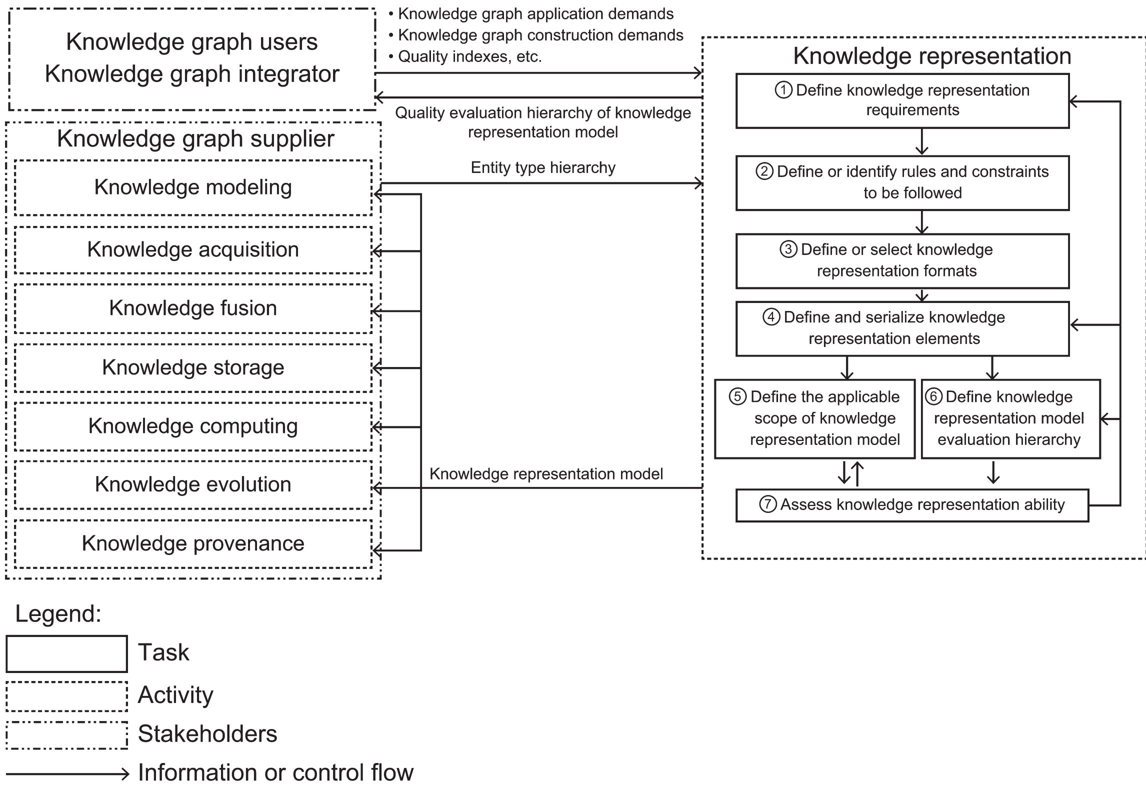

Figure 4—Task flowchart of knowledge representation

The tasks of knowledge representation shall include the following:

a) Define knowledge representation requirements, such as business problems to be solved and the business objectives to be realized.

b) Define or follow the rules and constraints, such as business rules and related constraints.

NOTE—For particular fields, it is necessary to design rules and constraints for scenarios not suitable for existing rules and constraints.

c) Define or select knowledge representation forms, such as N- triples and frames.

d) Define and serialize knowledge representation elements, and define the relevant constraints and rules that should be followed during the knowledge representation.

e) Define the applicable scope of the knowledge representation model, such as applicable scenarios, inapplicable scenarios, and precautions.

f) Define the quality evaluation system of the knowledge representation model.

g) Evaluate and clarify the expression capability of the knowledge representation model.

5.3.2.4 General quality description characteristics

General characteristics used to describe the quality of knowledge representation activities shall include, but are not limited to, the following:

a) Expressiveness: The knowledge representation model formed in this activity should have the ability to fully and completely express the knowledge required by the business in a specific domain.

b) Realizability: The knowledge representation model formed in this activity should have the ability to be transformed into an internal form of computer and be easily realized by algorithms.

c) Structured: The knowledge representation model formed in this activity should have the ability to explicitly express attributes and various semantic associations of objects.

d) Rigor: The knowledge representation model formed in this activity should have the ability to represent formal grammars, semantics, related inference rules, and so on.

e) Maintainability: The knowledge representation model formed in this activity can support maintenance and management of knowledge cells after completing knowledge graph construction.

5.3.3 Knowledge modeling

5.3.3.1 Inputs

The inputs of knowledge modeling shall include, but are not limited to, the following:

a) Knowledge graph application demands:
   1) Business demands
   2) Application scenarios
   3) Application constraints
   4) Data status: Results of data exploration related to business problems to be solved, mainly including data dictionary, data quality, data volume, and processed data structure
   5) Application feedback: Suggestions on the application of ontology models in other activities of the knowledge graph supplier

b) Knowledge graph construction demands

c) Auxiliary knowledge, such as follows:
   1) Industry knowledge, including industry term dictionary, industry term hierarchy, industry guides, industry standards, and other industry knowledge
   2) Expert knowledge

d) Quality indexes

e) Knowledge representation model

f) Knowledge cells, such as entity types and relation types, output by knowledge representation, knowledge acquisition, and knowledge fusion

5.3.3.2 Outputs

The outputs of knowledge modeling shall include, but are not limited to, the following:

a) Ontology model:
   1) Entity type hierarchy, such as entity types and upper–1ower relationships among entity types
   2) Attributes of entity types, such as the type of an attribute field, unique identifying attribute of an entity type, and status of whether an attribute is unique
   3) Relationships among entity types, such as whether the relationship has direction (directed and undirected); whether the relationship is transitive; and whether the relationship is a one-to-one relationship

   NOTE—Events can be considered a type of entity, and event types can also be a part of an ontology model.

b) Schema

5.3.3.3 Task composition

The task flow of knowledge modeling is shown in Figure 5.

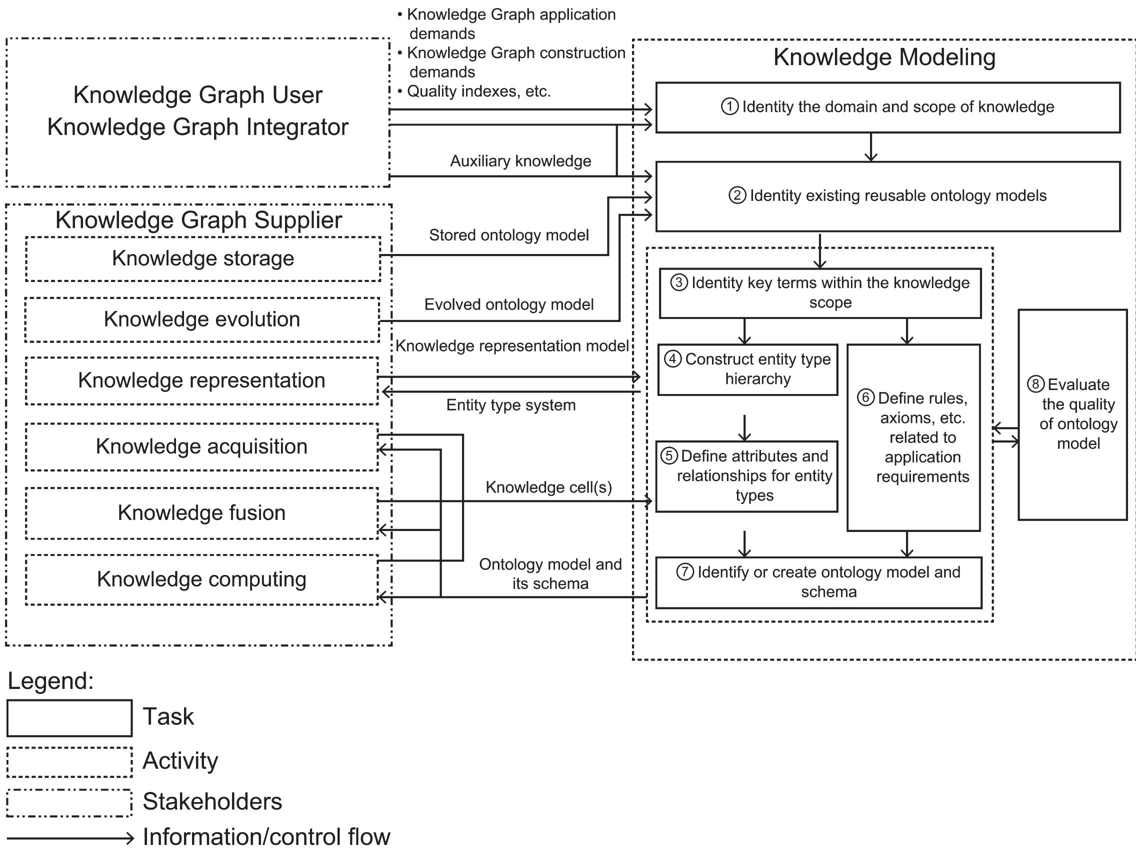

Figure 5—Task flowchart of knowledge modeling

The tasks of knowledge modeling shall include, but are not limited to, the following:

a) Identify the domain and scope of knowledge.

b) Identify existing reusable ontology models. The confirmation principles of a reusable ontology model can include the following:

   1) It is not advisable to add new entities if not necessary.

   2) Entity type fusion principle: If the instances of two types of entity types are the same, the corresponding entity types can be fused.

   3) Entity type splitting principle: If an entity type has many mutually exclusive attributes, it can be divided into multiple subdivided entity types.

c) Identify key terms within the knowledge scope.

d) Construct the entity type hierarchy.

e) Define attributes and relationships for entity types.

f) Define rules and axioms, and so on, related to knowledge graph application demands (optional).

g) Identify and create the ontology model and its schema.

h) Evaluate the quality of the ontology model.

5.3.3.4 General quality description characteristics

Knowledge modeling should form a well-defined ontology model and its schema, as well as conduct knowledge management according to characteristics and application features of input data to reduce data redundancy and improve application efficiency. General characteristics used to describe the quality of knowledge modeling include, but are not limited to, the following:

a) Rationality, which is to measure the extent that the entity types in the formed ontology model are divided reasonably and whether the relationships among the entity types are described reasonably

b) Availability, which is to measure the extent that the formed ontology model can support knowledge acquisition, knowledge fusion, knowledge computing, and other subsequent activities

c) Completeness, which is to measure the extent that the formed ontology model can support the representation of complex knowledge (such as events and time series) and support the use of anonymous entities

d) Scalability, which is to measure the extent that the formed ontology model can support the addition, deletion, and modification of entity types and their attributes and relations

e) Compatibility, which is to measure the extent that the formed ontology model can be compatible or inherited with the existing ontology model, for example:

    1) Whether the formed ontology model can support compatibility with other standard ontology models in the field

    2) Whether the formed ontology model can support the inheritance of the existing entity type hierarchy

    3) Whether the formed ontology model can support the adjustment of entity type attributes after the changes or updates of business or input data source

f) Reusability, which is to measure the extent that the formed ontology model can support the reuse among multiple knowledge graphs

g) Simplicity, which is to measure the extent that the created ontology model schema can comply with the principle of minimum redundancy to meet the application and visualization requirements of the ontology model in knowledge fusion and knowledge computing

5.3.4 Knowledge acquisition

5.3.4.1 Inputs

The inputs of knowledge acquisition shall include, but are not limited to, the following:

a) Data includes:

    1) Structured data, such as business data stored in a relational database

    2) Semistructured data, such as encyclopedia data

    3) Unstructured data, such as documents, pictures, videos, and audios

b) Existing ontology models and schemas

5.3.4.2 Outputs

The outputs of knowledge acquisition are knowledge cell(s) and shall include, but are not limited to, the following:

a) Entity information

b) Relation information between entities

c) Attribute information of entities

d) Missing information in ontology model, such as follows:

   1) Entity type information

   2) Relation information between entity types

   3) Attribute information of entity types

NOTE—Missing information in the ontology model can be fed back to the activity of knowledge modeling, which then further optimizes the ontology model.

5.3.4.3 Task composition

The task flow of knowledge acquisition is shown in Figure 6.

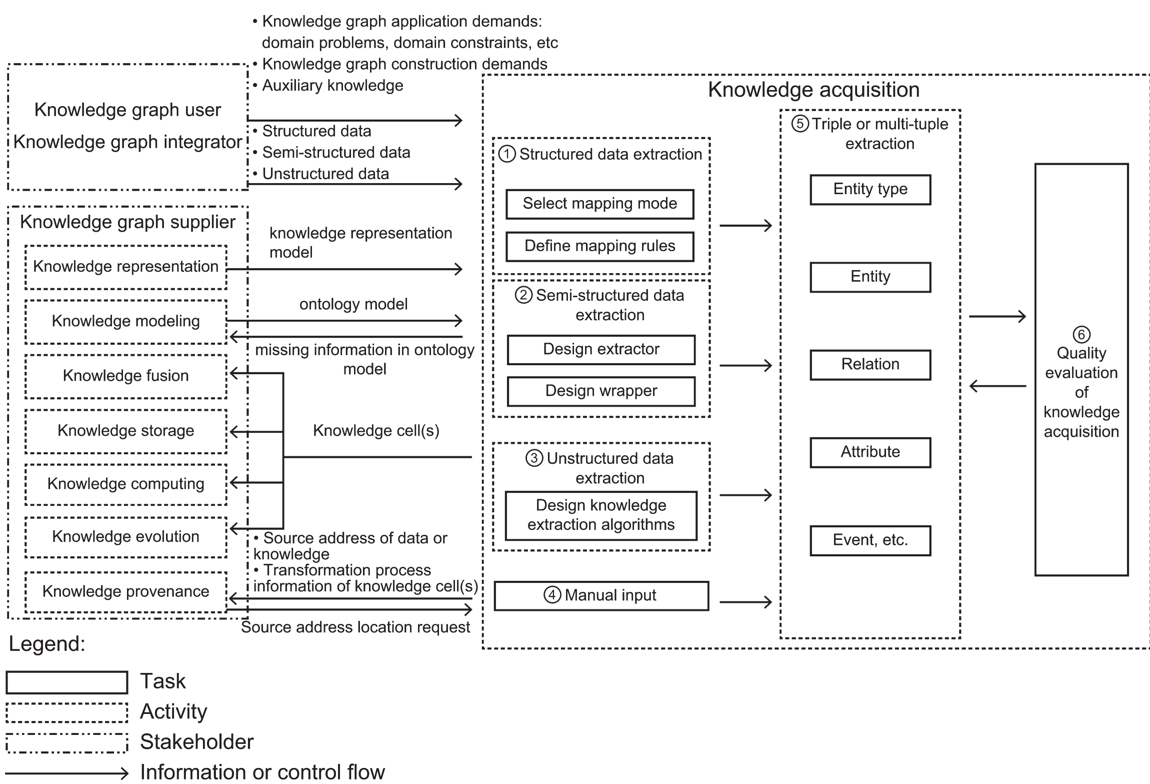

Figure 6—Task flowchart of knowledge acquisition

The tasks of knowledge acquisition shall include, but are not limited to, the following:

a) For extraction from structured data, the main subtasks include:
   1) Select mapping modes
   2) Define and configure mapping rules
b) For extraction from semistructured data, the main subtasks include:
   1) In terms of the semistructured data of the encyclopedia, design an extractor to extract knowledge cells
   2) In terms of the semistructured data of the web, develop a wrapper to extract knowledge cells
c) For extraction from unstructured data, the main subtasks include:
   1) Based on business demands and the ontology model constructed in knowledge modeling, select or design knowledge extraction algorithms specifically applied for business scenarios and data types
   2) Complete algorithm test and achieve extraction of knowledge cells
d) Manual input: Based on the ontology model formed based on business demands, the activity of knowledge modeling, and so on, extract and input knowledge cells manually
e) For extraction of triples or multituples, the main subtasks can include:
   1) Entity type extraction: Identify domain entity types based on extracted knowledge cells
   2) Entity extraction: Acquire entities in general or special domain based on the extracted knowledge cells
   3) Relation extraction: Acquire semantic relation between entity types or between entities based on the extracted knowledge cells
   4) Attribute extraction: Acquire description features included in the entity types or entities based on the extracted knowledge cells

      NOTE—Entities, relations, or attributes can be extracted jointly, which may not be dependent on entity extraction.

   5) Events extraction and others: Extract events structurally and other information based on extracted knowledge cells, such as time, places, causes, and participants of the events.
f) Quality evaluation of knowledge acquisition.

5.3.4.4 General quality description characteristics

The quality evaluation of knowledge acquisition can be obtained through comparing obtained knowledge cells with manually labeled data. The general characteristics indexes can include the following:

a) Precision, which is to measure the proportion of correct knowledge in acquired knowledge. Precision of knowledge acquisition is expressed in Equation (1).

$$P_A = \frac{TP_A}{TP_A + FP_A} \tag{1}$$

where

TP_A is the true positive: the number of entity types, entities, relations, or attributes identified that correspond to reality

FP_A is the false positive: the number of entity types, entities, relations, or attributes identified but do not correspond to reality

b) Recall, which is to measure the extent to which acquired knowledge covers correct knowledge. Recall of knowledge acquisition is expressed in Equation (2).

$$R_A = \frac{TP_A}{TP_A + FN_A} \tag{2}$$

where

FN_A is the false negative: the number of entity types, entities, relations, or attributes labeled as true but not identified

c) F1-Measure: which is to comprehensively measure the accuracy and completeness of the knowledge acquisition result. F1-Measure of knowledge acquisition is expressed in Equation (3).

$$F_{1-score_A} = 2 \times \frac{P_A \times R_A}{P_A + R_A} \tag{3}$$

d) The validation of relation constraints, such as follows:
    1) Whether it is a 1-to-1 relation (based on relation definition in the ontology model)
    2) Whether it is a 1-to-n relation (based on relation definition in the ontology model)
    3) Whether it is a n-to-n relation (based on relation definition in the ontology model)
e) The validation of attribute constraints, such as follows:
    1) Whether the attribute is unique (based on attribute definition in the ontology model)
    2) Whether the attribute is required to be non-null (based on attribute definition in the ontology model)

NOTE—For the overall capability evaluation of knowledge acquisition, a combination of entity-attribute or relation-entity can be considered to be a set of assessment data to assess precision rate, recall rate, and F1-measure.

5.3.5 Knowledge fusion

5.3.5.1 Inputs

The inputs of knowledge fusion shall include, but are not limited to, the following:

a) Ontology models and schemas outputted from knowledge modeling
b) Knowledge cell(s) outputted from knowledge exaction
c) Knowledge cell(s) from outside knowledge graphs

5.3.5.2 Outputs

The outputs of knowledge fusion shall include, but are not limited to, the following:

a) Unified ontology model:
    1) Unified entity types
    2) Unified relations between entity types
    3) Unified entity type attributes

b) Nonconflicting knowledge cell(s) with globally unified knowledge identification

NOTE—The ontology model can be further optimized after feeding back the missed information in the ontology model to the activity of knowledge modeling.

5.3.5.3 Task composition

The task flow of knowledge fusion is shown in Figure 7.

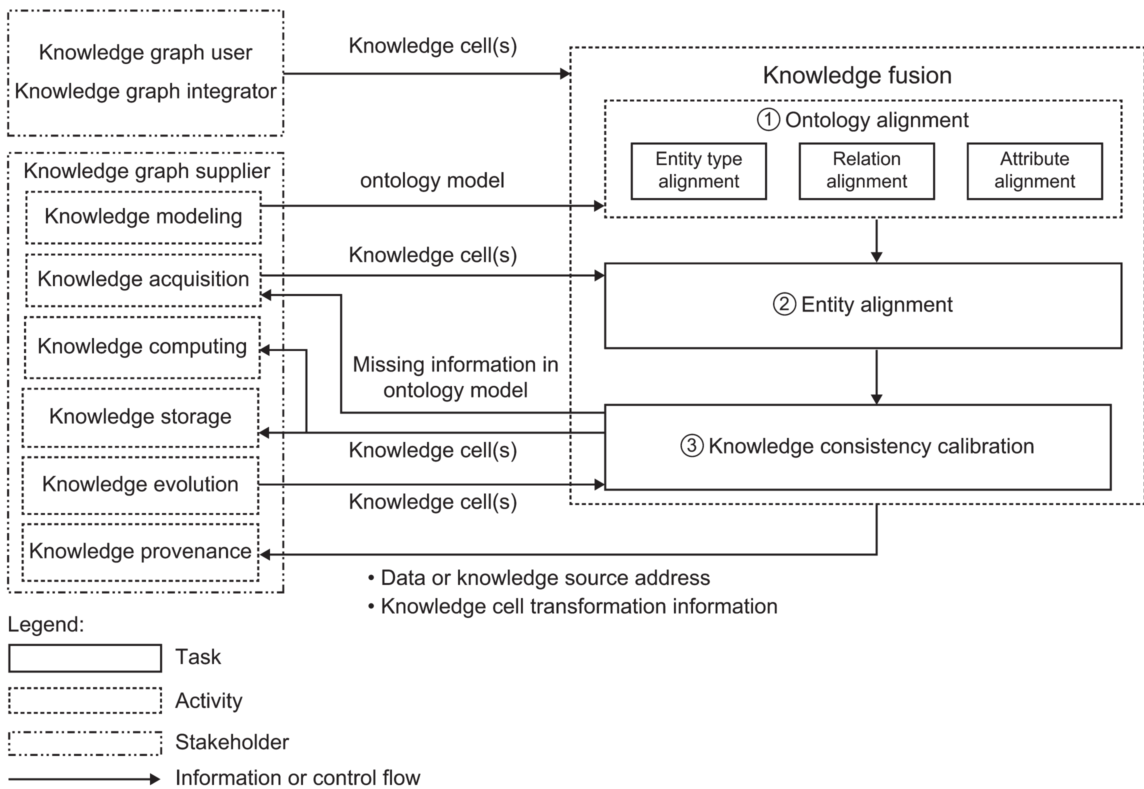

Figure 7—Task flowchart of knowledge fusion

The tasks of knowledge fusion shall include, but are not limited to, the following:

a) Ontology alignment, in which main subtasks can include:
   1) Entity type alignment
   2) Relation alignment: Align equivalent relations in different ontology models and merge them
   3) Attribute alignment: Align equivalent attributes in different ontology models and merge them into the same attribute
b) Entity alignment: Identify equivalent entities in knowledge cell(s), including entity normalization, entity disambiguation, and attribute value alignment and fusion
c) Calibration of knowledge consistency: Validate the consistency among knowledge cell(s) after fusion

5.3.5.4 General quality description characteristics

The quality of knowledge fusion shall be assessed by precision, recall, and F1 measures, as follows:

a) Precision, which is to measure the ratio of correct knowledge cells in the fused results to the total fused knowledge scale. Precision of knowledge fusion is expressed in Equation (4).

$$P_F = \frac{TP_F}{TP_F + FP_F} \tag{4}$$

where

TP_F is the true positive: The number of entities, relationships, or attributes in the fusion result that match the truth
FP_F is the false positive: The number of entities, relationships or attributes in the fusion result that have been fused but do not match the truth

b) Recall, which is to measure the extent to which fused knowledge covers correct knowledge. Recall of knowledge fusion is expressed in Equation (5).

$$R_F = \frac{TP_F}{TP_F + FN_F} \tag{5}$$

where

FN_F is the false negative: The number of entities, relationships, or attributes, which should be fused but not fused in the fusion result

c) F1-Measure, which is to comprehensively measure the precision and completeness of knowledge fusion results. F1-Measure of knowledge fusion is expressed in Equation (6).

$$F_{1-score_F} = 2 \times \frac{P_F \times R_F}{P_F + R_F} \tag{6}$$

d) *Hits@n*, which is to measure the proportion of correct entities, relationship, attributes, and entity types ranked in the top *n*. *Hits@n* is expressed in Equation (7).

$$HIT@n = \frac{1}{|S|}\sum_{i-1}^{|S|} 1_A(rank_i \leq n) \tag{7}$$

where

S is the collection of entities, relations, attributes, and entity types waiting to be fused
$|S|$ is the number of entities, relations, attributes, and entity types waiting to be fused
$1_A(\cdot)$ is the indicator function
n is the selected top rank number

5.3.6 Knowledge storage

5.3.6.1 Inputs

The inputs of knowledge storage shall include, but are not limited to, the following:

a) Ontology model and its schema

b) Knowledge cell(s) output from knowledge fusion, knowledge computing, knowledge evolution, and other activities

c) Version information with time output from knowledge evolution

d) Knowledge representation model

e) Rules, constraints, and algorithm models designed or output from knowledge modeling, knowledge computing, knowledge evolution, knowledge traceability, and other activities

5.3.6.2 Outputs

The outputs of knowledge storage shall include, but are not limited to, the following:

a) Database system after design or selection, such as follows:
   1) Knowledge query and editing interface
   2) Visualization module
   3) Storage management interface

      NOTE—Knowledge storage management interface mainly includes schema query and modification, copy quantity query and modification, index configuration, and so on.

   4) Support tools

      NOTE—Support tools include data import and export tools, connection tools with external business components, performance monitoring tools, backup, recovery tools, and so on.

b) Stored knowledge cell(s)

c) Stored ontology model

d) Stored rules, constraints, and algorithm models

5.3.6.3 Task composition

The tasks of knowledge storage shall include, but are not limited to, the following:

a) Complete selection and design of the data storage system, in which the main subtasks should involve the following:
   1) Select the type of data storage system, such as database and file system, according to the storage and application requirements of knowledge and resource configuration conditions
   2) Design the knowledge storage structure based on the selected data storage system type

b) Perform storage operations, in which the main subtasks should involve the following:
   1) Complete storage of knowledge cell(s)
   2) Complete query of knowledge cell(s)
   3) Complete maintenance of knowledge cell(s), such as adding, deleting, modifying, and updating knowledge cell(s)
   4) Complete visualization of the knowledge cell(s), such as displaying the content of the knowledge cell(s) in a visual way such as a graph

c) Complete storage management, in which the main subtasks should involve the following:
   1) Complete configuration of database setting information
   2) Record logs of knowledge storage process
   3) Establish data security mechanism to help ensure the security of data storage

5.3.6.4 General quality description characteristics

The general characteristics used to describe the quality of knowledge storage shall include, but are not limited to, the following:

a) Efficiency, which is to measure the degree of time occupation and resource occupation in the activity
b) Maintainability, which is to measure the ability of maintenance and management of knowledge cell(s) and the ability of database maintenance in the activity
c) Security, which is to measure the ability to protect knowledge cell(s) from loss or disclosure in the activity
d) Usability, which is to measure the ability to support other activities related to the knowledge graph construction, mainly including import and export of knowledge cell(s), distributed storage, index construction, and retrieval of a whole knowledge graph
e) Reliability, which is to measure whether a backup mechanism for knowledge cell(s) is established
f) Friendliness, which is to measure common data types supported by access interfaces, the friendliness of interfaces, and the ability of human–computer interaction

5.3.7 Knowledge computing

5.3.7.1 Inputs

The inputs of knowledge computing shall include, but are not limited to, the following:

a) Knowledge representation model
b) Ontology model and its scheme
c) Stored knowledge cell(s)
d) Obtained computing demands based on knowledge graph construction and application demands, such as algorithm models, (business) rules, provenance requests, and outside data
e) Inputs from knowledge provenance, such as provenance results and confidence of provenance results

5.3.7.2 Outputs

The outputs of knowledge computing shall include, but are not limited to, the following:

a) Obtained knowledge cell(s) through computing
b) Computing services on the knowledge graph offered for downstream tasks

   NOTE—Computing services include graph feature computing, subgraph computing, link prediction, graph embedding, graph search, algorithm model, and entity link.

c) Output to knowledge provenance: provenance requests

5.3.7.3 Task composition

The task flow of knowledge computing is shown in Figure 8.

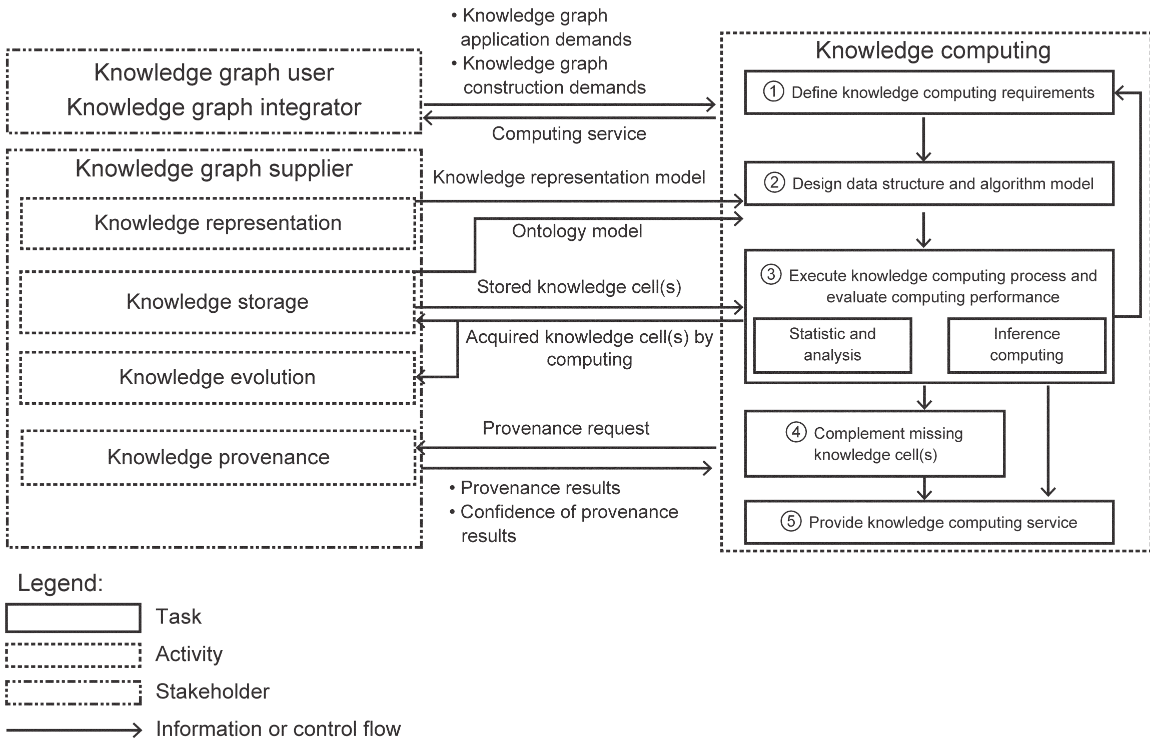

Figure 8—Flow diagram of knowledge computing task

The tasks of knowledge computing shall include, but are not limited to, the following:

a) Define knowledge computing demands, in which main subtasks can involve:
   1) Define the business problems to solve and the computing goals to implement
   2) Analyze the dependent ontology models, rules, and constraints
b) Design requested data structure and algorithm model for computing
c) Execute knowledge computing process and evaluate computing performance, in which subtasks can involve the following:
   1) Count and conclude the knowledge structure in the knowledge graph by statistic and analysis
   2) Find and dig implicit knowledge from existing facts and relations by inference and computing
d) Complement missing knowledge cell(s) based on mined implicit knowledge
e) Provide knowledge computing services by interfaces and so on, such as count of the knowledge graph basic information, graph search, triple classification, and link prediction

5.3.7.4 General quality description characteristics

General characteristics used to describe the quality of knowledge computing shall include, but are not limited to, the following:

a) Accuracy, which is to measure accuracy of formed algorithm model during the computing tasks
b) Resource consumption, which is to measure occupancy of hardware, software, and other resources in the activity

c) Response time, which is to measure occupancy of time in the activity

d) Computing power, which is to measure the support capacity for algorithms and rule types

e) Explain-ability, which is to measure the degree of explain-ability in computing process, such as logic explain-ability of defined rules in the activity

f) Availability, which is to measure accessibility of computing services

5.3.8 Knowledge provenance

5.3.8.1 Inputs

The inputs of knowledge provenance shall include, but are not limited to, the following:

a) Addresses of data or knowledge source

b) Sourcing requests

c) Information related to knowledge cell transformation in the knowledge graph construction activities, such as knowledge modeling, knowledge acquisition, knowledge fusion, knowledge computing, and knowledge evolution

5.3.8.2 Outputs

The outputs of knowledge provenance shall include, but are not limited to, the following:

a) Sourcing requests on address location

b) Sourcing results, such as follows:

   1) Knowledge resource address: the unique resource access used as identification for a knowledge resource

   2) Transformation path of knowledge cell(s)

c) Confidence degree of sourcing results, which is used to evaluate the reliability of sourcing results

5.3.8.3 Task composition

The tasks of knowledge provenance shall include, but are not limited to, the following:

a) Define structural description of a knowledge source address, such as creator or publisher, time, version, and format.

   NOTE—Time means time dimension and time granularity of data. The time dimension can include the dimension from version management and the dimension from fact.

b) Design knowledge provenance solutions, such as sourcing model, organizing, and expression of sourcing methods.

c) Source and position the knowledge resource address.

d) Determine calculating dimensions of the confidence degree, and calculate the confidence degree of sourcing results based on quantity, generation time, weight of data sources, and so on.

e) Perform version management in terms of updating the raw data and knowledge.

5.3.8.4 General quality description characteristics

General characteristics used to describe the quality of knowledge provenance shall include, but are not limited to, the following:

a) Accuracy that measures relevance among query results and target knowledge
b) Response time

5.3.9 Knowledge evolution

5.3.9.1 Inputs

The inputs of knowledge evolution shall include, but are not limited to, the following:

a) Existing ontology models
b) Stored knowledge cell(s)
c) Stored evolution rules
d) Updated ontology models
e) New knowledge cell(s) generated by other knowledge graph construction activities, such as knowledge computing and knowledge acquisition

5.3.9.2 Outputs

The outputs of knowledge evolution shall include, but are limited to, the following:

a) Evolved knowledge cell(s)
b) New version knowledge graph
c) Version information, such as time series information and knowledge source information

NOTE—To help ensure data quality and help avoid the impact of new knowledge on business, a knowledge graph supplier can consider adding the time dimension to the existing knowledge graph.

5.3.9.3 Task composition

The tasks of knowledge evolution shall include, but are not limited to, the following:

a) Identify the knowledge cell(s) to be modified in the existing knowledge graph
b) Design or match rules, algorithms, or models of evolution
c) Update the original knowledge cell(s), in which the main subtasks can involve the following:
    1) Making changes to existing knowledge
    2) Making corrections to incorrect knowledge
d) Generate a new version of the knowledge graph with information, such as updated time
e) Manage knowledge graph versions, in which the main subtasks should involve the following:
    1) Record changed information and version information of knowledge cell(s)
    2) Generate new paths of knowledge storage and knowledge evolution logs
    3) Freeze or eliminate the original version of the knowledge graph

5.3.9.4 General quality description characteristics

General characteristics used to describe the quality of knowledge evolution shall include, but are not limited to, the following:

a) Reliability, which is to measure whether control of multiple versions, rollback, and release of versions, can be supported
b) Reviewability, which is to measure whether knowledge to be updated can be reviewed, deleted, and so on
c) Evolution complexity
d) Scale of the evolved knowledge graph
e) Completeness, which is to measure the completeness of the knowledge graph and its version information after updating

5.3.10 Quality assurance

5.3.10.1 Types of quality assurance

The types of quality assurance of the knowledge graph supplier shall include the following:

a) Guarantee quality of the knowledge content, such as its accuracy, integrity, availability, consistency, and temporal-effectiveness
b) Guarantee quality of the knowledge graph construction process, according to evaluation indicators of knowledge graph supplier activities
c) Guarantee quality of fundamental knowledge graph services or tools, such as their functions and performances

5.3.10.2 Task composition

The tasks of quality assurance of the knowledge graph supplier shall include, but are not limit to, the following:

a) Obtain quality assessment demands
b) Complete quality inspection, in which main subtasks can involve:
    1) Achieve quality inspection of the knowledge graph construction process
    2) Achieve quality inspection of the completed knowledge graph and other deliverables
c) Complete error-correction or update of the knowledge content
d) Complete optimization and update of knowledge graph foundation services or tools, such as configuration parameters, functional modules, and performance criteria

6. Knowledge graph integrator

6.1 Inputs of knowledge graph integrator

The inputs of a knowledge graph integration shall include, but are not limited to, the following:

a) Inputs provided by the knowledge graph user(s), such as knowledge graph application demands, business data, aided knowledge, and information system

b) Input provided by the knowledge graph supplier(s), such as fundamental knowledge graph tools, fundamental knowledge graph services, and technical support of knowledge graphs

c) Input provided by the knowledge graph ecosystem partner(s), such as support data, knowledge, technologies, and services needed by development and integration of knowledge graph application system

6.2 Outputs of knowledge graph integrator

The outputs of a knowledge graph integrator shall include, but are not limited to, the following:

a) Outputs to the knowledge graph user(s), such as knowledge graph application system and service support (such as consultant services, operation and maintenance services, application services, system support)

b) Outputs to the knowledge graph supplier(s), such as knowledge graph construction demands, industry knowledge, and quality indexes

6.3 Composition of knowledge graph application system

The knowledge graph application system refers to a system that integrates the knowledge graph and the logic of the business implementation, and it is equipped with a whole information flow and preset functions related to the knowledge graph application. It shall include the following parts:

a) Business application module, whose functions mainly include:
   1) Provide business data processing, task management, and other services
   2) Provide business function invocation, interface opening, and other services

b) Fundamental knowledge graph tools or services [see item a) and item b) of 5.2].

c) Business integration module, whose functions mainly include:
   1) Integrate and encapsulate the business application module and the fundamental knowledge graph tools or services according to business logic
   2) Provide service of encapsulated interface call for the external

d) Application interaction module, whose functions mainly include:
   1) Provide knowledge visualization service
   2) Provide knowledge application and interaction services based on the knowledge graph(s)

e) Supporting module, whose functions mainly include:
   1) Support system security management and log auditing
   2) Support user management and permission management
   3) Support monitoring and running management
   4) Support quality control management
   5) Support operation and ability management

6.4 Main activities of knowledge graph integrator

6.4.1 Activity process

The activity process of the knowledge graph integrator is shown in Figure 9.

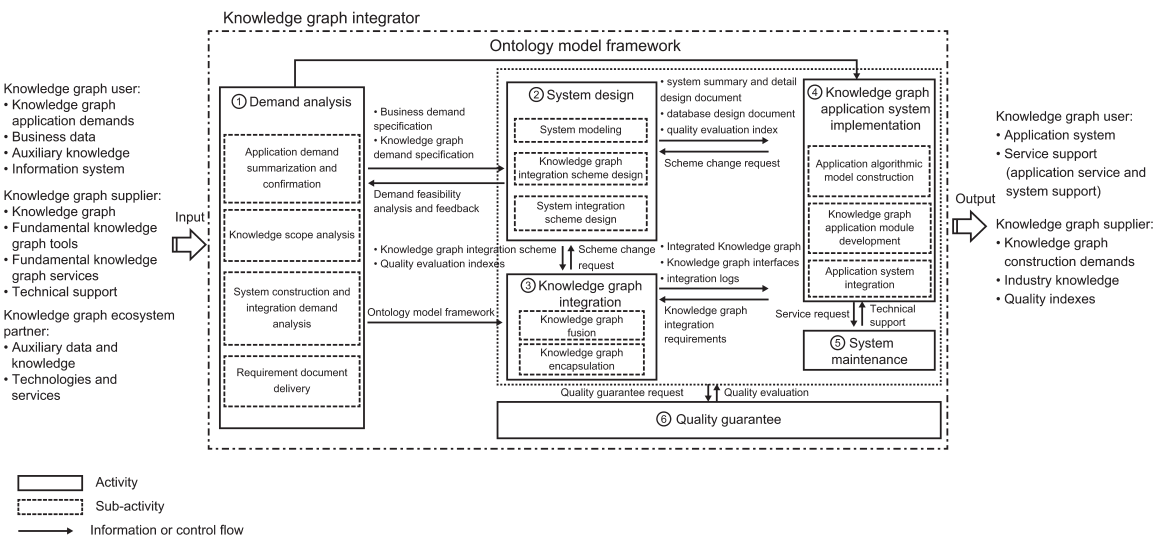

Figure 9—Activity process of knowledge graph integrator

The main activities of the knowledge graph integrator shall include, but are not limited to, the following:

a) Demand analysis, which analyzes and transforms the business requirements for the knowledge graph application system construction raised by the knowledge graph user(s)

b) System design, which completes the design of the knowledge graph application system and its integration scheme

c) Knowledge graph integration, which combines multiple knowledge graphs into a complete and unified knowledge graph or collects knowledge from multiple knowledge graphs and then merges these knowledge graphs into a new one

d) Knowledge graph application system development, which develops the algorithm models and function modules of the knowledge graph application system and completes the integration among its internal modules and external systems

e) System maintenance, which configures, monitors, updates, and maintains the knowledge graph application system (delivered or to be delivered), the integrated knowledge graph(s), and the running environment to help ensure the sustainable and stable operation of the system

f) Quality assurance, which monitors the quality during the implementation of the knowledge graph integrator based on the knowledge graph application demands and evaluates the quality of the implementation results

6.4.2 Demand analysis

6.4.2.1 Inputs

The inputs of demand analysis shall include, but are not limited to, the following:

a) Knowledge graph application demands, such as construction objectives of the knowledge graph application system, user interface, knowledge visualization, and so on

NOTE—The demands can be submitted to the knowledge graph integrator for confirmation through written documents, such as demand specification.

b) Business data
c) Auxiliary knowledge
d) Feasibility feedback of demand realization

6.4.2.2 Outputs

The outputs of demand analysis shall include, but are not limited to, the following:

a) Ontology model framework
b) Business and system specifications, which can mainly involve business objectives, data processing demands, business logic flow chart, term definitions, security demands, description of software demands, functional demands, performance indexes, functional requirements, interface requirements, service requirements, and maintenance requirements
c) Knowledge graph demand specification, which can mainly involve knowledge scope, data requirements, acceptance standards of the knowledge graph application system, data format for industry knowledge, requirements for both the ontology models and the algorithm models, and maintenance requirements

6.4.2.3 Task composition

The tasks of demand analysis can include, but are not limited to, the following:

a) Organize and confirm the application demands of the knowledge graph user(s), in which the main subtasks can involve the following:
    1) Collect and sort out the knowledge graph application demands and construction basis from the knowledge graph users, such as business demands, application scenarios, business data, expert knowledge, and other information.
    2) Communicate and confirm with the knowledge graph users to form a complete list of demands.
b) Analyze the knowledge scope, in which the main subtasks can involve the following:
    1) Unify terms required in the system construction process.
    2) Determine the ontology model framework.
c) Analyze the system construction and integration demands, in which the main subtasks can involve the following:
    1) Define the business demands on system integration, such as business problems, business objectives, and task lists.

2) Develop test cases and test plans.

d) Form the final complete and accurate demand documents, such as business and system specifications and knowledge graph demand specifications.

6.4.2.4 General quality description characteristics

General characteristics used to describe the quality of demand analysis shall include, but are not limited to, the following:

a) Accuracy, which measures the degree of compliance between the demand specifications and the demands of the knowledge graph users
b) Trackability, which measure the recording extent or traceability of the demand analysis process
c) Integrity, which is to measures the extent that the demand specifications cover the scope of user demands
d) Verifiability, which measures the extent that the demands described in the demand specifications can be verified
e) Realizability, which measures the extent that the development and integration objectives can be achieved under the specified time, budget, and technical constraints

6.4.3 System design

6.4.3.1 Inputs

The inputs of system design shall include, but are not limited to, the following:

a) Business and system demand specification
b) Knowledge graph demand specification
c) Fundamental knowledge graph tools or services
d) Integration instructions of knowledge graph ecosystem partners, such as instructions for integration with data, tools, and services from the knowledge graph ecosystem partners
e) Design change request

6.4.3.2 Outputs

The outputs of system design shall include, but are not limited to, the following:

a) High level and detailed design documents, such as follows:
    1) Dictionary for domain data
    2) System module design specification
    3) Flow control specification with flow diagrams
    4) Data storage module design document
    5) Entity relationship specification of the knowledge graph application system
    6) Data flow specification of the knowledge graph application system

b) Knowledge graph integration scheme, such as follows:
   1) Knowledge graph integration framework: domain concepts, terms, and unified semantic knowledge in the target scope of knowledge graph integration
   2) Knowledge graph integration specification: rules and constraints that should be observed
   3) Knowledge graph integration scope: integration boundaries, scope, and constraints
c) Quality evaluation metrics

6.4.3.3 Task composition

The tasks of system design shall include, but are not limited to, the following:

a) Complete system modeling, in which the main subtasks can involve the following:
   1) Transfer the business demands to system requirements, and design the system structure, subsystems, and their interaction interfaces
   2) Complete system function design
   3) Design dataflow, control flow, and state transition
   4) Design data storage module structure, such as data dictionary and schema
   5) Design the business processing logic, input elements, and output elements of the application modules
b) Design the knowledge graph integration scheme, in which the main subtasks can involve the following:
   1) Define domain terminology hierarchy
   2) Define knowledge graph integration scope
   3) Design integration solutions for ontology models and its instances
   4) Design knowledge cell storage solutions after integration
   5) Design knowledge graph evolution solutions and service interfaces
   6) Define integration control parameters and auxiliary data
   7) Define integration quality requirement
   8) Prepare and optimize integration scheme
c) Design the system integration scheme, in which the main subtasks can involve the following:
   1) Design system scope, integration solutions, and plans
   2) Design data and function interactions among subsystems of the knowledge graph application system, among the knowledge graph application system and the external integrated systems
   3) Define system interfaces
   4) Develop acceptance criteria of system integration
   5) Define evaluation system of system integration

6.4.3.4 General quality description characteristics

General characteristics used to describe the quality of system design can include, but are not limited to, the following:

a) Completeness, which evaluates the coverage of the design scheme to the knowledge graph integration demands and system integration demands
b) Readability, which evaluates the clearness and unambiguity level of the design scheme
c) Feasibility, which evaluates the operability of the design scheme to guide system development and implementation

6.4.4 Knowledge graph integration

6.4.4.1 Inputs

The inputs of knowledge graph integration shall include, but are not limited to, the following:

a) One or more knowledge graphs provided by the knowledge graph supplier(s)
b) Ontology model framework generated from demand analysis
c) Auxiliary data, such as annotations or descriptions of same entities and relations among knowledge graphs
d) Business data, such as data waiting for integration in the business system(s)
e) Integration tools, such as ontology matching tools
f) Control parameters, such as thresholds, judgment conditions, and version numbers

6.4.4.2 Outputs

The outputs of knowledge graph integration shall include, but are not limited to, the following:

a) Integrated knowledge graph
b) SDKs, APIs, and visualization tools of the integrated knowledge graph
c) Integration process data, such as various details about the integration process

6.4.4.3 Task composition

The tasks of knowledge graph integration shall include the following:

a) Knowledge graph fusion: Align, merge, and disambiguate knowledge cell(s) of different knowledge graphs under the same framework to obtain a globally unified knowledge identification and association. The main subtasks should involve the following:
   1) Normalize the knowledge cell(s) of multiple knowledge graphs to improve the subsequent fusion efficiency.
   2) Define rules or algorithms related to alignment, merging, association, disambiguation, and so on, of knowledge cells or ontology models.

      NOTE—For special fields, rules can be designed for scenarios that are inappropriate or lacking for existing rules and constraints.

   3) Execute the fusion process of knowledge cell(s).
   4) Evaluate the performance of knowledge graph fusion.

b) Knowledge graph encapsulation: Encapsulate the retrieval, reasoning, and other service capabilities of the knowledge graph, and export them in the form of interfaces, tools, or interfaces. The main subtasks should involve the following:

   1) Determine the packaging form, such as SDKs, APIs, and visual components.

   2) Determine the encapsulation content and complete the encapsulation, such as knowledge graph and its basic capabilities (retrieval, editing, etc.), algorithm models, and computing resource scheduling capabilities.

      NOTE—The algorithm models may include knowledge statistics, knowledge reasoning, graph algorithm, and other related algorithm models.

   3) Complete the encapsulation performance test and optimization.

6.4.4.4 General quality description characteristics

General characteristics used to describe the quality of knowledge graph integration shall include, but are not limited to, the following:

a) Resource expenditure, which measures the resource consumption in the integration process, such as software, hardware, and labor power

b) Time expenditure, which measures the time consumption in the integration process

c) Integration idempotent, which measures the extent that the same result can be obtained each time when the same knowledge graphs are input for integration

d) Accuracy, which measures the matching extent between the actual integration performance and the ideal integration performance

e) Compatibility, which measures whether conventional knowledge graph data formats and integration tools can be supported

f) Scalability, which measures whether full integration, incremental integration, or partial stock integration of knowledge graphs can be supported

6.4.5 Knowledge graph application system development

6.4.5.1 Inputs

The inputs of knowledge graph application system development shall include, but are not limited to, the following:

a) Schemes formed during system design

b) Ontology model frameworks formed during demand analysis

c) Knowledge graph and integration logs formed during knowledge graph integration

d) Service data and information systems to be integrated, which is provided by the knowledge graph users

e) Technical support provided by the knowledge graph supplier

6.4.5.2 Outputs

The outputs of knowledge graph application system development shall include, but are not limited to, the following:

a) Change requests for knowledge graph integration schemes and system integration schemes
b) Application algorithm models related to the knowledge graph
c) Integrated knowledge graph application system
d) Documents in the development process, such as integration reports, problem or fault reports, change reports, and acceptance reports

6.4.5.3 Task composition

The tasks of knowledge graph application system development shall include, but are not limited to, the following:

a) Develop application algorithm models based on knowledge graph application demands, such as follows:
   1) Complete the selection of both types and frameworks of application algorithm models.
   2) Complete the optimization and iteration of application algorithm models.
   3) Complete the testing and encapsulation of application algorithm models.
b) Develop application function modules based on the knowledge graph, such as follows:
   1) Define the input and output standards of the application modules, according to the knowledge graph application system design scheme.
   2) Preset and prepare the software and hardware environments and configuration tools required for operation of the knowledge graph application module.
   3) Complete coding, testing, and encapsulation of the knowledge graph application module.

   NOTE—According to differences in the application scope, development of application function modules can be divided into general application module development and industry application module development. The general application module based on the knowledge graph is applicable to various business fields, such as knowledge question and answer, semantic search, intelligent recommendation, and so on; the industry application module based on the knowledge graph refers to the knowledge graph application module that faces the demands of specific industries or fields.
c) Complete integration of internal modules of the knowledge graph application system and external systems, such as follows:
   1) Formulate integration plan and implement system integration according to the integration design scheme.
   2) Formulate test cases and test plans of the integrated system, and feedback test-failure information to system design.
   3) Iterate and optimize the knowledge graph integration scheme and the system integration schemes according to the test results.
   4) Organize stakeholders to check and accept the knowledge graph application system and the system service schemes to be delivered according to the integration demands, integration schemes, and test reports (see Annex A for stakeholder categories).

6.4.5.4 General quality description characteristics

General characteristics used to describe the quality of knowledge graph application system development shall include, but are not limited to, the following:

a) Integrity, which measures the coverage of the formed knowledge graph application system to business demands in different application scenarios

b) Security, which measures the protection ability of the formed knowledge graph application system to its knowledge, system function and performance, supporting software and hardware facilities, and so on. The security can be further divided into confidentiality, controllability, transparency, privacy, and so on, such as follows:

   1) Should establish a knowledge authentication and authorization mechanism

   2) Should confirm the completeness of the knowledge graph in the knowledge graph application system, and verify the storage security and transmission security of the knowledge cell(s)

   3) Should confirm security of the application modules in the knowledge graph application system, such as attacks preventing and tampering

c) Reliability, which measures the ability of the formed knowledge graph application system to complete the required functional and nonfunctional requirements under specified conditions

d) Responsiveness, which measures the quality of results returned by the formed knowledge graph application system after receiving the request and the ability expressed in the process of returning the results. It can include the consumption of time and resources, the quality of feedback results, and so on.

e) Portability, which measures the ability of the formed knowledge graph application system to transplant among different software and hardware environments

f) Usability, which measures the ability of the formed knowledge graph application system to understand, learn, use, and attract users under specified conditions

g) Maintainability, which measures the extent of modification, reuse, analysis, test, and so on, of the formed knowledge graph application system

h) Compliance, which measures the dependence of the formed knowledge graph application system and its knowledge graph on related standards and ethical rules in specific fields if involved

6.4.6 System maintenance

The tasks of system maintenance shall include, but are not limited to, the following:

a) Maintain the knowledge graph.

b) Maintain the application algorithm models, in which the main subtasks can involve the following:

   1) Detect the usage statuses and monitor performances of the deployed algorithm models, including knowledge graph algorithm models.

   2) Update, optimize, maintain, and upgrade the algorithm models in the knowledge graph application system according to changes of accessed data and application scenarios.

c) Expanse and maintain distributed deployment capabilities of the knowledge graph application system, in which the main subtasks can involve the following:

   1) Detect statuses on the distributed deployment environments of the knowledge graph application system.

2) Maintain or improve the distributed deployment ability based on the change or expansion of the knowledge graph application demands.

d) Maintain the knowledge graph application system, in which the main subtasks can involve the following:

1) Maintain strategies for situations, such as excessive retrieval traffic, which could lead to system downtime.

2) Regularly monitor the system statuses and key performance indicators with early warning or notification of failures.

e) Upgrade the knowledge graph application system, in which the main subtasks can involve the following:

1) Develop and deploy system patches for vulnerabilities in the application system detected by maintenance.

2) Expand and maintain the data processing capabilities required by the knowledge graph application system according to emerging application demands, such as data access, knowledge storage, knowledge exchange, and knowledge computing.

3) Expand and maintain the functions of the knowledge graph application system according to the emerging application demands, such as knowledge visualization, knowledge invocation, general applications, or industrial applications waiting to be developed.

6.4.7 Quality assurance

The tasks of quality assurance shall include, but are not limited to, the following:

a) Complete the quality assurance of the integration process of the knowledge graph application system by the following main subtasks:

1) Evaluate the quality of the development and integration process of the knowledge graph application system according to the activity evaluation indicators of the knowledge graph integrator.

2) Confirm the integration coupling of the knowledge graph application system and maintainability and security of its development process.

b) Complete the quality assurance of the functions and performances of the knowledge graph application system by the following main subtasks:

1) Confirm the completeness and reliability of functions of the knowledge graph application system.

2) Confirm the response time and other key performance indicators of the knowledge graph application system.

3) Formulate safeguard measures for possibly existing risks of the reliability of the system.

c) Complete the quality assurance of the knowledge of the knowledge graph application system by the following subtasks:

1) Confirm the quality of the integrated knowledge graph using the indicators, such as knowledge accuracy, completeness, availability, consistency, timeliness, and so on.

2) Update, maintain, or expand the knowledge graph of the knowledge graph application system.

d) Complete the quality assurance of the services of the knowledge graph application system by the following main subtasks:

1) Complete the version management of the integrated knowledge graph, and provide necessary interfaces, toolkits, and other services

2) Provide service description documents of the knowledge graph application system, such as specification documents, process documents, and terminology system documents.

7. Knowledge graph user

7.1 Knowledge consumer

7.1.1 Inputs

The inputs of knowledge consumers can include, but are not limited to, the following: knowledge cell(s) and other knowledge application services from the knowledge graph application system.

7.1.2 Outputs

The outputs of knowledge consumers shall include, but are not limited to, the following: application demands, such as business application demands, and service demands.

7.1.3 Main activities

The activities of knowledge consumers shall include the following:

a) Access and use the required knowledge cell(s).

b) For specific industry, the constrains on knowledge consumers can include, but are not limited to the use permission, the forms of knowledge visualization, the accuracy of knowledge query, and the speed of knowledge evolution.

NOTE—Taking the application of medical knowledge graphs, for example, the knowledge provided by the knowledge graph to consumers is limited to the field of medicine and health. It cannot provide financial knowledge, such as investment and financial management.

7.2 Knowledge maintainer

7.2.1 Inputs

The inputs of the knowledge maintainer shall include, but are not limited to, the following: knowledge cell(s) and quality control modules of the knowledge graph application system.

7.2.2 Outputs

The outputs of the knowledge maintainer shall include, but are not limited to, the following: added, updated, backed up, or restored knowledge cell(s) and knowledge maintenance demands.

7.2.3 Main activities

The activities of the knowledge maintainer shall include the following:

a) Knowledge operation and maintenance, which eliminates wrong knowledge and complete adding, updating, deleting, and other operations of knowledge cell(s) in the knowledge graph

b) Knowledge quality management, which is the activity to:

   1) Review the content quality of given knowledge items to help avoid unqualified knowledge from entering the knowledge graph

   2) Input and maintain the knowledge through interfaces

   3) Set the subrole of the knowledge quality manager separately for industries with strict quality control

c) Knowledge operation and promotion

d) For specific industries, such as medicine, health, finance, law, technology, and electricity, the knowledge maintainer should have corresponding professional qualifications when carrying out knowledge quality management

7.3 Knowledge provider

7.3.1 Inputs

The inputs of the knowledge provider shall include, but are not limited to, the following:

a) Fundamental knowledge graph tools

b) Knowledge graph application system

7.3.2 Outputs

The outputs of the knowledge provider shall include, but are not limited to, the following:

a) Knowledge cell(s), which can include original knowledge and common sense or specific domain knowledge that is preliminarily abstracted and expressed in certain organizational forms

b) Knowledge entry requirements

7.3.3 Main activities

The activities of knowledge providers shall include the following:

a) Extract entity types from actual knowledge.

b) Extract knowledge elements that meet the requirements from business data.

c) Participate in the definition or selection of knowledge representation formats required for the knowledge graph construction.

d) Participate in the construction of the ontology model required for the knowledge graph construction.

e) For specific fields, knowledge providers shall have knowledge reserves, which is consistent with the service fields of the knowledge graph application system.

   NOTE—For specific industries, such as medical care, knowledge providers need to have corresponding professional qualifications, and provide knowledge based on diagnostic criteria, expert consensus, and so on.

f) Knowledge provided by knowledge providers should satisfy the principles of acceptability, relevance, logic, professionalism, and so forth:

   1) Acceptability: The provided knowledge should be considered correct by most people at the cognitive level.

   2) Relevance: The provided knowledge should be guaranteed to be relevant to the given input scope.

   3) Logic: The logic of the relationship among the provided knowledge should conform to objective facts.

   4) Professionalism: The provided knowledge should have the necessary professionalism in its specific field.

8. Knowledge graph ecosystem partner

8.1 Inputs

The inputs of the knowledge graph ecosystem partner shall include, but are not limited to, the following: support demands of knowledge graph suppliers, knowledge graph integrators, and knowledge graph users during their activity implementation.

8.2 Outputs

The outputs of the knowledge graph ecosystem partner shall include, but are not limited to, the following:

a) Technical products: Digital infrastructures, technical tools, and data resources used to support the construction and integration of knowledge graph, such as graph database, basic database or knowledge base, open-domain knowledge graphs, and data governance tools

b) Technical services: Support technical services to the knowledge graph construction, such as text recognition and processing, image processing, pattern recognition, data governance technology services, security assessment technology services, and certification services

c) Solutions: Relevant solutions used to guide development, deployment, operation, and maintenance of knowledge graph products in specific industries and their services

d) Assessment reports: Technical or commercial assessment reports based on provided consultation services

8.3 Main activities

The activities of the knowledge graph ecosystem partner can mainly include infrastructure supply, data supply, data governance service, consulting service, safety service, assessment, and authentication service. Accordingly, the knowledge graph ecosystem partner shall be divided into infrastructures supplier, data supplier, data governor, consultation service provider, security service provider, evaluation and certification service provider, and other subroles. Annex B describes the main subroles of the knowledge graph ecosystem partner.

Annex A

(informative)

Knowledge graph stakeholder composition

According to the four groups of activities related to knowledge graphs and their supporting relationships, knowledge graph stakeholders can be divided into the following four categories, as shown in Figure A.1.

a) Knowledge graph supplier

b) Knowledge graph integrator

c) Knowledge graph user

d) Knowledge graph ecosystem partner

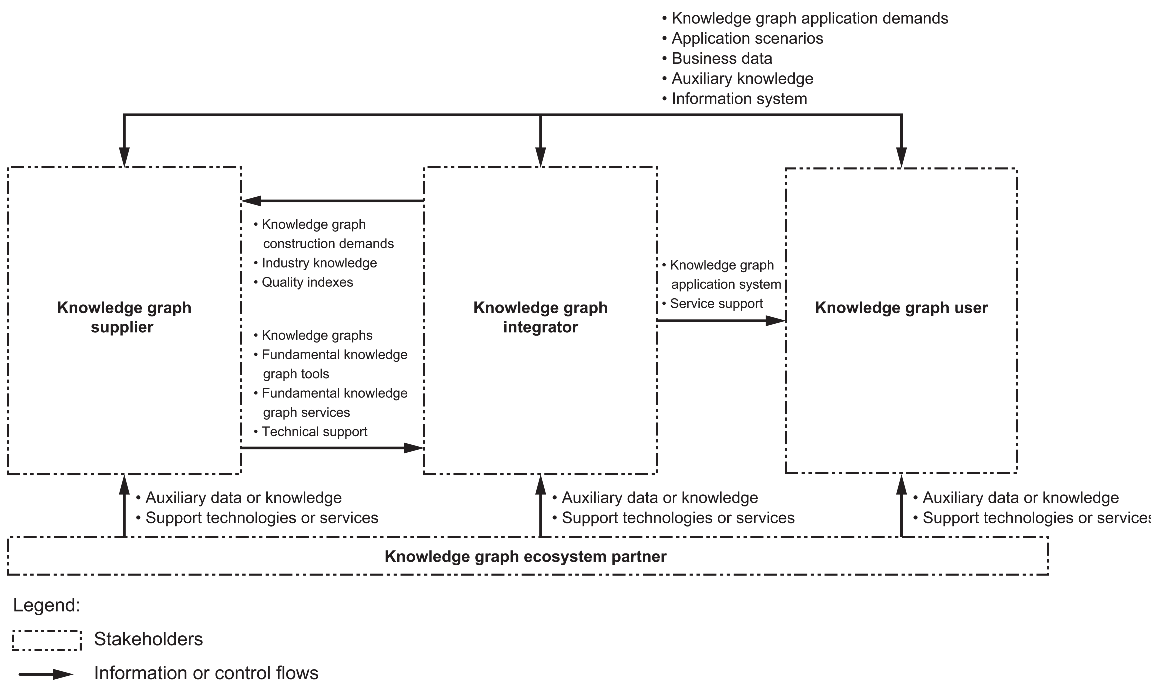

Figure A.1—Knowledge graph stakeholder composition

Annex B

(informative)

Subroles of knowledge graph ecosystem partner

The subroles of the knowledge graph ecosystem partner should include, but are not limited to, the following:

a) Digital infrastructure supplier can provide the software and hardware infrastructure required for the construction and application of knowledge graphs, such as hardware equipment, cloud service resources, big data storage and computing platforms, intermediate tools, or plug-ins.

b) Data supplier can import data into the knowledge graph application system and allow the system to discover, access, transform, and display the data. For example, open domain knowledge graphs can be accessed and imported through the open-source platforms on the Internet to support the construction of knowledge graphs.

c) Data governor can evaluate, guide, and monitor data related to the knowledge graph and its application process to help ensure the maximized value of data assets while compliance operating and risk control.

d) Consultation service provider can provide the expert knowledge needed for the key technologies and the application and maturity evaluation of the knowledge graph. In addition, the consultation service provider can help to determine the applicability, application scope, application degree, and relationship of the knowledge graph with other information technologies.

e) Security service provider can mainly provide the formulation and deployment of measures related to knowledge graph security, including security and privacy protection of labeled data or raw data, extracted knowledge and constructed knowledge graph, operation security of knowledge graph application system, external interface and access management, and trustworthiness management of the system performance.

f) Evaluation and certification service provider can mainly provide evaluation and certification of knowledge graph related products, services, design, and deployment capabilities.

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