Information System Aspects and the Ontology of Hypermedia Systems

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Summary. The emergence of Web technologies has made widespread the use of hypermedia systems as the underlying support for Information Systems in organizations. Hypermedia elements and their associated functionality in this context become organizational assets that are created, improved and delivered to users in an attempt to increase the overall value of the system. Semantic Web approaches to Information Systems focus on providing computational semantics to resources by means of shared meanings encoded as part of formal ontologies. These meanings are intended to enable the automation and delegation of tasks to software agents. This chapter addresses the ontological representation of hypermedia structures and their connection to the main aspects of Information Systems. Concretely, the integration of hypermedia concepts in a Knowledge Management context is described, and the role of adaptiveness is characterized as a function driven by organizational value inside such framework. The resulting ontological framework provides ground for the development of ontology-based Information Systems in which hypermedia assets are managed.

Key words: Hypermedia, Information Systems, Ontology, Semantic Web, Adaptive Hypermedia, Knowledge Management

1 Introduction

Hypermedia systems have become a part of everyday's work and life with the widespread adoption of the *World-Wide-Web*. Nonetheless, the Web as a distributed system is actually a concrete realization of the earlier concept of "hypermedia system" that traces back to the seminal writings of Bush [4]. As a result of the evolution and growth of the Web, hypermedia systems engineering — and specially Web engineering — has flourished as a discipline encompassing specific techniques, tools and methods. Montero et el. provide a review of outstanding methods in [19]. Since early hypermedia models can be considered as more general and richer in terms of possibilities than the

Web itself [21], the use of generic hypermedia models in research provides the benefit of a higher level of abstraction. Such abstraction covers both the elements of the current Web and prospective extensions like XLink or similar recommendations oriented to extending the representational constructs of the Web.

There is a large degree of overlapping between existing hypermedia meta–models[1], even though a lack of consensus on the precise definition of basic concepts like *node* or *content*, and the degree of granularity of the entities that can be represented with these models, still persists. Abstract models like Labyrinth [6] have been proposed as a framework covering existing ones, thus providing a common core of modeling constructs that can be used as a foundation for more concrete models, either technology–specific or domain–oriented. However, specific uses of hypermedia technologies still require further conceptualization efforts to come up with a general–purpose framework that could be used for interoperability and conceptual coherence between systems. A concrete case of such specialized use is that of Information Systems, understood as systems that serve an organizational purpose [8]. Such consideration introduces the dimension of organizational structure and role, and entails that hypermedia information resources and their specific usage have an associated value [5] that is contingent to the context and situation of the organization in which they are being created, updated or handled. Consequently, shared representations of Information Systems that use some sort of hypermedia technology as the information management and delivery paradigm should integrate organizational aspects with both core hypermedia concepts and specialized hypermedia assets. Particularly, learning objects [22] can be considered as hypermedia nodes that are used as resources in learning activities of any kind. Provided that the concept of value in Information Systems is closely connected with the concept of organizational learning and behavior [20], learning objects and the "learning designs" in which they participate deserve an special attention. As a matter of fact, the consideration of such kind of user interface and temporal and process aspects is actually considered in current approaches to Information Systems [11].

Formal ontologies [1] are a vehicle for the representation of shared conceptualizations. Ontologies based on description logics [10] or related formalisms provide the added benefit of enabling certain kinds of reasoning over the terms, relations and axioms that describe the domain, and broader notions of semantics could be used to extend the formal semantics for specific purposes [25]. Hypermedia information systems equipped with an ontology of hypermedia — at design and execution time — could then be viewed as a concrete class of ontology-driven information systems [11] supporting both their user interface and its functionality and also the connection to the organizational aspects that give a teleological dynamic to resource management. A pragmatical be-

[1] The term meta–model is introduced here to differentiate models of concrete hypermedia applications from the modeling frameworks used to produce it.

nefit derived from the use of formal ontologies is that it is accompanied by a growing body of Semantic Web [2] tools, techniques and knowledge.

In this chapter, the integration of technical hypermedia concepts in the framework of organizational Information System is described. To do so, a hypermedia core ontology is first identified, and then it is put in connection with the concepts of individual and organizational knowledge. This in turn entails that the tailoring of the hypermedia structure should be driven by organizational value. The use of current description–logics languages like OWL [9] in this conceptual framework enables a seamless integration of comprehensive organizational contexts with information resources. The ontology here described may be extended, updated or changed, since its purpose is that of serving as the basis for further research and technical developments.

The methodological approach for the development of the ontology uses some ideas in the Helix–Spindle model [17] and tailors them to the specifics of this case in two aspects. On one hand, the core elements of the hypermedia ontology are derived from the existing Labyrinth model, in a sort of literature–based process [26]. The rationale for it is that Labyrinth was actually the result of a process of bringing together elements that were found fragmentary in precedent models, and thus it can be considered as a shared conceptualization in itself. On the other hand, the specific aspects of Information Systems value are based on the recent ontology of Knowledge Management (KM) described by Holsapple and Joshi [14], in which learning and information assets are put in the context of organizational activities. The informal and structured processes for ontology engineering were yet carried out by Holsapple and Joshi, so that the remaining work was that of formally integrating general–purpose and specific hypermedia concepts. The large and stable OpenCyc (http://www.opencyc.org/) commonsense knowledge base (an open–source version of Cyc [18]) has been used as a framework to restrict the definitions to those specific of the domain, reusing the concepts and relations in OpenCyc. For brevity, only the main ontological definitions will be discussed.

The rest of this chapter is structured as follows. Section 2 describes the core elements of the ontology of hypermedia systems, from a technical viewpoint. Then, Section 3 provides the details of its integration with main Information System aspects. Concretely, hypermedia elements are described as knowledge assets in the context of KM. Then, adaptive hypermedia objectives are re–formulated as value–driven in that context. Finally, conclusions and future research directions are described in Section 4.

2 Structural Elements of the Ontology of Hypermedia Systems

The engineering process of an ontology of hypermedia needs to explicitly cover all the concepts in existing hypermedia models. In consequence, our point of departure has been an existing (meta-)model: the Labyrinth hypermedia model [6, 7]. This model in particular was selected for its abstract nature as well as for the fact that it was crafted as an extension of the union of concepts of previous hypermedia models (see [6]). In addition, the Labyrinth hypermedia model has been recently extended to cope with imprecise information [28], which is present in any system that observes its users in search for tacit knowledge or preference elicitation [27]. For our purposes, the ontology should provide the elements to relate the hypermedia structure to issues of interest a diversity of stakeholders. At the broadest level, this focus includes the user, the design, the activities involved, and the content that is actually used and re-used [23].

From a pragmatic viewpoint, such ontology should explicitly cover all the elements of current Web technology, as well as a concrete realization of the hypermedia concept. This requires the inclusion of content models that reach the fine granularities that are currently addressed by XML-based Web languages like XPath. The conceptual intersection of general hypermedia systems and the concrete Web technology, results in an ontology enabling several levels of descriptive detail. In addition, semantic annotations about the hypermedia elements should be provided, using a flexible approach not constraining potential uses or applications. The rest of this section provides the basic definitions by using elements of the OntoClean framework proposed by Welty and Guarino [37].

2.1 Nodes, Contents, Links and Hyperdocuments

The concept of hyperdocument in Labyrinth is expressed in terms of "basic hyperdocuments" defined as tuples (1) with some elements and functions. The first seven elements in (2) are those of users (and groups of them), nodes, contents, anchors, links, attributes and events, respectively. The last four elements are functions determining, respectively, the location of contents in a node, the list of attributes, the list of events, and the access category of an element.

$$HD^B = (U, N, C, A, L, B, E, lo, al, el, ac) \tag{1}$$

Personalized hyperdocuments are considered as variants of basic hyperdocuments, but this aspect of adaptiveness will be discussed in the next section. The model of Labyrinth for that is fairly limited since it does not represent adaptive processes, but only their results.

From an ontological perspective, the definition in expression (1) does not separate the elements according to their *unity*, in the sense given in [37], since the concept of nodes, contents and anchors can be considered as a system of digital wholes, separated from the rest of the elements. This holds even for links, which can be considered independent entities that are *dependant* —but not necessarily part of— nodes and contents.

Table 1 provides an alternative ontological definition, separating the different aspects of the static hypermedia structure, and providing the analysis of relevant terms following the methodological guidelines provided by OntoClean [37]. Dynamic aspects (E, el), as described in detail in [7], are not analyzed in this chapter.

Aspect	Relevant terms	Web interpretation
Hypermedia content structure (N, C, A, lo)	Content +R+O-D, Node∼R+I+D+UM, Anchor +R+O+D	Nodes are the units of navigable contents, e.g. HTML pages or other files that are directly navigable with a browser.
Hypermedia navigational structure (L)	Link +R+O+D	Links as determined by $< A >$ or $< IMG >$ elements.
Hypermedia users (U, ac)	User +R+I, Group+R-U+O-D	not applicable
General descriptive elements (B, al)	any axiom or constraint	Descriptions in $< META >$ tags.

Nodes in Labyrinth are considered as "containers of information" of different media types. This definition is closely connected with the OpenCyc notion of `InformationBearingThing`, and even with its specialization `ComputerFileCopy` if a more restrictive view on the "storage" layer [12] of hypermedia elements is considered. Surprisingly, the notion of "content" is also defined as "a piece of information". The subtle difference lies in that nodes can be arbitrarily composed while contents are considered as atomic pieces of information with a specific type (audio, video, etc). This entails that contents can be considered as suppliers of identity conditions (+O), while nodes in such view have an identity derived from their parts (-I). Contents are also rigid and do not depend on any of the other elements.

In addition, the consideration of what is a node is somewhat conventional, since it is a unit of navigation of the hypermedia space, i.e. nodes are rendering units in the user agent (browser). Nodes are considered as rigid entities that can be the destination of a link traversal and thus depend on the existence of some content. Their identification according to their structure of parts (nodes or contents) makes them mereologically extensional (+ME), and the notion of morphology, as understood by the location of contents as part of nodes, provides them with morphological unit (+UM). It should be noted that such morphology in Labyrinth concerns both "position" and "time", giving room to the synchronization of contents that are at the essence of the multimedia concept. Since nodes that are embedded in others may not be considered as units of navigability, thus depending on the navigational structure, we have considered the concept as anti–rigid. Then the notion of Anchor determines the space of possible linking in the node–content mereology. Current Web specifications like XPointer support the definition of anchors to virtually every element of

Web content, which results in that such expressions are self–identifying (+O) and dependant on, at least, one content or node element.

The notion of Hyperdocument can be assimilated to that of Node, and specified in a purely conventional manner, thus being anti-rigid ∼R. This ontological commitment comes from the fact that the boundaries of what hypermedia "applications" or "documents" are, becomes in many cases a matter of functional convention, that heavily depend on the uses they are given in specific contexts.

Links are first–class citizens in hypermedia models, contrary to the realization of links in the Web, where they are embedded in nodes (i.e. pages) as concrete markup elements. Considering links as independent entities allows the definition of multi-directional, complex relational structures, as can be defined in XLink. In addition, links can also be used as assets in themselves, since they may embed type information [35] useful as personalized information connecting tools [29]. The description of full–fledged links can be derived from the XLink specification in terms of *locators* and *arcs* that conform graphs with edges labeled by types. Therefore, links depend on the locators they connect, i.e. through the notion of Anchor. It should be noted that a concrete user–interface related interpretation of both multi–dimensional links and link types is not currently agreed. This fact could also be represented in the hypermedia ontology as annotations to the link–describing elements themselves.

The concept of User in Labyrinth encompasses both individuals and groups of individuals. This convenience definition requires a differentiation in ontological terms, since groups as considered in hypermedia provide no unity condition with respect to their constituents. In addition, individuals are considered to carry —but not to supply— identity conditions, since the identity derived from the *Person* (+O) should be clearly differentiated from the contingent relationship of Persons to some tasks. These can be modeled by the abstract notion of *Role*, which determines specific usages of the hypermedia space. It is relevant to point out that the concept of role is used in learning activity modeling languages like IMS LD (http://www.imsglobal.org/learningdesign/) as a differentiated activity–oriented concept.

General (meta-)descriptive elements of each of the hypermedia elements were modeled in Labyrinth as attributes in the set B. However, when describing the hypermedia models as instances in an ontology, such descriptive attributes can be simply modeled by property constraints on the classes representing each element. This provides the benefit of flexibility, as well as the advantage of having available the reasoning and consistency checking tools of logic languages to act on the definitions of the hypermedia structure and description.

2.2 Semantic Annotation of Hypermedia Elements

Many existing approaches to annotating Web resources are based on extending markup elements or embedding metadata fragments in the nodes, e.g.

[13]. Other approaches make use of separate metadata files that use URIs to reference the elements described (in fact, this is the approach implicit in the IEEE LOM metadata, which provides a "Identifier" category to refer to external content).

Nevertheless, when using ontological knowledge bases to represent metadata, both approaches have the drawback of separating the representations of the resources from the element itself. This entails that hypermedia elements and their relationships are not represented as concepts and properties in the ontology, missing the opportunity of obtaining a richer level of representation. The approach described by Sicilia and Garcia [33] entails a representation of hypermedia wholes and their parts in the same ontological language as annotations, thus providing a coherent integration of both. When using Web–based ontology description languages [9], ontology instances of hypermedia elements become identified by URIs, thus coming to a flexibility in producing distributed and loosely–connected annotations for public or organizational hypermedia descriptions.

A company developing a project proposal for a given organization or client company, for example, could be interested in automating a task consisting of gathering hints about those elements in the proposal that were highly valued in previous proposals for the same or other target institutions. Provided that the different parts of previous proposals are structured as nodes and contents, links can be defined as connectors of the important parts of the documents with the target, typed as *valuedByTarget*. This knowledge could be later automatically or manually reused in similar proposals. Links that connect hypermedia contents to representations of organizational partners allow a form of associative corporate memory that intimately connect hypermedia to entities relevant to the organization, without a separation in the representation language between them. Other kinds of knowledge could relate hypermedia elements according to their content. For example, the detection of inconsistent policies for the choices given to the same customer could be marked as a link connecting the inconsistent parts of the document considered relevant (instances of *anchors* referring to *node* parts).

3 Aspects of the Hypermedia Ontology inside an Information Systems Framework

Hypermedia–based Information Systems use the infrastructure described above as the delivery mechanism of information resources. Nonetheless, the consideration of the organizational framework requires a conceptualization of the role of hyperdocuments in organizational behavior. In this context, Knowledge Management provides an appropriate context in which hypermedia structures represent interconnected knowledge assets, and adaptiveness becomes a mechanism for the optimization of asset delivery to the users that requires them at each moment according to organizational needs. In the rest of this section, these issues will be described in detail.

3.1 Hypermedia resources as knowledge assets

Hypermedia in the organizational context requires a specific conceptualization that connects with the notions of value [5] that drive Information Systems assessment and design. The connection point can be considered as that of identifying hypermedia elements as a particular class of potential value–providing elements in a process–oriented view of organizational learning. Existing conceptualizations of Knowledge Management (KM) provide the framework in which such integration can take place.

The ontology of Holsapple and Joshi [14] describes fundamental KM concepts and axioms. Other authors also provide integrative views of the diverse perspectives on KM for specific elements. This chapter focuses on the concrete class of knowledge processes that result in *learning* activities, even though other kinds of activities could be modeled in a similar way. Our interest in learning is that its enabling activities are directly related to learning processes as those that are supported by modern *e-learning* standardized technology, for which some *OpenCyc* previous integration work has also been described [30, 31]. The provision of knowledge representations integrating KM and e–learning standards has been pointed out as an important research direction elsewhere [33].

Recent work has provided an explicit formulation of H & S ontology in terms of OpenCyc definitions [32]. In what follows, a brief summary of these definitions is provided (references to H & S definitions appear between brackets), and the concrete aspects related to hypermedia elements are further developed to frame them properly in the KM context.

The definition of KM in H&J ontology "An entity's systematic and deliberate efforts to expand, cultivate, and apply available knowledge in ways that add value to the entity [..]"[DKMC1] requires the early definition of "entities" capable of engaging in KM, which are considered to include at least individuals, organizations, collaborating organizations and nations, as stated in [DKMC2-5]. The term `#$Organization`[2] in *OpenCyc* covers such entities. The concept of knowledge processor [DKMC10] as a member of an entity can be modeled through the concept of `#$IntelligentAgent`, which are by definition "capable of knowing and acting, and of employing their knowledge in their actions". Humans are, by logical definition, intelligent agents; certain software pieces may also fit this definition, since they are not restricted to not being able to *know* [AKMC10]. The subtype `#$MultiIndividualAgent` fits the definition of collective agents [AKMC11].

The definition of Knowledge as "that which is conveyed by usable representations" [DKMC6] can be integrated in *OpenCyc* by considering usable

[2] The '#$' prefix is the *CycL* convention for constants.

representations [AKMC2] as information bearing things, i.e. "Each instance of `InformationBearingThing` (or "IBT") is an item that contains information (for an agent who knows how to interpret it)." The type of representations described in [AKMC1] are similar to some *OpenCyc* subclasses like `SoundInformationBearingThing`, and are specific of *contents* according to the core hypermedia model.

The recognizable kinds of knowledge manipulation are referred to as Knowledge Manipulation Activity (KMA) [DKMC12]. Activities in *OpenCyc* are represented as `#$Action`s, a collection of `#$Event`s carried out (`doneBy`) by a "doer". This generic concept of action can be specialized to represent KMA executions by restricting them to be carried out by intelligent agents. The predicate `ibtUsed` can be used to represent the knowledge representations manipulated by KMAs. In addition, since KM activities are deliberate, it is probably more adecuate to use the subclass `#$PurposefulAction` and the predicate `performedBy`.

The definitions just described provide three main integration points with the core ontology of hypermedia described above:

1. `#$IntelligentAgent` includes the definitions of User and Group. The inclusion of the `#$Role` resolves the issue of different kinds of involvement that were implicit in Labyrinth's model of hypermedia.
2. `#$IBT` as a subsumer of Node and Content provides the characterization of hypermedia elements as knowledge assets. It is important to highlight here that Links should also be considered as stand–alone `#$IBT`s (as considered in [29]).
3. `#$PurposefulAction`s allows the introduction of the notion of value. The static hypermedia elements require purposeful efforts to obtain a timely and targeted delivery of information [8] that produces an effect in the organization as a whole.

In H&J ontology, learning is defined as "a process whereby KRs are modified; an outcome of a KME involving change in the state of an entity's knowledge" [DKMC17] (KME are episodes involving KMAs). Current approaches to Web–based learning are based on the concept of learning object, for which several definitions have been proposed. Reusability is considered to be an essential characteristic of the concept of learning object as the central notion for modern digital learning content design. For example, Polsani [22] includes reuse in his definition of learning object as "an independent and self-standing unit of learning content that is predisposed to reuse in multiple instructional contexts". Wiley [38] also mentions the term in his learning object definition "any digital resource that can be reused to support learning". Existing work has dealt with the integration of that concept in *OpenCyc* [30][31]. Learning objects are currently centered on Web technology, and thus, the hypermedia ontology described above is a generalization of those definitions. The main difference is that the concept of *LearningObject* should be considered as anti–rigid (∼R) because those hypermedia structures are considered learning objects by virtue of their use (or by a consideration of their potential utility) in specific learning contexts. Thus, learning objects are so by *extrinsic* determination, e.g. by the selection of a part of a hypermedia whole as a resource which is adequate for a coming learning need. Links as independent learning assets were described in [29], so that they can be assimilated also to the same definition.

Following the mapping of learning objects, IMS LD learning activities and associated higher level wholes of activities (methods, plays, acts) can be considered as templates of actual `#$PurposefulAction`s. This allows a seamless mapping of KM concepts to common learning technology practice.

A final but important issue to be considered in the mapping of hypermedia to KM is that value is not an intrinsic property of hypermedia elements, but a function of temporal conditions that depends on several dimensions. Figure 1 depicts these overall aspects.

Value assessment is therefore attached to the actual activities that disseminate the IBTs. A hypermedia element can be indirectly assessed as an stand-alone resource, hence summarizing the assessment of the activities in which it was involved. In addition, some *value notions* must be considered in the assessment process, and consequently be part of the overall ontology. For example, a straightforward notion of cost-benefit analysis could be considered, where costs are defined as the acquisition of the required knowledge assets plus the costs of designing and carrying out the purposeful activity. However, much work is still required in formalizing and comparing value assessment models that use the kind of comprehensive knowledge bases described herein. Both the previous background and competency of users in the activity, and the alignment with organizational objectives should also be considered. To this respect, knowledge gap analysis based on ontologies of competencies could be used as a starting point [34].

3.2 Adaptive hypermedia as a value carrier

Adaptive hypermedia systems [3] extend hypermedia with the capability of tailoring contents, links and navigation to the diverse preferences, knowledge or objectives of users or groups. The use of an ontological account of adaptive hypermedia would eventually enable the interchange of semantic user model data (enhancing user model servers [16]) and even that of adaptive behaviors. Additionally, it would provide a reference framework to evaluate the appropriateness of concrete adaptive technologies with regards to concrete contexts of use.

Existing knowledge representation of adaptive hypermedia systems can be expressed, in many cases, in terms of ontologies with an added support for reasoning. In systems that consider uncertainty or imprecision explicitly, the use of recent advances in fuzzy description logics could add a flexible numerical representation of imperfect information [27]. The main technical

Fig. 1. Elements in the assessment of value.

elements of such integration are the representation of vague categories and modes of inference [28].

The integration of an ontological representation of hypermedia within the KM framework, as described above, results in a reformulation of common evaluation criteria for adaptive systems. Research in adaptive hypermedia often considers usability as the main objective of introducing adaptivity [15]. The reformulation consist in putting the usability criteria under the constraint of organizational needs and objectives, while retaining the interconnected aspects of efficiency, effectiveness and satisfaction usually connected to it [36]. Then, it could be said that usability and utility must be constrained by the notions of value used in the assessment of organizational behavior.

In terms of the core ontology of hypermedia described, adaptiveness could be formulated in terms of tailoring functions aimed at two basic objectives. On one hand, to change the rendering of hyperdocuments or the nodes and contents they integrate. On the other hand, to dinamically create tailored nodes from pieces. In fact, learning object composition and adaptive linking as well as adaptive content technologies [3] fall under the latter category. Nevertheless, adaptiveness as a process can be considered as an additional form of value–producing `#$PurposefulAction`, this time taken by `#$IntelligentAgent`s that are not human. In abstract terms, a generic term `AdaptiveCreationAgent` can be used as a subsumer or any kind of adaptive functionality. Such agents have some differentiated characteristics:

- They have knowledge of some *value notion*(s), as described in Figure 1.
- They are organization–specific, and thus they have knowledge of some or part of the ontology that describes the *organization*.
- They have knowledge about at least some of the characteristics of users and/or groups.
- They manipulate and join together existing instances of *Node*, *Content*, *Anchor* and *Link* with a purpose related to the preceding elements, or alternatively, modify some of their properties to come up with personalized versions.

Knowledge about the various elements described could be expressed in terms of statements, which may additionally include any kind of domain ontology describing part of the organization or its context. Such statements are in reality the semantic annotations of the hypermedia elements as described before in this chapter. The selection of which classes of statements to use and the decision procedures to tailor them are the determinants of each concrete adaptation technique. It should be noted that this generalistic approach provides a broader an more integrated view to "semantic adaptive systems" compared to other frameworks. For example,

The above characterization offers a framework to compare and classify existing approaches to personalization. For example, pure social filtering techniques as that of the original GroupLens [24] are only aware of statements in the form $rating(user, item, value)$, where the items are contents describing commercial products or any other information, and the decision procedures are based on using those statements to build models of similarity between users.

4 Conclusions and Future Work

Hypermedia models as a generalization of Web technology are an important element in ontological approaches to Information Systems. Existing integrative hypermedia models can be used as the basis for a core ontology of hypermedia elements, and Knowledge Management and organizational learning artifacts can be expressed as concrete realizations of such elements. In this context, adaptive hypermedia becomes a function oriented to increase organizational value by tailoring hypermedia nodes to the characteristics of users or groups in the context of concrete organizational activities.

The work presented here is intended as a basis for an integrated approach to Ontology-based Information Systems with hypermedia characteristics. The ontological definitions described in the paper are not intended to be definitive or close-ended. On the contrary, they are posed as an initial definition to motivate further engineering in both the formal and the conceptual aspects of organizational learning. Future work should refine and extend the ontological framework sketched by introducing additional elements related to the organizational context, as well as more specific notions of value for information assets.

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