Multifaceted Hyperimage-Based Organization and Interaction with Bio-Medical Images

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Abstract

The abundance of complex media-rich information in state-of-the-art bio-medical sciences underlines the importance of paradigms for organizing, searching, browsing, and assimilating such data. In this context, image-based information, derived from a plethora of biological and medical devices, presents unique challenges. This is partially due to the richness of information expressible through visual media and the complexity of the underlying semantics. There is today a paucity of paradigms that allow organization and browsing of large image collections, in manners that capture the intricacies of image semantics and support experiential factors in information assimilation and user-data interactions. This paper presents our research in designing such an organizational framework. Central to our approach is the philosophy of recognizing and directly capturing the heterogeneity of semantics that may exist even for a single bio-medical image. Using this as a starting point, we extend the notion of image hyperlinking to support multiple semantic associations between bio-medical images. By using these associations, expressed as hyperlinks, image collections can be organized simultaneously from different biological or medical perspectives. We also consider the issues of creating, storing, and managing information in such an organizational paradigm. Finally, we describe a unified presentation-interaction environment that facilitates user interactions including information organization, querying, and exploration. Examples and case studies demonstrate the promise and broad applicability of this research.

1. Introduction

Contemporary medical and biological investigations involve extensive use of sensor-base technologies such as Computer Tomography, Magnetic Resonance and its derivatives, X-ray imaging as well as molecular biology techniques such as cellular assays, immuno-histochemistry, and expression analysis all of which produce image-based data. Such data constitutes some of the most fundamental pieces of evidence supporting clinical and biological decision making. Thus capabilities that improve organization and assimilation of such image-based information are critical. For example, in the case of making a diagnosis, a clinician could formulate novel hypotheses and based on it, review and retrieve similar cases. This requires that query formulations be flexible and intuitive. Furthermore, human-machine synergy and experiential factors need to be emphasized [5].

In understanding the challenges, it is important to note that information contained in medical images differs considerably from that residing in alphanumeric format. The difference can be attributed to three main characteristics: (1) the semantics associated with images is non-unique and emergent, in that media is endowed with meaning by placing it in context of other similar media and through user interactions [8]. Furthermore, the semantics of medical knowledge extractable from images is imprecise [11]; (2) images contain spatial and geometric information that is simultaneously implicit as well as difficult to formalize in conventional languages; (3) diagnostic inferences derived from images rest on an incomplete, continuously evolving model [11].

The goal of our research is on developing a paradigm for organizing and navigating bio-medical image collections along conceptual dimensions that relate the information. We seek to, specifically:

- Capture the heterogeneous and emergent semantics that relate one image to another in the collection.
- Support efficacious yet simple interactions between users and the data, both from the perspective of defining the semantics as well as for navigating and exploring.

2. Prior Research

The majority of image retrieval and navigation research has been developed from a "content-based" perspective, where image features such as shape, color, or texture are used to determine relationships between images (see for example [1, 6]). In such cases, the primary mode of interacting with the data is through "query-by-example" [3] and possibly relevance feedback [15]. For a review of these techniques we refer the reader to [10]. In the context of bio-medical images, [7] represents the content through attributed relational graph and uses R-tree based indexing for efficiently searching the database. More recently, [9] emphasizes the uncertainty inherent in biological and medical data and propose techniques that account for the probabilistic nature of the data. Researchers have also attempted to directly address the central problem of multifaceted semantics associated with image data. The MIMS system [2] uses a graphical representation to describe image objects, their attributes, and interrelations. Another example is [11], where a generic schema is combined with object-oriented iconic queries and semantics by association with prototypes.

3. Solution Philosophy and Terminology

The proposed approach takes a holistic view of the twin problems of content organization and navigation and has two primary characteristics. *First*, it seeks to capture image semantics that is multifaceted and possibly emergent. *Second*, it seeks to provide a natural framework for navigating image collections in context of the aforementioned semantics. To address the above, it proposes the notion of *multifaceted hyperimages*

A *hyperimage* is an image that supports hyperlinks between its regions and regions of other images. *Facets* refer to categories used to characterize information in a collection [4]. For instance, *arrhythmia* is a facet in the domain of cardiac ailments. A facet may be either hierarchical or flat and in both these cases, it is associated with a set of labels that describe it. In context of the example just considered, *tachycardia* (abnormally rapid heartbeat) and *bradycardia* (slow heartbeat rhythm) are possible labels associated with the facet *arrhythmia*.

In a multifaceted hyperimage collection, regions of various images are related (hyperlinked) to each other using links that support multiple facets. Given a region in a hyperimage, when a facet (or a label) is selected, all images having similar faceted (labeled) links are retrieved for browsing. Multifaceted Hyperimages provide two powerful facilities. *First*, they allow images to be treated as non-monolithic data types. Second, they provide a mechanism to model, organize, and interact with the semantic heterogeneity that exists within images. The intuition behind our idea becomes clear by observing that traditionally, categories have been used as a set of labels that are organized to capture the concepts relevant to a domain. Multifaceted hyperimages take this idea forward in the following two ways: (1) A facet corresponds to a set of category hierarchies that are relevant to the image collection. Thus, each image (or region in an image) possibly gets many labels from the different hierarchies relevant to it. In this sense, multifaceted hyperimages are similar to the representation called hierarchical faceted categories (HFC) [14]. (2) Unlike HFC, where the content satisfying the information goal is only accessible after appropriately navigating the corresponding HFCs, multifaceted hyperimages are defined directly on the content. This not only takes advantage of the human—machine synergy but also enhances the experiential factors involved in sensor-rich image-based content.

4. Designing Multifaceted Hyperimages

We consider the design of a system for organization of image-data by utilizing the notion of multifaceted hyperimages from the following two perspectives: (1) design and storage of multifaceted hyperimages and (2) display and browsing image collections organized on the basis of multifaceted hyperimages.

4.1. Design and Storage of Multifaceted Hyperimages

Fundamentally, multifaceted hyperimages are data structures that support any number of hyperlinks defined between arbitrary (but specific) regions of images and categories associated with these links. To support this notion, each hyperimage is defined to have an arbitrary number of regions. Each region is identified by the coordinates of an encapsulating polygon (typically a bounding box), region properties, and a universal resource indicator (URI) of the image it belongs to. The regions may be defined manually by direct selection on the image or through image processing operations such as region segmentation. In the extreme case, an entire image can also be represented as a region. Regions in the hyperimage are related to each other through hyperlinks. In the proposed approach, hyperlinks play a critical role since they describe semantically relevant organizations of the data. This is reflected by the facets corresponding to each hyperlink. The facets and labels can be manually created and or determined through image analysis and association. Currently, we have implemented a manual annotation entry interface. It is important to note that the facets represent diverse relationships between two regions (images). This can be used to describe semantics that are variable and/or emergent in nature.

Information in multifaceted hyperimages is represented through an XML schema (Figure 1) and can be stored using an XML database or in the image header itself. Using an XML representation, allows us to utilize efficient query mechanisms available for XML data [12]. In our current implementation, we have investigated storing the hyperlink information as part of the image and in an XML database (BerkeleyDB). For instance, if the images are JPEG files, the image header is composed of three parts: the *JPEG header*, the *Exif Segment*, and the *Application Segment*. In this case, the XML-encoded information is stored in the application segment. Specifically, we define the special marker "EF" to encode the data as follows: (1) The byte code "FF" is utilized in the standard manner for the segment separation (oxff) (2) The byte code "EF" is used to identify the XML segment (oxef) (3) This is followed by the number of byte needed for the whole segment of stored data ('size'), and (4) Finally, the XML data ('xmldata') is inserted.

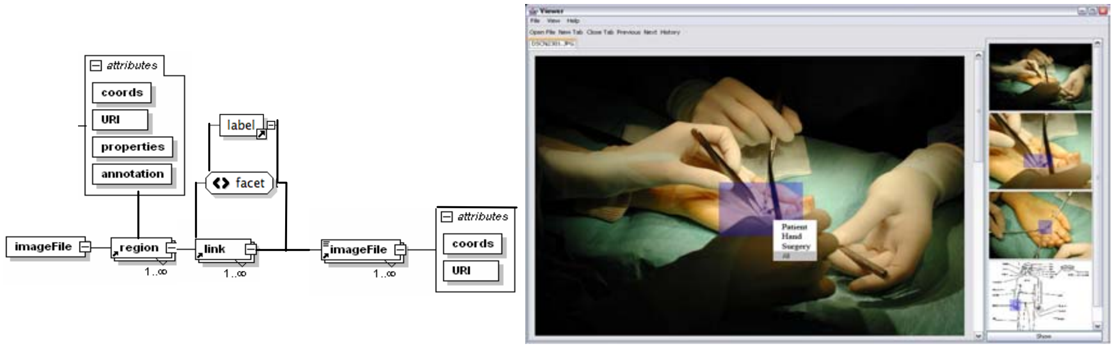

Figure 1 (Left): The XML-schema for multifaceted hyperimages. Each image can contain multiple regions. The regions are hyperlinked to each other and corresponding to each hyperlink are one or more facets. (Right): Creating and browsing multifaceted hyperimages. The nearly-transparent layer around the hand being operated on indicates that this region is hyperlinked to other image(s). Positioning the mouse over a hyperlink brings up the (possibly multiple) facets associated with the region. By selecting a facet, all relevant hyperlinked images are displayed.

4.2. Display and Browsing

We have designed a specialized interface to annotate, display, and browse multifaceted hyperimages. Given an image, specific functions that are supported include (1) display of image regions that are hyperlinked, (2) display of images/regions to which the given image is hyperlinked, (3) Display of facets (4) Creation/editing of facets and (5) traversal of the data by hyperlinks, including browsing by selecting facets. Once an image is selected in the viewer, all regions hyperlinked in it are highlighted using a nearly-transparent layer which is superimposed on the regions (see Figure 1). This creates a focus of attention around the hyperlinks without compromising the visual information. A hyperlink is created by selecting regions of interest in two or more images and clicking on a "Create Link" button. The corresponding facets are then entered. To facilitate hyperlinking an image to a pre-existing set of images that are semantically strongly related (sharing the same facet), at the time of hyperlink creation, the user has the option to link the new region to all, none, or a few (manually identified regions) related in terms of the facet.

Display of images related by hyperlinks and traversals of the data collection in terms of the semantic constraints induced by the facets is initiated by selecting an image of interest as a starting point. Once an image is selected, all its hyperlinked regions are displayed. Clicking on a region and selecting a facet brings up all the images that are hyperlinked to this region in context of the selected facet. These hyperlinked images are displayed in a scrollable panel (see Figure 1). Clicking on a specific hyperlinked image in this panel, brings it to the central panel and the scrollable panel is repopulated with other images that are hyperlinked to this image. Such a one-image-at-a-time mode of traversal is similar to how web-pages are typically navigated. The system also supports a unified view where the history of a traversal pattern is depicted with a tree-view. The tree-view can be generated and updated simultaneously to show the entire history of a one-image-at-a-time traversal mode. This not only provides an overview of the traversal but helps in navigation and information assimilation by retaining user and data context.

5. Case Study

As an example case study, we consider the problem of supporting unified and semantically related views over multi-patient biomedical images: currently large volumes of such information exist from various imaging modalities. We consider two challenges in organizing such information: first, even though such data is saved in folders of individual patients, it is highly complex to obtain an overview of all interventions/data related to a specific patient. Second, and more importantly, the current organization strategies create information silos that are specific to each patient. This complicates access and comparison of information across patients related by the same pathology or medical intervention. Figure 2 illustrates how the use of multifaceted hyperimages can easily ameliorate these complex problems: each patient is represented by a medical diagram of the human body. Specific regions of the body, where pathologies/interventions have occurred are hyperlinked (represented by broken lines) to the relevant image data. The facets correspond to the specific pathology and/or intervention. This provides a uniform and easy to assimilate view at the level of specific patients. For example, the first patient has X-ray and imaging data on the ligament below the right thumb as well as information on surgery on the left elbow. Further, another hyperlink, corresponding to a separate facet (diagrammatically represented by the solid horizontal line), relates different patients who have had similar pathologies/interventions. By simply clicking and following these hyperlinks, a medical professional can locate similar intervention across patients.

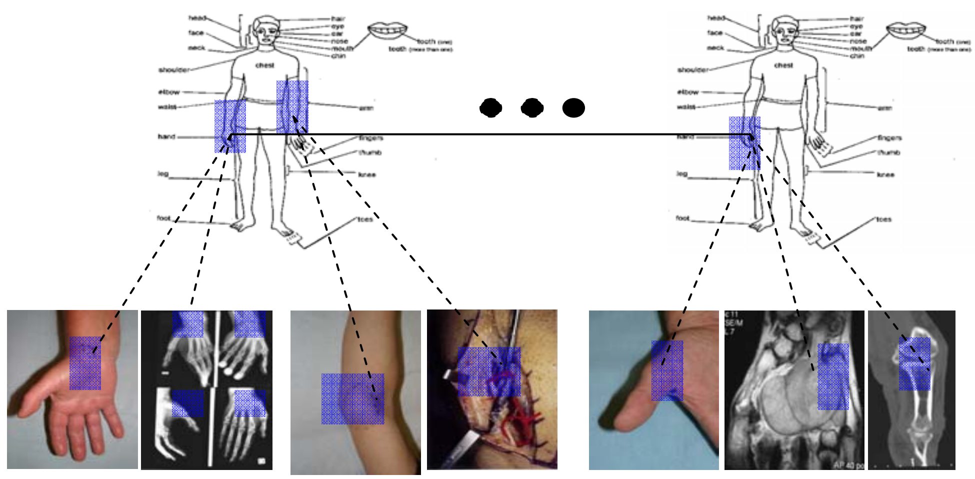

Figure 2: Application of multifaceted hyperimages to biomedical imaging data allows unified organization of data for each patient (represented by dashed hyperlinks), as well as linking information on similar medical interventions across patients (represented by solid hyperlinks).

6. Conclusions

In this paper, we have outlined an approach for context-based organization of images through the use of multifaceted hyperimages – images, which support hyperlinked regions where associated with each hyperlink is a set of categories called facets. On one hand such a model extends the well established notion of hypertext to images. On the other, it extends the notion of hyperlinks to take into account the richness and fundamentally distinct nature of semantics associated with images. The system described in this paper stores the hyperlink schema associated with images as part of the image header or in a XML database. It also provides a user interface that supports creation of hyperlinks between images, assignment of facets, and facet-driven browsing and search.

The simple idea of multifaceted hyperimages allows us to directly address many complex issues associated with the nature of images, such as their emergent semantics and their experiential nature. Further, the simplicity of the proposed notion allows it to be used in simultaneous conjunction with other notions around which different strategies of image organization can be conceived. This attribute underlines the applicability of multifaceted hyperimages to a wide class of problems where organization and browsing of image-based data is critical.

7. References

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