Data and Sessions Management in a Telepathology Platform

Pedro Nunes[1], Rui Jesus[1], Rui Lebre[1,2][a] and Carlos Costa[1]
[1] *Institute of Electronics and Informatics Engineering of Aveiro, University of Aveiro, Portugal*
[2] *University of A Coruña, Spain*

Keywords: Whole-Slide Imaging, Collaborative Platform, Digital Pathology, PACS, DICOM, RBAC.

Abstract: Digital pathology refers to the acquisition, storage, and interpretation of pathological data gathered by scanners and displayed in a digital environment, using a distributed network system. This paper discusses the challenges and opportunities of a collaborative platform applied to digital pathology considering the advantages that it may carry on regarding education and training but also new paradigms of telepathology and telemedicine. Furthermore, it proposes the implementation of a secure collaborative platform that integrates a web pathology viewer with personal areas and virtual archives. The described approach introduces a modern collaborative concept into the digital pathology workflow supported by a customized medical imaging infrastructure where data management is ensured by an innovator DICOM standard multi-repository server. The solution was designed to serve distinct usage contexts, including telepathology and e-academy.

1 INTRODUCTION

Digital pathology refers to the whole workflow since the scanning of a microscopic image and the associated metadata, until its distribution and visualization. It became popular in the last years due to technological developments and to the increasing trend of adoption of digital scanners. The digital pathology scanners produce what is named Whole-Slide Images (WSI) (Pantanowitz, 2010).

WSI designates the image digitization by scanning microscopy glass slides (Pantanowitz, 2010; Pantanowitz et al., 2011; Saco et al., 2016). The process of digitization comprises multiple magnifications and focal planes, producing high-resolution digital images that can aggregate several gigabytes of data (Farahani et al., 2015). Digital pathology is replacing the conventional light microscopy, potentiating new applications in education, training and diagnosis (Saco et al., 2016; Triola and Holloway, 2011).

Opposing a traditional pathology environment, the specimen storage is cheaper as the samples do not require specialized protection carried out by trained staff.

A wide variety of advantages emerge from this modern branch of medical imaging in production and clinical environments as, for instance, the process of storing and remote viewing, annotation, and reporting. Unlike the traditional slides, the whole-slide images do not deteriorate over time and it is possible to assure homogeneity of the display quality of the images (Foster, 2010). Moreover, further pros come across, for instance, improvements in the diagnostic accuracy, integration with hospital information systems or availability of distributed work processes as collaborative work and telepathology (Pantanowitz et al., 2011; Bueno et al., 2016a).

WSI has introduced new methods to teach histology and pathology in the academic field that was not possible until nowadays (Saco et al., 2016; Pantanowitz et al., 2012). The teaching of pathology is simplified by the digital trend as the slide can be accessed simultaneously by as many teachers and students as required, and it is only necessary to hold a computer or a smartphone to operate the image, unlike the physical specimen which can only be handled by a handler at a time. Additionally, the availability of a slide in the digital format allows the remote access from anywhere and from any device instantly, including previous examinations that could be hard to find in the traditional physical archives. Yet, systems like these demand strong access security since they can be operated in open networks. Many of the cases require confidentiality considering the sample private data related to the patient and the regulations in force (Abouelmehdi et al., 2018).

[a] https://orcid.org/0000-0002-3230-0732

Nunes, P., Jesus, R., Lebre, R. and Costa, C.
Data and Sessions Management in a Telepathology Platform.
DOI: 10.5220/0008969904550462
In *Proceedings of the 13th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2020) - Volume 5: HEALTHINF*, pages 455-462
ISBN: 978-989-758-398-8; ISSN: 2184-4305

Concerning the clinical environment, WSI and digital pathology make the diagnosis simpler and faster as the slide can be dynamically viewed, navigated and magnified on screens in a network (Bueno et al., 2016b). Professional WSI viewers can be integrated into the hospital databases and be accessed within the network or made available for research, remote diagnosis and consultation (second opinions, among others) (Bueno et al., 2016b; Pantanowitz et al., 2015). Some authors (Pantanowitz et al., 2015; Chordia et al., 2016) report a crescent need for telepathology and digital pathology in the daily routine practice. In (Chordia et al., 2016), 98% of the 247 histopathologists interrogated, felt the need for telepathology and digital pathology. However, only 34% declared the use of telepathology in medical practice. These facts may reveal demand for solutions of telepathology and collaborative platforms not only for clinical but also for educational purposes.

However, the development of a capable user interface to aid in the adoption of these new technologies is one of the improvements that can help the teaching and collaborative diagnosis nowadays. The integration of new features impossible to include in the traditional methods became a reality, as the presence of a thumbnail to allow a fast and immediate panning, the possibility of annotate regions of interest directly in the sample and live discussion platform, for instance.

This paper proposes a solution[1] for the lack of collaborative platforms suitable for both teaching and clinical paradigms by deploying a secure architecture integrated with a digital pathology viewer[2]. The platform integrates a pure web pathology viewer (screenshot in figure 1) fully compliant with Digital Imaging and Communications and Medicine (DICOM) standard and a security layer to restrict and control the access to studies (Lebre et al., 2018b), taking advantage of the Dicoogle open-source project (Valente et al., 2016) support for WSI storage.

The collaborative viewer supports new features like an image handling toolbox, shared pointers, and synchronized actions. In the persistence layer, the archive server was redesigned to support an innovator multi-repository concept. Data management security is ensured through the integration of an accounting mechanism specifically developed to medical imaging environments, allowing the creation of virtual archives for each user. For instance, it allows the restriction of access to only particular studies within a group domain. The mechanism allows the centralization of the storage, creating different permissions of access to different institution resources.

[1]Demo Video: https://youtu.be/Mmsb25edcOo

[2]Demo: http://demo.dicoogle.com/pathobox

2 BACKGROUND

2.1 PACS-DICOM Universe

Implementations of Picture Archiving and Communication Systems (PACS) have risen with the move towards digital radiology (Beckwith, 2016). A PACS is a set of distinct hardware and software technologies comprising medical image and data acquisition equipment, storage equipment, and display workstation, all of which are integrated by digital networks. PACS relies on DICOM. DICOM is one of the most popular standards in the medical imaging field (Silva et al., 2019). DICOM provides a guide to support interoperability between multiple vendor equipment and systems (Bidgood et al., 1997).

In the early time of the launching of DICOM, the propose was to create a standard format for storing and handling of radiology images (Godinho et al., 2017). Notwithstanding, other modalities were introduced, such as nuclear medicine or Breast tomosynthesis (Beckwith, 2016) and, more recently, microscopy, as a result of the rapid spread and adoption of the standard. Later on, the publication of the supplement 145, addressing digital pathology, boosted the development of the automated whole-slide scanners (Bueno et al., 2016a).

DICOM standard is being continuously updated by the addition of new extensions with the goal of keeping it up-to-date regarding the needs. However, unlike the traditional patient-centric DICOM information model, WSI are considered specimen centric as the specimen is the most relevant object (Daniel et al., 2009; Daniel et al., 2011a).

NEMA, the organization behind DICOM, introduced adjustments to the standard foreseeing the support for WSI, taking into account the necessary adaptations to hold the high-resolution images. Nowadays, the standard integrates the data elements, the definition of the workflow of the preparation, acquisition, handling, and storage of WSI (Beckwith, 2016; Daniel et al., 2011b).

2.2 WSI Visualization

One of the key challenges of the display and visualization of the whole-slide images is the big amount of pixels produced by the scanners so the information may have the required quality. With the increase of the number of pixels, also the file size increases, making the remote display via a web browser of the samples difficult. Once their size is much greater than the regular medical images and cannot be displayed locally due to the amount of memory available in most

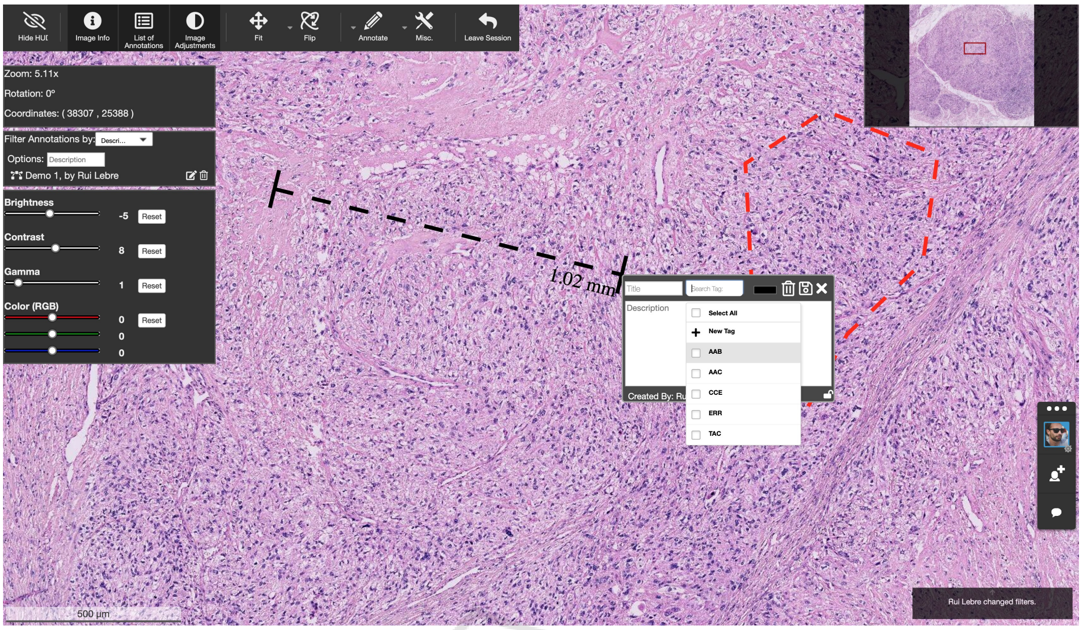

Figure 1: Collaborative web pathology framework screenshot.

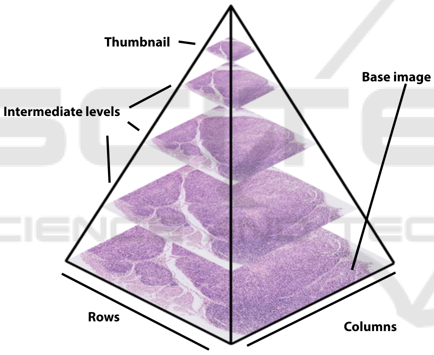

Figure 2: DICOM supplement 145 proposes storing Whole-Slide Images in tiles from a multi resolution hierarchy in multi-frame object. Adapted from (Daniel et al., 2011a).

computers (Goode et al., 2013). Nowadays, as a result of the presented challenges, navigation in the digital slide is performed using a pan and zoom approach. The solution comprises a pyramid approach (Figure 2). In this pyramid approach, intermediate levels are generated until the thumbnail is obtained. Figure 3 shows the workflow where pathologists must browse and select a region of interest in the thumbnail for further zoom in to a higher resolution.

Nowadays, solutions like Google Maps or Libraries Digital Catalogs (e.g., New York Public Library, National Library of Australia) adopted this approach for image and maps handling.

2.3 Related Work

In this scope, solutions that support digital pathology with a collaborative platform on both commercial applications and scientific literature were taken into account. An in-depth analysis of the retrieved studies was carried out and allowed us to conclude that no solution, commercial or not, is available publicly, supporting a collaborative viewer of DICOM WSI on a standard PACS.

However, the literature revised reports works where collaborative systems where multiple users can access and work on the same image. Daniel et al. (Daniel et al., 2011a) that Collaborative Digital Anatomic Pathology can only be achieved using medical informatics standards. Some authors (Beckwith, 2016; Daniel et al., 2011a; Tuominen and Isola, 2010) refer to DICOM supplements 122 and 145 as the standards focusing the whole-slide imaging handling. They also describe how WSI can be integrated into standards like DICOM and HL7.

In (Lauro et al., 2013), the authors propose a set of web-based tools to support the workflow of digital pathology consulting and allow the viewing of WSI over the web. The authors also state that the digital pathology segment is dominated by a set of vendors who have developed their own proprietary format and viewing solutions. Furthermore, it is reported that most of WSI vendors provide their own viewing solutions. In the cases where the viewer is available, it only supports the proprietary formats of each vendor,

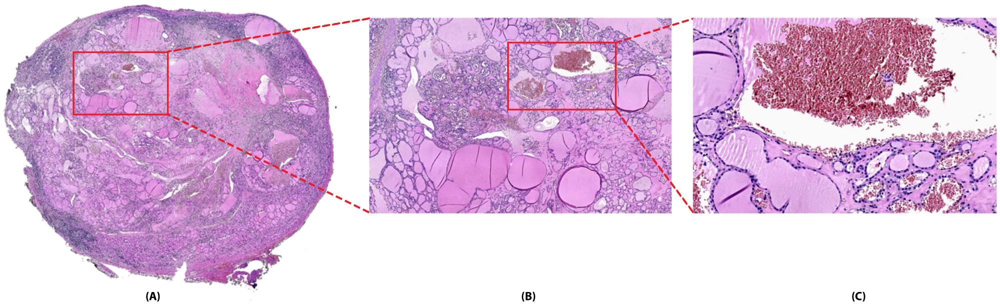

Figure 3: Example of zooming a Whole-Slide Image in the viewer presented. (A) Thumbnail of the digital slide; (B) Intermediate level of zoom; (C) Full zoom level of the image.

in a standalone usage.

Chandrakanth et al. (Bernard et al., 2014) presents guidelines and problems related to the reason why telepathology for primary diagnosis has not yet become current practice. In the same paper, the authors reveal iPath (Brauchli and Oberholzer, 2005), a Web-based telepathology platform that permits the online presentation and discussion of cases within user groups.

Díaz et al. propose in (Díaz et al., 2018) a web-based telepathology framework for collaborative work of pathologists. However, this platform does not comply with the DICOM standard neither addresses the academic scenarios.

Moreover, the research came across with similar platforms in the area of radiology (Zhang et al., 2000). Bankhead et al. (Bankhead et al., 2017) propose an extensible open-source software for digital imaging named QuPath, powering users with scripting tools. However, it does not address the collaborative environment and DICOM support.

Carestream[3] (Snyder et al., 2001; Weiss, 2012) is a commercial platform built on a consulting basis and not suitable for collaborative environments. Besides, Carestream is only applicable to radiology and cardiology modalities.

3 ARCHITECTURE

This section describes the modules that compose the collaborative platform and the integration with the Dicoogle PACS repository, intending to provide real-time collaboration between users. The architecture was designed to be as flexible as possible, hence why it is divided into multiple independent modules, making it possible to develop and add features to each module, without affecting the remaining, as well as completely swap one of the parties while retaining the functionality.

The system is divided into the following three major components: a PACS archive where the case studies are stored; a web viewer that fetches the slides from the case studies in the archive; the collaborative platform that informs the viewer about the session details and their participants and where the user can manage their sessions. These interactions are depicted in Figure 4. The PACS archive and the Viewer had already been developed in a previous work (Godinho et al., 2017), however, it was necessary to redesign those elements and implement new mechanisms to support real-time collaboration between users.

TogetherJS[4] is an open-source technology that provides real-time collaboration features. It is used by the web viewer to manage the sessions, handling the synchronization of events across all the participating users.

The collaborative platform is agnostic to the web viewer, due to an abstraction layer defined between the two components that facilitate the use of different viewers with minimal adaptation efforts. This is possible because the actions of multiple users throughout a session can be made abstract, i.e., independent from the source (viewer) they came from.

3.1 Management of Sessions

A working session is a collaborative session created over an image from the PACS repository. The collaborative platform is responsible for the creation of these sessions and the management of its participating users and their permissions. A session is composed by its creator, a list of users and their respective permissions, the PACS archive image, the list of events that happened in that session and additional information to tell the web viewer how to handle this session.

A session is defined by a unique ID that allows the sessions to be uniquely identifiable across the system.

[3]https://www.carestream.com/en/gb/medical

[4]https://togetherjs.com/

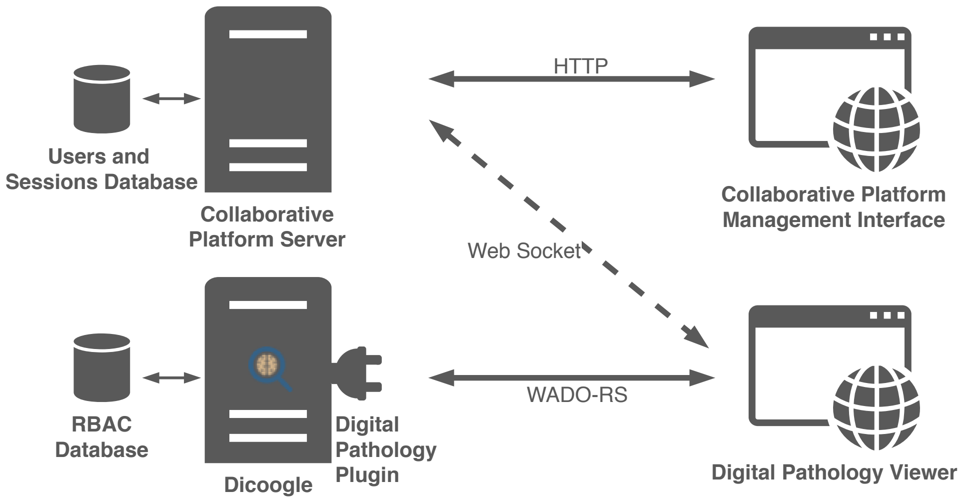

Figure 4: System general architecture. Dicoogle and its plugins serve the Web Viewer with the WSI. At the same time, the viewer is connected to the collaborative platform server via WebSockets to retrieve the session details and users' permissions. The collaborative platform management interface provides a dashboard to manage all the sessions, users, and groups.

This aspect is crucial since one image can have multiple sessions associated with it, with each session having its own users and events. Furthermore, one user can create multiple sessions using the same image.

The creation of sessions was designed to facilitate the invitation of other users. Therefore, a unique web link is generated for every user in a session. The uniqueness of this weblink is guaranteed by combining the ID of the session with the ID of the user.

Weblinks allow access to a session without having to use the platform itself. Only the creator is required to be logged into the platform since it is still necessary to define the configurations of the session. For further automation of the system, emails are used as IDs to identify the users on the platform. By using emails, it is possible to share the web links of the session automatically, turning the process of the invitation of new users transparent and agile.

Additionally, by sending the invitation links through email, it is naturally secured the access to this link, since only the owner of the email has access to it.

By having the user IDs on the web link, it is possible to register the sessions that each of the potential participants were invited to, so that if a user did not sign in into the platform yet, the access to all the sessions he was asked to is still granted, as long as the email used to sign in is the same as the one sent with the invitation.

On the viewer side, since the user will be accessing it through the web link and the link contains both the user ID and the session ID, it is possible to query the collaborative platform for the details of the session and the permissions of the user. At the same time, it can also verify if this user already is connected to the session.

Since sessions are based on web links, the concurrent access control is assured by which link is in use at the current time, due to notifications sent from the viewer to the platform, preventing the same link from being used simultaneously in another viewer, in the case if a user shared the unique and non-transferable link. It is, therefore, possible to keep control of the number of users in a session, and it is assumed that their identity is also correct since the unique access links were sent via email.

On the other hand, it is possible to use a public link, which is missing the user ID. This modality seeks to give the creator permissions to invite users without the need for an email. A limit can be defined on the number of people that can access a given session through a public link. The generation of this link is optional.

This way, the creator can invite a specific group of people without knowing their emails by creating a public link, with a possible max limit for its usage, and manually share it. In this scenario, the invited users can access the viewer session, but would not be able to access the managing platform, which requires their email to be added to the session.

3.2 User Actions and Synchronization

To maintain synchronicity between the users, each event performed upon the image in the Web Viewer, such as zooming in or changing the saturation, is broadcast to the remaining users, using TogetherJS.

This structure allows the separation between the entity which records the actions of the session and the entity that replicates the session.

Additionally, the events are stored in a database, ensuring that users that lose the connection temporarily, or are joining in an ongoing session, retrieve the missing events, keeping up with the rest of the users. This also allows users to open a standalone copy of a session, a replay session, replicating chronologically the events, in which a user can inspect the actions performed.

Since many users can interact with the image at the same time, certain events can happen in a different order from user to user, leading to inconsistent states throughout the session. Therefore, an asynchronous system is used in which all the users will eventually be in the same state. Despite having multiple sessions states across the different viewers, the database is keeping only one of those versions, which ultimately will be the final one.

Furthermore, only certain actions, like zooming or panning the image, create these different states, and all users are sent to the same state right after one of these events happen, without conflict. I.e., when two different zooms on the image are executed at the same time, the users might end up on different zoom levels. If a third zoom is effectuated, all of the users will end up in the same zoom level, keeping all the session users synchronized. A study was conducted to evaluate the impact on the usability of the viewer with these inconsistencies. Since a user will only be in an inconsistent state for a very short time and since the most crucial actions, like color filters or annotations, do not cause an inconsistent state, it was considered that no delay should be added to the propagation of the action. So, it was concluded that the user actions should be responded immediately after the execution, rather than wait for the server confirmation.

Due to the nature of the working sessions and due to the dimensions of the whole-slide images, many zooming or panning type of events are generated, even though they have minimal if any, visual impact. Thus, despite all events being broadcast to keep the synchronization between the users, when storing in the database, the events are filtered, guaranteeing that only the events that make a noticeable difference are stored. This prevents a heavy workflow of messages being sent between the components and improves the loading time of an ongoing session in the web viewer, as well as, improves the replay experience, due to the presence of only relevant information.

3.3 Access Control Mechanism

This article proposes a collaborative platform architecture that supports multiple users with associated resources, including personal data archives with sensitive information. General Data Protection Regulation (GDPR), applied from May 2018, defines specific guidelines in healthcare and the use of best practices to minimize the risk of a security breach (art. 32). It requires that personal data needs to be protected against illegitimate processing, accidental loss, destruction or damage. Following this regulatory obligation, the platform was provided with resources ownership mechanisms that protect resources from unauthorized access. Those resources may be image objects, management or organizational services.

As a result, the collaborative system is obligated to work with a multi-archive paradigm that must be supported at the persistence layer, i.e., at the standard medical imaging repository without interfering with regular DICOM workflows. In practice, it is requested an accounting mechanism that must be capable of associate the repository resources permissions, and delegation of rights, to third entities. The solution adopted is based on the Lebre et al. (Lebre et al., 2018a) RBAC (Role-Based Access Control) mechanism for standard DICOM archives.

The solution provides ownership concept and access control over medical imaging resources, allowing to deploy different permissions to multiple users and institutions. It opens doors to the creation of numerous virtual archives with various studies each that can be shared between users of different realms. For instance, digital pathology studies can be shared between distinct institutions and a working session can be created with a study shared among multiple users from different institutions.

The proposed access control model is an abstraction of real-work medical imaging environments. It allows the management of Organizations, Facilities, Users, Permissions, Resources, and Permission Sharing. For instance, in the academic context, the organization shall be the University. Bellow the hierarchic position of the organization, the Schools are representing the Facilities. Belonging to the schools, there are the Students A, B and C, the Professor and the Resources 1, 2 and 3. At the collaborative layer, the security mechanism is allowed to create a session for a limited number of users who have permission to access only some of the studies. Assuming that a class is composed of students from two distinct departments, where the studies to be analyzed belong to both the departments, with this accounting mechanism framework, it is possible to share permissions between students and professors so that everyone can work in a collaborative workflow. Furthermore, the access can, hypothetically, be restricted to some hours of the day. For instance, access can be limited to class time only.

4 USE CASES

This section presents the possible use cases of a collaborative pathological viewer. It was already shown the advantages of using a WSI web viewer to work on digital pathology samples for diagnosis and academic purposes. By turning such a viewer into a collaborative one, where several users can interact and discuss one sample at the same time, it extends the viewer's utility, improving the concept of telepathology. There are two main fields where a collaborative viewer could prove very useful: the educational field and the clinical environment (Pantanowitz et al., 2011; Saco et al., 2016; Triola and Holloway, 2011; Bueno et al., 2016a; Patterson et al., 2011).

In the educational field, the presented system allows, for instance, the following use cases:

- Create groups per class and teach that class online, with the possibility of enforcing a schedule to attend;
- Create an exam and analyze each student's responses through the replay tool;
- Give an open lecture allowing the public to follow it through the public link;
- Create study sessions amongst students.

On the other hand, the clinical research environment is, perhaps, the environment that benefited the most from the implementation of an accounting system. The introduction of such a mechanism allows the restriction, control, and auditing of the access performed to specific patient or study data. Among the multiple use cases in this field, there are cited below:

- Ask for a consultation on a case by inviting a fellow doctor into a session;
- Create a work session to discuss a medical case with other doctors;
- Review diagnostics performed on cases through the replay feature (if the diagnostic was done on a previously created session).

Both the environments benefit from services like the session-catch replay that consists in the fast replay of all the operations performed until the present moment. Additionally, a session administrator may revoke access and terminate the session.

5 CONCLUSIONS

Collaborative work is a fundamental improvement in the modern medical image environments, addressing educational and diagnosis purposes.Digital pathology and telepathology are an emerging modality in the clinical decision-making laboratories and with the clinical staff supporting the development of new tools. (Bellis et al., 2013). This paper describes an architecture for a real-time collaborative digital pathology viewer with access control mechanisms integrated. The proposed system is based on the concept of working sessions that can record the actions performed by the users over time. The design was created using merely web technologies to address interoperability with multiple platforms. The potential benefits and gains in using a system like the one presented are justified with the clinical and educational points of view presented in the use cases section.

ACKNOWLEDGEMENTS

This work has received support from the ERDF European Regional Development Fund through the Operational Programme for Competitiveness and Internationalization, COMPETE 2020 Programme, and by National Funds through the FCT, Fundação para a Ciência e a Tecnologia within the project PTDC/EEI-ESS/6815/2014.

REFERENCES

Abouelmehdi, K., Beni-Hessane, A., and Khaloufi, H. (2018). Big healthcare data: preserving security and privacy. *Journal of Big Data*, 5(1):1.

Bankhead, P., Loughrey, M. B., Fernández, J. A., Dombrowski, Y., McArt, D. G., Dunne, P. D., McQuaid, S., Gray, R. T., Murray, L. J., Coleman, H. G., et al. (2017). Qupath: open source software for digital pathology image analysis. *Scientific Reports*.

Beckwith, B. A. (2016). Standards for digital pathology and whole slide imaging. In *Digital Pathology*, pages 87–97. Springer.

Bellis, M., Metias, S., Naugler, C., Pollett, A., Jothy, S., and Yousef, G. M. (2013). Digital pathology: attitudes and practices in the canadian pathology community. *Journal of Pathology Informatics*, 4.

Bernard, C., Chandrakanth, S., Cornell, I. S., Dalton, J., Evans, A., Garcia, B. M., Godin, C., Godlewski, M., Jansen, G. H., Kabani, A., et al. (2014). Guidelines from the canadian association of pathologists for establishing a telepathology service for anatomic pathology using whole-slide imaging. *Journal of Pathology Informatics*, 5.

Bidgood, W. D., Horii, S. C., Prior, F. W., and Van Syckle, D. E. (1997). Understanding and using dicom, the data interchange standard for biomedical imaging. *Journal of the American Medical Informatics Association*, 4(3):199–212.

Brauchli, K. and Oberholzer, M. (2005). The ipath telemedicine platform. *Journal of Telemedicine and Telecare*, 11(2_suppl):3–7.

Bueno, G., Fernández-Carrobles, M. M., Deniz, O., and García-Rojo, M. (2016a). New trends of emerging technologies in digital pathology. *Pathobiology*.

Bueno, G., Fernández-Carrobles, M. M., Deniz, O., and García-Rojo, M. (2016b). New trends of emerging technologies in digital pathology. *Pathobiology*, 83(2-3):61–69.

Chordia, T., Vikey, A., Choudhary, A., Samdariya, Y., and Chordia, D. (2016). Current status and future trends in telepathology and digital pathology. *Journal of Oral and Maxillofacial Pathology*, 20(2):178.

Daniel, C., García Rojo, M., Bourquard, K., Henin, D., Schrader, T., Mea, V. D., Gilbertson, J., and Beckwith, B. A. (2009). Standards to support information systems integration in anatomic pathology. *Archives of Pathology & Laboratory Medicine*, 133(11):1841–1849.

Daniel, C., Macary, F., Rojo, M. G., Klossa, J., Laurinavičius, A., Beckwith, B. A., and Della Mea, V. (2011a). Recent advances in standards for collaborative digital anatomic pathology. In *Diagnostic Pathology*, volume 6, page S17. BioMed Central.

Daniel, C., Rojo, M. G., Klossa, J., Della Mea, V., Booker, D., Beckwith, B. A., and Schrader, T. (2011b). Standardizing the use of whole slide images in digital pathology. *Computerized Medical Imaging and Graphics*, 35:496–505.

Díaz, D., Corredor, G., Romero, E., and Cruz-Roa, A. (2018). A web-based telepathology framework for collaborative work of pathologists to support teaching and research in latin america. In *Sipaim–Miccai Biomedical Workshop*, pages 105–112. Springer.

Farahani, N., Parwani, A. V., and Pantanowitz, L. (2015). Whole slide imaging in pathology: advantages, limitations, and emerging perspectives. *Pathology and Laboratory Medicine International*, 7:23–33.

Foster, K. (2010). Medical education in the digital age: digital whole slide imaging as an e-learning tool. *Journal of Pathology Informatics*, 1.

Godinho, T. M., Lebre, R., Silva, L. B., and Costa, C. (2017). An efficient architecture to support digital pathology in standard medical imaging repositories. *Journal of Biomedical Informatics*, 71:190–197.

Goode, A., Gilbert, B., Harkes, J., Jukic, D., and Satyanarayanan, M. (2013). Openslide: a vendor-neutral software foundation for digital pathology. *Journal of Pathology Informatics*, 4.

Lauro, G. R., Cable, W., Lesniak, A., Tseytlin, E., McHugh, J., Parwani, A., and Pantanowitz, L. (2013). Digital pathology consultations—a new era in digital imaging, challenges and practical applications. *Journal of digital imaging*, 26(4):668–677.

Lebre, R., Bastião, L., and Costa, C. (2018a). Shared medical imaging repositories. In *MIE - Medical Informatics Europe*, pages 411–415.

Lebre, R., Godinho, T., Silva, L., and Costa, C. (2018b). A performant and fully dicom compliant web pacs for digital pathology. In *International Journal of Computer Assisted Radiology and Surgery*, volume 13, pages 147–148.

Pantanowitz, L. (2010). Digital images and the future of digital pathology. *Journal of Pathology Informatics*, 1.

Pantanowitz, L., Evans, A., Pfeifer, J., Collins, L., Valenstein, P., Kaplan, K., Wilbur, D., and Colgan, T. (2011). Review of the current state of whole slide imaging in pathology. *Journal of Pathology Informatics*, 2(1):36.

Pantanowitz, L., Farahani, N., and Parwani, A. (2015). Whole slide imaging in pathology: advantages, limitations, and emerging perspectives. *Pathology and Laboratory Medicine International*, page 23.

Pantanowitz, L., Szymas, J., Yagi, Y., and Wilbur, D. (2012). Whole slide imaging for educational purposes. *Journal of Pathology Informatics*, 3.

Patterson, E. S., Rayo, M., Gill, C., and Gurcan, M. N. (2011). Barriers and facilitators to adoption of soft copy interpretation from the user perspective: lessons learned from filmless radiology for slideless pathology. *Journal of Pathology Informatics*.

Saco, A., Bombi, J. A., Garcia, A., Ramírez, J., and Ordi, J. (2016). Current status of whole-slide imaging in education. *Pathobiology*, 83(2-3):79–88.

Silva, J. M., Godinho, T. M., Silva, D., and Costa, C. (2019). A community-driven validation service for standard medical imaging objects. *Computer Standards & Interfaces*, 61:121–128.

Snyder, P. D., Hasso, C. A., and Masi, L. P. (2001). Pathology dependent viewing of processed dental radiographic film having authentication data. US Patent 6,195,474.

Triola, M. M. and Holloway, W. J. (2011). Enhanced virtual microscopy for collaborative education. *BMC Medical Education*, 11(1):4.

Tuominen, V. J. and Isola, J. (2010). Linking whole-slide microscope images with dicom by using jpeg2000 interactive protocol. *Journal of Digital Imaging*, 23(4):454–462.

Valente, F., Silva, L. A. B., Godinho, T. M., and Costa, C. (2016). Anatomy of an extensible open source pacs. *Journal of Digital Imaging*, 29(3):284–296.

Weiss, M. (2012). Apc forum: carestream health's it transformation. *MIS Quarterly Executive*, 11(1):8.

Zhang, J., Stahl, J. N., Huang, H. K., Zhou, X., Lou, S.-L., and Song, K. S. (2000). Real-time teleconsultation with high-resolution and large-volume medical images for collaborative healthcare. *IEEE Transactions on Information Technology in Biomedicine*, 4(2):178–185.