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Clustering of distinct PACS archives using a cooperative peer-to-peer network

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ABSTRACT

To face the demanding requirements of the clinical environment, PACS archives need to be resilient and reliable, supporting high availability and fault tolerance. Often, to ensure no data loss, PACS archives retain two copies of images on separate physical machines, using distributed data storage facilities. However, PACS do not take advantage of the various replicas to improve the transfer rates of medical images. This happens mostly because the DICOM standard does not comply with distributed fetching of image fragments while performing a store. Inspired by this unexplored opportunity, we designed and implemented a new solution that takes advantage of the distributed image replicas and, at the same time, respects the DICOM standard. Our strategy brought significant improvements in the exchange rates, load balancing and availability of installed PACS archives. Moreover, the adopted strategy forms a cluster of PACS archives that transparently enables horizontal scaling, facilitates the creation of backups, and gives to healthcare professionals a unified view of the distributed repositories.

1. Introduction

The Picture Archiving and Communication System (PACS) concept embraces typically dispersed sub-systems, ranging from image archiving, acquisition and distribution to visualization. With the introduction of the Digital Imaging and Communication in Medicine (DICOM) standard, PACS received a positive boost, due to the fact that PACS vendors were no longer able to lock a healthcare institution into proprietary communication protocols, forcing it to purchase only their PACS solutions. Regarding communications, DICOM relies on a set of well-defined services that binds together PACS distributed devices [1]. The PACS archive is the heart of an image center, and it is responsible for safely storing all exams produced within the healthcare institution. Due to the importance of clinical exams, these archives typically rely on data redundancy to prevent data loss and resource redundancy to guarantee continuous availability. In other words, current fault-tolerant PACS archive solutions always keep at least two copies of the same image at two different physical machines (archive server and backup server) [2,3]. The complexity of such PACS archives is high and such reliable solutions are typically associated with high purchase costs for healthcare institutions. Therefore, smaller imaging centers are not able to own a state-of-the-art PACS archive and typically rely on a centralized machine to store exams. We implemented a system that upgrades transparently any DICOM compliant PACS archive regarding availability, aggregation of resources, and scaling at low prices. Furthermore, our system also takes advantage of the image replicas already existent and improves the transfer rates between DICOM devices. This paper describes the

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implementation of the system that upgrades the PACS archive in several dimensions in a transparent and straightforward manner.

2. Background

The PACS archive is one of the key components of the healthcare workflow, and its malfunctioning might jeopardize the delivery of high quality care services [2,4,5]. Therefore, it is desirable that PACS should be an extremely reliable system: fault-tolerant, continuously available and with an acceptable performance to satisfy the daily operations of the healthcare institution [6].The importance of the PACS archive becomes even more vital with institutions following a paperless and filmless approach in serving their patients [2]. The reliability level of a computer system can be measured by the number of single points of failure it incorporates. As the expression suggests, single points of failure increase the risk of system failure or malfunction. The risk increases when critical components to deliver a service are unique. For instance, if the power supply unit of a centralized server fails, the entire server will fail and, as a consequence, the services it provides will be unavailable until the power unit is replaced. Therefore, the conventional centralized storage server is not suitable for the healthcare environment, because if the storage server fails, all the PACS services dependent on it will also fail.

To build a reliable computer system, the single points of failure must be eliminated or minimized to the extent possible. Typically, this is achieved by resource redundancy. As a result, if a system resource (physical or virtual) fails, there will be at least one backup resource to fill the gap and the requested service will not be at risk. Therefore, the storage archives serving the PACS workflow tend to be a distributed storage system (or storage network), where several machines cooperate in the storage task and ideally, if one of them fails the other machines will compensate for the failure without jeopardizing the storage service. A distributed system, besides eliminating single points of failure, also reduces bottlenecks in the workflow by distributing the workload among the several machines enabling performance improvements. Furthermore, these distributed architectures are able to scale horizontally, which brings significant economic and planning benefits compared to vertical scaling [7]. Scaling horizontally allows a system to scale progressively and according to needs in an efficient and cost friendly manner, the only drawbacks being its complexity to implement and manage compared to vertical scaling.

One good example of scaling-out strategies is peer-to-peer networks (e.g. BitTorrent [8,9]) where a peer is at the same time a server and a client, similar to a DICOM device capable of performing the roles of Service Class User (SCU) and Service Class Provider (SCP). In this kind of distributed system the data is spread among the peers, each peer holds a small portion of the network's available data, and there is data redundancy since different peers may hold replicas of the same file. Peer-to-peer networks achieve good levels of availability and fault-tolerance since if a peer fails or disconnects the data it holds, this will almost certainly be available on another peer. Besides, peer-to-peer networks take advantage of this multiplicity of peers holding the wanted file and instead of downloading the entire file from one peer they download the various fragments composing the file (blocks) from multiple peers, bringing load balancing advantages and also improving the file transfer rates [10,11]. Before peer-to-peer networks, other distributed systems had used this strategy, for instance, Andrew's File System (just on read-only files) [12] and OSF's file system in a Distributed Computing Environment [13]. Of course, a conventional peer-to-peer file sharing network such as BitTorrent would not be appropriate for the medical context because the PACS archive must ensure that all exams are available 24/7 and there is no guarantee that the peers holding some piece of data will always be online. However, we believe that peer-to-peer inspired networks could suit the healthcare situation well. Peers must be more reliable and controlled by the healthcare institution (PACS archives). Moreover, they should cooperate in order to support the clinical workflow, providing reliable, widely available and high-performance services at lower prices.

3. Materials

Nowadays, PACS may be seen as a mature technology. They are present in the majority of medical imaging centers around the world. This worldwide acceptance was due in part to the success of the DICOM standard which, among other things, enabled interoperability inside healthcare institutions, allowing the devices having a role in the PACS workflow to communicate transparently [14]. PACS archives are no exception. Typically, an archive is expected to implement at least the DICOM services of Storage, Query and Retrieve. As we mentioned before, our system does not intend to replace the healthcare institution's existent PACS archives. Ultimately it intends to improve the performance, availability, fault-tolerance, management and search capabilities of the PACS distributed archive. Therefore, the core of our peer-to-peer network is based on these three DICOM services which most PACS archives support, i.e. in order for a PACS archive to be extended with our system it must support the DICOM services of: Storage, Query and Retrieve. In this section we will present the technologies and software components that were used to build our system.

3.1. *DICOM standard*

Around the world there are many manufacturers of non-invasive medical imaging equipment (modalities). In the past, manufacturers developed their own proprietary communication and data exchange standards, making the interaction between equipment from different vendors impossible [15–17]. This situation was comfortable for most manufacturers who could lock customers, but at the same time unsustainable for healthcare institutions. Therefore, in 1992 the Digital Imaging and Communication in Medicine (DICOM) standard was established and has since become the standard for exchanging medical images in digital format [1,18]. DICOM facilitates the implementation of PACS solution and enables interoperability in a multi-vendor environment [16]. This non-proprietary standard is very complete and has many dimensions. However, it is best known for the definition of