Retrieval as Exploration of Large Multimedia Document Bases

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Abstract

We propose an approach to information retrieval from multimedia databases based on the interpretation of the retrieval task as query by refinement using an explorative design process as guiding metaphor. The combined use of an intensional Index Layer and an extensional Information Layer allows for a flexible incremental structuring of the semantic space according to the requirements of the task at hand. In addition, the system provides a number of operations to assist the user in the exploration of the solution space. Possible contributions of various techniques from the areas of description logics and inductive logic programming are discussed.

1. Introduction

To access large collections of multimedia documents efficiently, it is commonly agreed upon that dedicated access structures — i.e. *indices* — are required. Furthermore, for effective retrieval the structure of the associated index space has to reflect the model of the problem solving procedure the user wants to follow. Our present work is situated in the domain of creative architectural design, where we advocate the interpretation of the problem solving task of *designing* as a special case of the generic "query by refinement" approach. Borrowing from Kaplan and Moulthrop's theory of ontological design [15], we expect our system to assist the user in the exploration of the combined *architectonic*[1] and *semantic* spaces of the domain: the architectonic space accounts for objective design properties, while the introduction of novel associations between elements of the multimedia database takes place in the "indefinitely filled" semantic space [15]. Consequently, the dimensions of the domain are not limited and cannot possibly be fixed *a priori*.

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[1]Note that "architectonic space" is a technical term not specifically related to the discipline of architecture.

2. Theoretical Background

A great deal of work in the research community has established a wide range of design models, including design critics (e.g. [9, 10, 13]), reflection in action [33], and design as argumentation [28,22], to name just a few. In our work we draw on the model of *Design as Exploration* introduced by Smithers and Troxell [34]. In this exploration-based model of design, knowledge about the nature and structure of the design domain has to be acquired before design goals can be expressed in a sufficiently precise manner. This stands in contrast to e.g. the widely uncritically accepted model of Newell and Simon [27], where goal states have to be defined *a priori*. In the exploration-based model, desired goal states emerge throughout the design process and may change during the design activity. A design task starts with the description of a *single* design requirement. Through the exploration of the space of possible design solutions the structure of this space is revealed and new requirements emerge. The result of the design process is a consistent description of requirements and an associated design specification. Problem discovery and solution discovery are therefore strongly interrelated.

The formal description of design as exploration following Smithers and Troxell is a six-tuple (P_s, T, $R_{i\text{-}f}$, H, D_s, E_d), where

- P_s is the space of possible solutions partially defined in terms of precedents that are represented by completely defined states and by sets of properties, constrained in terms of value ranges and property relations;
- T is a set of operations that compute new properties from existing ones. This is where state descriptions are refined or inconsistencies are detected;
- $R_{i\text{-}f}$ is a poset of non-empty sets of properties. These properties define the attributes for the required design solution. R_i is the initial set, R_f the final set that fully determines the found solution. In between are sets of intermediate requirements with the current one being referred to as R_c;
- H is the design history: it is a set of sequences of property sets and applied transformations;
- D_s is an initially empty set of solution states that possess attributes meeting the requirements defined by an R_c;
- E_d is the exploration process that extends D_s by taking P_s, T, R_c, and H as input and producing a series of transformations on R_c.

Drawing on this formal model of the design process we can relate the notation of Smithers and Troxell to our understanding of the retrieval process in large multimedia document bases in the domain of architectural design.

- P_s are abstractions of precedent cases in architecture;
- T comprises operations that we will further specify below;
- $R_{i\text{-}f}$ are expressed in concepts of the domain;
- H is the history of the retrieval process;

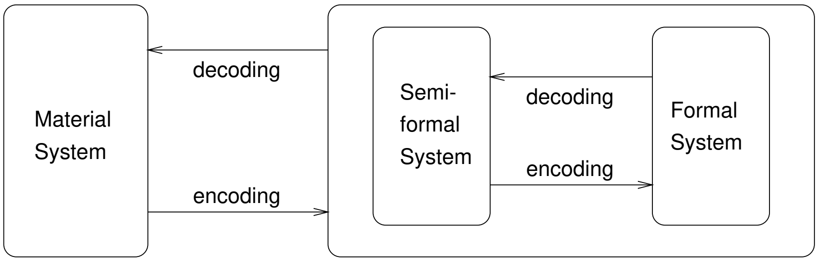

Figure 1: The levels of abstraction

- D_S is the set of retrieved multimedia documents;
- E_d is the retrieval process.

The essential point for the retrieval process is the definition of *vocabularies* that suit the needs of modeling real world objects as well as being capable of abstracting the application domain knowledge. Following the formalism of the task model, the requirement descriptions $R_{i\text{-}f}$ are constructed from terms supplied by multiple *indices*. The associated design specifications D_S are contained in substructures of semi-formal multimedia documents.

Figure 1 shows the relation between these different vocabularies. Two different levels of abstractions are introduced in the formalization of the Material System. This multi-stage approach is taken to bring causal relations that exist in the material world in congruence with implications expressed in a suitable formalism. Objects and relations of the Material System are encoded and thus abstracted in the Semi-formal System. The result of this encoding process is a description of the Material System, taking advantage of the semi-formal character of (structured) multimedia documents [15, 21]. A second abstraction step finally yields the Formal System.

The construction of the Formal System is constrained by the evolving nature of the index structure, which enforces an iterative approach for the encoding of the Semi-formal System. As in other domains (e.g. [7, 29] for a well-known medical example), also in architectural design the development of concepts is complicated because of the differing vocabularies used by different experts to talk about the same entities of the Material System. Moreover, the meaning of natural language concepts depends on the specific context (*'the meaning of a word is its use in the language'* [39]). These concepts are defined extensionally through the set of "things" they refer to. At the same time these "things" are qualified by those references from concepts. Borrowing from Wittgenstein's theory of language-games we coined the term language-game abstraction (LGA) [17] for an abstraction mechanism mapping between a set of related concepts and the corresponding set of related information items[2].

Our proposed retrieval process in multimedia document bases draws on this LGA mechanism to assist users in locating relevant information. The users specify an initial requirement R_i intensionally by choosing a corresponding concept or extensionally by selecting a set of relevant design solutions D_s encoded in the Semi-formal System. In either case, the system "parachutes" the users to a position respectively within the context of the explicitly chosen LGA or of a fitting one (i.e. an LGA that contains concepts that match well with the extensional specification of R_i). The users can now explore this context by examining related concepts, related information items, and relations between these objects. While doing so, sets of R_c are expanded and the retrieval process is tracked in the history H. The retrieval process terminates when the information need of the user is satisfied.

3. HySAT

Having presented our conceptual interpretation of retrieval in multimedia databases we will now discuss HySAT (Hypertext System for Architectural Typology) [14], our proposal of a system which is aimed at supporting the architectural design process by offering customizable access to an extensible repository of pertinent multimedia documents.

3.1. The Architecture of HySAT

Figure 2 outlines the overall architecture of HySAT. The Semi-formal System as introduced in the previous section forms the Information Layer of the HySAT architecture. The Index Layer — a collection of multiple indices reflecting the different viewpoints on the underpinning multimedia documents — formally encodes the domain knowledge.

In the Information Layer different media can be employed to cover many different aspects of the architectural domain: natural language text can be used to characterize the salient properties of three-dimensional space as well as supply meta-information in the form of interpretations and personal evaluations. Visual documents of different kinds cover the wide range from abstract concepts to concrete shapes: e.g. sketches encode key design intentions; drawings abstract the geometric properties of real-world objects; photographs store snapshots of realized environments; and digital movies provide the closest approximation to reality. Acoustic information can be used to e.g. capture the atmosphere of particular surroundings.

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[2]While using words from architectural terminology as names for concepts can assist in the construction of indices by reminding the user of the intended semantics, we are well aware of the dangers associated with the implicit introduction of 'meta-information' into formal systems. However, considering the pragmatic restrictions of any given implementation, we are inclined to assume that the practical benefits of this additional informal channel of communication between users of the system will outweigh the dangers of potential disagreement between the interpretation of concepts by users and the system itself.

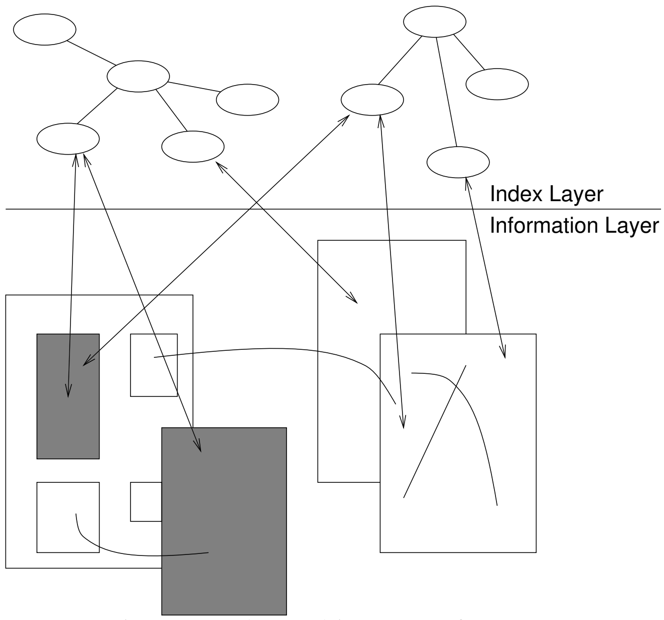

Figure 2: The architecture of HySAT

HySAT allows users to browse across multiple index structures as well as to build custom indices, where differing indices embody concurrent views on the underlying document material. Indices consist of concepts which are related to other concepts of the same view, sets of documents, or both. Reference indices are maintained by experts to represent their understanding of architecture, thus placing an emphasis on different themes of the domain. Relations between concepts and documents reflect subjective characterizations of the referenced documents.

3.2. Supported Operations in T

These operations serve to refine the problem description given a set of preliminary requirements. We can distinguish two main classes of operations. The first class is defined on elements of a single LGA, while the other class supports the identification of new requirements across different LGAs. These operations aid the narrowing of the gap between the information need of the user and the information content of the selected documents D_S.

The first class of operations furthers the exploration of the local context: the current point of view is explored in more depth. These operations follow from the application of description logics for the encoding of the Index Layer and comprise the capability of capturing the interrelationships between terms, the verification of integrity constraints, the stating of weakened queries, the support of query by refinement, and the delivery of intensional answers [5]. As representatives of the second class of operations we briefly discuss the opportunities for application of two different techniques: the identification and exploiting of regularity relations between hierarchies of the Index Layer and the application of automatic classifiers, especially inductive relational learners, to identify relations between the Information and Index Layers.

Regularities exisiting between the structures of content-descriptors of documents can be used for reasoning about the relationship between the documents themselves. Mili and Rada [23] state the example of content-descriptors organized in hierarchical semantic nets. They define *regularity* as a mapping between two different but related conceptual domains such that two hierarchically related concepts in one hierarchy map to two hierarchically related concepts in another one. Regularity-based inferences may be used in a two-fold way. On one hand, the regularity principle can be used to guide the classification of new knowledge to be added to a hierarchy. On the other hand, new property values for existing concepts may be inferred on the basis of the relationships to other concepts in other hierarchies.

An important application domain for relational learning systems [25, 19, 26] is the generation of classification rules for real-world databases. These collections are characterized by a large size and the presence of inconsistent entries. The algorithms therefore have to be efficient and noise-tolerant. Relational learning systems have successfully been applied to real-world problems. In sufficiently rich domains some systems constructed new knowledge of interest for researchers in the application area [16, 37, 38]). In the present context, these techniques are used for the generation of concise descriptions of given selections of documents in terms of vocabularies of one or multiple LGAs. This task is of relevance for the identification of relevant structures in the Index Layer to which a given collection of documents chosen by the user can be mapped — especially at the beginning of a design session. Furthermore, it provides support for navigation between different LGAs (i.e. "shifting of perspective"): based on the extent of the concepts currently considered by the user is determined, the learner generates another intensional description of this document collection using a different LGA. This alternative LGA can either be explicitly prescribed by the user or can be automatically chosen by the system according to the ranking of the quality of the computed alternative descriptions.

3.3 Scenario

The architectural design process rests largely on precedents. Based upon the typically under-constrained problem description, designers have to decide on a *"key idea*" to which to subordinate all other aspects of the design problem. Browsing the collection of precedents serves as an important source of inspiration. The designers then can evaluate the overall impact of their decisions and checkfor major constraint violations. The available precedents now also serve as compact (operational) representations of allowable combinations of constraints: it is the designers' responsibility to recognize possible adverse effects of their current choice. If all aspects are considered to be acceptable, a valid design solution is found.

The following requirements for a system to support this scenario become apparent:

- An essential role is played by the collection of cases, which are accessed for different purposes at various stages of the design process. A rich collection of formats and media is required to ensure appropriate coverage of the domain.
- Support for accessing relevant documents, where the relevance is a function of the point of view currently under investigation. The system therefore has to allow for both exhaustive exploration of a single standpoint as well as the shifting between different main themes.

We will now describe the course of interaction for a hypothesized design example (see Figure 3). We use the notion of *exploration* for both the design process and the retrieval process using the system, because as the user explores the knowledge space looking for information relevant to her design problem, she also collects new requirements associated to her problem and gains new insight into the actual structure of her problem space. The drawings in Figure 3 stand for information items while the term hierarchies represent concepts in the Index Layer. We used two architectural textbooks, *Precedents in Architecture* [6] and *Logic of Form* [36] to extract two example LGAs. The numbers (1 to 11) in Figure 3 state the chronological order of the exploration steps.

The designer sets out with the question: “How to design a wide-spanned roof sheltering a gymnasium on a rectangular site?”. After retrieving some design cases described by the concept Roof of the LGA Construction (1-3), she gets interested in an example of a dome-shaped roof (4). Because she wants to know the consequences of a dome-shaped roof for the ground plan, she seeks for a corresponding example in the LGA Formative Idea[3]. The descriptor in the LGA Construction for the selected roof is Dome (5). At this point, the user wants to change point of view and asks the system to determine an alternative description[4] of the documents referred to by Dome. The proposed solution combines the concepts Roofs of the current LGA with the concept Concentric of a different LGA. The user subscribes to this new perspective (6). Additional information items retrieved for Concentric (7) turn out to be inconsistent with the rectangular site prescribed in the problem definition.

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[3]Note the polysemy of the term “Formative Idea” in the example, i.e. its different use in different LGAs.

[4]E.g. by applying the Minimum Description Length principle [24].

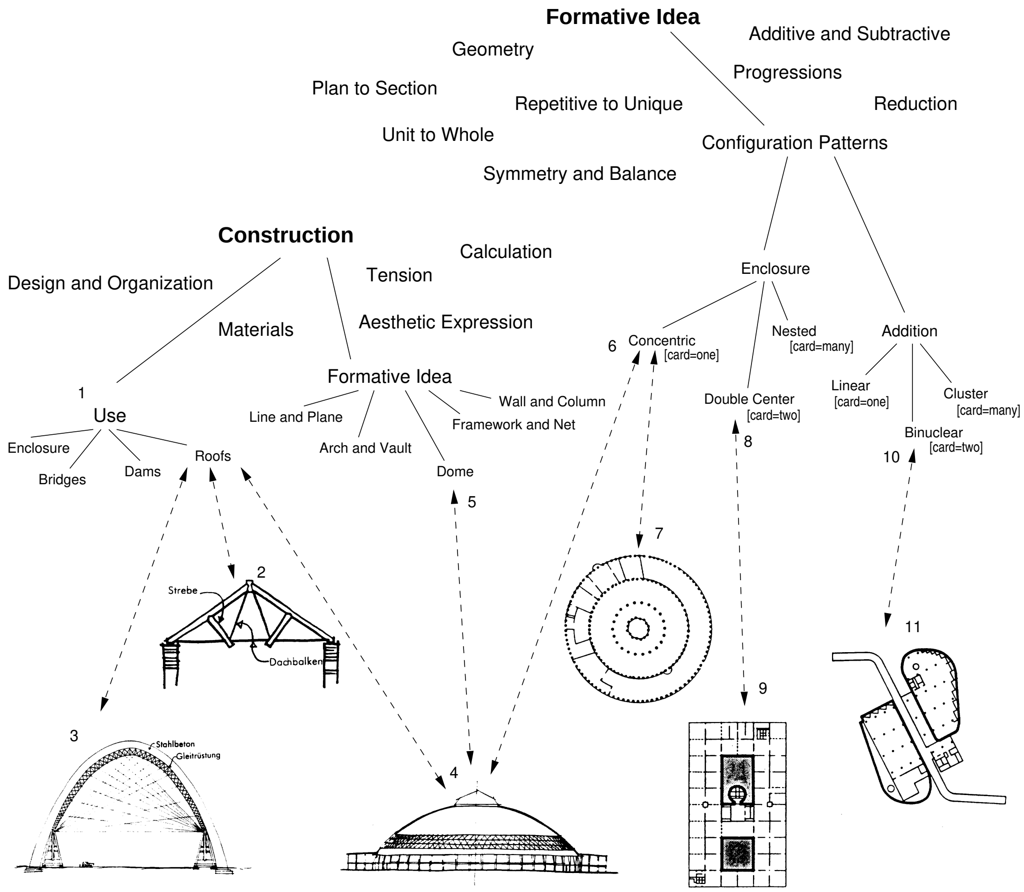

Figure 3: Information retrieval as exploration process

To find alternative solutions, the user tries to weaken the requirement in the current LGA and discovers Double Center (8) as a closely related concept concerning Enclosure. Examples prove to be suitable for a rectangular site (9), e.g. two domes. At this point, the user furthers the search by asking the system for alternatives to the found solution (which supersedes some of the interimistic assertions, such as the concept Dome). Using the regularity identified between the Enclosure and Addition hierarchies of the LGA Formative Idea, the system chooses the concept Binuclear (10) and proposes the documents referenced by it (11). This concept is finally accepted as *key idea* by the user, who ends the session. Note how the information retrieval process led to the exploration of regions of the design space — represented by selections of multimedia documents — that the user was previously unaware of.

4. Related Work

The special consideration of the *dynamic* aspect of the design task that immediately follows from its interpretation as exploration is an essential and distinguishing feature of our system. As detailed above, this view contrasts with familiar models of the design task.

The level of assistance a computer system can provide in an information retrieval task is clearly related to the amount of domain knowledge that is explicitly represented[5]. Early research aimed at developing systems supporting designers' argumentation activities was originated by Rittel [28] whose work in turn drew on the Issue Based Information Systems (IBIS) introduced by Kunz [18]. However, later developments such as SEPIA [35] and Aquanet [20] demonstrated a number of problems related to premature commitments to specific knowledge structures which moreover were mostly limited to covering the architectonic space.

The development history of the ARCHIE project [11, 18] exemplifies the subsequent shift of emphasis towards the semantic space; at the same time most of the detailed structuring of the architectonic space was abandoned. While ARCHIE suffered from an overly detailed decomposition of the covered design cases, ARCHIE-2 tried to overcome problems by using informal story-based case representations. This group of systems, which also includes the family of ASK systems [31, 32, 1], proved very successful for cases where the user information need had been correctly anticipated (using the question-based indexing method). On the other hand this positive result was bought at the price of a limited applicability of the approach.

Overemphasizing either the architectonic or the semantic space thus turns out to limit the usability of the resulting systems: in the former case, the user is confronted with a detailed vocabulary that artificially restricts the accessible domain space; the latter approach results in brittle systems which cannot provide any assistance at all for unprecedented usage patterns. Following this line of thought, the recent work on DEDAL and DE-KART [2, 3, 4] can be interpreted as an effort towards a more balanced equilibrium between these extremes: DEDAL's conceptual index is based on a model of the artifact being designed; at the same time a growing number of *proximity retrieval heuristics* tap into the semantic space and thereby ensure that the users are not strictly confined to the part of the architectonic space that is already explicitly incorporated in the system's knowledge base. DE-KART is an example of the kind of incremental extension of the index space we have also planned for HySAT. A main difference between DEDAL/DE-KART and HySAT results directly from the respective intended uses: while DEDAL is currently aimed at the retrieval of technical documentation, HySAT's domain of creative design places an even higher demand on effective support for incremental development of multiple indices along with associated navigation aids.

5. Current Work

We are about to start an empirical evaluation of the applicability of this technology to the index structures used by students in analytical studies of buildings that are part of the curriculum in architectural design education. The idea is to use learning algorithms to assist in the creation of new concepts characterizing a given set of documents, using existing index concepts and relations as vocabulary. This could be of value e.g. in the early stages of a new design analysis project when

[5]Statistical approaches (e.g. [30]) nonwithstanding.

especially inexperienced users might struggle to identify the characterizing attributes of a collection of documents they “feel” are of relevance for their intended approach. Furthermore, the system could try to find alternative, more succinct definitions for existing intensionally defined concepts.

To this purpose, we plan to set out using categories similar to those used in ASK systems to structure the indices, with the addition of typed attributes (e.g. cardinal values as exploited in the example for identification of a regularity between hierarchies). Intra-index relations would thus include “refocusing” (along the subsumption hierarchies) and “comparison” (analogies vs. alternatives), while inter-index links would include “advice” relations connecting a source concept with “opportunities” (e.g. which kind of lighting to employ in large closed spaces) and “warnings”. In the course of this evaluation, we hope to gain further insight into a number of issues, including: the relevance of support for versioning; the need for contradiction handling; the importance of completeness of reference indices; the required minimal richness of modeling of the Index Layer; the required minimal size of the instantiated Index Layer.

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