Case Study: Medical Imaging; From Toolbox to Product to Platform

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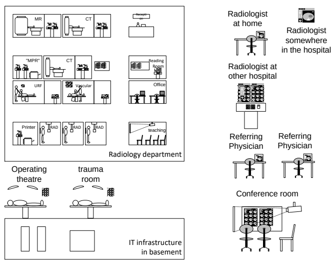

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Abstract

Medical Imaging was an early large scale Object Oriented product. Originally intended to become a re-useable set of toolboxes, it evolved in a family of medical workstations and servers.
This article describes the evolution from different viewpoints, to serve as background material for a number of case studies of the Gaudí project.

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1 Introduction

The Medical Imaging workstation was an early large scale Object Oriented product. Originally intended to become a re-useable set of toolboxes, it evolved in a family of medical workstations and servers.

This article describes the evolution from different viewpoints, to serve as background material for a number of case studies of the Gaudí project.

2 Product Context

2.1 Philips Medical Systems

Philips Medical Systems is a major player in the medical imaging market. The main competitors are GE and Siemens. The Product Creation focus of Philips Medical Systems is modality oriented, as shown in figure 1.

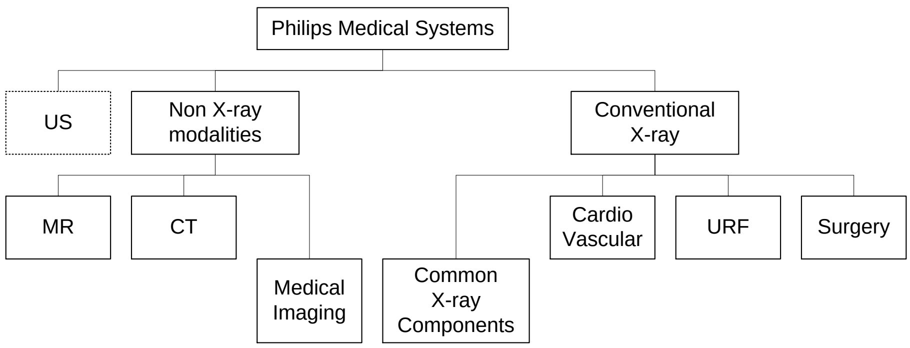

Figure 1: Philips Medical Systems, schematic organization overview.

The common technology in conventional X-ray systems is developed by component oriented business groups, which make generators, tubes, camera's, detectors, et cetera. The so-called "System-groups" have a more clinical focus, they create the clinical oriented systems on the basis of the common available components.

The non X-ray groups[1] mainly build large complex general purpose imaging equipment. The imaging principles in CT and MR are less direct, which means that an image reconstruction step is required after acquisition to form the viewable images.

Ultra Sound (ATL) is acquired by Philips Medical Systems recently. It is not fully integrated in the organization.

[1]A poor name for this collection; The main difference is in the maturity of the modality, where this group exists from relative "young" modalities, 20 a 30 years old.

The main markets of Philips Medical Systems are radiology and cardiology, with a spin off to the surgery market.

2.2 Radiology

Traditionally the radiologist makes and interprets images from the human body. A referring physician requests an examination, the radiologist responds with a report with his findings. Figure 2 shows a generic set of Radiology drivers.

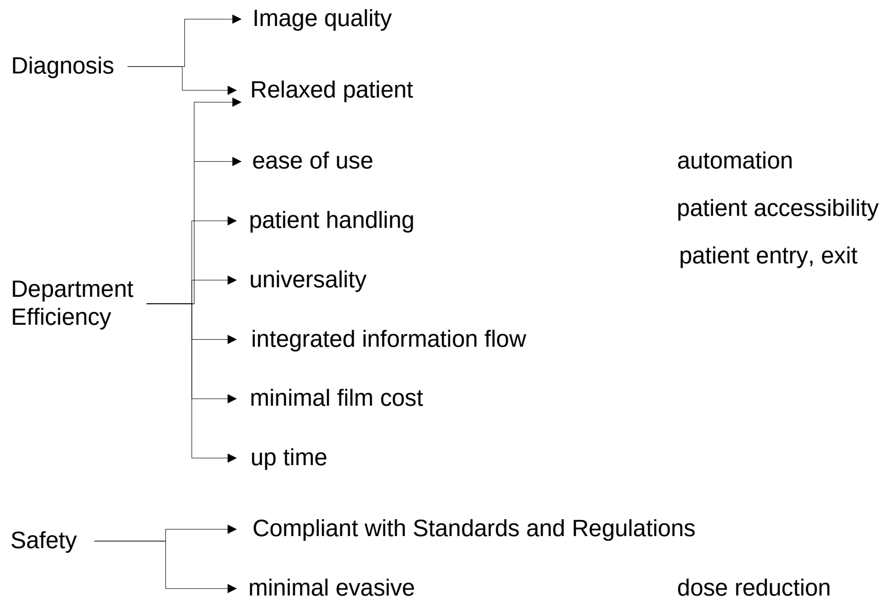

Figure 2: Generic drivers of Radiology Departments

Philips Medical Systems core is the imaging equipment in the examination rooms of the radiology department[2]. The key to useful products is the combined knowledge of application (**what**) and technology (**how**).

3 Historic Phases

The development model of Medical Imaging has changed several times. Roughly the phases in table 1 can be observed. The first phase can best be characterized

[2]equally important core for Philips Medical Systems is the cardio imaging equipment in the catherization rooms of the cardiology department, which is out of the Medical Imaging Workstation scope.

as technology development, with poor Market and Application feedback. The next phase overcompensates this poor feedback by focusing entirely on a product.

- 1987-1991 Advanced Development ("Common Viewing"), result: Basic Application plus toolboxes
- 1991-1992 Development of 1^{st}product: Medical Imaging R/F
- 1992-1994 Parallel Development of 2^{nd} product: Medical Imaging CT/MR
- 1994-1997 Family Development
- 1997-2000 Transformation in re-useable components

Table 1: *Phases of Medical Imaging*

Philips Medical Systems has been striving for re-useable viewing components at least from the late seventies. This quest is based on the *assumption* that the viewing of all Medical Imaging Products is so similar, that *cost reduction* should be possible when a common implementation is used. The lessons learned during this long struggle have been partially consolidated in [2].

The group of people, which started the Common Viewing development, applied a masive amount of technology innovations, see table 2.

- Standard UNIX based workstation
- Full SW implementation, more flexible
- Object Oriented design and implementation (Objective-C)
- Graphical User Interface, with windows, mouse et cetera
- Call back scheduling, fine-grained notification
- Data base engine, fast, reliable and robust
- Extensive set of toolboxes
- Property based configuration
- Multiple coordinate spaces

Table 2: *Technology innovations introduced by the initial developers of Common Viewing*

3.1 Basic Application and Toolboxes

The goal of the common viewing development was to create an extensive set of toolboxes, to be used for viewing in all imaging products. The developers of the final products had fine-grain access to all toolboxes. This approach is very flexible and powerful, however the penalty of this flexibility is that the integration is entirely the burden of the product developer.

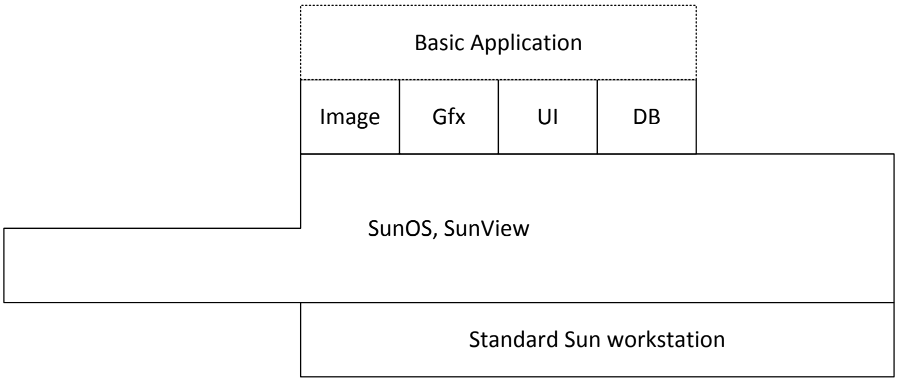

Figure 3: Idealized layering of SW toolboxes and Basic Application in september 1991

The power of the toolboxes was demonstrated in a **Basic Application**. This basic application was a superset of all available features and functions. From clinical point of view a senseless product, however a good vehicle to integrate and to demonstrate.

Figure 3 shows the idealized layering of the toolboxes and the the Basic Application in september 1991. the toolbox layer builds upon the Sun computing platform (Workstation, the Sun version of UNIX SunOS and the Sun windowing environment Sunview). The core of common viewing is the imaging and graphics toolbox, and the UI gadgets and style.

3.2 Medical Imaging X-Ray

Figure 4 shows the X-ray rooms which are involved from the examination until the reading by the radiologist. Around 1990 the X-ray system controls were mostly in the control room, where the operator of the system performed all settings from acquisition setting to printing settings. Some crucial settings can be performed in the room itself, dependent on the application. The hardcopies were produced as literal copies of the screen of the monitor. The printer was positioned at some non-obstrusive place.

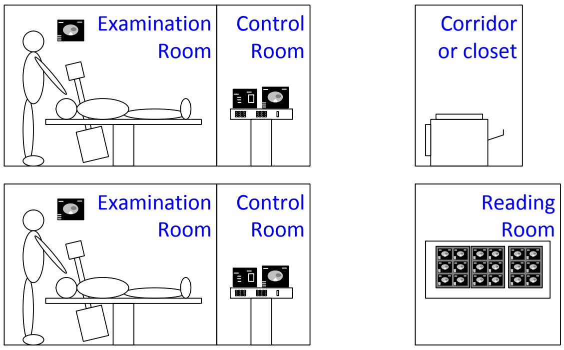

Figure 4: X-ray rooms from examination to reading around 1990

The consequence of the literal screen copy was that a lot of redundant information is present on the film, such as patient name, birth date and acquisition settings. On top of that the field of view was supposed to be square or circular, although the actual field of view is often smaller due to the shutters applied.

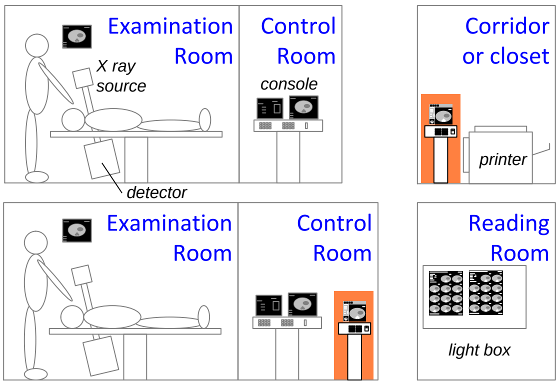

Figure 5: X-ray rooms from examination to reading, when Medical Imaging is applied as printserver

The economic existence of Medical Imaging X-ray was based in 1992 on improvements of this printing process. The patient, examination and acquisition information is orderly shown in one viewport, removing all the redundant information near the images itself. A further optimization is applied by a *fit-to-shutter* formatting. These 2 steps together reduce the film use by 20% to 50%.

The user actions needed for the printing are reduced as well, by providing print protocols, which perform the repetitive activities of the printing process. The effectiveness of this automation depends strongly on the application, some applications require quite some fine-tuning of the contrast-brightness, or an essential selection

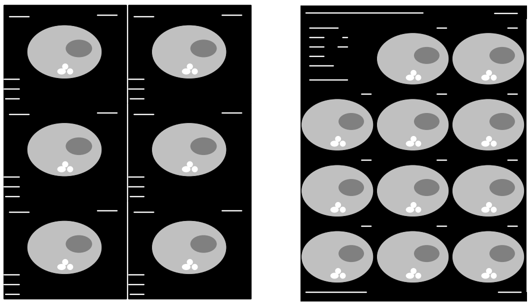

Figure 6: Comparison of convential *screen copy* based film and a film produced by Medical Imaging. This case is very favourable for the Medical Imaging approach, typical gain is 20% to 50%.

step, which require (human) clinical knowhow.

A prominent sales feature at conferences was the 9-button remote control. The elementary viewing functions, such as patient/examination selection, next/previous image and contrast/brightness. This remote control lowered the threshold for clinical personnel, both radiologist as well as technical, enough to catch their interest: The Medical Imaging was not sold as a disgusting computer or workstations, rather it was positioned as a clinical appliance.

The definition of the Medical Imaging was done by marketing, which described that job as a luxury problem. Normally heavy negotations were required to get features in, while this time most of the time marketing wanted to reduce the (viewing and user interface) feature set, in order to simplify the product.

From software point of view the change from basic application to clinical product was tremendous. The grey areas in figure 7 indicate new SW. The amount of code increased from 100 klines to 350 klines of code.

3.3 Second Concurrent Product: Medical Imaging CT/MR

Upto 1992 the Medical Imaging organization had a single focus, first on toolboxes, later on Medical Imaging R/F. In 1993 it was decided to apply the Medical Imaging also on CT and MR.

The printing functionality of CT and MR scanners improves significantly when Medical Imaging is applied as printserver. However the CT and MR applications can benefit also from interactive functionality, more than the X-ray applications. An clear example is the Multi Planar Reformatting (MPR) functionality, where arbitrary slices are reconstructed from the volume data set.

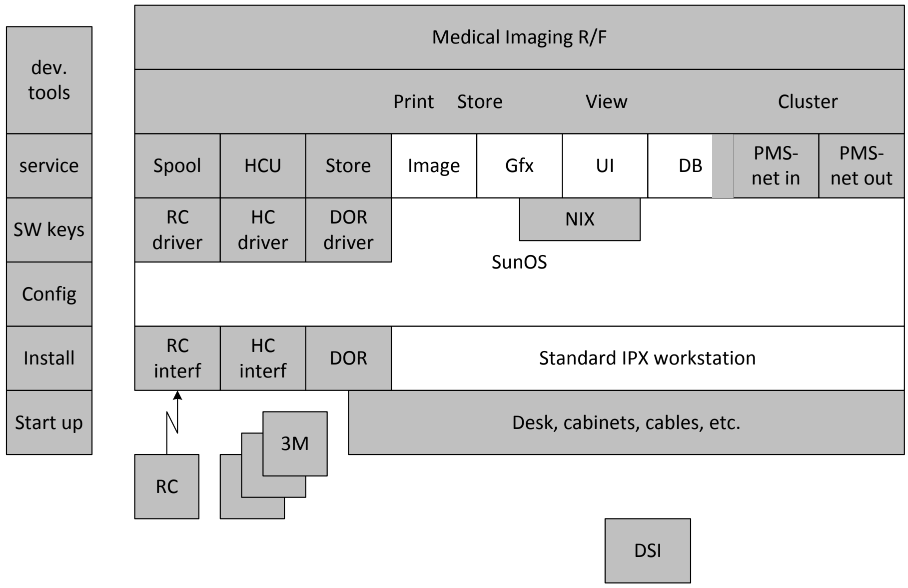

Figure 7: Idealized layers of the Medical Imaging R/F software in september 1992

Superficially X-ray viewing looks the same as CT and MR viewing. However the viewing is different in many subtle ways. A fundamental difference is that X-ray images are *projection* images, while CT and MR images are *slices*, which means that CT and MR images have a 3D "meaning", which is missing in X-ray images. The 3D relationship is amongst others used for navigation, a *point-and-click* type of user interface: clicking on a scanogram immediately shows the related slice(s) at that position.

The greylevel mapping for these modalities is performed in technical terms by means of a clipped linear mapping. From implementation point of view the difference in user perception between contrast/brightness for X-ray images (angle

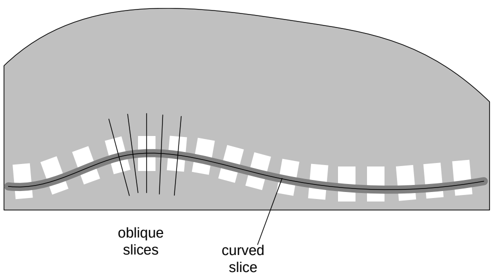

Figure 8: Example of Multi Planar Reformatting applied on the spine

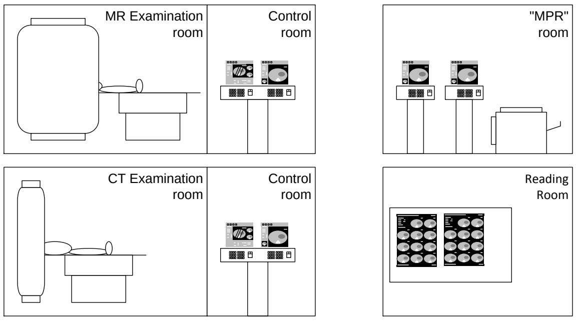

Figure 9: Example of CT and MR department, where Medical Imaging is deployed

and offset of the linear mapping) versus the window width/window level for CT and MR images was totally underestimated.

	X-ray	CT	MR
image	projection	slice	slice
structure	single image	stack	stack
	or time series	or volume	or more complex
greylevel mapping	contrast	window width	window width
	brightness	window level	window level
resolution	1024^2	512^2	256^2
contrast noise ratio	10 bit	12 bit	8 bit
value		absolute	acquisition dependent

Table 3: *Differences between X-ray, CT and MR images*

Table 3 shows the differences between the images of these modalities. The combination of different image characteristics and different clinical application propagates into the specification and design. Table 4 shows a list of differences in the specification caused by the differences in table 3.

The software was significantly extended, the code size increased from 350 klines to 600 klines. Note that this is not only an extension with 250 klines, from the original 350 klines roughly half was modified or removed. In other words a significant amount of refactoring has taken place concurrent with the application extensions. Figure 10 shows the (idealized) SW structure at the completion of Medical Imaging CT/MR and the second release of Medical Imaging R/F. Light grey blocks represent new code, dark grey represents major redesigns.

All diagrams 3, 7 and 10 are labelled as *idealized*. This adjective is used

- viewing and print preparation
  - navigation support
  - multi-image view
  - greylevel control
- specialized clinical functions
  - vascular and cardio analysis (X-ray)
  - dental (CT)
- print protocols
- information model

Table 4: *Specification differences caused by modality differences*

because the actual software structure was less *well structured* than presented by these diagrams. Part of the refactoring in the 1992-1994 time frame was a cleanup, to obtain well defined dependencies between the software-”groups”. These groups were more fine-grained than the blocks in these diagrams.

3.4 Towards Workflow

Medical Imaging R/F and Medical Imaging CT/MR were psotioned as *modality enhancers*. The use of these systems enhances the value of the modality. They are used in the immediate neighborhood of the modality, before the reporting is done. From sales point of view these Medical Imagings are additional options for a modality sales.

The radiology workflow is much more than the acquisition of the images. Digitalization of the healthcare information flow requires products which fit in the broader context of radiology and even the diagnostic workflow. Figure 11 shows the competitive positioning of Medical Imaging in 1995, and the positioning of a new class of Medical Imaging products which focus more on workflow added value. Figures 12 and 13 show the increasing context where the workstation technology can be deployed.

The increasing context causes new extensions of the SW building, as shown in Figure 14.

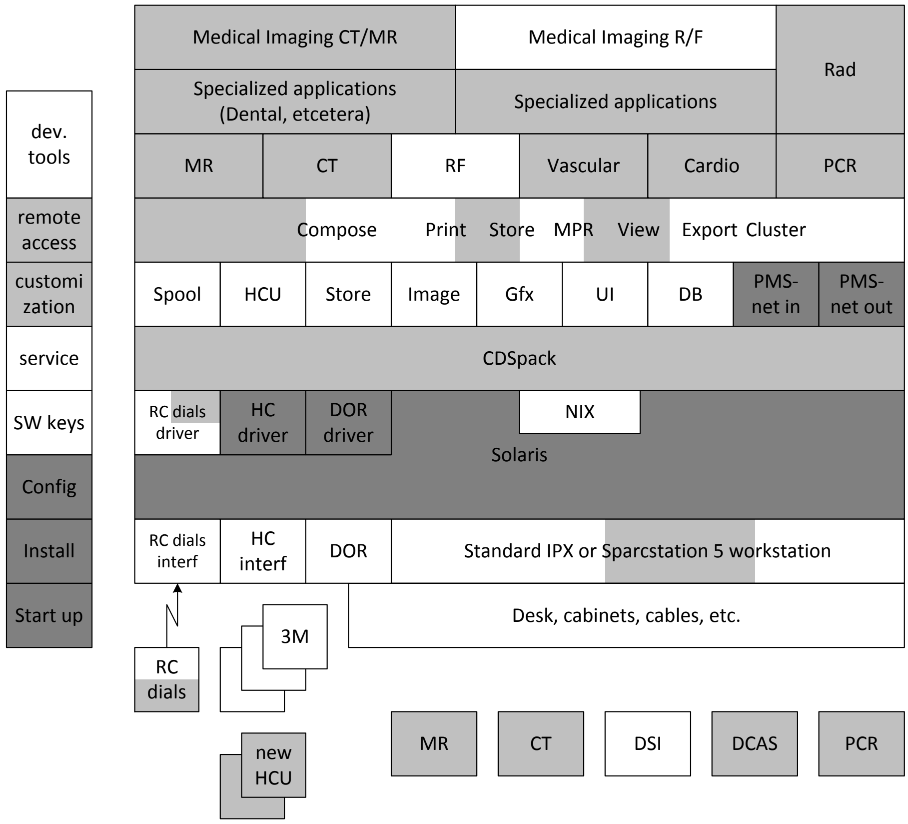

Figure 10: Idealized layers of the Medical Imaging software in june 1994

4 Process and Organization

4.1 Common Viewing

Common Viewing was a self sustained group, reporting to and financed directly by the PMS management. Somehow this group collected creative and rather self-willed individuals, which determined their own course. This is reflected by the technology choices (see table **??**), but also by the processes and organization.

To a certain degree the culture is similar to Extreme Programming [1], such as short iteration cycles and peer programming. If this book had been published ten years earlier it would have been used by this group for sure, which would have helped them amongst others in getting a better application focus and more regression testing.

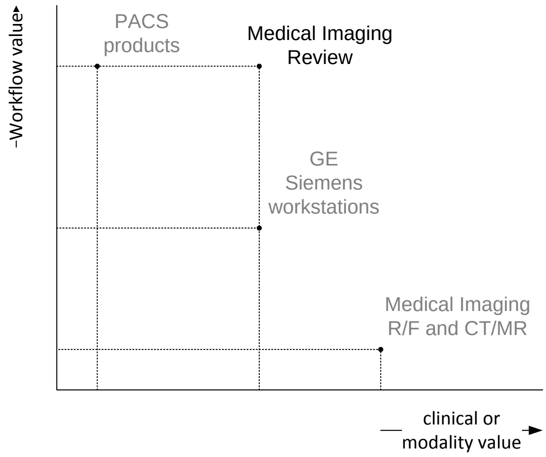

Figure 11: Competitive positioning of Medical Imaging, existing products and potential products

4.2 Medical Imaging R/F

The common viewing department was combined with the "DSI"[3] development team to form the Common Digital Systems (CDS) department. CDS was formally part of the X-ray product group.

This combination eased the development of Medical Imaging R/F, because both sides of the interface were developed within the same organizational entity.

Two entirely different cultures were merged here in one organization. In practice it remained two separate groups under a single management team.

5 Acknowledgements

Hans Brouwhuis reviewed the article, providing valuable feedback with respect to the reader viewpoint.

References

[1] Kent Beck. *Extreme Programming Explained: Embrace Change*. Addison-Wesley, Reading, MA, 2000.

[2] Gerrit Muller. Product families and generic aspects. `http://www.gaudisite.nl/GenericDevelopmentsPaper.pdf`, 1999.

[3] DSI is the image processing chain and user interface of the URF X-ray systems. It is a very focused design, fitting in the right price performance points for the cost sensitive URF market

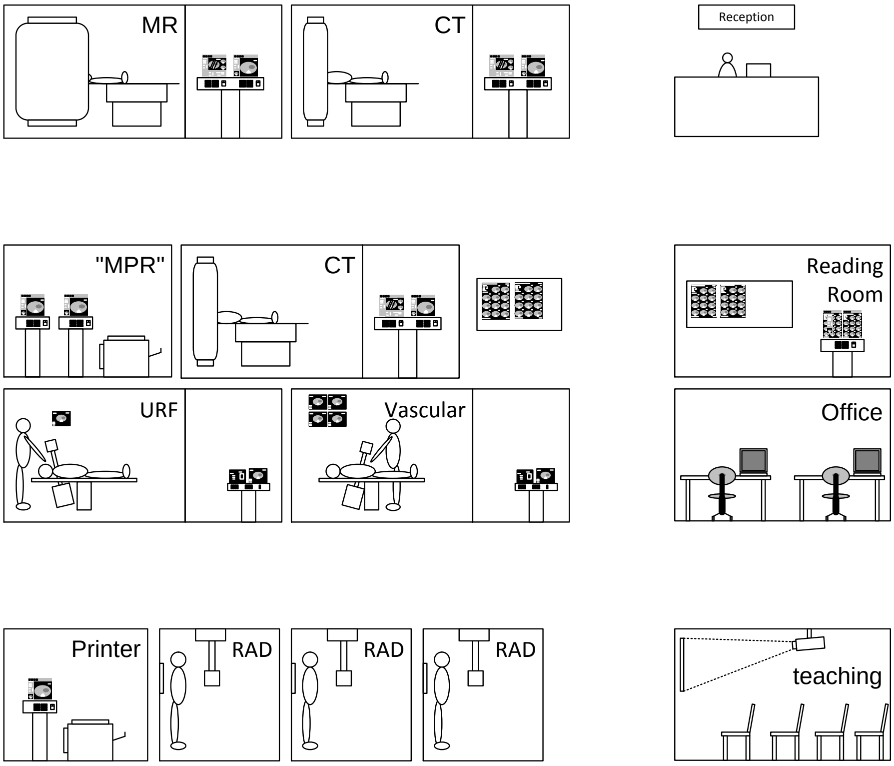

Figure 12: Radiology department as envisioned in 1996

[3] Gerrit Muller. The system architecture homepage. `http://www.gaudisite.nl/index.html`, 1999.

History

Version: 0.5, date: August 23, 2025 changed by: Gerrit Muller

- adapted Figure filenames

Version: 0.4, date: January 20, 2003 changed by: Gerrit Muller

- minor changes

Version: 0.3, date: August 5, 2002 changed by: Gerrit Muller

- minor changes

Version: 0.1, date: September 21, 2001 changed by: Gerrit Muller

- abstract added

Version: 0, date: April 20, 2000 changed by: Gerrit Muller

- Created, no changelog yet

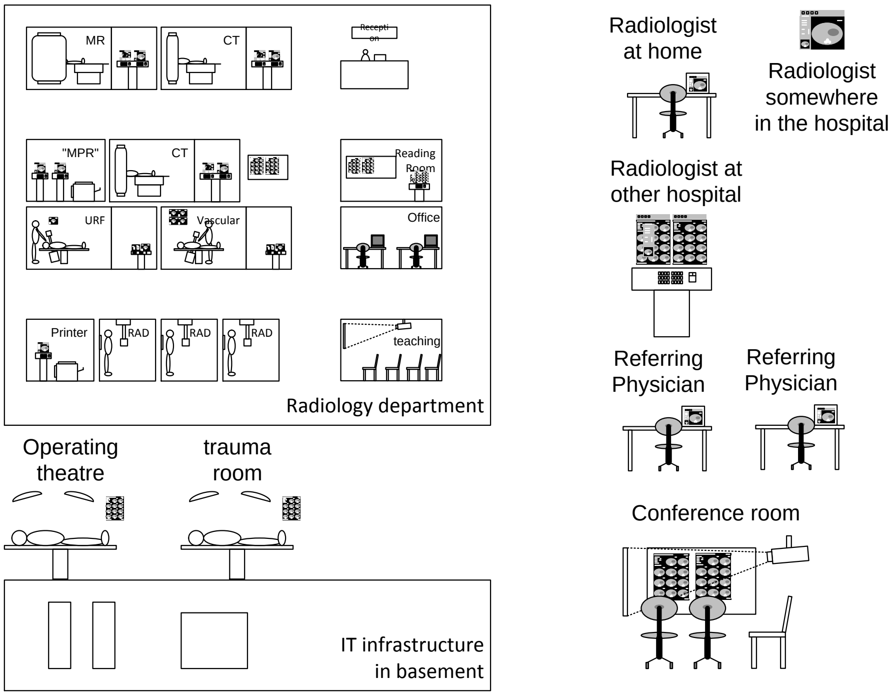

Figure 13: Medical Imaging in healthcare workflow perspective, as envisioned in 1996

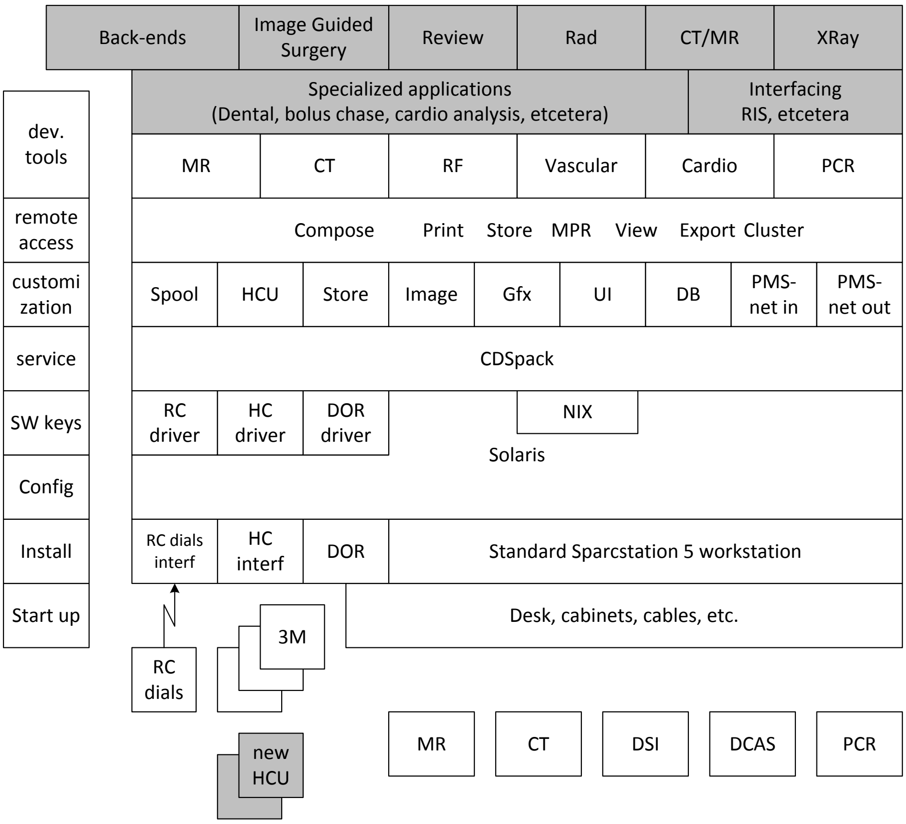

Figure 14: Idealized layers of the Medical Imaging software in 1996