Visual Interpretation with Three-Dimensional Annotations (VITA): Three-Dimensional Image Interpretation Tool for Radiological Reporting

Sharmili Roy · Michael S. Brown · George L. Shih

Abstract This paper introduces a software framework called Visual Interpretation with Three-Dimensional Annotations (VITA) that is able to automatically generate three-dimensional (3D) visual summaries based on radiological annotations made during routine exam reporting. VITA summaries are in the form of rotating 3D volumes where radiological annotations are highlighted to place important clinical observations into a 3D context. The rendered volume is produced as a Digital Imaging and Communications in Medicine (DICOM) object and is automatically added to the study for archival in Picture Archiving and Communication System (PACS). In addition, a video summary (e.g., MPEG4) can be generated for sharing with patients and for situations where DICOM viewers are not readily available to referring physicians. The current version of VITA is compatible with ClearCanvas; however, VITA can work with any PACS workstation that has a structured annotation implementation (e.g., Extendible Markup Language, Health Level 7, Annotation and Image Markup) and is able to seamlessly integrate into the existing reporting workflow. In a survey with referring physicians, the vast majority strongly agreed that 3D visual summaries improve the communication of the radiologists' reports and aid communication with patients.

Keywords Visual summary · Radiology reporting · Volume visualization · Clinical workflow · Information visualization · Volume rendering

S. Roy (✉) · M. S. Brown
Department of Computer Science, School of Computing, National University of Singapore, Computing 1, 13 Computing Drive, Singapore 117417, Singapore
e-mail: sharmili@comp.nus.edu.sg

G. L. Shih
Weill Cornell Medical Center, 1305 York Avenue, New York, NY 10065, USA

Background

Imaging is a vital component of modern medicine. A typical workflow involves a referring physician who requests an image exam and a radiologist who interprets this exam and prepares an exam report. The exam interpretation often involves using image-based tools available to markup annotations on the exam's images, for example, drawing geometric primitives to denote lengths and volumes of interest, drawing arrows with text annotations, and selecting key images from the exam that represent images of clinical significance. A final text-based report is prepared to summarize the findings.

The benefits of the visual annotations made in the exam report are well known in the medical community [1–3]. Unfortunately, however, this information is not always easily viewed by the referring physician. This is due to several reasons starting from software incompatibilities to tedious workflows which require the referring physicians to sift through exams that often contain thousands of images [4] to find and match annotations with the findings described in the report. In addition, because the annotations are made only on a few key images, the context of the annotation within the three-dimensional (3D) volume may not always be clear, especially to the patient.

In some cases, Picture Archiving and Communication System (PACS) vendors employ proprietary annotation implementations. As a result, it is often not possible to view annotations generated in a radiologist's PACS workstation on other Digital Imaging and Communications in Medicine (DICOM) viewers like the ones present in the referring physician's offices or on data given to the patients (e.g., CD-ROMS). As a result, referring physicians sometimes rely only on the text-based reports as primary means to interpret exams and communicate diagnosis to their patients. The inherent disadvantages of text-based reports are well documented in the literature [3, 5, 6].

The project outlined here aims to improve the clarity of communication between radiologists and referring physicians and their patients by presenting a software framework that allows the automatic generation of 3D visual summaries of exam findings. Our application framework, called Visual Interpretation with Three-Dimensional Annotations (VITA), extracts annotations made in the PACS server and generates a visual summary in the form of an animated 3D-rotating volume of the exam with the radiologist's annotations clearly highlighted. VITA summaries are intended to augment radiologists' text-based reports by placing the annotation into a better visual context in the 3D volume. This can help providers both in understanding the radiological reports as well as assist them in communicating diagnosis to their patients.

The key research challenge lies in exploiting annotations commonly made by radiologists to produce a structured visual report. The VITA report is generated as a series of DICOM images which is distributed back to the PACS archive. Since the annotations are now embedded in the DICOM pixel data of the visual report, many issues of software incompatibilities with regards to annotation implementation across PACS vendors are avoided. This also allows our VITA framework to seamlessly integrate within the existing workflow as no additional input is needed from the radiologists and the results are available in PACS. In addition, we have the ability to produce video versions (e.g., AVI, MOV, or MPEG) of the VITA summary for sharing with patients and for situations when access to PACS or DICOM viewers is not readily available.

Materials and Methods

Institutional review board approval was obtained for retrospective analysis of de-identified patient images. The images used in this study are taken from the publicly available cancer imaging archive [7] provided by the National Cancer Institute of National Institute of Health. Twenty-two medical studies were downloaded and annotations were generated by the authors to serve as representative examples. A survey was performed with seven participating referring physicians to gauge their opinion of the usefulness of VITA.

Radiology Reporting Overview

Figure 1 gives an overview of a typical radiology reporting workflow employed in clinical practice. Central to this framework is the PACS server [8] which is used as the central repository of image-based studies and the Radiology Information System (RIS) which is typically where the text-based report of the radiology exam is stored. Medical images are stored in the PACS archive in the DICOM format [9].

Figure 1 also outlines how our visual report module VITA integrates with the current radiology workflow. VITA uses the exam images and annotations employed by the radiologist during exam interpretation to produce a visual summary. This visual summary is sent to the PACS server as a new DICOM series which can be downloaded by the referring physicians for diagnosis.

Annotation Implementation

While PACS and DICOM are supported by all vendor software, the manner in which proprietary software encodes annotations and markup is often a source of incompatibility. Most software, however, use a structured format like Extendible Markup Language (XML) to implement annotations. Furthermore, in order to unify annotations across PACS frameworks, the National Institutes of Health Cancer Biomedical Informatics Grid has initiated the Annotation and Image Markup (AIM) project [10–12] which provides a standards-based annotation format that can be shared between different PACS. With AIM, it is now easy to extract and utilize annotations generated using all PACS workstations compatible with the standard. A few PACS implementations have incorporated AIM already [13–15] and it is being used by other academic institutions [15, 16] for radiological reporting. One key benefit of AIM is that it provides a well defined and structured format using XML for radiological annotations that can be easily parsed. VITA supports the AIM initiative and is compatible with its latest version. AIM has been chosen as a representative standard to present the idea behind VITA; it is not hard to incorporate other clinically used standards like Health Level 7 in VITA to implement the visual summaries. VITA has a built-in module to parse structured annotation files. The current version parses the AIM schema and also XML-based structured format used by ClearCanvas. The parser can be extended to read other popular formats as well.

Other works described in prior literature have examined how to use annotations to automatically generate text-based reports [16]; however, VITA system is the first to target 3D visual reporting. The VITA system does not require any high-level processing or understanding of the annotations; it simply uses what is already provided by the radiologist in routine practice.

VITA Implementation

Our VITA system was developed in C++ using Nokia's Qt cross-platform application and UI framework [17] on an Intel core i5, 2.4-GHz processor with 3-GB random access memory (RAM) and NVIDIA GeForce GT 330-M graphics
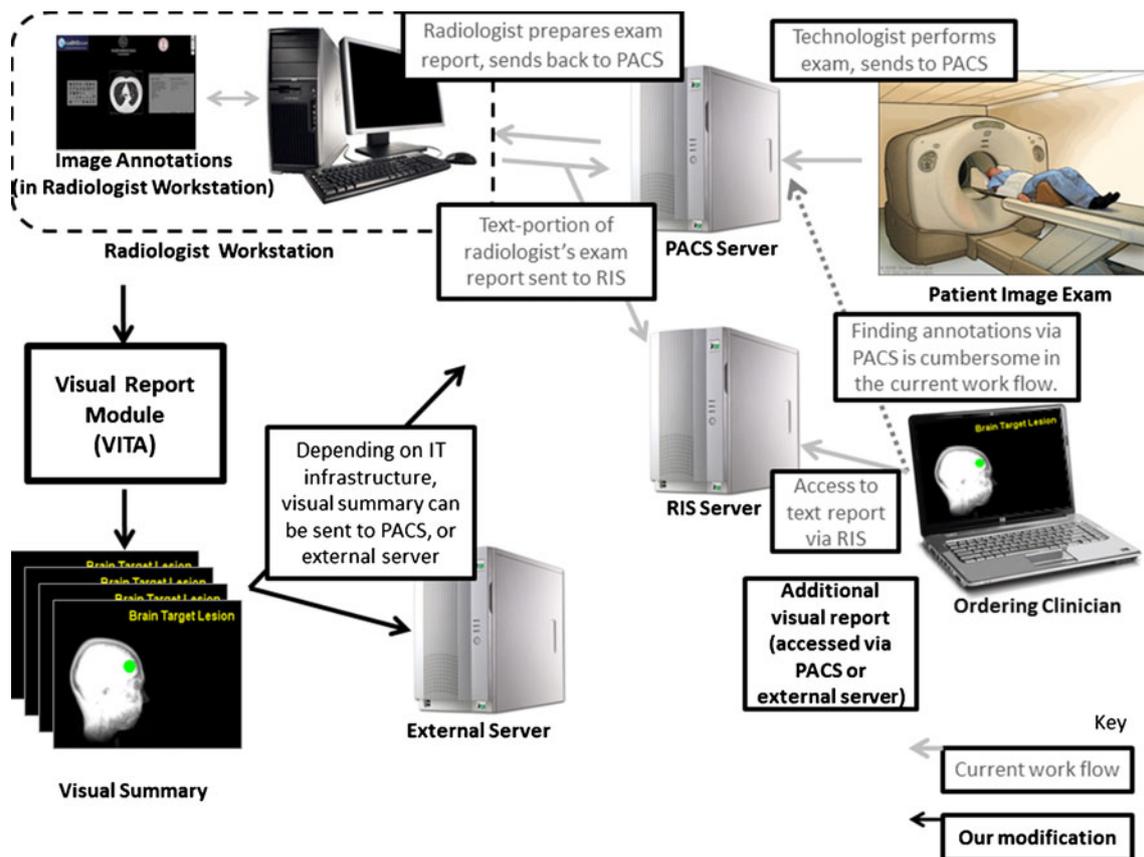
Fig. 1 This figure gives an overview of a typical radiological reporting set-up and explains how our visual report module can be integrated into the existing workflow. Our framework can work either directly with PACS, RIS, or even an external database that is cross-referenced via RIS

card. VITA can be used on standalone computer or with ClearCanvas [13] PACS workstation. ClearCanvas workstation is a free and open-source workstation with an active developer community. It is currently used by 20,000 healthcare professionals worldwide and the clinical edition has been approved by the Food and Drug Administration.

ClearCanvas workstation allows radiologists to draw geometric shapes over images, e.g., lines, ellipses, etc. and associate text with the drawn geometry. This markup is saved either as ClearCanvas study file in the XML format or in the unified AIM schema in both XML and DICOM-Structured Reporting format.

VITA has a built-in XML parser module that mines ClearCanvas study files and AIM XML files associated with a medical exam to extract the annotated geometric primitives, observations, and text tags. The geometric primitives are sent to the rendering engine of VITA which produces a visual summary in the form of a 3D volume animation that renders the volume as it spins 360 ° around the spinal axis. The geometric primitives are distinctly highlighted in the volume. Figure 2 captures this pipeline.

VITA uses ray casting as the primary method to generate 3D volume images. To exploit modern high-end graphic

processing units (GPU), a GPU-based ray casting engine (using NVIDIA's Cg toolkit [18]) has also been implemented which can render high-quality volume images at interactive speed. The ray casting engine takes the pixel data from the exam images and the annotated geometric primitives to first compute a rotating volume with geometry highlighted. The text tags and observations, if any, are then placed over the corresponding geometry to generate the complete summary. Figure 3 outlines this procedure.

As the volume spins, the visual report is saved by generating image files in the DICOM format at every 10 ° rotation of the volume. The Insight Segmentation and Registration Toolkit [19] is used to generate the DICOM images. Open-source DICOM Toolkit (DCMTK) library from OFFIS [20] is used to insert appropriate DICOM tags that compose this new set of DICOM images into an image stack that forms an additional series in the original exam. VITA then pushes this series to the PACS archive using DICOM message exchange functions available in DCMTK. This summary series can now be downloaded by the referring physicians and played in cine mode in their respective DICOM viewers.

Although the VITA visual report is presently generated as a DICOM stack, it is possible to prepare it in other more

VITA Framework

Radiologist performs annotations and markup.

Annotation XML files

Geometric primitives and text tags are extracted from the annotation files.

Visual summary is produced as an animated 3D volume, rendered with highlighted annotations. Format can be a DICOM series or other encodings (MPEG4, flash, etc).
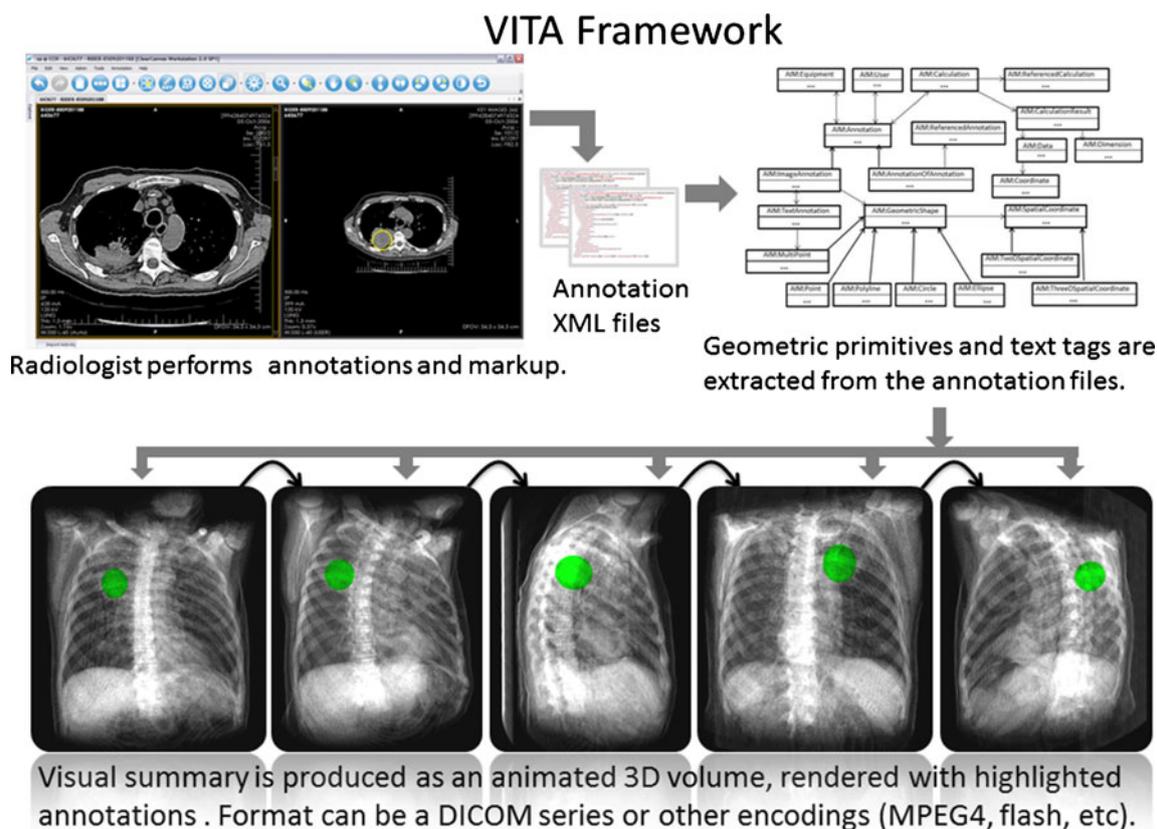
Fig. 2 The VITA framework uses radiologist annotations prepared using a structured format (e.g., XML, AIM). Geometric primitives are extracted from the annotation encodings and used to produce visual summary in the form of a rotating 3D volume rendering

compact video formats such as MPEG4 or Flash, which may be stored in other information systems such as the RIS. This non-DICOM solution might prove to be more efficient for the referring physicians and patients as the reports can now be entirely encapsulated without the need for a DICOM viewer or PACS system allowing for easier access on mobile devices such as tablets or smart-phones.

VITA Evaluation Methodology

To test the effectiveness of VITA, a user satisfaction study was conducted with seven participating referring physicians. The participants were shown three anonymized radiological reports with the corresponding key images that had the graphical overlays of the annotations. The first case reported a solitary pulmonary nodule in lung CT exam, the second case reported tumor in brain magnetic resonance (MR) images, and the third case was about calcified lesion in the liver diagnosed in abdominal CT. For these three cases, participants were also given the visual summaries generated by VITA. Physicians were asked three questions: (1) whether the VITA summaries improve clarity of communication between referring physicians and radiologists, (2) whether the

VITA summaries would be useful in assisting physicians in communicating diagnosis to patients, and (3) whether they would be willing to use the VITA service in their clinical routine if made available. The first two questions asked the participants to rate their answers on a 5-point Likert scale with *1* being strongly disagree and *5* being strongly agree.

Results

A computer running ClearCanvas PACS workstation [13] and the VITA application was connected to a PACS server that contained CT and MR exam images from the online cancer image archive [7]. Images were downloaded from the PACS server onto the workstation and sample annotations were created using ClearCanvas image-based measurement tools and the tools available with the AIM plug-in. VITA parsed these annotation files using its inbuilt XML parser and generated visual reports for each exam based on the respective annotations. These reports were automatically sent by VITA to the PACS server over the network as additional DICOM series to the respective exams. To communicate with the PACS server, VITA requires the server name, server application entity title, and the port on which

Three-Dimensional Visual Summary Generation

The geometric primitives from the annotations are extracted and embedded in the volume to generate 3D volume images

The text tags are then laid over the respective shapes in the 3D images

VITA takes the original study and the annotations as input

Visual Report Module (VITA)

VITA Output
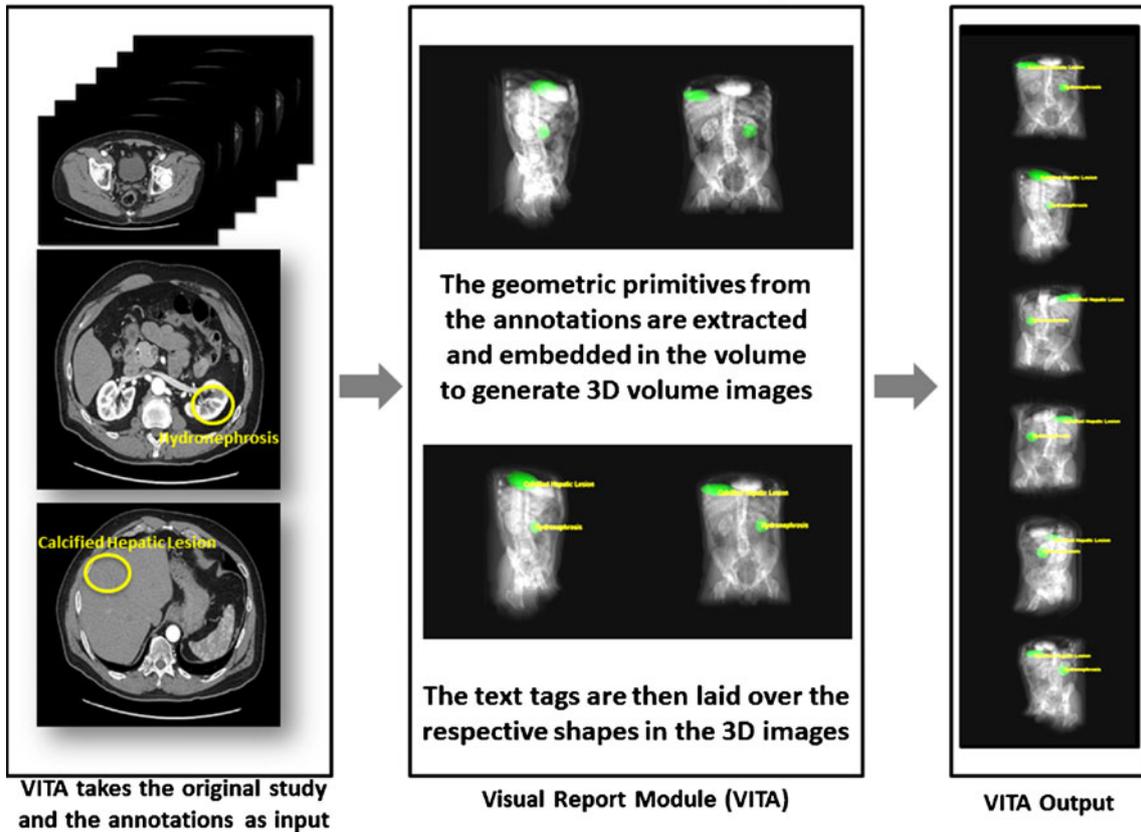
Fig. 3 VITA needs the original stack of DICOM images and the annotation information (e.g., geometry, text tags) to generate the visual summary. The geometry is first embedded in the volume and the text tags are then overlaid to compute the final report
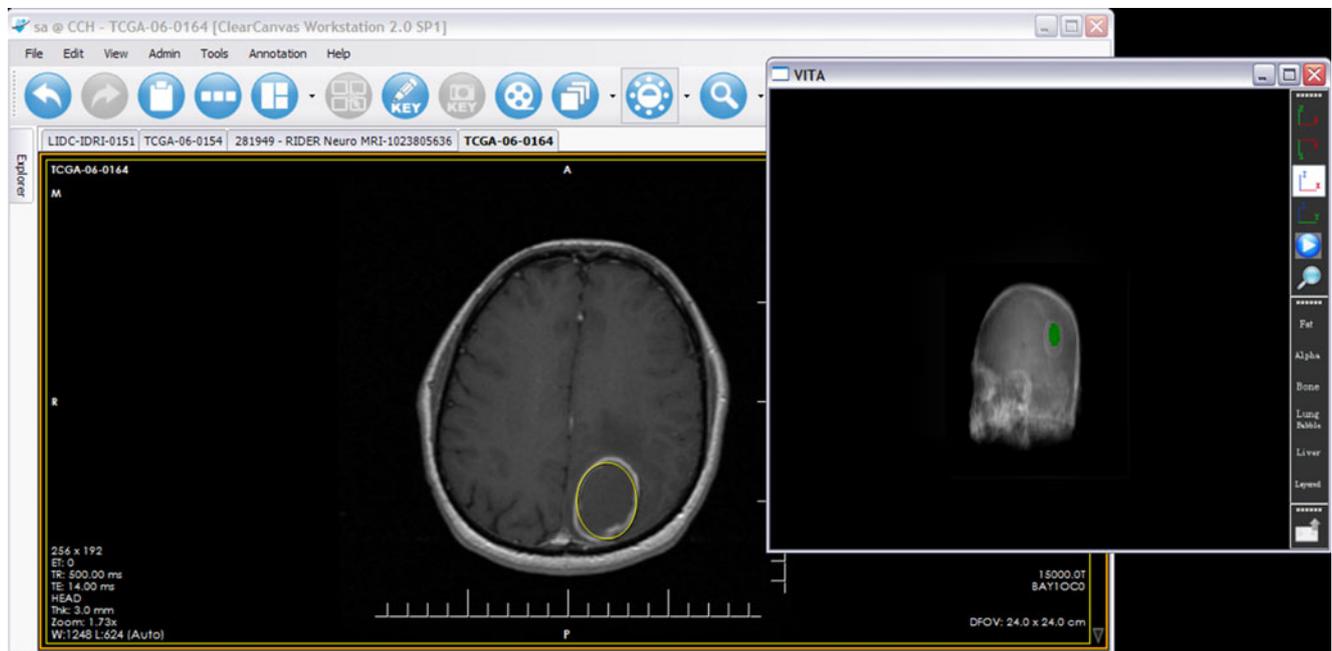
Fig. 4 This figure shows a snapshot of VITA when used with ClearCanvas PACS workstation. VITA reads the annotations made in ClearCanvas and embeds them in the visual report

the server is running at the remote machine. The summary exams were then downloaded and checked in another workstation to ascertain that all the information was properly rendered and saved.

Figure 4 shows a snapshot of VITA. A ClearCanvas measurement tool was used to mark an elliptical region of interest in an MR image of the brain. ClearCanvas workstation stores annotations generated using the measurement tools in the XML format. Figure 4 shows the visual report generated by VITA using the elliptical annotation. The geometric shape in the 3D visual summary shows the shape and position of the radiologist's annotation.

Figure 5 shows example images taken from a visual summary generated by VITA. The annotations visible in this report were generated in the standardized AIM schema using the AIM plug-in available in ClearCanvas workstation. The AIM annotation files are also stored by ClearCanvas in the XML format. The images used in this figure are of a healthy patient; the annotations are representative examples only.

It is possible to control the way annotation text is overlaid on the geometry. For example, VITA can place the text over the geometry and let both spin together, or have the text stationary and color-code it with the respective spinning geometry. Figure 6 shows examples of both the scenarios.

VITA can also selectively highlight important tissues while generating the visual report. This is achieved by applying transfer functions to the exam images such that only the relevant tissues are visible. Figure 7 shows images from

two such reports. The left image is part of a visual report which selectively highlights the bone tissues and the right image is from a report that shows no bone tissues but emphasizes the lung tissues.

After VITA placed the visual reports in the PACS archive, studies having visual reports were downloaded at another computer running a PACS workstation. Visual reports appeared along with pre-existing exam images. The animated visual summary was viewed in cine mode which played the report images at the user desired playback speed. Figure 8 shows a snapshot of the ClearCanvas workstation displaying the visual report.

Figure 9 shows the results of the evaluation survey. Six out of seven participating referring physicians strongly agreed that 3D visual summaries improved clarity of communication between radiologists and physicians and also strongly agreed that 3D visual summaries would aid patient communication. One physician agreed that visual report improves clarity of communication between radiologists and providers and was neutral on whether visual summary aided patient communication. Six participants were willing to use the system in their routine clinical practice. Comments from participants were also positive, samples include "it is a new brilliant concept for patient understanding" and "this is an excellent intervention which helps in better collaboration between physician and radiologist." The only physician who was neutral on using VITA commented "3D rendering does not add additional information for clinician. It looks nice for the layperson i.e., patient, but clinical use is very limited."

Fig. 5 The visual summary consists of a rotating volume with annotations distinctly highlighted. The volume spins to provide a comprehensive 3D context of the important clinical observations. θ in the figure demonstrates the angle of rotation with respect to the spinal axis
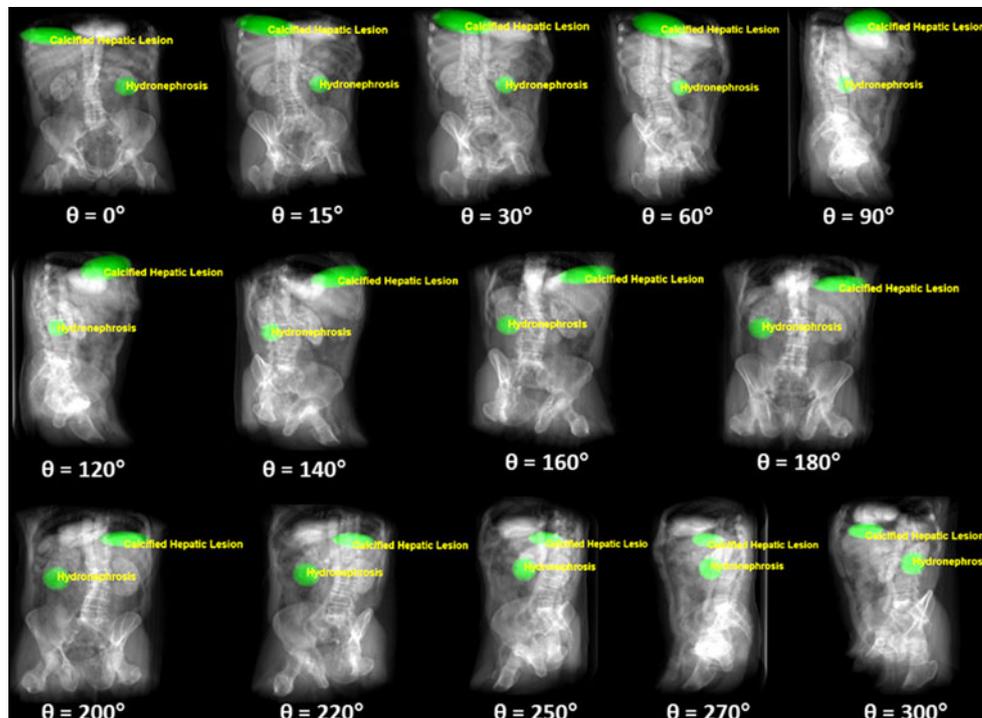
Fig. 6 It is possible to either let the text tags move with the geometry as the volume spins or have the text stationary and color-coded with the geometry
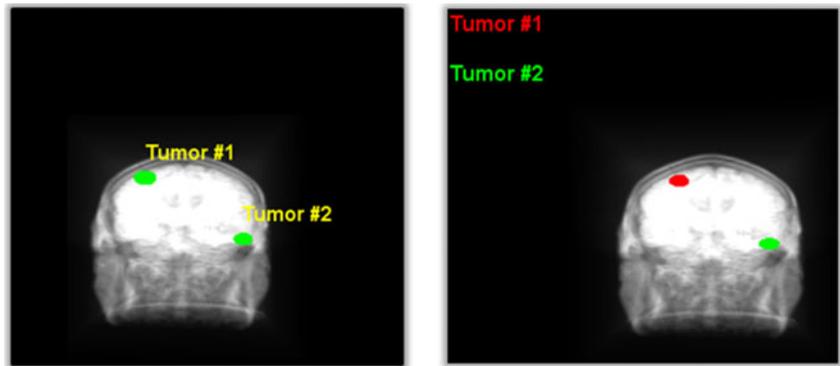
Discussion

We have presented the VITA framework that is able to augment radiological text reports by generating a 3D visual summary that communicates important clinical findings denoted by annotations and markups. Our framework embeds radiological annotations in an animated series of 3D volume images derived from the radiologist report and saves it in the universally used DICOM format. These DICOM images can be distributed using the PACS server and viewed in any DICOM viewer irrespective of the way annotations are implemented in it.

Because VITA framework requires minimal changes to the current radiological workflow, we can easily integrate it into existing systems. Currently, PACS and Electronic Medical Record servers are used to share exam images and text-based reports among radiologists and doctors in a typical clinical set-up. The same infrastructure, along with VITA, is sufficient to share the 3D visual summaries. Radiologists can continue to use their native PACS workstations for annotations. VITA reads these annotations and places a visual summary at the PACS server for easy access to the providers. In addition, VITA requires no user interaction; it can run in the background and automatically generate and archive summary images. If radiologists want to change the transfer function, it can be done by a single click. VITA uses the computing power of GPU available in most modern computing devices. The computation time depends upon the size of the medical exam and the hardware used. On an average, for an exam consisting of 300 images, the total time to compute visual summary is less than 1 min on an Intel core i5, 2.4 GHz processor with 3-GB RAM and NVIDIA GeForce GT 330-M graphics card.

Usability is another aspect of deploying an application into a clinical routine. We have demonstrated our VITA tool to a number of radiologists in Cornell Medical Center and at the 98th annual meeting of the Radiological Society of North America. VITA was appreciated by radiologists and the initial feedback was positive even though information about usability is yet unavailable.

In small-scale medical infrastructures (e.g., smaller community hospitals) it is quite common that a PACS server will be shared by a cluster of institutions via a service provider, while RIS servers will be operated by the institutions themselves. In such scenarios, it may not be practical for VITA to send data to the PACS server. In such situations, the visual reports may be generated in MPEG4 or Flash formats and placed at the RIS server or any external database maintained by the hospital's information system administration. Furthermore, reports in these compact video formats can be easily accessed in mobile computing devices that run no PACS applications.

The recent trend towards patient empowerment advocates that patients' access to their imaging reports be facilitated [21, 22] and radiology reports, or the information in them, should be made more patient-centric. A recent article by

Fig. 7 Certain body tissues can be highlighted using presets available in the volume rendering module of VITA. The *left image* is generated using a preset which accentuates bone tissues and the *right image* is generated by accentuating the lung tissues
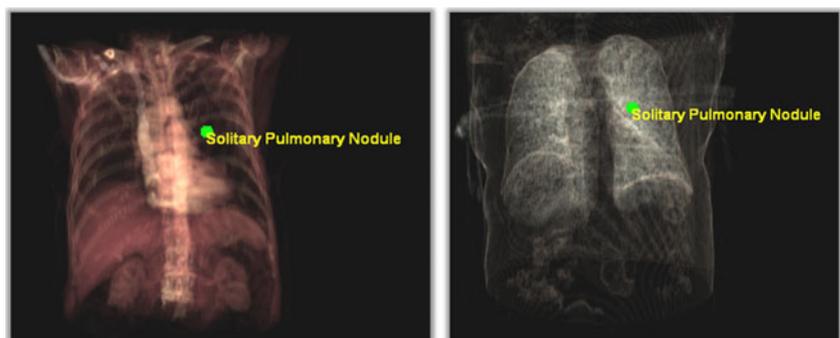
Fig. 8 Once the visual report is placed back in the PACS archive as an additional DICOM series, it can be accessed by clinicians in their respective DICOM viewers. The animated summary can be viewed in the cine mode available in most DICOM viewers
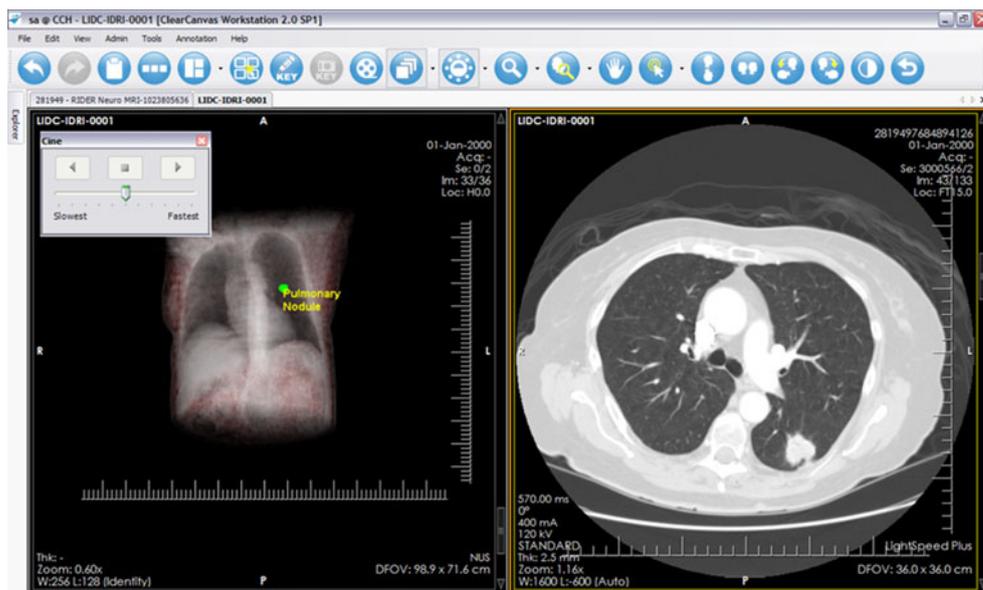
Berlin [23] concludes that radiologists have a medical–legal duty to directly communicate with patients. We believe that 3D images of the VITA visual report are well suited for this patient–radiologist communication. The 3D nature of the images in the visual report and the embedded annotations therein can greatly enhance patients' comprehension of the pathology. Patients can be given visual reports in video formats like MPEG4 or Flash so that they can view the important findings noted by the radiologist on the imaging study without having to access a PACS workstation.

For optimum results, it is desirable that radiologists associate some semantic information with the image markup. Nonetheless, for generation of visual summary, semantic tags are not a pre-requisite. By highlighting the geometric primitives drawn by the radiologist in the visual summary, the annotations are put into a context and the referring physicians and their patients get a better 3D comprehension of the pathology which is lacking in the report and the key images. Furthermore, we believe that if radiologists know that their annotations will be used to generate 3D visual summaries that are useful to referring physicians and patients, they may be more willing to add associated text annotations along with geometric primitives. An idea for future work is to try to extract this additional text information from the text-based report itself. This is a non-trivial problem given the potential unstructured nature of text reports.

We acknowledge that the user satisfaction study for evaluation of VITA is limited with only three sample cases shown to the participating physicians. Visual summary can be generated for all radiological exams that comprise of 3D images; however, the visual displays of image annotations may be most useful in lesion tracking cases.

As referring physicians start to use VITA visual summaries, it is also possible to develop a simple yet powerful visual reporting language that can allow radiologists to provide directives on how the visual summary should appear in

Fig. 9 This figure shows the results of the user satisfaction study performed with seven referring physicians. Six out of seven participants strongly agreed that visual summary improves clarity of communication between radiologists and referring physicians and also agreed that visual summary aids patient communication. Six participants were willing to use this service, if provided
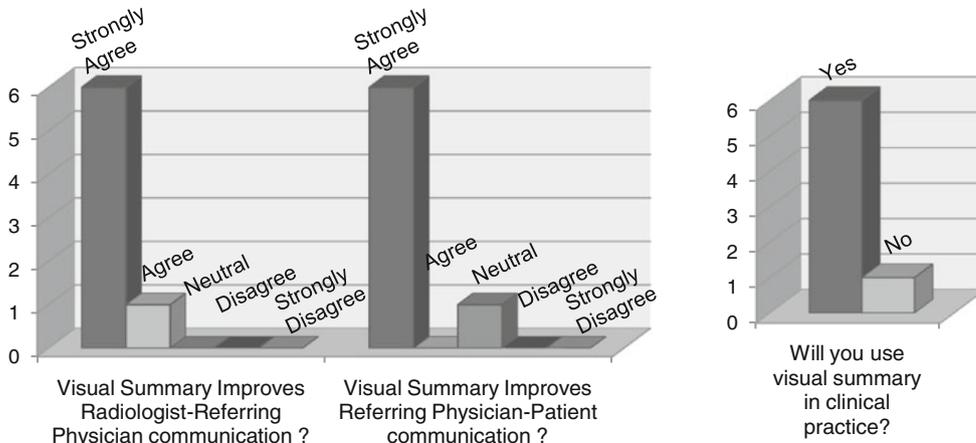
order to visually highlight salient findings to assist the referring doctor's understanding of the patient's disease processes. For example, in a case where a patient has multiple small lesions and one big lesion, the visual language can allow simple keyword annotations, e.g., <highlight> Pulmonary lesion </highlight>, as a directive to the volume rendering engine that this annotation should be displayed in a more prominent manner. By defining a small set of simple tags, radiologists could have more control over the final visual summary. This can help better guide the referring provider's focus towards key findings.

The current version of VITA tool is licensed under a BSD type license and is publically available at http://www.comp. nus.edu.sg/~sharmili/projects/VITA/index.html along with the source code and documentation.

Conclusion

We have developed an open-source 3D visualization and reporting tool for radiological reporting to communicate important image observations to referring physicians in the form of an auto-generated visual summary of imaging studies based on the radiologist's expert annotations. We believe that VITA tool can help deliver better healthcare services by visually aiding provider's diagnostic tasks and empowering their patients with comprehensible exam findings.

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