A Unified Timeline Model and User Interface for Multimedia Medical Databases

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December 14, 1995

Abstract

A multimedia medical database model and prototype is described for supporting a timeline-based presentation of information. The database links image and text data in a way that permits users to view medical information in a single unified view. Various visualization programs permit the user to view data in various ways, including full image views, graphs, and tables. Our technology is applied for proof-of-concept to two areas: thoracic oncology and thermal tumor ablation therapy of the brain. This effort is part of the multidisciplinary KMeD project in collaboration with medical research and clinical treatment projects at UCLA.[1]

Keywords: Multimedia databases, time-based data modeling, medical imaging, medical informatics.

1 Introduction

Health care and treatment of patients frequently results in a multitude of multimedia data, including alphanumeric data, images, long text, perhaps video streams, and now even voice or sound. The types and volume of data which are being generated are growing dramatically as medical science progresses.

We introduce herein a unified multimedia timeline model and prototype system to support the information management requirements that we have identified as being

[1]Portions of this research and development supported by: National Science Foundation (NSF) grant no. IRI9224559; the Cigarette and Tobacco Surtax Fund of the State of California through the Tobacco-Related Disease Research Program of the University of California, Grant #2RT0081; and PHS Grant #P01 CA-51198-05 awarded by the National Cancer Institute.

common to various medical research and clinical treatment challenges. The ability to store, manage, and access multimedia information involving the current situation, progress, and reaction of medical abnormalities to various medical treatment protocols is one such major requirement.

In this paper, we introduce a next-generation multimedia database system to maintain the patient records, models, and images that are relevant to a particular medical imaging application domain within a single overall timeline representation. It shows the applicability of the technology that has been developed in the Knowledge-Based Multimedia Medical Distributed Database (KMeD) project [1] at the University of California, Los Angeles (UCLA) in close collaboration with thoracic oncology and brain tumor thermal ablation treatment projects at the UCLA Center for Health Sciences. Using the modeling constructs provided by KMeD, our database can store patient records and images, associate them with each other, and present this data as a multimedia timeline of images, graphs, tables, and reports.

Section 2 describes thoracic oncology imaging and thermal ablation therapy timeline requirements, which were used as proofs-of-concept for our timeline model. Section 3 describes the new, generic data modeling constructs that have been defined in the course of our work. Section 4 describes the database model or schema to meet requirements. Section 5 outlines the user interface and illustrates our timeline display paradigm. Section 5.3 describes the interface that we have designed for the interactive display and visualization of CT (computed tomography) images (MR images, used for thermal ablation therapy, may be visualized in a similar manner). We conclude in Section 7 with a summary of the paper and an overview of further research that is currently going on within the KMeD laboratory.

2 Medical Imaging Timeline Requirements

The management of patients with cancer represents a significant departure from traditional ambulatory medical practice. These patients are committed to complex multimodality treatments attendant with potentially significant morbidity and extending over long periods of time. Large amounts of clinical and imaging data may be generated on extremely ill patients, making trends difficult to identify. Several oncology groups have realized the need for computer-based decision support systems that can organize patient-specific information according to a care continuum rather than as a series of event-specific data [2, 3, 4]. Most of these systems have been designed to integrate alphanumeric data exclusive of radiologic image data. While inherently visual, the content of medical images is communicated primarily as free-text. It is often intuitively easier to grasp changes in tumor burden by directly reviewing pertinent image data [5, 6]. Moreover, in contemporary medical oncology practices where large numbers of patients are enrolled in clinical trials requiring meticulous data management and scrutiny, a visual record that abstracts pertinent information would serve critical auditing needs. The unique character of image data poses a challenge to traditional medical informatics: how best to integrate and display image data with other electronic medical data to efficiently and intuitively convey information.

The following subsections briefly describe two specific areas that our multidisciplinary research group has explored using this desired multimedia timeline technology.

2.1 Thoracic Oncology

The area of thoracic oncology would greatly benefit from a common documentation media for medical oncologists, other oncology care providers, and thoracic radiologists. Support programs can collect, abstract, and insert into a timeline electronic patient information from a radiology information system (RIS), hospital information system (HIS), and picture archiving and communications system (PACS). This data can be used to express the temporal medical continuum of thoracic oncology patients. By presenting this data in timeline format, the database gives the passage of time a visual dimension.

An additional goal of the thoracic oncology group is to improve the consistency of data entry and image-related computations. Variability in the calculation of tumor burden results both from observer variability and from technical limitations of image acquisition and segmentation. In current practice, the radiologic assessment of treatment response in oncology patients follows criteria established by the World Health Organization and is typically derived from measurements obtained on computed tomography or other cross-sectional images. By convention, the cross-sectional area of a lesion is calculated as the product of its maximum diameter and maximum perpendicular diameter taken at the widest axial level of the image. When there are multiple lesions or metastases, global tumor burden is derived from the measure of the largest three lesions, called indicator lesions [7]. Observer variability results in several ways: the selection of the indicator lesions to be serially followed, the selection of the axial level from which diameters are measured, and from differences in exactly how diameters are drawn on irregularly shaped lesions [8]. CT studies in lung cancer patients have shown moderate interobserver variability for the measurement of mediastinal lymph nodes. The variability is greatest for small lesions and in specific lymph node chains [9].

Volumetric datasets using helical CT provide more accurate measures of tumor burden than the calculated product of lesion diameters. However, even these newer acquisition technologies require robust image segmentation methods in order to achieve accurate measures of tumor volume. Although these technical issues are beyond the scope of this database project, the oncology imaging timeline does partially address inconsistencies of measurement relating to observer variability by providing a mechanism for permanently indexing and annotating the images from which lesions diameters are obtained.

2.2 Thermal Ablation Therapy

Thermal ablation therapy is another domain selected for demonstration of our multimedia database advances. Thermal ablation is the use of focal heating for the treatment of tumors. Techniques for thermal ablation of brain tumors were pioneered at UCLA [10, 11, 12, 13, 14, 15, 16, 17, 18]. The procedure is particularly important in the treatment of brain tumors, where invasive surgery is either impossible or poses the risk of severe brain damage. Using specially designed interventional magnetic resonance instruments, a radiofrequency (RF) electrode is directed into the tumor with MR guidance. Instead of the usual surgical craniotomy exposure, a 2mm twist drill hole is used for access in the skull of the patient, who remains awake during the procedure.

Local anesthesia is used for skin, scalp, periosteum, and dura — the brain itself does not have pain receptors. With the assistance of MR visualization, the tumor is destroyed as the local temperature of the tissue is heated above 60° C, necessary to denature proteins and cause coagulation necrosis. Patient demographics, treatment information, and imaging-derived information about the lesion before, during, and after treatment are stored in the database for manipulation and retrieval.

3 Data Model Overview

We introduce a multimedia data model called M that directly supports the new and unique concepts of medical databases and their imaging timeline requirements. Detailed discussion of M is reserved for a different document; this section only provides an overview of the model and its uses.

3.1 Backward Compatibility with Our Previous Work

It should be noted that the M data model is an evolution of previous data modeling work by our research group; it functions as a superset of the constructs described before. This work includes the image stack data model, presented in [19], and the annotation data model, presented in [20].

Further, our stream data model interacts with or "plugs into" the temporal evolutionary data model, or TEDM [21]. The combination of TEDM and our multimedia and stream models results in a set of constructs that can represent almost any type of temporal data, at varying logical levels.

3.2 Basic Concepts

Our basic data model framework is a synthesis of entity-relationship (ER) and object-oriented (OO) data models. We have tried to combine the diagrammatic simplicity of

ER with the richer semantics of OO. Fig. 1 summarizes the basic ideas and notation behind the model.

3.3 Multimedia Types

The foundation for the multimedia functionalities in this data model is the *multimedia type*. Multimedia types are designed to behave like atomic data types within the system: the database provides all of the operations necessary to transparently manipulate them, just as a user can manipulate numbers, strings, or characters.

Multimedia types are viewed as encapsulated "black boxes" by the user. They can be presented on a screen or a speaker, assigned to attributes, compared to other values, or manipulated through pre-defined operations and/or methods. Although the actual implementation of such black box functionality is, internally, much more complex than with numbers or characters, the user-level view of these operations remains the same.

Fig. 2 shows, in the notation that we defined in Fig. 1, a number of the most common multimedia types and some of their attributes.

3.4 Streams

A stream is *an ordered, finite sequence of entities or values*. These entities or values are called *elements* of the stream. The sequencing is temporal: in other words, elements e_i and e_j of a stream entity S are distinguished by i and j being different instances in time. This temporal ordering is further described by a *frequency*, indicating the speed by which the elements of the stream travel through time. Streams also have the notion of a *current time* from which the *current element* in the sequence can be determined — particularly useful when iterating over a stream's elements or when the passage of time is halted within a stream (i.e. viewing individual frames of a movie loop, for example). These concepts will be examined in further detail in a later section, after our data model's view of time is defined more formally.

Fig. 3 illustrates the notation for some of our basic stream-related constructs.

4 Application Domain Logical Data Model

In this section, the logical data model (or schema) of the thoracic oncology imaging timeline database is described. The model uses an extended version of the combined object and entity-relationship model used in the KMeD project. New constructs are capable of expressing objects that exist as a series of multiple states through time.

A high-level abstraction of the comprehensive schema that we have designed for an overall multimedia medical database can be seen in Fig. 4. More detailed subschemas are shown in Figs. 5 and 6.

In the interests of brevity and clarity, we shall limit the detailed discussion in succeeding sections to the subschema in Fig. 5; note that most of the concepts presented there will be highly applicable to the thermal ablation therapy domain and many other multimedia domains as well.

4.1 Patients, Procedures, and Processes

The standard KMeD representation of a patient is shown in Fig. 5. This representation stores an individual `Patient` as an entity participating in the relationship *undergoes* in conjunction with one or more `Health Care Activity` entities (in the text, the names of data model relationships are set in italics). A 1-to-1 relationship going in the other direction also shows that any given `Health Care Activity` *is performed on* one and only one `Patient`.

The thoracic oncology database keeps track of many types of health care activities, as shown in Fig. 5. Radiology procedures are performed in the Department of Radiological Sciences; these are the procedures that are of primary interest to the oncology imaging timeline domain. Pathology procedures occur in the main hospital, while treatment protocols are administered at UCLA's Boyer Clinic. Each health care procedure generates different kinds of results, which are discussed in the next section.

`Patient` entities also have a relationship *has processes* with `Biologic Function` entities; these entities model the processes that go on within the patient's body. A multitude of biologic processes exist, as defined in the UMLS (Unified Medical Language System) metathesaurus and semantic network [22]; the specific process of interest in the thoracic oncology database is the `Lung Neoplasm`.

4.2 Radiologic Reports, Images, and Findings

A `Radiology Procedure` entity *results in* a `Radiology Report` entity and *contains* one or more `Radiology Image` entities. The `Radiology Report` captures, in a textual format, a transcription of the radiologist's reading of the image that was generated by a `Radiology Procedure`. The text of these reports is analyzed by our free-text analysis system in order to extract the structure of the concepts and findings contained within the report text [23].

The `Radiology Report`'s text can be viewed as the radiologist's interpretation of the corresponding `Radiology Image`'s visual appearance. This correspondence is modeled through the `Radiology Finding` entity, which *is included in* a `Radiology`

`Report` after being *extracted from* a `Radiology Image`.

As can be seen in Fig. 5, the `Radiology Finding` entity (including its subclasses) *is visually represented by* a `Frame` within an `Image Stream`. The `Image Stream` entity is modeled using our new stream constructs, as described in Section 3.4.

A similar kind of entity called a `Document Stream` is also defined. Like an `Image Stream`, a `Document Stream` is a time-ordered sequence of entities, although this time the components are `Report` entities instead of image `Frame`s. These `Report`s present the text and other data of `Radiology Reports`, `Laboratory Reports`, `Pathology Reports`, etc., within the context of an overall sequence of documents generated over time.

Because one of the key requirements for the database is to track changes in the size of a patient's indicator lesions over time, the `Lesion` entity *is visually represented by* an `Image Stream` entity, where each snapshot (or `Frame`) within the stream represents the condition of the `Lesion` (or another kind of `Radiology Finding`) during a corresponding radiologic exam. This condition includes the measured size of the lesion at that point in time and the CT image from which these lesion measurements were taken.

Because a patient also leaves a "paper trail" during his or her treatment at the hospital, the documents or reports generated during that treatment are also of interest. Their presentation in the form of a `Document Stream` aids clinicians and researchers by giving the passage of time a visual dimension.

4.3 The Timeline

The individual `Image Streams` of a patient's indicator lesions and the patient's `Document Stream` are combined into an overall oncology imaging `Timeline` entity that forms a comprehensive visual history of the patient's disease. The formal data modeling that supports this aggregation of stream entities, called a multistream, automatically provides temporal synchronization and alignment, so that documents and images are displayed in the correct temporal order when viewed as a single overall timeline (see Fig. 7). This final construct is a comprehensive visual history of the patient that includes both image and textual data, all accessible using the simple and familiar paradigm of a timeline.

4.4 Images

Data modeling of images has long been a focus of the research with our multidisciplinary group [19, 24]. For the thoracic oncology database, we extend the image stack construct introduced in [19] and further developed in [24, 25, 21] and [1].

The image stack construct is an aggregation of related images along a third dimension. The image stack data model maps very well to the volumetric nature of CT data, and this is how we chose to represent such CT scans. These scans constitute a subclass of `Radiology Image` entities, as are other imaging modalities such as X-ray, magnetic resonance, and digital subtraction angiography.

An individual `Frame` of a `Timeline` *is extracted from* these `Radiology Images` when the radiologist selects an image, or series of images, from the CT study that contains the best visual representation of each indicator lesion (primary tumor and several metastases) at that point in time. For example, the first row of images in Fig. 7

shows the best axial representation of the primary tumor obtained from serial CT scans; the second and subsequent rows display the other indicator lesions or pathology of interest obtained from the respective exams. For each selected `Frame`, the radiologist selects a bounding box to identify the region of interest (ROI) and uses calipers to draw and measure the lesion diameters, as is routine in current clinical practice. Once the `Frame` is marked, all annotations are preserved on the timeline. These frames serve as formal documentation of the calculations of tumor volume and as a road map for future comparisons.

We are aware that ideally, all three dimensions should be taken into consideration when tracking the size and nature of lesions. True enough, we would want to base treatment decisions on tumor volume rather than area or linear dimension. Unfortunately, the reality of the current situation is that the physician must frequently make even life-and-death decisions based on very limited data.

5 User Interface

In this section, the interface developed for the thoracic oncology database previously presented in Section 4 will be described. Architecturally, the interface is a custom layer built on top of the KMeD database server, designed specifically for the thoracic oncology application domain. Other application domains may build custom interfaces in this manner to suit their particular needs. Or, they may use the generic KMeD interface that permits greater querying/retrieval flexibility at the expense of additional user interface complexity using the generic PICQUERY+ language. PICQUERY+ is a knowledge-based object-oriented query language for pictorial and alphanumeric database management [25].

5.1 The Main Timeline Display

Fig. 7 illustrates the overall timeline display for thoracic oncology. The display is divided into three primary parts: the main patient list is shown on the upper left corner, a detailed view of the selected patient is shown to the right, and the timeline view itself occupies most of the bottom half of the window.

To highlight the generality of our approach, we have implemented the same type of user interface for the thermal ablation domain. We have added corresponding data from the MR images used in thermal ablation therapy into a virtually identical window as Fig. 7. This data was added to the interface with a minimum of modification to the oncology imaging timeline window — specifically, the timeline display was reset to access a different database. It can be assumed that the succeeding facilities, defined specifically for the oncology imaging timeline, are also applicable to thermal ablation therapy.

5.1.1 Patient Information

To use the timeline, the user must first click on the patient list to select a patient for examination. When this happens, the patient detail view fills itself out with patient information such as his or her name, ID, birthdate, and medical data such as a characterization of the patient's lung neoplasm, its TNM class, stage, and current treatment plan. Below this alphanumeric data is a list of the patients imaging exams (corresponding to the `Radiology Procedure` entities in Fig. 5), indicator lesions (corresponding to the `Radiology Finding` entities in Fig. 5), and technical comments describing the specific technical parameters used for a given exam. These parameters will often be duplicated on successive studies in order to facilitate comparisons between exams. Because this application is tailored specifically for the thoracic oncology group at UCLA, the terms "Radiology Procedure" and "Radiology Finding" in the overall schema are replaced by "Imaging Exam" and "Indicator Lesion" in the user interface; these terms are more familiar and have more meaning to members of the thoracic oncology group than the more generic schema labels.

Clicking on an imaging exam will bring out the state of the patient's indicator lesions on that exam. These lesions are displayed with an ID number, description, location, and measurements (as can be seen in the Imaging Findings list on Fig. 7). If the user clicks on a lesion, details about that specific lesion appear on the righthand side, showing the image number in the study from which the lesion was extracted, window level settings, and graphs or tables of the lesion's measurements. The graphs are explained in greater detail in Section 5.2.

5.1.2 The Imaging Timeline

The most prominent portion of the timeline interface is, of course, the imaging timeline itself. Each row of the imaging timeline represents the individual timeline of one of the indicator lesions. The individual frames of each indicator lesion's timeline are aligned so that the user can also read the display vertically as a snapshot of the user's overall lesion state at the time of the imaging exam.

Section 4.4 described how a region of interest is defined around each indicator lesion at the time that the image is read. When invoked, the imaging timeline takes this region of interest and uses it to center the individual timeline frames around the indicator lesions. The region of interest, as seen in Fig. 7, appears as a red rectangle. Individual line segments, also in red, indicate the diameters drawn electronically by the radiologist who originally read the image (this functionality is provided by our system).

From the imaging timeline display, the user may use scroll bars to view the rest of the selected image, use the mouse to magnify certain portions of the image or to make annotations on it, or invoke a full CT image viewer (described in Section 5.3). The imaging timeline display also determines the way time is scaled in the document timeline (described in the next section), where documents are displayed so that they line up temporally with the images themselves.

5.1.3 The Document Timeline

Below the imaging timeline is the document timeline, which follows the same time scale as the imaging area. Within the document timeline, icons representing various kinds of reports or other events are presented, lined up according to the date when the reports were generated or when the event happened. In Fig. 7, the imaging exams are displayed as date stamps, radiology reports are displayed as miniaturized CT scans, and pathology reports are displayed as red cell icons. When more than one report or event occurs on the same day, the icons are "stacked" together (as can be seen with the set of pathology reports in the lower left corner of Fig. 7).

These event or report icons function as hypertext-style links to the reports themselves. By clicking on an icon, the user invokes a full display of the corresponding report (or event).

5.1.4 Heterogeneous Database Integration

The integrated view of the imaging and document timelines provides a single, at-a-glance display of the patient's overall history. In addition, current hospital systems will typically store image and alphanumeric data in different places; the UCLA Medical Center is no exception. Thus, in practice, the overall timeline view also functions as a heterogeneous database integration mechanism, whereby data from multiple systems and even platforms are seamlessly brought together for the user. Our own integrated view takes advantage of lower-level database integration work that our group has undertaken previously [26].

5.2 Graphs and Tables

As discussed previously, the main timeline display includes mini-graphs of the currently selected indicator lesion. These graphs chart, over time, the product of the lesion's measured diameters and the percent change in these products from baseline. This information is derived from the actual annotations made on the image by the reading radiologist, which are then mapped to millimeters or centimeters by using calibration information provided with the study.

Radio buttons are available to the right of the mini-graph views for selecting a graph or table view of the measurement data. The radio buttons toggle the area occupied by the mini-graphs between the graphs and a table of measurements. If a more comprehensive data display is required, the user can click on the Full View button on the upper right corner of the lesion detail display; clicking on this button open a full graph-and-table window as shown in Fig. 8.

The full graph window features enlarged versions of the mini-graphs in the main timeline display. In addition, it also integrates a measurement table listing and two other summary graphs.

The individual measurement graph, size change graph, and table display all pertain to the indicator lesion that was currently selected when the Full View button was clicked. A lesion selection menu on the upper right corner of the full graph window permits the user to view the graphs and tables for different lesions without having to dismiss the window itself. In addition, summary graphs are shown at the bottom of the full graph window; these graphs are the same for all indicator lesions.

The two summary graphs display a combined view of all lesion measurements and the mean change in size from baseline, respectively. In all graphs, a red circle highlights the individual data point that marks the exact indicator lesion that is currently being examined. All of these visual elements are illustrated in Fig. 8.

5.3 CT Scan Visualization

From the imaging timeline section of the main display, the user can select any single image frame and ask it to "open in full." This invokes our CT scan visualization tool, which is illustrated in Fig. 9.

The CT scan visualizer consists of three main sections: the main image view, the control panel, and the tile view. A small message line also appears at the bottom, for giving out occasional status information.

5.3.1 Main Image View

The main image view, on the upper left corner of the visualizer window, displays an individual CT scan image at its full resolution (512×512 is our default setting, but this is not the limit). In addition to the image itself are any annotations that may have been placed there by a radiologist. In Fig. 9, these annotations include the bounding box for the primary indicator lesion and the diameters drawn through the lesion.

From the main image view, a user may add further annotations, display a magnified view of the image, or perform other functions and operations that may be deemed useful in the future. Because the visualizer is built within an object-oriented development environment, it is relatively easy to add more functions to the image view as the need for them arises.

5.3.2 Control Panel

On the upper right section of the visualizer window is the control panel. The screenshot in Fig. 9 shows a magnification menu, cine mode controls, and window width and level settings. The use of these controls is quite intuitive: to invoke them, the user either clicks on a button, selects an item from a menu, or types a value into a text field. The result of the operation is immediately visible on the main image view.

The cine mode section displays the image number that is currently on display, and permits either frame-by-frame or continuous display of the entire CT study in either direction. The cine buttons on the extreme left and right of the control panel permit the user to jump to the first and last image in the CT study, respectively.

Window width and level may be selected using either pre-configured settings from the menu or by entering custom Hounsfield units (HUs) in the appropriate input fields. For the purposes of the thoracic oncology system, three pre-configured window settings are available: lung, soft tissue, and bone. When these configurations are selected, the width and level input fields on the right display the corresponding values. In Fig. 9, the lung window is currently in use, showing a width of 1600 HUs centered at level -550 HUs.

5.3.3 Tile View

The tile view occupies most of the bottom half of the visualization window. In this section, the entire study is laid out as a set of thumbnail icons. The icons are arranged eight to a row, and are scaled down to 128×128-pixel resolution. The image that is currently in the main view (image number 17 in Fig. 9) is highlighted with a thick red border.

Each image thumbnail is actually a mouse "hot spot" — clicking on it will bring the corresponding image to the main view. A scroll bar on the right side permits the user to scroll through the study, which almost always includes more than 16 images.

5.4 Practical Application by Radiologist

The timeline is designed to provide all functions currently needed by the radiologist in the course of primary diagnosis. We have migrated to a softcopy environment for primary diagnosis of cross-sectional imaging. Ideally, the radiologists workstation will toggle between primary diagnostic review modes and the timeline database; alternatively, the workstation can include separate but integrated hardware platforms upon which the image display monitors and the timeline are situated. After signing onto the workstation, the radiologist can select a patient of interest from the directory listing, thus invoking all information stored on the database for that patient. The technical parameters used to acquire previous studies appear on the menu for easy review and duplication. New imaging examinations to be incorporated onto the timeline are then reviewed.

Based on the data abstracted on the imaging timeline, the radiologist selects axial images from the new examination that best capture the indicator lesions in maximum cross-section. The radiologist applies the bounding box to the frame, lesion diameters are drawn and any additional electronic annotations are performed; these frames are stored on the timeline. Workstation software allows for the automatic calculation of lesion area from the perpendicular diameters. Radiographic tumor response relative to prior exams is also calculated by reference to the prior measurements of the respective indicator lesions and the percent changes are preserved on the graphical and tabular displays described in Section 5.2.

Currently, all data on the timeline is entered manually by the radiologist at the time of primary diagnosis and by dedicated data coordinators from the thoracic oncology group. As automated free text indexing schemes under development become available, automated data retrieval from the RIS/HIS will considerably facilitate time line generation and maintenance.

6 Hardware/Software Implementation

The system has been implemented by our multidisciplinary team as an initial prototype using various technologies being investigated by our KMeD research team [1, 26, 25, 21]. The hardware used includes Sun servers, workstations and RAID (redundant array of independent disks) systems in a Unix environment (Sun Microsystems, Mountain View CA). To provide the multimedia timeline database outlined herein, images are transmitted from the UCLA Picture Archiving and Communication System (PACS) to a KMeD server, while reports and other patient data are transmitted from the UCLA Hospital Information System (HIS) and Radiology Information System (RIS) databases [27, 28]. The software used includes VisualWorks (ParcPlace Systems, Sunnyvale CA) for front end user interfacing and presentation, and the object database management system GemStone (GemStone Corporation, Alameda CA).

7 Conclusions

In this paper, we have described a new unified timeline data model and a corresponding proof-of-concept application domain for multimedia medical databases. The data modeling constructs introduced add to current state-of-the-art modeling tools by providing unified constructs for the representation of multimedia and time-based data.

The proof-of-concept databases are built as a high-level application running on top of the KMeD system which our group has been developing since 1991. Significant features of the database include the ability to display and track lesion development over time, the ability to view relevant documents in full and in relation to the entire timeline history, and the ability to visualize and examine the entire CT studies from which the frames of the timeline were extracted.

The thoracic oncology database presented here, including its data model, timeline interface, and visualization facilities, represents what has been implemented as a real system to date (a medically-oriented description of the use of the system in the overall thoracic oncology process is described in [29]). Similar work has also been done in a different application domain, thermal ablation therapy [30].

Our multidisciplinary group intends to build further on these results by working on full implementation of the multimedia type, intelligent visual entity, and stream models, development of more sophisticated visualization and annotation techniques, and addition of the third dimension (lesion volumes, positioning, etc.) to the overall information model. In addition, we are researching automated and semiautomated image segmentation techniques that will reduce the effort required to obtain accurate and reproducible measurements of tumor volume from CT scans in thoracic oncology. Techniques for natural language processing and free text analysis of radiology reports are also being explored as alternative approaches at automatic data retrieval and generation. As these techniques are developed, the results can be easily incorporated into the models as well.

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