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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Web-based data model for Internet of things and smart city systems and services

ITU-T Y-series Recommendations – Supplement 69

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Supplement 69 to ITU-T Y-series Recommendations

Web-based data model for Internet of things and smart city systems and services

Summary

Data models play a critical role in data, applications, systems, and businesses across various industries as they provide the definition and format of data to support data, computer systems, and related businesses. Supplement 69 to ITU-T Y-series Recommendations provides a web-based data model for Internet of things (IoT) and smart cities. More specifically, this Supplement covers the following:

– Suggestions for generic considerations of data format;

– Necessity for a new type of metadata for interoperability;

– Necessity and importance for a common data model for bridging existing data models;

– Necessity, importance, and adequacy of microdata formats for data management in web environments;

– Fundamental concepts and background of current web environments and microdata formats in terms of structuring and managing data in detail;

– A new category of metadata, called procedural metadata, and its basic principles.

History

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Web-based data model for Internet of things and smart city systems and services

1 Scope

This Supplement to ITU-T Y-series Recommendations provides a web-based data model for Internet of things (IoT) and smart city systems and services including:

– a general discussion on data formats and metadata;

– basic concepts and types of data model;

– microdata formats for web data management; and

– procedural metadata for semantic web of things (WoT).

2 References

None.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 application [b-FG-DPM TS D0.1]: A structured set of capabilities which provide value added functionality supported by one or more services, which may be supported by an application programming interface (API).

3.1.2 capabilities [b-FG-DPM TS D0.1]: Quality of being able to perform a given activity.

3.1.3 data [b-FG-DPM TS D0.1]: Information represented in a manner suitable for automatic processing.

3.1.4 data management [b-FG-DPM TS D0.1]: The activities of defining, creating, storing, maintaining and providing access to data and associated processes in one or more information systems.

3.1.5 data processing [b-FG-DPM TS D0.1]: Systematic performance of operations upon data.

NOTE – Management and converting of data from the raw state into a required output.

3.1.6 data processing and management [b-FG-DPM TS D0.1]: The combination of all activities either directly performed on or indirectly influencing data.

3.1.7 ecosystem [b-FG-DPM TS D0.1]: A network of interconnecting organisations, forming a distributed, adaptive, open socio-technical system with properties of self-organisation, scalability and sustainability.

3.1.8 Internet of things [b-FG-DPM TS D0.1]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

3.1.9 interoperability [b-FG-DPM TS D0.1]: The ability of two or more systems or applications to exchange information and to mutually use the information that has been exchanged.

3.1.10 procedure [b-ISO 9000]: Specified way to carry out an activity or a process.

3.1.11 process [b-ISO 9000]: Set of interrelated or interacting activities that use inputs to deliver an intended result.

NOTE – Whether the "intended result" of a process is called output, product or service depends on the context of the reference.

3.1.12 raw data [b-FG-DPM TS D0.1]: Data that has not been processed for use.

3.1.13 requirements [b-FG-DPM TS D0.1]: Need or expectation that is stated, generally implied or obligatory.

3.1.14 security [b-FG-DPM TS D0.1]: Condition that results from the establishment and maintenance of protective measures that ensure a state of inviolability from hostile acts or influences.

3.1.15 service [b-FG-DPM TS D0.1]: A set of functions and facilities offered to a user by a provider.

3.1.16 system [b-ISO 9000]: A set of interrelated or interacting elements.

3.2 Terms defined in this Supplement

This Supplement defines the following terms:

3.2.1 microdata format: Structured data markups that describe and embed meanings of resources on the web along with their properties and relationships by utilizing tags to convey additional metadata and other attributes in small data units.

3.2.2 procedural metadata: Category of metadata that includes descriptive information on procedures and/or processes by utilizing other metadata and flags.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

API	Application Programming Interface
C3IM	Cross-Cutting Context Information Management
CSS	Cascading Style Sheets
GPS	Global Positioning System
HTML	Hypertext Markup Language
ICT	Information and Communication Technology
IoT	Internet of Things
JSON	JavaScript Object Notation
JSON-LD	JavaScript Object Notation Linked Data
NGSI	Next Generation Service Interface
NGSI-LD	NGSI with Linked Data
RDF	Resource Description Framework
RDFa	Resource Description Framework in Attributes
SensorML	Sensor Model Language
SWoT	Semantic Web of Things
TD	Thing Description
WoT	Web of Things
XML	Extensible Markup Language

5 Conventions

None.

6 Overview

Data is now considered as the new oil for the emerging fourth industrial revolution, a new valuable asset, and an indispensable driving force of innovation [b-Forbes 1]. Both data volume and diversity are increasing overwhelmingly. The web has become the largest medium for information storage, processing, transportation, sharing, and discovery. Hence, it is critical to link the data on the web semantically. There are rising demands to intelligently manage data in a way that its properties and meanings can both be perceived and interpreted well and so that the performance and opportunity for web data sharing and mining can be significantly improved.

However, it is becoming increasingly complex to be aware of data's contexts and relations. This is because the purposes, types, characteristics, and other properties of data are highly heterogeneous. Additionally, how metadata are defined and used currently on the web leans toward linking and connecting the resources based on their generalized properties and relationships rather than describing the context of the data in structured details and connecting them minutely.

Moreover, in order to cope with smart city and Internet of things (IoT) applications toward a future data-driven eco-society, a large variety of new data formats will emerge. At the same time, different and heterogeneous metadata concepts and formats from consortia/fora or individual organizations are being investigated without consensus on the future data eco-society. Data interoperability and data format conversion will be one of the pressing issues that will need to be solved in the near future. Various industries such as energy, transportation, health, biology, and geography are developing their own data formats and data models. For future convergence markets including IoT applications, the future data formats and models should be well defined and standardized for both information and communication technology (ICT) industries and other industries.

In IoT and smart cities, many different industries are collectively combined to provide converged services and applications, and so are the data from different fields. Moreover, as cloud computing is emerging, opportunities for sharing resources from various industries and fields are becoming more frequent than ever. Accordingly, the boundaries between industries are gradually disappearing. However, the data formats and models have been developed to satisfy the specific requirements of each industry and each application. Previously IoT and cloud computing, applications each relied on their own proprietary database and application-specific software. The software applications were often developed at one point in time and for a particular group and were thus optimized for their main function and were unlikely to have considered data sharing as a primary requirement [b-HBR]. Consequently, data are stored and managed in silos and data migration and integration are restricted.

The current fragmented-data ecosystem incurs high costs to process and manage data since most of the data analytic work is focused on data preparation. According to [b-Forbes 2], data preparation takes up about 80% of data scientists' work. Within that 80%, collecting data sets accounts for 19% and cleaning and organizing data accounts for 60%. Data integration and migration with interoperability in IoT and smart cities are issues that have been raised by many research papers such as [b-Ahlgren], [b-Corici] and [b-Broring]. While the needs of data migration and integration are rapidly increasing, it is almost impossible to reformulate the existing data formats and models since they have been settled in the current forms over a period to resolve issues at each moment and to fit one-off requirements. Therefore, data formats, or encodings, which allow data to be structured and explained in detail are important. With well-structured and explained data, data models can include tools to achieve interoperability.

7 General discussion on data formats and metadata

To support interoperability and common understandings of data on the web, many web data formats, models, vocabularies, ontologies, and other technologies have been introduced, not only in the traditional ICT-related industries but also in other non-ICT industries, such as energy, transportation, health, geography, etc. Consequently, more and more heterogeneous data concepts, formats, models, and ontologies from many consortia/fora and organizations are being investigated without a consensus on the future data eco-society. Therefore, interoperability remains as the urgent issue in the process of moving towards a future data-driven eco-society.

7.1 Considerations for a standardized data format

For future digital data formats, the key considerations are that they should support data to be easily searched, discovered, and parsed from big piles of data. The data should be well produced so that it can be found and used without additional expert skills, which can be a barrier for users to utilize the data and for data to be widely propagated. Descriptive data helps data to be retrieved from a large volume of data files. Management data also helps data to be used in appropriate domains by those who have proper rights. For improved IoT and smart city ecosystems, the data formats and metadata need to properly support the data. To do so, generic considerations of future data formats can be suggested, as described hereafter [b-ITU-T TP]:

Raw data format

Various data formats are tuned with their own objectives for creation, delivery, processing, storing, sharing, and distribution. Their specifications for reading or writing the raw data files should be understood differently since all the data formats have their own rules and syntax. Additionally, the corresponding protocols should be understood as well while transferring, processing, converting, sharing, and distributing the data file, which depend on hardware types of devices, networks, and storage as well as on software environments such operating systems, databases, and application platforms. Future data applications for convergence of energy, transportation and health industries as well as IoT applications will inevitably create a lot of new data formats. As a result, too many new specifications may be published to handle data formats for future convergence applications, with consequent difficulties in understanding new data specifications and the related protocols.

Accordingly, outstanding issues include how to minimize the understanding of data specifications and protocols while handling the data. The generic considerations of future raw data formats may include the following:

– Minimize the interpretation and understanding of data formats and syntax;
– Minimize conversion and translation overheads among data formats;
– Minimize the dependency of hardware types and software environments including encoding and decoding technologies.

To meet these generic considerations, the well-known data formats are recommended, which are easily understood or interpreted by both human and computing systems. This means that future data formats should be well defined without complicated specifications or additional explanation. If future data formats have similar rules and syntax to natural human language, it will be easier for people to understand new data specifications.

Descriptive data or metadata format

For searching data files or data sources, the data should be well identified by their physical or virtual locations. To find the proper or correct contents, the data sources should be described with what kinds of contents are included. In addition, the data encoding formats should be declared. To resolve these issues, the data sources should be well described and the corresponding metadata should contain the semantic information for identifying, processing, and managing the data files.

Some data files or sources may include tag or index information which is linked by metadata information and/or detected by a search machine.

Currently, there are many different metadata standards for specific purposes, specific domains or particular types of data. The metadata specifies the meaning of data sources, the data format, and representation rules. Additionally, many different metadata schemes are being developed according to applications such as e-commerce, education, science and engineering, etc. In future convergence applications, people with domain-specific or industrial-specific knowledge will need a new metadata format. Similar to the raw data format, the outstanding issues are how to minimize the metadata format without any additional interpretation. Therefore, the generic considerations of metadata formats may include the following:

– Well specified without any source of confusion and misinterpretation;
– Minimize the interpretation and understanding of metadata formats and syntax;
– Minimize the searching, sorting, classification capabilities of raw data files or data sources;
– Be flexible or safe on technology developments toward a future information and knowledge society;
– Optionally, the descriptive metadata is located inside the data file or linked to other separate forms.

The metadata specifications are closely aligned with the usage of the raw data format, especially for the level of intelligence on target applications.

Management data format

Some data may include private or sensitive information and need data security and copyright protection. To protect the data and restrict the usage, many different security and copyright protection mechanisms are widely developed and used in the current digital market. However, some mechanisms only belong to specific markets and applications. For future convergence applications, multiple security and protection technologies should be developed. Therefore, the generic considerations of management data formats may include the following:

– Minimize the data field format for management purposes both in raw data format and metadata format;
– Be convertible or interchangeable between the original data sources and encrypted data sources for management if the data and metadata information are designed to be open to the public;
– Minimize the interpretation and understanding of management formats and syntax.

7.2 Conventional metadata and their primary uses and properties

In order to empower IoT to intelligently and actively engage in smart systems, IoT devices and data need additional descriptions of not only their various aspects but also their roles within smart systems. Many approaches have targeted providing common descriptions of devices and data, and metadata has been the widely used solution to complement data and other resources with additional information. There are various types of metadata for different purposes and characteristics as described in Table 1 [b-Riley]. However, these conventional types of metadata face some shortcomings, as more autonomic systems are desired. Recent services and applications are expected to perform intelligent decision-making and actions, which require information on know-how or accumulated knowledge on data, devices, and systems. Correspondingly, the decision-making and task-performing procedures should be able to be described in machine- and human-readable ways.

Table 1 – Types, primary uses, and properties of conventional metadata [b-Riley]

<table>
<tr><th colspan="2">Metadata</th><th>Description</th><th>Primary uses</th><th>Example properties</th></tr>
<tr><td colspan="2">Descriptive metadata</td><td>It includes basic information for finding or understanding a resource, such as title, author, subjects, keywords, publishers.</td><td>– Discovery
– Display
– Interoperability</td><td>– Subject
– Genre
– Publication data</td></tr>
<tr><td rowspan="3">Administrative metadata</td><td>Technical</td><td rowspan="3">It includes information to help manage the data resource. It provides information about not only how the data can be opened, read, used, etc. but also how it should be managed for future use and rights of the data.</td><td>– Interoperability
– Digital object management
– Preservation</td><td>– File type, size
– Creation date/time
– Compression scheme</td></tr>
<tr><td>Preservation</td><td>– Interoperability
– Digital object management
– Preservation</td><td>– Checksum
– Preservation event</td></tr>
<tr><td>Rights</td><td>– Interoperability
– Digital object management</td><td>– Copyright status
– Licence terms
– Rights holder</td></tr>
<tr><td colspan="2">Structural metadata</td><td>It includes information on how the components of an object are organized or structured and describes the relationships of parts of resources to one another.</td><td>– Navigation</td><td>– Sequence
– Place in hierarchy</td></tr>
<tr><td colspan="2">Markup languages</td><td>It provides structural or semantic features within the data content by integrating metadata and flags (tags/indexes).</td><td>– Navigation
– Interoperability</td><td>– Paragraph
– Heading
– List</td></tr>
</table>

7.3 Web of things and IoT interoperability

Due to the wide-varying nature of IoT, the data is currently overwhelming in not only its volume but also its diversity. Generated from heterogeneous sources, data is collected, stored, processed, transported, shared, and used across different platforms and application domains. Therefore, it is difficult to achieve interoperability, and efforts to homogenize the data ecosystem and empower semantic linkages are needed.

Through the concepts of web of things (WoT) and semantic web of things (SWoT), enhanced interoperability in IoT ecosystems can be attained on the web, which is an information space consisting of data resources. The web has been developed for data semantics in order to embrace heterogeneous data, platforms, and application domains. Accordingly, the web provides technologies that support the interoperability of IoT. WoT is based on the idea that connected devices are accessible via the web to enable interoperability across heterogeneous IoT platforms and application domains [b-Raggett], [b-Kajimoto]. Furthermore, SWoT brings semantic Web and WoT together to associate semantically annotated information to web-enabled IoT [b-Kamilaris], [b-Scioscia].

To achieve semantic annotation and linkage of data, many WoT approaches have targeted providing common descriptions of IoT devices and data. However, today's advanced IoT and smart city systems and services require intelligent decision-making and task performance, which involve bidirectional interactions of sensing and actuating. In order to empower IoT devices to intelligently and actively engage in smart systems, devices and data need additional descriptions of not only their various aspects but also their roles within smart systems, specifically in the areas of decision-making and performing of tasks.

Therefore, there is a need for methods to provide common understandings and descriptions of logic and workflows of aggregated devices in smart systems. Self-management and autonomic capabilities are considered to be the driver in the development of solutions to the scalability and heterogeneity problems of IoT [b-Miorandi]. Merely providing the descriptions of properties, relations, and functionalities of devices and data is not enough for intelligent smart systems and services. Accordingly, common understandings of not only data and devices but also cooperative decision logic and action workflows need to be established for automation and interoperability. Consequently, approaches to achieve interoperability in processes are emerging, and a new category of metadata also needs to be specified to cope with them.

8 Basic concepts and types of data model

Data models play a critical role in data, application, system, and business across different industries as they provide the definition and format of data to support data, computer systems, and related businesses. Currently, the needs and importance of managing metadata is recognised for efficiently handling a massive amount of data in various industries, and data models are used as one of the most prevailing metadata management tools or sources [b-Dataversity 1], [b-Dataversity 2].

The necessity of data migration and integration between existing data models in a perspective of interoperability by shifting the current application-dedicated approach to a data-driven approach is shown Figure 1. If the same data models are used for data storage and access, then different applications can easily share data. Figure 2 describes the benefits that data models deliver to data, systems, and businesses. However, systems and interfaces often cost more than they should and may constrain the business rather than support it since data models in applications and systems are arbitrarily different. This results in complex interfaces to share data between the applications and the systems, which can account for between 25-70% of the cost of current systems [b-EPISTLE].

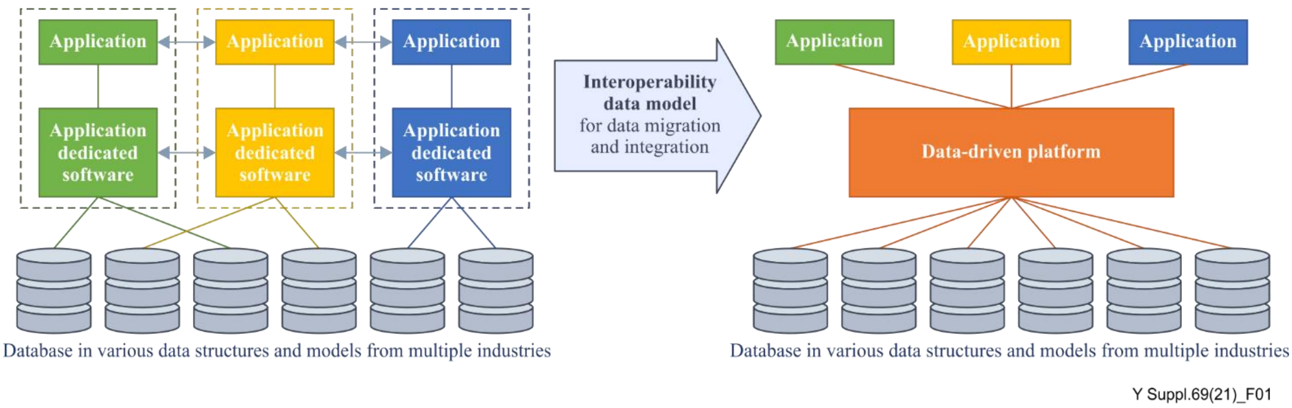

Figure 1 – Data-driven approach for interoperability data models

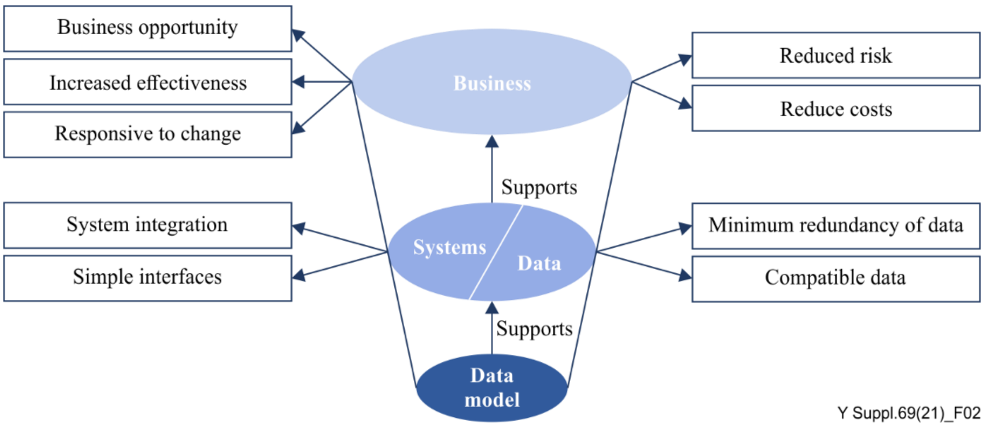

Figure 2 – The benefits that data models deliver [b-EPISTLE]

8.1 Types of data model

In 1975 ANSI described data models in three levels of data-model instance: conceptual, logical, and physical. A conceptual data model is an underlying model that describes the semantics of a domain; a logical data model adds details to the conceptual model to describe the semantics; and a physical data model represents the way in which data is physically stored [b-ANSI]. Table 2, Figure 3 and Figure 4 describe the data modelling today and the features of three-level data models.

Table 2 – Features of three levels of data modelling [b-DataWarehouse]

Feature	Conceptual	Logical	Physical
Entity names	✓	✓	
Entity relationships	✓	✓	
Attributes		✓	
Primary keys		✓	✓
Foreign keys		✓	✓
Table names			✓
Column names			✓
Column data types			✓

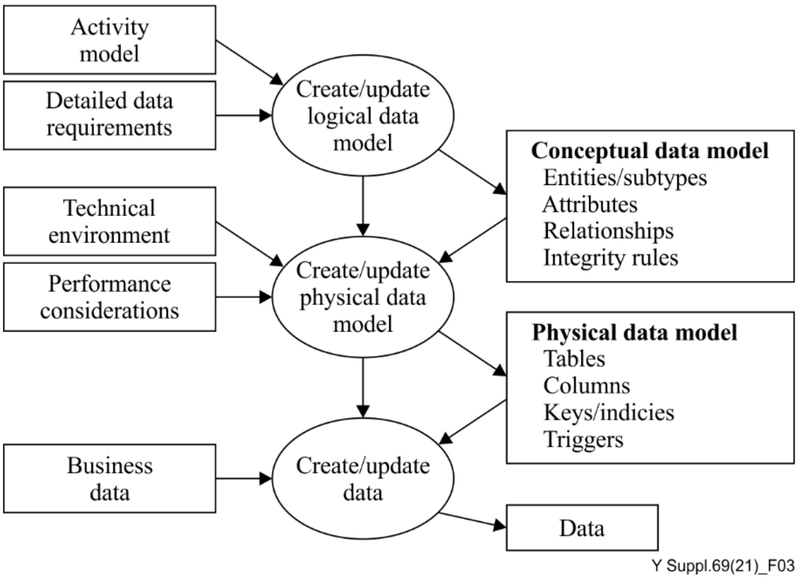

Figure 3 – Data modelling [b-EPISTLE]

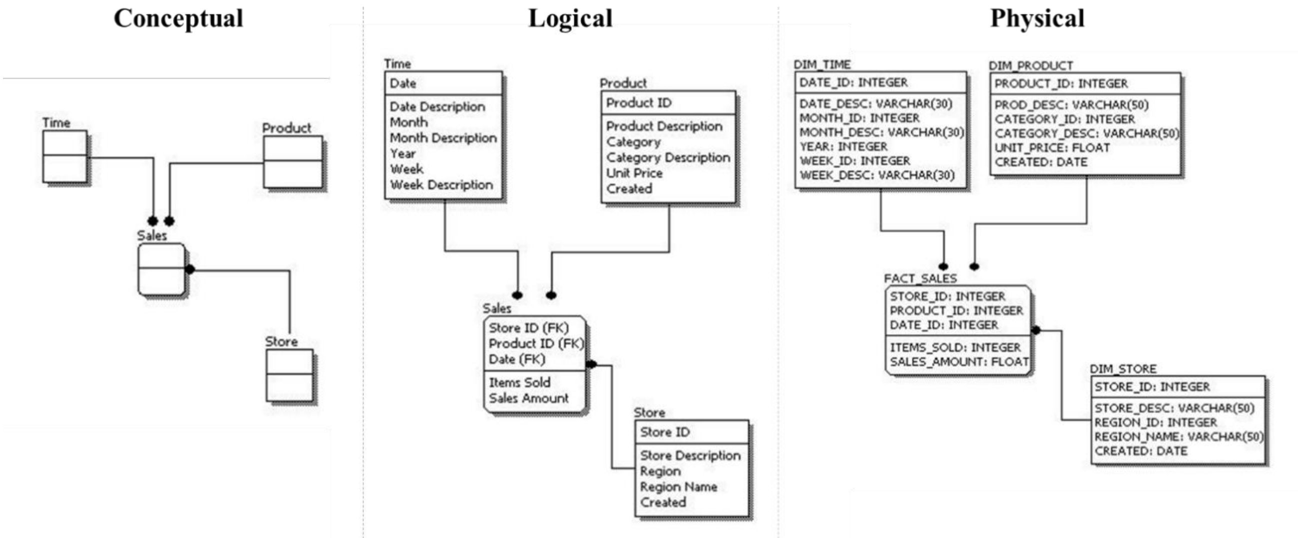

Figure 4 – Example of three levels of data model [b-DataWarehouse]

As the ICT and intelligence era has emerged, how the data can be semantically described in its domain has been continuously evolved in conceptual and logical data modelling. Moreover, as the IoT era also arrived, more than ever before a tremendous amount of data is being generated from different fields. Accordingly, the physical data model, how the data is stored in a database and how the database is structured to efficiently embrace the data, have entered upon a new phase of the study.

8.2 Common data structures

Data structure is a way in which data is stored, so that the data can be used efficiently. As the data structure is fixed as stored, the initial processing to format the data in appropriate structures for future use at the time of collection or generation is important. Many data structures have been suggested, but common data structures are described below, and their visual representations are shown in Figure 5:

– **Array**: It systematically arranges similar objects to store values, often in rows and columns.

– **Hash table**: It implements an associative array abstract data type and maps keys to values by indexing.

– **Linked list**: It consists of a group of nodes representing a sequence. The sequence is a linear collection of data elements each of which points to the next.

– **Stack**: It is an abstract data type that serves as a collection of elements with two principal operations, push to add an element on the top of the collection and pop to remove the top element of the collection.

A database model is how a database is structured and used. Database models are designed to suit specific requirements or purposes of applications and are closely related to data query, algorithm, and other processing and management techniques. Accordingly, database models play the key role in data processing and management along with data models. Many database models have been suggested, but common ones are listed below, and their visual representations are shown in Figure 6:

– **Flat**: It consists of two-dimensional array of data elements organised in relationships.

– **Star**: It consists of a few fact tables and referenced dimension tables.

– **Hierarchical**: It forms a tree structure. Similar to a network model, but the hierarchical model does not allow an arbitrary graph.

– **Network**: It organises data with records and sets. Records contain fields and sets define one-to-many relationships between the records.

– **Relational**: It is based on the first-order predicate and describes a database as a collection of predicates over a set of predicate variables.

– **Object-relational**: As a middle ground between relational databases and object-oriented databases, it is similar to a relational model, but directly supports objects, classes, and inheritance.

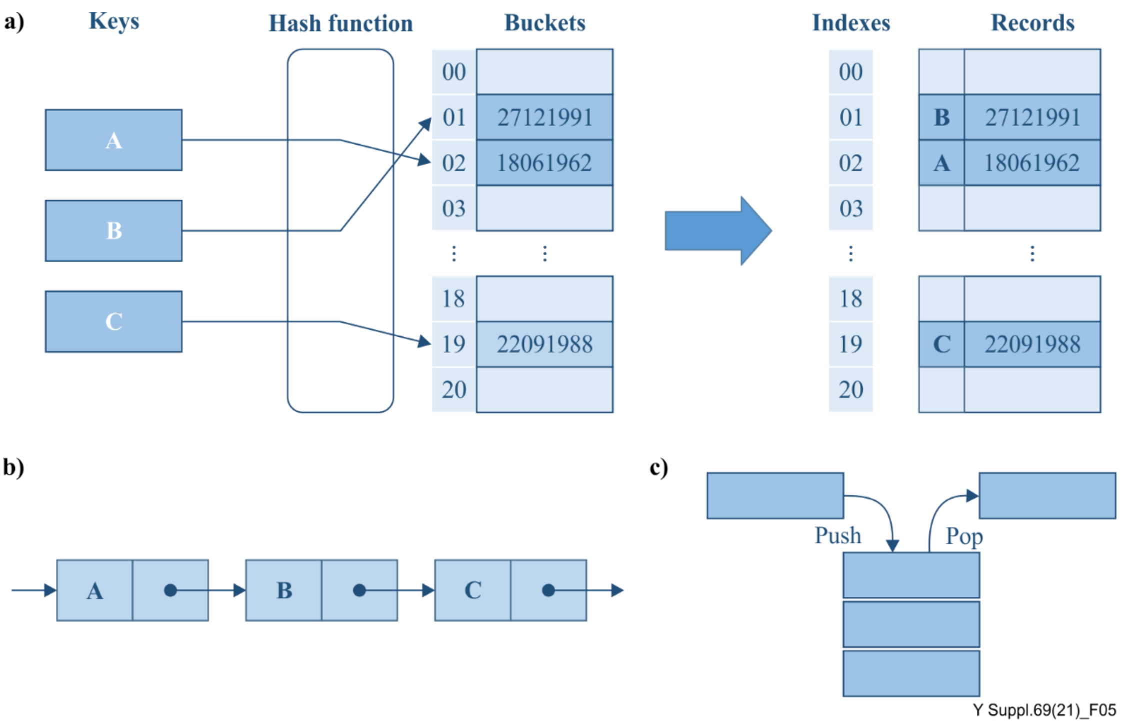

Figure 5 – Visual representation of the common data structure; a) Hash table, b) Linked list, c) Stack

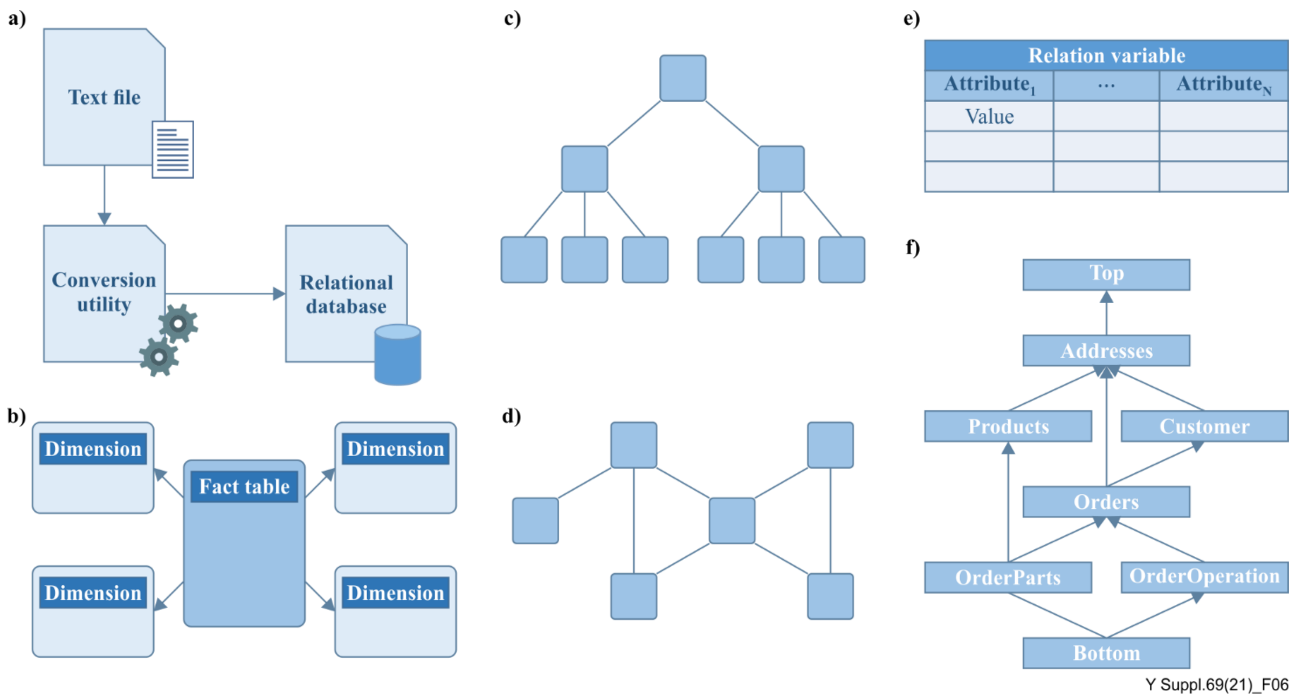

Figure 6 – Visual representation of the common database models; a) Flat, b) Star, c) Hierarchical, d) Network, e) Relational, f) Concept-oriented

Data models, data structures, and database models are closely related to the data types, which also depend on applications. For instance, in the telecommunication and broadcast industry, encrypted digital data are delivered and recorded; in location-related industry, not only global positioning system (GPS) but also two-dimensional and three-dimensional geographic data are handled along with data from transportation, agriculture, and many other fields; Internet and the web embrace most kinds of existing data including file, image, video, documents, etc. Depending on what types of data are being handled, data models and structures have been evolved in application-dedicated directions to suit the service requirements. Therefore, there are holes in the data ecosystem that disconnect data industries.

However, the integration and migration of data between different industries and fields are crucial to create added value to the data, especially in IoT and smart city where all kinds of data are needed together to operate. Moreover, bridging the holes between different industries is an inevitable issue to be solved in order to support businesses well with reduced unnecessary interface costs, which are caused by arbitrarily different data models in applications and systems. However, at this moment in time, there is as yet no solid solution or approach to resolve this issue with consensus, or how to support interoperability between data from different industries in which the environment is the issue that remains for the emerging IoT and smart city era.

9 Microdata formats for web data management

The web was initially developed for data exchanges and focused on rendering and visualizing data in hierarchical structures. Hypertext markup language (HTML), cascading style sheets (CSS), and JavaScript together are the triad cornerstone technologies for the web, and they are used by most web pages for user interfaces of many web and mobile applications to create visually engaging environments. However, how the data is related and structured has evolved and become complicated, and the need has risen for more complicated and advanced methods to manage data. As the root of the web, HTML was designed for visual representation of data with hierarchical structures. CSS facilitates the separation of the style from the content to manage the visual style of documents written in markup languages. JavaScript adds dynamics and interactivity as its code is written inside and sent within HTML documents to the browser to execute certain works.

However, while these triad cornerstone technologies are still the basis of the web, they are short on ability to apprehend the meanings, properties, and hierarchies of data and to represent or visualize the structure of data in meaningful ways. They do not have enough capability to precisely impart the meanings and relations of the information nor to intelligently visualize the data according to its semantic meanings. To alleviate these shortages, many approaches have been developed for representing structured data on the web.

9.1 Structured data

The structured form refers to the structured data with a high level of organization. The structuring process of linked data saves time, reduces errors, and improves data integrity. Well-structured data and markups with link information provide better understanding of data without ambiguity. Unstructured data hinders visualization, semantics, context-awareness, and intelligent decision making based on contents. Therefore, in advance of data analytics, classification, annotation, searching, and other data processing, the data needs to be organised well in structured forms to improve processing performance and utilization. HTML was initially designed to describe presentation for organization and display of the elements on web browsers rather than to semantically link or utilize the data on the web. Hence, HTML focuses on content visual representation and often encounters limitations to semantically define structures in order to attach properties and relations of data minutely and precisely. According to the HTML structure, elements are assigned only in a hierarchical manner: headings, paragraphs, images, etc.; therefore, it is inadequate to minutely or precisely describe the information and intelligently render the contents according to their semantic meanings. However, when the data on web pages are organised well in structured forms, the meanings of each element become explicit and suitable to be linked as described Figure 7.

To support structured data on the web, many approaches have been developed, such as the XML markup and resource description framework (RDF) metadata data model. Beyond simply linking resources with hyperlinks, these approaches enable data to be organised in structured forms and attach semantics to the web by coupling structured data with their properties and linking resources with their relations. However, they alone are as yet insufficient to fully complement the limitations of HTML to represent and describe data minutely and precisely in a unit that is small enough for machines and programs to easily parse and extract information from the resources.

These approaches focus more on how to semantically link resources rather than how to fragment bulk data into small sizes in advance of defining relations and imparting semantics to ease the processes. Therefore, the resulting syntax and data model are more likely to generalize or summarize the overall contents of the resources, not to distinguish specific information from data chunks in details to minutely attach meanings for each different part of the content. On the other hand, while organizing data in well-structured form, microdata formats break down block of data into small pieces as shown in Figure 8 to enable data items to be managed in small data units; hence, they have apparent advantages in semantically and intelligently processing, managing, and visualizing data according to meanings and relevant annotations nested in a simple way to lower the barriers for new data formats.

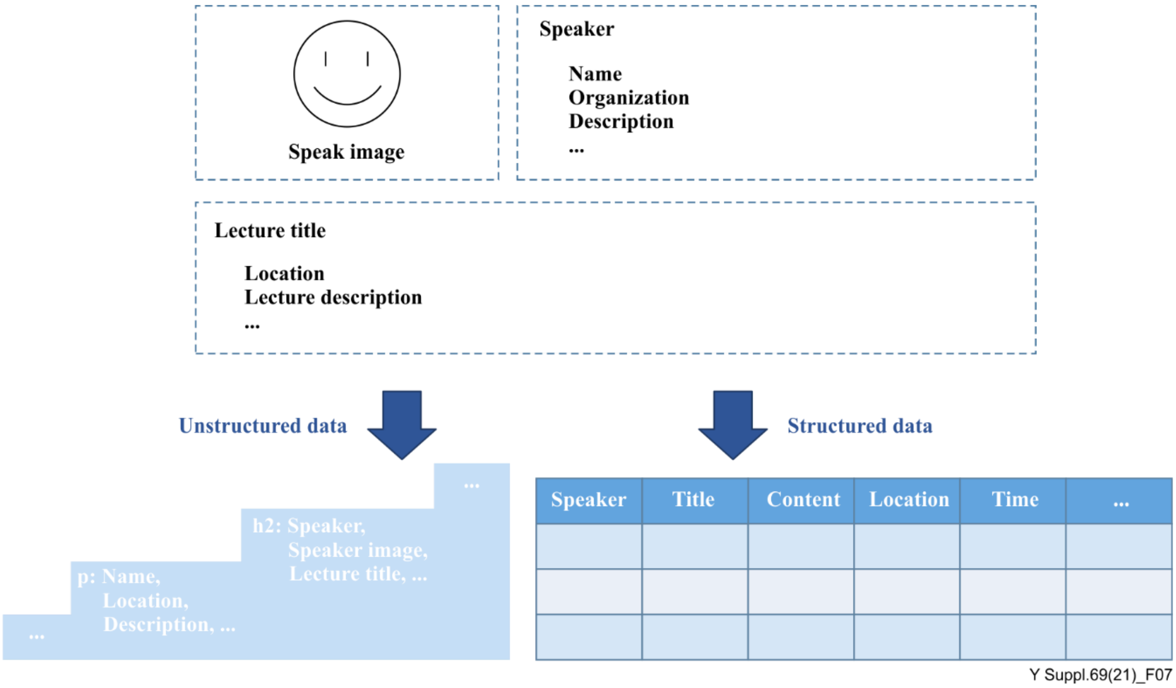

Figure 7 – Hierarchical unstructured data and structured data

HTML:

```
<h2> Speaker Image </h2>
<img src = "SpeakerImage.jpeg">




<div>

  <h2>
    Speaker
  </h2>
  <p>
    Name
    Organization
    Description
  </p>



  <h2>
    Lecture Title
  </h2>
  <p>
    Location
    Lecture description
  </p>

</div>
```

Microdata:

```
<span itemscope> <meta itemprop = "name" content = "Speaker Image"> </span>
<figure>
  <img src = "SpeakerImage.jpeg">
  <figcaption> Speaker Image </figcaption>
</figure>

<div itemscope itemtype="http://schema.org/Event">

  <h2 itemprop="performer">
    Speaker
  </h2>
  <div itemscope itemtype="http://schema.org/Person">
    <p>
      <span itemprop = "name"> Name </span>
      <span itemprop = "membeOf"> Organization </span>
      <span itemprop = "description"> Description </span>
    </p>
  </div>

  <h2 itemprop="name">
    Lecture Title
  </h2>
  <p>
    <span itemprop = "location"> Location </span>
    <span itemprop = "description"> Lecture description </span>
  </p>

</div>
```

Figure 8 – Comparison between HTML and microdata

9.2 Microdata format

Microdata formats, or structured data markups, describe and embed meanings of resources on the web along with their properties and relationships. These microdata formats utilize HTML or XML tags to convey additional metadata and other attributes in web pages so that data items can be managed in small data units. Microdata formats break down paragraph or blockquote data into small pieces in structured forms, so that the contents can be more parseable and the programs can more easily extract information from it. As described in Figure 9, when the data in a resource coalesces in an unstructured form, the metadata meets the limitations to represent the content information in details; however, when structured and annotated with microdata formats, the contents can be described in a much more detailed manner and the meanings of the data become more apprehensible for enhanced data processing and management.

Imparting more semantic meanings to content and data, microdata formats provide elaborate means to express the contents of web pages and help machines and programs understand the detailed meanings of the web contents. Now, microdata formats are widely used and are recommended to be used for resource locating and retrieval and for microservices as suites of small services on the web. Microservices is an approach to design for a software architecture that builds a large complex application from small independently deployable components [b-Fowler]. For data locating and retrieval, the data needs to be extracted and its meanings should be understood by machines and programs with given metadata. Therefore, more precise metadata provided by microdata formats facilitates resource locating and retrieval on the web. Moreover, microdata formats not only help to quickly and accurately locate the resources but also raise the opportunity for the resource usability when the contents of the resources are structured and described well enough. As shown in Figure 10, when the content of a resource is segmented into small pieces and the microdata-formatted metadata explicitly describes meaning and information of each data piece in minute details, the appropriate resources can be effectively retrieved by utilizing the given metadata, and the resources gain higher chances of being found and used. On the other hand, with metadata whose descriptions generalize the overall paragraph or blockquote data, the resource is barely searchable or retrievable even though the resource has exactly identical content.

Moreover, in microservices, for which the approach is to develop a single application as a suite of small services, microdata formats are used to assemble the small services together. Each small service runs individually and communicates with a lightweight mechanism; therefore, these services are independently deployable as a plug and play approach. Compared to monolithic services for which the application is built as a single unit, microservices have advantages in managing, updating, and scaling services with fewer overheads. With microdata formats, detailed information on each service, such as purpose, performance, characteristics, etc., can be well described, and thus well integrated and visualized as a single application with high interoperability, accessibility, and readability.

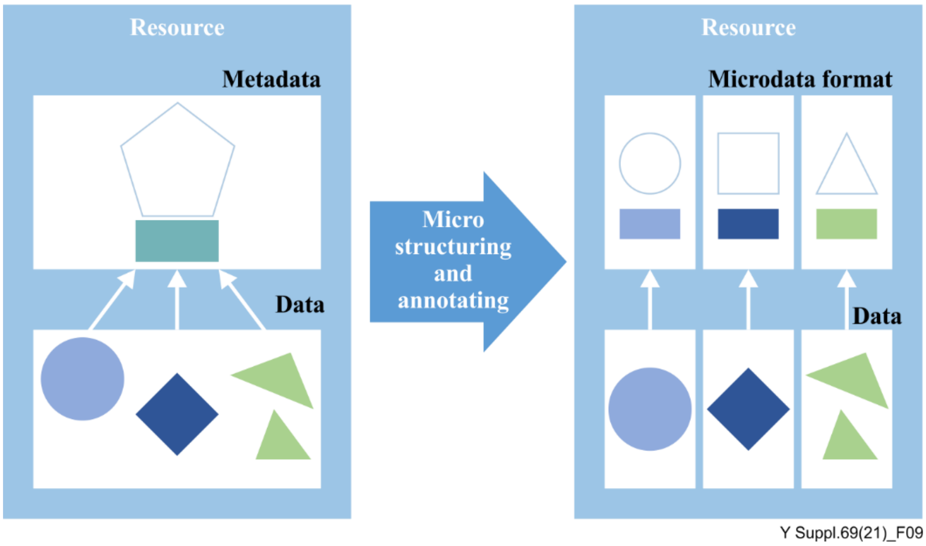

Figure 9 – Structuring and micro-annotating a resource with microdata format

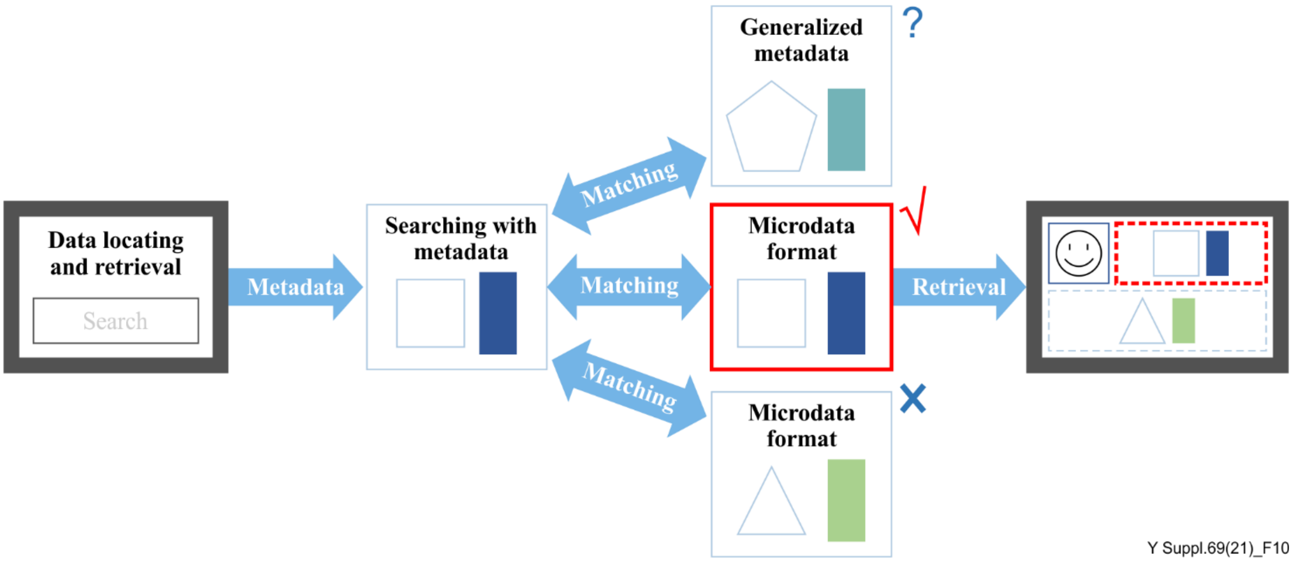

Figure 10 – Use of microdata format in search engine data retrieval

9.3 Leading microdata formats

To structure and markup data in small pieces on the Web, several microdata format approaches have been introduced over the years, and currently a couple of them are settled and pervasively used: microdata, RDFa, and JavaScript object notation linked data (JSON-LD). Among them, microdata suits the emerging Web environment as the simplicity and the richness are well balanced. The characteristics of each format are described in Table 3 [b-Google].

Microdata minutely attaches nested value pairs to documents along with the original contents and allows semantic and intelligent processing of information intended for end-users such as contact information, geographic coordinates, calendar events, etc. Moreover, it facilitates the encoding and extraction of detailed data, which improves data query, retrieval, reusability, etc.

Maintaining the traditional RDF expressions, RDFa is one of the earliest models of microdata formats and is considered to be the most comprehensive, rich standard. However, the complexity of RDFa is considered to be too much for the web. As schema.org was launched in 2011, which provides vocabularies for structured data, microdata has since developed [b-Wetherill].

On the other hand, JSON-LD recently emerged as a simpler and more lightweight linked data format. It facilitates JSON data to interoperate on the web and separates the presentation layer from contents so that it allows blocks of code that can be injected easily. Since JSON-LD directly provides the separate metadata blocks, it does not require a parser to try to use the contents to uncover and extract meanings of data like RDFa and Microdata, which use attributes of HTML tags to express data.

Table 3 – Microdata formats and descriptions [b-Google]

Microdata format	Descriptions
Microdata	Microdata is a nested structured data within HTML content. It uses HTML tag attributes to name the properties of the structured data.
RDFa	RDFa is an HTML5 extension that uses HTML tag attributes that correspond to the user-visible contents to support linked data.
JSON-LD	JSON-LD is a JavaScript notation separate from the HTML body. The markup can be detached from the user-visible text and dynamically injected into the contents.

However, ambivalently JSON-LD's detachment of the metadata from contents can lead to some overheads and problems in validating, locating, and visualizing the data on web browsers.

Uncoupling the metadata from the content impedes data and metadata validation and can lead to inconstancy between what the data truly is and what metadata describes it as. Moreover, the process to automatically uncouple the metadata from the contents is straightforward, but the inverse process is not. When the nested metadata get uncoupled, some detail information on the location of particular data inside the content can be lost, and it is difficult to restore the loss in coupling them back together as described in Figure 11.

Therefore, JSON-LD has an advantage in data transferring and exchanging because of its lightweight format, but it results in higher overheads to locate the particular data residing in contents and to render or visualize the data on web browsers. In other words, JSON-LD facilitates resource searching in a big database, but Microdata is more suitable to parse data residing in the searched resources in order to visualize or make a use of the data for services on the web.

As the leading microdata formats, Microdata, RDFa, and JSON-LD are widely used and recommended to optimize the web environment. These microdata formats convey additional metadata and other attributes in web pages, and they enable data items to be indexed, searched, stored, or cross-referenced in small data units so that the detail data can be minutely utilized. Microdata, RDFa, and JSON-LD have each different advantages and strengths over the others in a view of the trade-offs of structured data format requirements described in Figure 12.

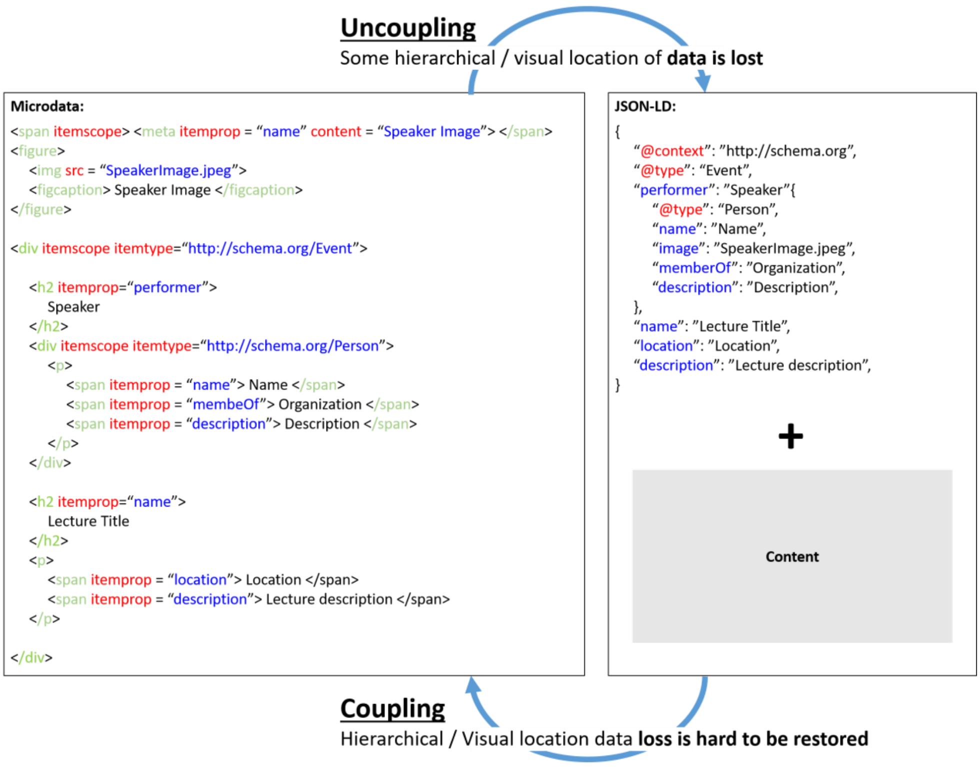

Figure 11 – Uncoupling and coupling data and metadata

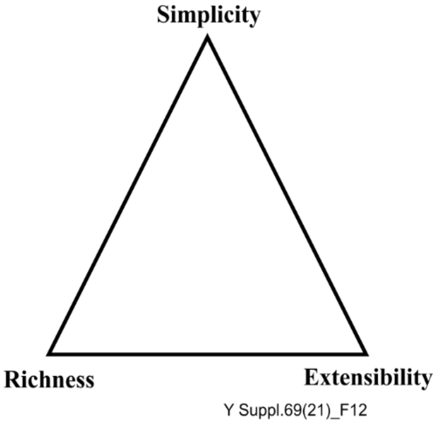

Figure 12 – Trade-offs of structured data format requirements

10 Procedural metadata for semantic web of things

In WoT, devices and data should be properly managed and engaged by relations and procedures. Utilizing microdata formats, the devices and data can be well-defined to be granularly managed, but the data models and ontologies with conventional metadata have shortcomings to convey common descriptions on procedures among data elements, devices, and systems. Accordingly, a new metadata category needs to be introduced, so-called procedural metadata [b-ITU journal]. The goal of procedural metadata is to provide the common descriptions on composable procedures of not only individual devices but also smart systems as a whole based on existing data models and ontologies. A general description, primary uses, and example properties of procedural metadata are provided in Table 4. With procedural metadata, a device or a system can make decisions and perform tasks automatically by cooperating with heterogeneous devices and systems. Since procedural metadata helps different types of data, devices, and systems to collaborate as long as they support micro- formatted metatag structures, it facilitates a high-level of interoperability in WoT. All emerging approaches that share the same concept of procedural metadata and meet the principles can be categorized as procedural metadata.

Table 4 – Description, primary uses, and properties of procedural metadata

Metadata	Description	Primary uses	Example properties
Procedural metadata	It includes information for common descriptions on procedures and/or processes by utilizing metadata and flags (tags/indexes).	– Navigation – Interoperability – Procedure automation	– Function – Algorithm – Work instruction – Work flow

10.1 Concept of procedural metadata

Smart systems indicate IoT environments consisting of one or more connected devices, in which applicable data models and ontologies are not restricted to one type of solution. It is assumed that the common descriptions on the data and device level are accomplished based on other previous and ongoing works. Instead, the concept of procedural metadata aims at a higher level of interoperability, with common descriptions on procedures. The procedure in procedural metadata refers to a specified way to carry out an activity or a process, which is a set of interrelated or interacting activities that use inputs to deliver an intended output [b-ISO 9000]. In the context of IoT, the activity can be seen as not only simply processing data to compute and estimate values for properties and defining their relationships but also making decisions and performing tasks based upon them. Heterogeneous types of data, devices, and systems can engage interoperable information and support automation by composing a set of procedures described in granular components of data, devices, and systems.

As a category of metadata, procedural metadata refers to the additional data that describes composable logic, functions, and workflows among data, devices, and systems. With the descriptions, the IoT data, devices and systems can interoperate and automatically engage together to make decisions and perform tasks. To empower semantics, WoT data is often micro-formatted and structured in parsable forms so that the data can be expressed and managed with their relationships and properties in granular scales. The procedural metadata utilizes the microdata and provides the composable knowledge to make decisions and perform tasks by expressing the procedural relations among data elements, devices, and systems in granular scales. Consequently, procedural metadata facilitates data, devices, and systems to be fully or partially composed efficiently. As described in Figure 13, a set of procedural metadata can be composed as a part of data, devices, and systems for complex decision-making and performing tasks. These procedures are not necessarily defined for specific environments, applications, services, systems, devices and data, but they rather can be designed to be generally applied in diverse situations for various data from multiple domains. Emerging approaches that share the same concept, such as process description with sensor model language (SensorML) or context information with NGSI with linked data (NGSI-LD) and cross-cutting context information management (C3IM), can be considered to fit in the procedural metadata category.

Procedural metadata can be internally and externally managed as a part of the data itself or as accompanying data. As described in the Figure 14, the procedural metadata can be directly attached to the devices and data published by the devices, or it can be retrieved from an external source as needed. Another example in Figure 15 shows how a set of procedural metadata can be integrated with a different approach, W3C's thing description (TD). W3C provides the semantic metadata and functional description of devices in events, properties, and actions [b-Charpenay], [b-Kaebisch]. In this example, procedural metadata can be externally stored and managed in a repository like TD, and the procedural metadata can be utilized on proper platforms and APIs.

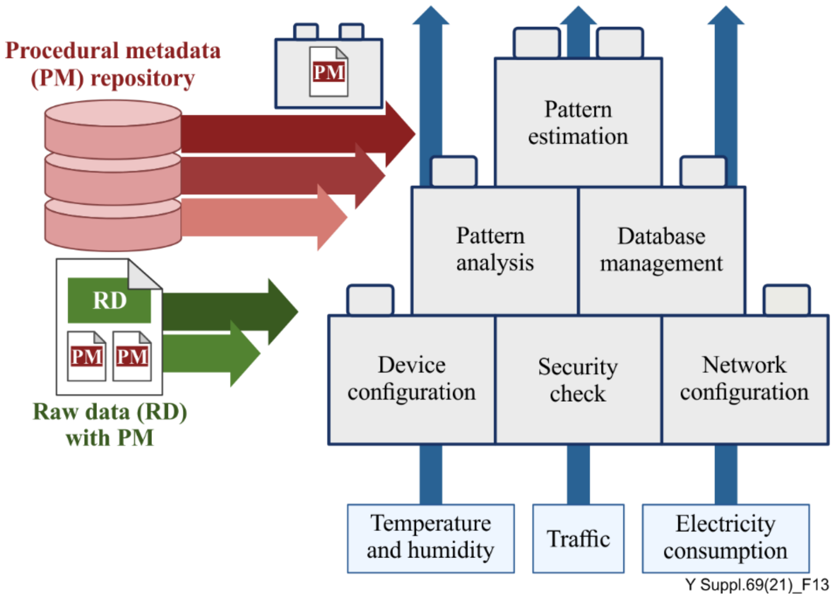

Figure 13 – Example of procedural metadata composing [b-ITU journal]

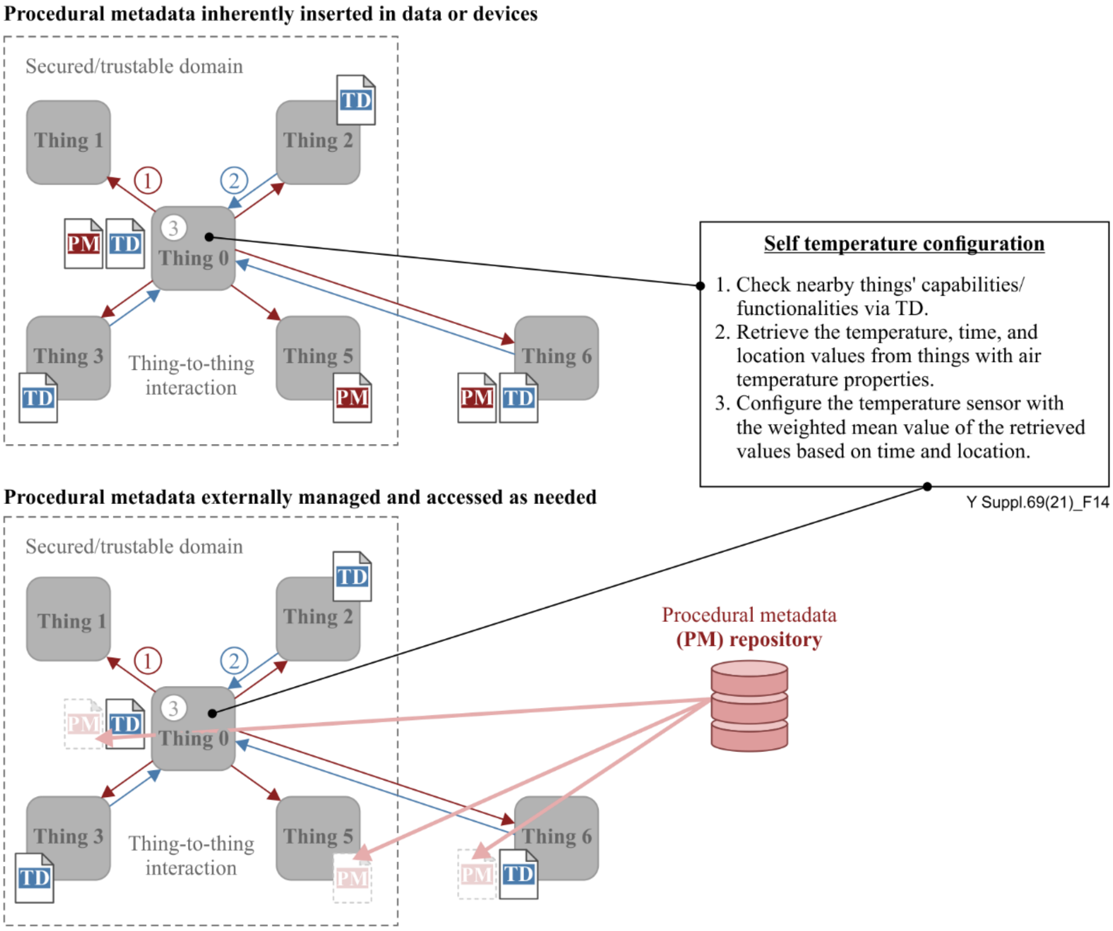

Figure 14 – Example of procedural metadata embedment [b-ITU journal]

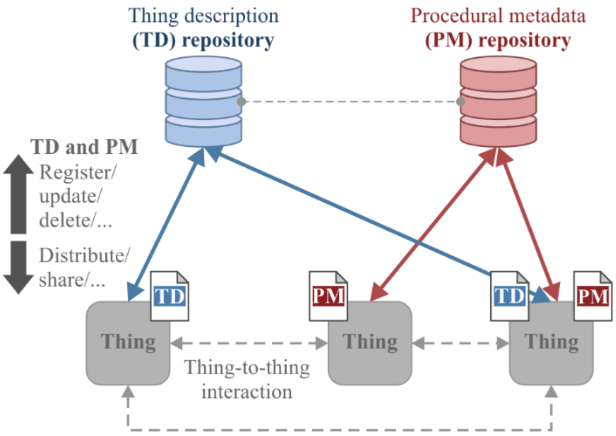

Figure 15 – Applying procedural metadata in W3C's TD concept [b-ITU journal]

To achieve process automation and data interoperability of a process and a system across domains, enhanced IoT applications and services have been studied and developed. SensorML aims to provide semantically-tied means of defining process and processing components associated with the measurement and post-measurement transformation of observations [b-OGC]. SensorML defines a process that takes one or more inputs, to generate one or more outputs based on a set of parameters and a methodology. In the perspective of SensorML, a process is the same concept for a procedure in procedural metadata since it considers that a process can be a single atomic operation, or an explicitly defined network of operations. In SensorML, components are modelled as a process, which can be divided into two types: physical and computational operations. The physical processes are those for which information regarding their positions may be relevant, such as detectors, actuators, and sensor systems. The computational processes are those which can be treated as mathematical operations or functions. They both receive input and generated output, which may be digital numbers or physical stimuli, based on configurable parameters and methodologies. With a process defined in SensorML, the automation of the processes for IoT devices, systems and services are achievable.

The NGSI-LD and C3IM concepts enable linking of disparate but related information across various domains. Context information is defined as informational representation of a set of entities with which an entity has defined relationships, together with the categories and properties of these entities, their relationships and their properties [b-ETSI CIM UC]. Through accessing, gathering and merging a set of context information from multiple domains, IoT systems, applications, and services can be enhanced with cross-domain data utilization and process automation. For example, in a smart street-light use case provided by ETSI in [b-ETSI CIM UC], weather monitoring, lighting-management, traffic management and street-monitoring systems can be engaged together through a context information compliant platform. Integrating the context information offered from various systems, more enhanced and diverse street-light services can be developed.

In these approaches, the defined process, context information, procedure, or whatever it is called in each approach can solely stand alone or be sequentially linked with one another to represent both simple and complex processes of functions, applications, services, and systems. This concept of interoperability and composability in procedures, processes or contexts is the intersection of SensorML, NGSI-LD, and procedural metadata. However, procedural metadata presents a slightly different approach as it aims to achieve the interoperability in a process itself, not specifically limited to a certain domain, device, property or attribute. This means that a single defined procedural metadata could be applied to multiple systems, devices and properties without requiring any modification.

10.2 Principle of procedural metadata

In order to not only support interoperability but also manage procedural metadata efficiently and accessibly, there should be basic principles in generation, organization, and utilization of procedural metadata. Some underlying principles of procedural metadata are provided below. The data that provide additional information on procedure and compliance with these principles can be considered to be procedural metadata.

– Procedural metadata is not a mandatory part of data, devices, and systems, but it is optional.
– Procedural metadata should not affect data's original formats, models, vocabularies, ontologies, etc.
– The inputs and outputs of each procedural metadata should be clarified so that a set of procedural metadata can be composed through output-input connections.
– The inputs and outputs of procedural metadata need to be a set of IoT resources or data and a sort of action needed to be taken, including actuating, sensing, data managing, etc.
– As an executable script-type data, procedural metadata needs to be described based on sets of conditions and actions of IoT resources, vocabularies, relationships, and controls both when it is managed internally and externally.
– If inserted in data internally, procedural metadata needs to be marked with proper tags so that it is efficiently searchable and parsable.
– Internal embedment in data or a device is recommended when the procedure is specific to a certain data, device, system, or application domain.
– For generic usage, it is recommended to manage procedural metadata externally and in universal vocabularies.
– For the procedural metadata externally managed in a repository, the modification made after the first creation and its version should be specified.

– The maintenance policies should be articulated, especially the manner in which access, change, usage, etc., of the procedural metadata are allowed.

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