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Data Processing and Presentation for a Personalised, Image-driven Medical Graphical Avatar

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Abstract— **With the continuing digital revolution in the healthcare industry, patients are being confronted with the difficult task of managing their digital medical data. Current personal health record (PHR) systems are able to store and consolidate this data, but they are limited in providing tools to facilitate patients' understanding and management of the data. One reason for this stems from the limited use of contextual information, especially in presenting spatial details such as in volumetric images and videos, as well as time-based temporal data. Further, lack of meaningful visualisation techniques exist to represent the data stored in PHRs. In this paper we propose a medical graphical avatar (MGA) constructed from whole-body patient images, and a navigable timeline of the patient's medical records. A data mapping framework is presented that extracts information from medical multimedia data such as images, video and text, to populate our PHR timeline, while also embedding spatial and textual annotations such as regions of interest (ROIs) that are automatically derived from image processing algorithms. We developed a prototype to process the various forms of PHR data and present the data in a graphical avatar. We analysed the usefulness of our system under various scenarios of patient data use and present preliminary results that indicate that our system performs well on standard consumer hardware.**

I. INTRODUCTION

Modern healthcare has led to numerous forms of digital multimedia data, such as multi-dimensional medical images, photos, videos, sensor and text-based data, frequently being used in a wide range of clinical applications [1-2]. Unfortunately, when patients are entrusted with such data (typically in print, email or on an optical disc), most simply file it away without fully understanding or using the information [3-4]. In order to facilitate improved understanding and sharing of digital health data, many healthcare providers, such as the Australian government's eHealth record system, now provide centralised electronic personal health record (PHR) systems for use by the public [5-6]. To make these technologies more inclusive, recent PHRs have been designed to serve as user-friendly, patient-facing digital repositories that consolidate an individual's medical history and provide tools for communications [7-8].

In addition, PHRs have the potential to be used in a number of critical auxiliary healthcare tasks. These include, increasing understanding of one's own personal health, improving practitioner-patient communication, tracking the course and causes of medical ailments, bridging language barriers and tracking the growth and development of a patient. However, these uses require that data be presented in a context that renders it meaningful and informative to the end-user. Presently available systems do not do this, instead serving largely as repositories or sharing hubs for primarily static data [2,7]. Even so, PHRs are seeing increasing use due to their benefits in data availability, storage and security [2]. Thus, there is a clear need to expand upon the existing PHR capabilities in order to support wider uses and meaningful browsing of the data by patients without special medical skills or knowledge.

A number of researchers have investigated this need [9-11], where medical data visualisations such as timelines, symbols and icons are used to make for an understandable browsing experience in both PHR and practitioner-facing electronic health records (EHR). Each of these, though, focuses on a subset of the problem, such as only examining single medical data types [8] or using less feature-rich displays [10-11]. Further exploration is required to gather meaningful contextual information and present visualisations for the full array of medical data with considerable spatial and temporal contextual data.

Recent studies have begun to investigate the use of avatar-based displays, wherein medical data is delivered by means of a digital 3D atlas of the human body [9,12-13]. Such displays have been shown, in other fields, to enhance self-awareness and recognition memory [13] as well as to improve understanding and information retention [14]. This, in turn, is able to improve patient-provider communication [2], which is known to significantly raise the actual and perceived standard of care [15]. Furthermore, advances in automated image processing and annotation algorithms such as image segmentation and registration, are now readily available [16]. These algorithms can provide a wealth of contextual and semantic data, which can be used to automatically add structure and relationships to otherwise static data. The use of this information to enrich a PHR and improve its display of data is a new and unexplored field with huge potential to improve patient care.

In this study, we present a PHR system, the medical graphical avatar (MGA), designed to explore data processing methods that support a wide array of medical data types, including clinical X-Ray, CT, PET, PET-CT and MRI images, as well as clinical endoscopic video, textual notes, textual annotations and spatial annotations. The processed data is used to automate the presentation of the medical events, being the nodes on the patient's timeline. The avatar us personalised such that the anatomy is constructed from the patient's medical images. Our MGA system highlights spatial regions of interest (ROIs) based on focus date using a timeline navigation bar. Further, the raw medical data is

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displayed 'in situ' over the avatar when a detailed view is selected. We have taken advantage of the advanced capabilities of the HTML5 and WebGL standards to facilitate widespread adoption and to enhance the usability of our system. A prototype is demonstrated to provide comprehensive coverage of medical data types.

II. METHOD

A. Overview

The overall flow of our MGA system is presented in the flow chart in Fig. 1, which illustrates the way in which medical data is processed to extract contextual information. These data are parsed into discrete events, and inserted into a time-based representation of the patient's medical history alongside details for appropriate event-specific data viewers. We define three major data viewers: (i) image viewer; (ii) video viewer; and (iii) miscellaneous viewer to allow the system to handle other data types, e.g., text and signal data.

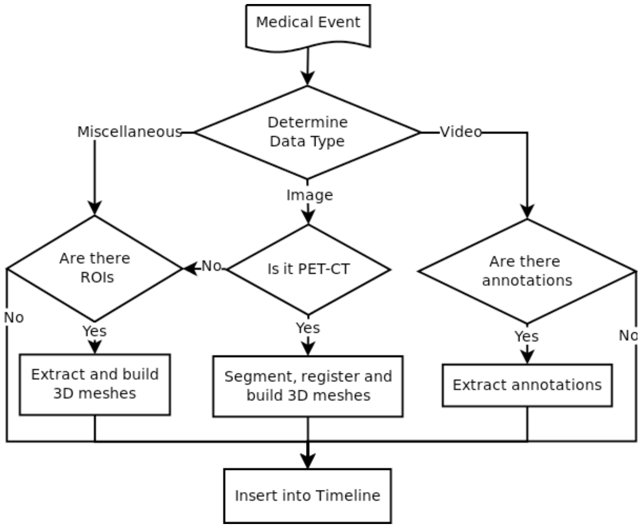

Figure 1. High level overview of our MGA system

B. Image Segmentation and Registration

Whole-body PET-CT image volumes were used in our MGA. Major organs and structures were segmented from both PET and CT data. From the CT, the following were segmented: (i) multi-atlas technique was used to segment the liver [18]; (ii) lung structures with adaptive thresholding followed by estimating the two largest tissues [19]; and (iii) skeleton structure was segmented by intensity thresholding based on Hounsfield Units (HU) [20]. From PET, due to the patient-specific variations in intensity values, Cellular Automata based interactive segmentation technique was used to segment the heart, bladder and tumours [21-22].

C. Data Mapping

1) Displaying Core Event Information

All medical events contain a set of core, textual details. These are: the date of the event, a description, a heading or title, and the anatomical focus of the study. This information is presented on the information panel to the right of the avatar, as in Fig. 2(d).

2) Mapping Image Data

We implemented a specific viewer for images to support image volumes of any modality in standard DICOM format. The image viewer presents the image stack 'in situ' over the avatar, as shown in Fig. 2(b) for PET. Using the core event information, we created a method to spatially locate the event's anatomical focus by traversing the hierarchy structure of the avatar with string matching criterion before rendering the image viewer on the scene using the body part's bounding box. As a result, the viewer displays the medical data (image slice) over this focus and creates navigation buttons that it adds to the information panel.

3) Mapping Video Data

The video viewer similarly uses hierarchy traversal to locate the focus, but the video is instead situated to one side of the avatar as shown in Fig. 2(d), such that no part of the body is obscured by its content. This allows us to use the avatar itself to visually convey meaningful contextual information that aids user understanding, by adding time-stamp-based textual and spatial annotations relevant to the video. In this image, the yellow cone indicates the annotation with respect to the liver and the orange backed writing in the information pane is the textual annotation.

4) Mapping Other Data, Miscellaneous Viewer

With such a wide range of medical data types, it was not feasible to develop specific viewers for every possible medium. As such, a miscellaneous viewer was created to handle all other data types. It works by spatially indicating the anatomical focus of the event, in addition to the core metadata. The notation used is a right-brace symbol, as shown to the right of the body in Fig. 2(c). This allows for the visualisation to add additional spatial cues to aid understanding, no matter the type of medical data.

D. The Avatar and Timeline

1) Avatar Construction and Mesh-based Rendering

In our avatar design, we partitioned the human body into a 10-node hierarchy. This can be seen in the tree structure to the right side of Fig. 2(b), and is based on the key segmented structures of our image data. This hierarchy was used in loading meshes as well as mapping medical events.

For patient studies without an image data, we used the Zubal Phantom [23] to provide these structures, as shown in Fig. 2(a). The Zubal Phantom is a simulated whole-body CT that contains and labels all the major anatomic structures.

Starting from the segmented volumetric images, we first translated these objects into polygonal surface meshes using MeVisLab [24]. These meshes were then losslessly converted to Wavefront Obj format and then rendered by Three.js [25]. A side-by-side comparison is shown in Fig. 3. PET-CT images were fused via data-intermixing with a lookup-table preset [26].

2) Timeline Construction

Our system displays the events in the PHR on a navigable timeline, providing simple browsing of the medical event history. We automated the timeline event insertion via textual parsing based on the SIMILE timeline toolkit [27].

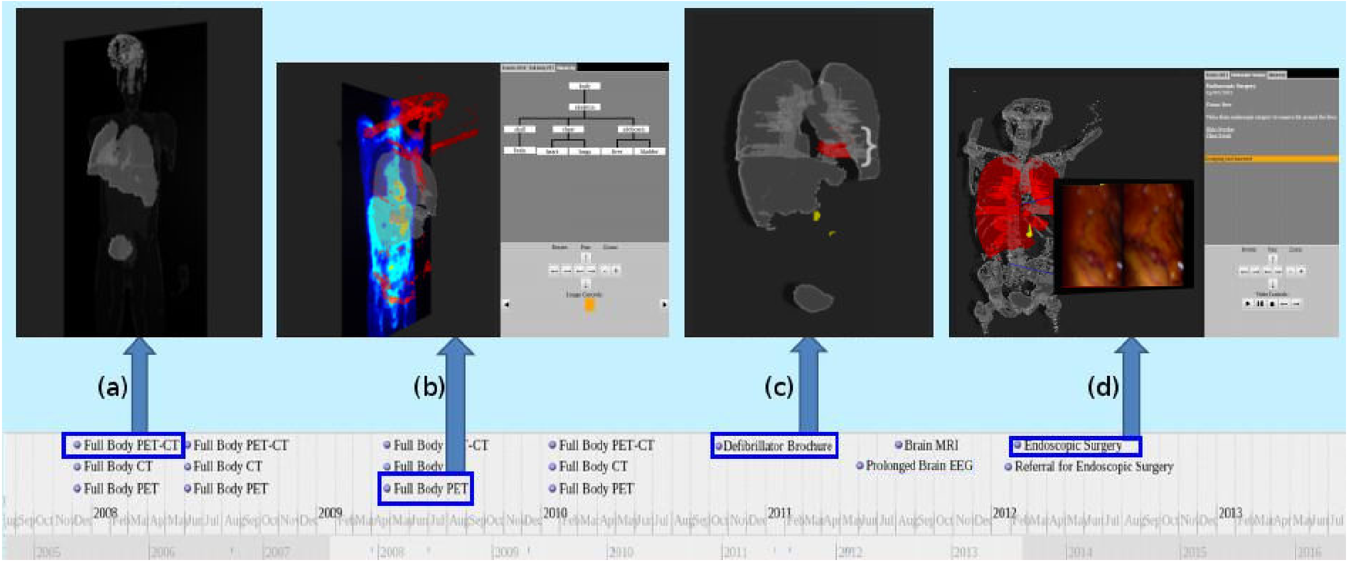

Figure 2. Example of medical events for a PHR showing various data viewers in a timeline (simulated).

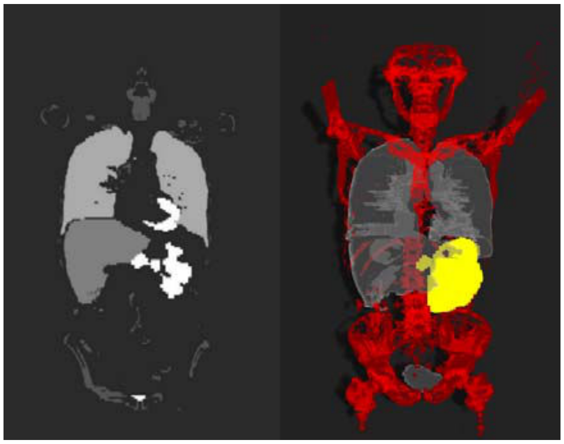

Figure 3. A PET-CT slice compared to the matching WebGL-rendered Wavefront mesh, including ROI tumours highlighted in yellow.

E. Mapping Clinical Data Types

To ensure that the developed system correctly maps medical data, a representative set of clinical data was constructed from multiple anonymised clinical patient data sets. The data were entered into the MGA system in order to test whether events would be mapped to the appropriate body parts and displayed using the appropriate viewer. The results summarised in Table I, combined with the notion that clinical data can be reduced to five main types (image, video, text, signal and spatial), indicate that our MGA correctly classifies and appropriately displays all types of clinical data. That is, sub-types of these data types, e.g. PET is a sub-type of image, load with the correct viewers and are placed on or next to the correct body part of the avatar.

F. Interactive Visualisation and Navigation

To demonstrate that our MGA system correctly updates the 3D scene through timeline navigation, we manually scrolled along the timeline ensuring that the avatar itself, including focus body parts, such as the selection of the heart in Fig. 2(c) were updated.

TABLE I. EVENTS ARE VIEW AND PLACEMENT

Data Type	Tests (Number)	Body Parts (Number)	Correctly Chosen	Correctly Placed
Images[a]	14	6	6	5[b]
Video	6	4	4	4
Other[c]	8	8	8	7[b]

a. Images included 4 CT, 4 PET-CT, 1 MRI and 1 X-Ray study

b. Events mapped to body were placed on the skeleton due to no body mesh being available

c. Other consists of text and signal data

G. Performance

The interactive performance of the MGA system was measured on a desktop PC with an Intel Core 2 Duo 2.50 GHz CPU, 4GB DDR2 RAM and a 512 MB NVidia GeForce 9500M graphics card. Frame rate across all scenarios was a constant 30 frames per second (fps). Load times were measured to test the performance of the system using the Google Chrome Developers Network Panel.

TABLE II. PERFORMANCE OF THE SYSTEM

Number of Events	Initial Load Time (s)[a]	Update Avatar + 1 ROI (s)[b]	Update Avatar + 2 ROI (s)[b]	Update Avatar + 5 ROI (s)[b]
20	8.49	5.03	5.14	5.06
50	9.28	5.06	4.98	5.09
100	9.34	5.10	5.07	5.11

a. Tests were performed with localhost to avoid network variance; Averaged over 10 tests

b. This is transition time for loading new ROI, the HTML page/DOM did not change

We simulated heavy use of our MGA system with a large number of events: 20 events in 5 years, 50 in 10 and 100 in 20. The results in Table II show consistency throughout use of the various viewers and the increasing number of events, suggesting that our system is scalable and that the performance is not limited to the number of events.

III. DISCUSSION AND FUTURE WORK

In this study, we demonstrated the capability of our MGA system to map many different types of medical data to a personalised avatar by extracting information about their temporal and spatial context. Our preliminary results demonstrate that our visual approach can potentially be used to improve understanding of the medical data by extending the capabilities of current PHR systems, such as using our avatar for recognition memory and information retention. The limitations of our study include the lack of complete automation in connecting components of the data flow and processing such as segmentation and creating video annotations. Our future studies will investigate approaches toward automating these tasks, with a view of creating a fully automatic, contextually augmented data flow between clinicians and their patients. An additional expanded aim is that of integrating more data types to be natively supported through viewers. This could extend to building the avatar from MRI and PET-MRI data.

Security is another important issue, which we will investigate as part of our future study. As a web application, our system can easily adopt security standards such as secure sockets layer (SSL) encryption. With further development of our system, we will conduct usability evaluation on users to gather their views and perceived usefulness.

Another possible improvement available through expanding our aims includes connection to ontologies such as SNOMED-CT [28]. This will allow us to provide more detailed information for localising specific events upon the avatar, and could be used to construct relationships between events. Moreover, a similar possibility of connection to ‘dictionary’ avatars such as the Zygote Body [29].

IV. CONCLUSION

Our prototype MGA system presented a new method of processing and displaying medical data on a personalised, image-driven avatar. We have shown that this can be performed through the use of spatial and temporal contextual information that is available with all forms of medical data. Further, our research has been able to plot this data on a timeline to allow intuitive browsing and exploration of one’s own medical data. In doing so, we built and tested the system using entirely clinical medical data.

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