



Dicoogle Framework for Medical Imaging Teaching and Research

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Abstract—One of the most noticeable trends in healthcare over the last years is the continuous growth of data volume produced and its heterogeneity. In the medical imaging field, the evolution of digital systems is supported by the PACS concept and the DICOM standard. These technologies are deeply grounded in medical laboratories, supporting the production and providing healthcare practitioners with the ability to set up collaborative work environments with researchers and academia to study and improve healthcare practice. However, the complexity of those systems and protocols makes difficult and time-consuming to prototype new ideas or develop applied research, even for skilled users with training in those environments. Dicoogle emerges as a reference tool to achieve those objectives through a set of resources aggregated in the form of a learning pack. It is an open-source PACS archive that, on the one hand, provides a comprehensive view of the PACS and DICOM technologies and, on the other hand, provides the user with tools to easily expand its core functionalities. This paper describes the Dicoogle framework, with particular emphasis in its Learning Pack package, the resources available and the impact of the platform in research and academia. It starts by presenting an overview of its architectural concept, the most recent research backed up by Dicoogle, some remarks obtained from its use in teaching, and worldwide usage statistics of the software. Moreover, a comparison between the Dicoogle platform and the most popular open-source PACS in the market is presented.

Index Terms—Dicoogle, PACS, Medical Imaging, DICOM, Teaching, Learning pack

I. INTRODUCTION

In an information society, data is a cornerstone for scientific progress. This is not an exception in healthcare, wherein the usage of digital medical imaging has become predominant and fundamental in clinical practice [1], [2]. The development of new modalities and the continuous improvements in digital medical imaging systems has led to the increase of data produced in institutions. The concept of Picture Archiving and Communication System (PACS) comprises the many technologies for acquisition, archiving, distribution and visualization of digital images using a computer network for diagnosis and revision in dedicated stations [3].

PACS is deeply linked with the Digital Imaging and Communications in Medicine (DICOM) standard, which defines data formats, storage organization and communication protocols of digital medical imaging [4]. As an international

standard, it guarantees the interoperability between equipment and information systems [5] in a PACS, by ensuring normalized data formats and processes among each component. This environment has subsequently led to a steadfast research and conception of new systems, namely of imaging acquisition modalities [6] and tools for data analysis. Moreover, as the number of medical imaging data produced is ever increasing, the means of searching for relevant information in a medical imaging archive poses as a challenge that, in recent years, has been tackled with new ways of searching for information [7], [8]. Hence, the increased complexity of a modern PACS makes proper training on how these systems work and interact a necessity.

In the last decade, the University of Aveiro Bioinformatics research group has been developing the Dicoogle project¹ as a tool to achieve this goal, with its current use having been expanded to the industry, academia and research labs. Placing it as a platform for both users and developers, Dicoogle provides a comprehensive view of the operation of PACS and DICOM standard technologies, as well as tools to expand these technologies. In this article, we expose Dicoogle Learning Pack framework for research and education, describing how its resources teach the necessary understandings of medical imaging informatics with the use of a modern PACS archive and helping to overcome the difficulty of usage and navigation of the system. As such, this document targets students and researchers, but also raises its equivalent potential use by the industry. Furthermore, Dicoogle is compared with other open source PACS solutions, according to a defined set of requirements.

II. RELATED WORK

Until recently, PACS systems were not used as academic tools because existing systems did not offer easy-to-use functionality or the ability to augment them in a decoupled fashion. However, the fast development of medical imaging systems and networks (evidently expanded to beyond the traditional concept of radiography), and the increasing legal requirements of digital information in developed and developing countries

¹Official website: www.dicoogle.com

have made education an essential requirement for all physicians and radiologists. As such, the creation and usage of these systems seemed inevitable [9].

Small steps have been made towards this goal over the last decade. For instance, several authors have tried to use PACS for the creation of electronic teaching files (ETF), which comprise clinical-case medical images, pertinent information about the clinical details, and diagnosis. Lim et al. [10], [11] developed an ETF server which retrieves DICOM images from a PACS and enables users to create teaching files, while Wilkinson et al. [12] integrated digital data supplied by an institutional PACS system into teaching files.

On the other hand, there are also attempts to integrate teaching modules with PACS. For instance, Sinha et al. [13] developed an interactive teaching module, linked to a PACS database, for teaching radiology. Likewise, Towbin et al. [11] developed a computer-based radiology simulator that mimicked the local hospital PACS to create a learning tool to help prepare first-year residents for being on call.

In terms of research, there were also some notable concerns, since the traditional clinical PACS archive was insufficiently flexible for the requirements of research. This is mainly due to the existence of two completely separate workflows: the clinical workflow and the research workflow. In the clinical scenario, data is transferred daily to the institutional PACS, normally from local imaging devices, and viewed using proprietary software. Whereas in research, data enter the system from a rich variety of sources and both the original data and the processed results usually reside in a personal space, without any common organizational structure or centrally available history of the processing methods performed [14]. Hence, due to the existence of these two distinct workflows, the need for a *research oriented PACS archive* arose.

In this line, Doran et al. [14] described a prototype research PACS framework, which is based on XNAT in association with tools of data selection and archiving. Also, Haak et al. [15] integrated DICOM data into electronic data capture systems (EDCS) regarding the workflow in clinical trials and a PACS archiving node for research.

Jodogne et al. [16], [17] described an open-source standalone DICOM store for healthcare and medical research, capable of deploying multiple instances in a hospital network or a standalone computer, providing a RESTful API, and can be bundled with an embedded Web interface. On the same line, Warnock et al. [18] describes dcm4chee Archive, a modular designed PACS built out of the previously tools and frameworks of JDicom. Woodbridge et al. [19] shows MRIdb as a self-contained image database designed to manage MRI datasets. Eichelberg et al. describes in [20] DCMTK, a collection of libraries and applications implementing parts of the DICOM standard and Stott et al. [21] created a open-source archiving and management of ultrasound images.

Furthermore, other traditional PACS archive solutions have been identified: Xebra, CDMedic PACS Web, JSVdicom server, DicomServer@Medical Connections, ClearCanvas, K-PACS and ConquestDICOM.

III. LEARNING PACK FRAMEWORK

A. Dicoogle Concept

Dicoogle is an open-source PACS archive software that replaces the traditional database model with an extensible indexing and retrieval framework [22], [23] and provides easy expansion of functionalities through the use of plug-ins. It was designed to accommodate automatic information extraction, indexing, and storage of all meta-data detected in medical images, without re-engineering or reconfiguration requirements, thus overcoming the limitations of traditional DICOM query services [24]. By presenting the technical assets for plug-in development such as a Software Development Kit (SDK), developers are free to expand the archive independently and non-exclusively, without changes to the core platform.

This extensible architecture of Dicoogle has enabled its use in research and the healthcare industry, as many use cases can be fulfilled in the same deployment [6], [25]. This is very relevant nowadays, given the need to improve, monitor and measure the efficiency of medical imaging systems, as well as to extract knowledge from the produced medical images, including healthcare quality indicators. As such, Dicoogle has been successfully used as a base platform for DICOM data mining [26], [27] and as an archive for exploiting multimodal information retrieval methods [8].

B. Framework Architecture

Figure 1 presents the architecture of Dicoogle. The design of the framework is separated in five distinct categories according to its functionality: *Index*, *Query*, *Storage*, *Web Services*, and *Web UI Components*. Each category is tied to a specific application programming interface (API), which is implemented by plug-ins. Through these interfaces, the plug-ins provide operations that are orchestrated by the core Dicoogle platform.

The life cycle of each plug-in is controlled by Dicoogle's core, that during the application startup scans the plug-in directory and identifies the plug-ins which are then loaded according to their directives present in the configuration file.

The Dicoogle SDK provides the necessary software components for interconnecting plug-ins with the core system. Although it is not presented as a center-piece, this SDK simplifies development by establishing the APIs that the plug-ins must abide to, as well as implementing interfaces with the system for accessing indexed and non-indexed data, dispatching tasks, fetching settings and logging the software's functions.

Further instructions for helping the Dicoogle plug-in development are available online at Dicoogle Learning Pack ².

C. Service Interface

Dicoogle provides a modern single-page web user interface, which can be delivered to local and remote users without a previous installation process on the client machine.

To accommodate new use cases from both ends of the software stack, Dicoogle also includes a dynamic pluggable web component architecture. Rather than manually including

²Available at: <https://bioinformatics-ua.github.io/dicoogle-api/>

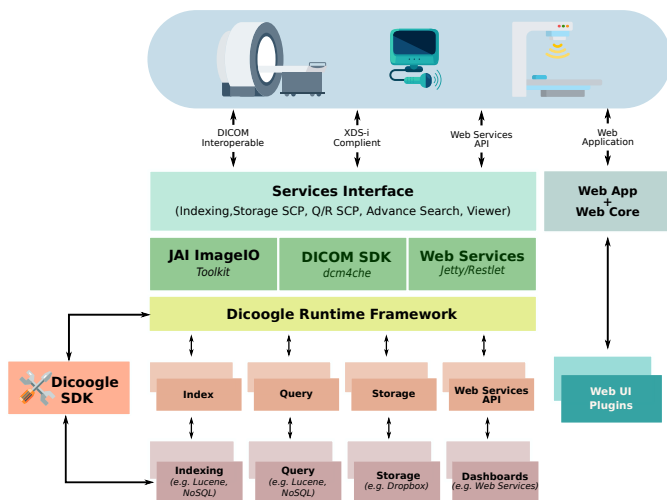


Fig. 1. Dicoogle Architecture

new menus and actions to the web application, the Dicoogle *Web Core* establishes a backbone for web UI component retrieval and rendering in runtime at the browser. This enables the exposure of new features on the main web application without rebuilding the source code.

To achieve this in practice, three components were developed:

- 1) A set of web services in the Dicoogle web server for providing the web-based plug-ins and their meta-information;
- 2) The Web Core component, a JavaScript library that runs in the user's browser for retrieving and exposing the extra user interfaces;
- 3) A project scaffolding tool to facilitate the creation of web UI plug-ins.

Each user interface plug-in is scoped to a particular view of the application, into divisions called slots. Slots describe the kind of interface that a plug-in for the same slot is meant to portray. For example, the `settings` slot is available in the management section. When observing a list of results, a `result-entry` slot is created for each item, so as to perform a particular operation over an item, such as visualize the image in a separate service). In contrast, plug-ins of the type `result-batch` are scoped to the entire list of results, allowing the exposure of new forms for data visualization, exporting, and manipulation.

The interactions of the Web Core with these slots and the main web application are represented in Figure 2. Once the user is logged in, the application fetches the list of web user interface plug-ins available for that user, using standard asynchronous requests. The actual components, specified as Javascript modules, are subsequently loaded and rendered to the indicated slot on the page. The Web Core architecture relies on standard HTML5 web components to augment slot elements for this functionality.

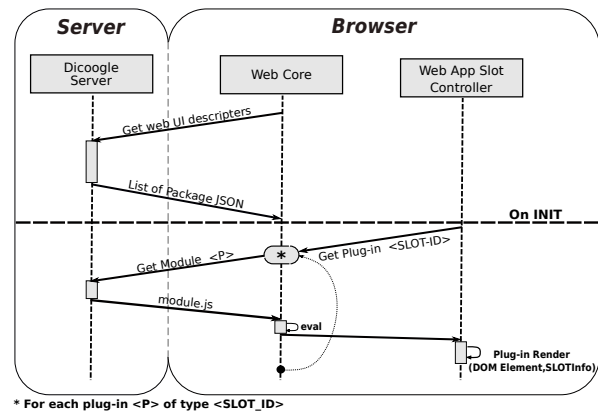


Fig. 2. Dicoogle Web Core sequence diagram

D. Learning Pack Resources

Medical imaging informatics is a major subject and teaching offer is becoming increasingly frequent. The notable increase in higher education degrees and courses that combine radiology concepts with medical imaging informatics is a direct consequence of their impact on healthcare.

Therefore, teaching how to use an open-source PACS archive in a medical imaging informatics context to students is an essential counterpart to the development of the actual software. With this in mind, the Dicoogle Learning Pack was created to teach users with no prior or deep knowledge to tackle new advances of the field in an academic environment, backed by the Dicoogle archive. The resources were designed to be as simple and objective as possible to be a relevant tool to minimize and smooth the open-source PACS and DICOM standard learning curve.

The Dicoogle Learning Pack³ is available as an open-access static site hosted on GitHub Pages. The website itself is open-source, and users of Dicoogle are invited to read and provide their feedback through GitHub's issue tracker. This approach takes advantage of freely available resources for open-source projects while making them accessible to researchers and students alike. Moreover, the opening of issues and active participation of the community in discussion, allows the improvement of both the Dicoogle Learning Pack and Dicoogle itself, meeting the expectation of the players overtime. The Learning Pack provides also documentation, configurations, and code examples, guiding the user to, for instance:

- Install Dicoogle for the first time on a local machine with any operating system;
- Configure indexers, services and plugins of any kind;
- Index a data set and perform searches over the indexed data;
- Develop plugins for the Dicoogle back-end, using Dicoogle SDK, in which a background in Java is assumed and following a specific workflow as shown in Figure 3;

³<https://bioinformatics-ua.github.io/dicoogle-learning-pack>

- Develop web user interface plugins for the Dicoogle web application, in which a basic background in Javascript programming knowledge and notions of HTML are assumed;
- As a more advanced topic, the build the main Dicoogle application is introduced, divided by building of the back-end and front-end;
- Debug the Dicoogle main application source-code and web-app, as well as the plugins source-code.

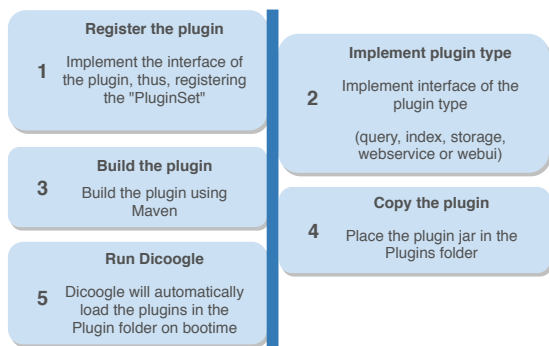


Fig. 3. Workflow of the development of a Dicoogle Plugin

1) *Index and Query Plugins*: Being an archive, features as indexing and retrieving information are crucial in Dicoogle. Dicoogle can have its technologies for storing DICOM metadata or even processed data extended. That way, Dicoogle is not bound to a single implementation. This is achieved with the Query and Index plugin pair, which usually go hand-in-hand:

- The indexer plugins are triggered when incoming requests for indexing objects reach Dicoogle and processes it for future retrieval;
- Query plugins interpret queries from the user and return lists of results based on the provided parameters.

2) *Storage Plugins*: Data storage is one of the main goals of a PACS archive. As the technology evolves and more patient data is acquired, medical imaging storage requirements have become increasingly demanding. The server's local file system has become inadequate in some use cases. Delegating storage to cloud services, for instance, have been thoroughly discussed in recent years [28], [29].

Storage plugins are responsible to deal with the place where files can be read and stored, and sometimes also define how these files are stored and read. The storage plugins are triggered every time the PACS archive receives a C-STORE request and handle the persistence of the DICOM object. The Dicoogle Storage API serves the following two purposes:

- creating an abstraction over the underlying storage technology, thus being able to use and evaluate different sources of data storage (e.g. cloud storage services such as Amazon S3) and different forms of persistence (e.g. using a document-oriented database instead of a file system). With this common API, DICOM object reading and

storing becomes possible, regardless of the underlying technology;

- enhancing the storage and retrieval procedures with certain algorithms, such as for anonymization, compression, and encryption.

3) *Web Services Plugins*: Web services are one of the most flexible ways of expanding Dicoogle with new features. Currently, there are two ways to achieve this:

- Jetty Servlets can be created and registered using a plugin of type `JettyPluginInterface`. In this type of plugins, one can create their own servlets, then attach them into a handler list. The servlet API is a versatile mean of creating services in Java server applications. A servlet class should inherit from the `HttpServlet` class. It may then override one or more of the HTTP request method handlers (`doGet`, `doPost`, `doPut`, and so on).
- Rest Service plugins consider a subset of the REST framework API, allowing developers to create and attach simple server resources. The RESTlet API is more straightforward than Jetty Servlets, albeit more limited in some cases. The REST services implemented are directly described by method prototypes and annotations instead of a fixed set of methods.

4) *Web UI Plugins*: Dicoogle web user interface plugins are pluggable components that can be integrated in the web application. The developers are mandated to specify a type of plugin, often with the "slot-id" property. This type definition specifies the way that the web plugins are attached to the application. The Web UI plugins can be found in four types:

- *menu*: menu plugins are used to extend the main menu. A new entry is added to the side bar, and the component is created when the user navigates to that entry.
- *result-option*: result option plugins are used to provide advanced operations to a result entry. If the user activates "Advanced Options" in the search results view, these plugins will be attached into a new column, one for each visible result entry.
- *result-batch*: result batch plugins are used to provide advanced operations over an existing list of results. These plugins attach a button which will pop-up a division below the search result view.
- *settings*: settings plugins can be used to provide additional management information and control. These plugins are attached to the "Plugins & Services" tab in the Management menu.

IV. USAGE SCENARIOS

Dicoogle has been used for fulfilling a variety of use cases in medical imaging informatics since its inception. For instance, in the last decade, more than ten PhD students made use of Dicoogle framework in their research works. Below, it is presented the experimental use of the Dicoogle Learning Pack for teaching, followed by two of the latest lines of research where Dicoogle served as the backbone.

A. Teaching Networks and Services in Imaging

At the University of Aveiro, a particular subject is simultaneously attended by radiology (physicians) students and computer science students. On a yearly basis, the Electronics, Telecommunications, and Informatics department gives Master's and Doctoral degree students in computer science, as well as Master's students in medical imaging technologies, the opportunity to enroll on the subject of Networks and Services in Imaging. The class teaches an average of 30 students every year. Prior to their enrollment, Medical Imaging Technology students have limited knowledge of computer science. On the other hand, computer engineering students are not familiar with either the DICOM standard or the PACS concepts. The teaching of systems and networks in medical imaging comprises two complementary perspectives:

- Experts in *radiology* may understand the main purposes of a PACS archive and know how to use them for research and clinical use, including some understanding of the technical challenges overcome by these systems;
- From a perspective of *computer engineering and software development*, students are given the necessary background of PACS systems and networks, including the DICOM standard, in order to develop end-user solutions.

As such, the objective of this joint course is to introduce students to the generic concept of PACS and the DICOM Standard, addressing the main medical imaging modalities, as well as quality management and control issues in PACS environments and radiology information systems.

In order to learn and consolidate these concepts, students have to execute a three-month long development projects related to the PACS/DICOM universe, for which most students have used Dicoogle and the Learning Pack. For instance, the projects "Workflow Management in Distributed Medical Imaging Environments" and "3D Defacing - Visual Anatomic Anonymization", which culminated into the production of scientific publications [30], [31]. At the end of the academic year, students are asked to evaluate these tools as learning resources.

Overall, the results obtained from the forms indicated that, regarding Dicoogle:

- 63.7% found Dicoogle very useful as a learning resource;
- 54.6% thought it was easy to set up;
- 42.8% found the process of creating plug-ins easy;

On the other hand, regarding Dicoogle Learning Pack:

- 74.5% considered the Dicoogle Learning Pack was well structured;
- 87.5% thought it was useful in setting up and general usage of Dicoogle;
- 57.2% felt that the learning pack made the development of plug-ins significantly easier;

These results provide some insight that these resources are useful as a learning resource and as a tool of knowledge consolidation regarding concepts like PACS and the DICOM Standard. For those who used Dicoogle in their subject final

project, it was deemed a vital tool for the creation of new projects.

B. Dicoogle as a framework in Research

Nowadays, the exploration and analytics of medical data from the medical imaging laboratories is a compelling component in the healthcare institutions businesses. The huge amount of data can reveal statistics and help to forecast measures to improve the quality of healthcare services, for instance. Godinho et al. [32] described a business intelligence framework taking advantage of the Dicoogle data mining tools over DICOM.

Pedrosa et al. [33] presented a collaborative platform of the SCREEN-DR project. The SCREEN-DR project addresses the automatic detection of diabetic retinopathy (DR) by developing computer-aided methods. The authors deployed, on top of Dicoogle open-source PACS, a platform to collaboratively annotate visually and textually the DICOM images dataset. The ultimate goal is to use those annotations to the conception of machine learning methods to aid the screening process.

Medical image search capabilities are boosted by the combination of textual and visual features. Yet, there is still a lack of support in the most of the imaging archives, as they only index the available meta-data. In [34], the authors described an architecture for automatic labeling, extracting visual information from DICOM images. This work extended Dicoogle capabilities by adding support for automated content discovery with multi-modal querying that, otherwise, would only be possible with a CAD framework incorporation.

With the technological assistance of the Dicoogle platform, a reversible de-identification mechanism was developed by Silva et al. [6]. In this use case, standard medical imaging objects are fully de-identified, including meta-data and pixel data. At the same time, it provides a reversible de-identification mechanism that retains search capabilities from the original data. The goal was to deploy this solution in a collaborative platform where data is anonymized when shared with the community, but still searchable for data custodians or authorized entities.

During the last decades, Digital Pathology has been arising as a new branch of pathology [35]. Digital Pathology is the aggregation of hardware and software designed to substitute traditional devices, like microscopes. The acquisition of pathology images (whole-slide images) is performed by whole-slide scanners. Those obtained images can have a resolution of several gigapixels and, therefore, consume large amounts of space when stored. The developed system by Godinho et al. [36] allows the deployment of a performant and fully DICOM compliant viewer of whole-slide images using Dicoogle as the base PACS archive. Dicoogle was also extended to support the creation of DICOM WSI image pyramid. The solution provides a tiling engine and the viewer uses standard DICOM Web services implemented as Dicoogle plug-ins.

V. RESULTS

In order to evaluate the impact of Dicoogle among the scientific community, a survey was conducted to discover

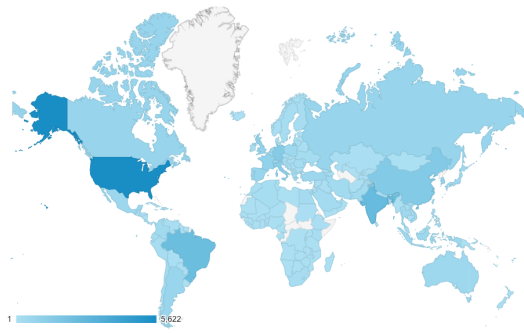


Fig. 4. Distribution of Dicoogle usage worldwide, based on the number of accesses to the official website.

currently available open-source PACS software. The research was based on the past review papers [37], [38] and by the use of the query "open-source PACS" in Google Scholar search engine. The list of the gathered 12 solutions encompassed Dicoogle [22], [23], Orthanc [16], [17], MRIdb [19], DCMTK (Offis) [20], dcm4chee [18], Xebra, OSPACS, CDMedic PACS Web, JSVdicom server, DicomServer@Medical Connections, ClearCanvas, K-PACS and ConquestDICOM.

First, we compared the different open-source PACS in terms of usability and ease of development. To this end, we verified if the source code of the PACS system was still available as well as the date of their last update. We discarded all PACS that no longer had source code available or that did not receive an update for the past few years. The remaining PACS were: DCMTK (Offis), Orthanc, dcm4chee, MRIdb and Dicoogle.

In this extended analysis, some parameters were selected, such as supported platforms, user guide, the existence of integrated web viewer, plug-in based extensibility, development framework available, documentation available, REST API, DICOMWeb support and digital pathology support. The results were standardized and shown in Table I.

Dicoogle and Orthanc have shown more coverage in terms of satisfying criteria, being the strongest deployed systems both on academic and clinical production environments.

In fact, Dicoogle started to attain worldwide visibility since the release of the official Dicoogle website in 2014. As shown in Figure 4, Dicoogle is used worldwide as a research and teaching platform, with the largest number of users being from the United States, Europe, Brazil and India.

The website was rebuilt from scratch at the end of 2017 and the Learning Pack was made available to the community, attaining a greater user reach and a stronger impact in the community with about 175 downloads per month during 2018 and almost 200 downloads per month until November 2019.

As shown in Figure 5, the number of monthly downloads of this framework has been increasing over the years, suggesting an increase in the use and adoption of this technology. This increase makes us believe that this tool, together with the learning resources that promote the usage and navigation of this system, can have a big impact in research and education.

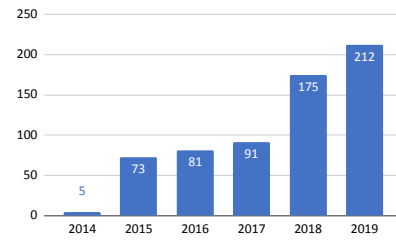


Fig. 5. Average number of Dicoogle downloads per month in each year.

VI. CONCLUSIONS

This paper presents the Dicoogle project and its Learning Pack as a resource designed to support research and academia. Dicoogle is a web based open-source PACS archive with expandable capabilities, providing an insight over its learning resources that enable researchers to quickly set up and use this platform. Some representative uses of this tool have been show-cased in distinct application areas, supported by different technologies that were appended to Dicoogle as plug-ins. Finally, a comparison between the most popular open-source PACS in the market and Dicoogle is presented, as well as evidences of Dicoogle's worldwide growth in terms of platform usage and its usefulness in education. Hence, it is concluded that Dicoogle is a relevant tool that, together with the appropriate learning resources, can have a big impact in research and education of medical imaging informatics.

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TABLE I
ANALYSIS OF THE MOST UPDATED OPEN-SOURCE PACS IN APRIL 2020.

	Last Update	Sourcecode Availability	Supported Platforms	User Guide	Web Viewer	Plug-in Extensible	Development Framework	Docu-mentation	REST API	DICOMWeb Support	DICOM Pathology Support
MRIdb	07/08/2018	GitHub	Linux		✓			✓		✓	
DCMTK (Offis)	01/10/2019	GitHub	Windows Linux Mac					✓	✓		
Orthanc	21/04/2020	GitHub Bitbucket	Windows Linux Mac	✓	✓	✓	✓	✓	✓	✓	✓
dcm4chee	10/04/2020	GitHub	Windows Linux Mac		✓	✓	✓	✓	✓	✓	
Dicoogle	12/09/2019	GitHub	Windows Linux Mac	✓	✓	✓	✓	✓	✓	✓	✓

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