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A digital interface designed for sharing diagnostic medical imaging with patients

— Final Report —

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Abstract

In a world where access to data is becoming faster and easier, how could we prevent the society from the desire to have a better and more systematic **access to medical data**? In particular, in the field of **Medical Imaging**, which propose a range of routinely used methods, to produce precise representations of the inner human body and diagnose serious diseases? And especially, in the **United Kingdom**, where The sharing of medical images with patients is not routine practice? We can't, and some solutions are popping up on the way to deal with it.

Indeed, some studies have already been undertaken in the United States concerning the creation of a **"patient portal"** [1]. Aim of these being to provide the patient with a **suitable graphical interface** that would display their medical images. **Prof. Fernando Bello** and **William Cox** sought to expand on the existing work in that particular area by assessing the benefits and risks that could come from the conception of such an interface. Indeed, they proposed to effectively implement this interface, as a final personal project to the **department of Computing Science at Imperial College of London** together with the **Chelsea and Westminster Hospital**.

Consequently, the following report offers an overview of the work undertaken during the last three months on the creation of **"A digital interface designed for sharing diagnostic medical imaging with patients"**. From specifications to conception, through design and testing, the aim of the following document is to present the different stages of the interface realisation, including issues, skills earned, and the final output that will be left as a basis for further development.

Acknowledgements

Contents

1 Introduction

According to a study published in January 2018 from **National Health Service (NHS) England** [2], 41.4 million **imaging tests** have been reported in England between October 2016 and December 2017. Indeed, **medical imaging** exams are routinely used all over the world to explore internal body structures and/or diagnose diseases. This generic term encompasses various clinical imaging techniques, such as, **Magnetic Resonance Imaging** (MRI), **Computerized Tomography** (CT-Scan) or **X-Ray**, which produce a 2D or 3D representation of physical internal structures.

Methods used for those exams are common, and since the introduction of the **DICOM standard** in 1985 [3], so is the professional storage and communication system. However, when it comes to sharing diagnoses with patient, each country has developed its own methods. In the **United Kingdom**, it is uncommon that a patient gets, or even requests, access to its medical data. On demand, and providing payment, one can get his data, but, generally, patients have only access to their clinical report, by means of a general practitioner, and the medical images, themselves are never seen by the patient.

Simultaneously, with the evolution of technology continually improving access to data; access to **medical information**, including imaging data, has become more commonplace . However, the issue about sharing those sensitive data, is not only to promote access, but essentially to make those images understandable for non clinicians. Research has already been undertaken in the United States concerning the creation of a **"patient portal"** [4] - fully designed to facilitate **patient understanding** - exploring the related opportunities, and scaling different levels of benefit.

Considering those facts, **Dr Fernando Bello** and **Pr William Cox** have decided to deepen the subject of designing a **patient portal**. First, by exploring the **benefits and risks** of sharing medical information with patients, and thereafter by effectively building such an interface. Consequently, after a year of background researches, they offered to work on the creation of **"A digital interface designed for sharing diagnostic medical imaging with patients"**, as a final personal project to the **department of Computing Science at Imperial College of London**, together with the **Chelsea and Westminster Hospital**. Aiming to build an interface **suitably made for imaging patients** in order to let them access and understand their medical results in the most significant and comprehensible way.

The following report contains an overview of the work undertaken during almost three month beginning mid May 2018 under the supervision of **Dr Fernando Bello** and **Pr William Cox**. The following sections will develop in a logical order - for better understanding - the several steps reached during the conception of the interface, including issues, skills earned and personal review.

//Introduce the plan - will do once it is certain

2 Background and Related Work

2.1 Project context

As mentioned in the introduction, **medical imaging** methods are widely used everyday for numerous reasons, including the diagnosis of more or less serious inner physical diseases. Using different imaging methods such as **Magnetic Resonance Imaging** (MRI), **Computerized Tomography** (CT-Scan) or **X-Ray**, this allow to produce a precise 2D or 3D representation of the internal structure of the human body. Since the introduction of the **DICOM standard** in 1985 - see following section - which provide a unified protocole to store and share imaging data, storage and communication has become easier between different healthcare services. However, when it comes to data sharing there is no uniformed protocol neither on the manner of doing so, nor on the fact that those data should be shared. Naturally, once an exam has been performed, patients will automatically be given their clinical results, in terms of wellness or sickness, but medical images won't be automatically shared with them. Depending on the issuing country, medical images can be shared, either automatically or on demand, more or less easily, with a patient.

In the scope of this project, the targeted area is the **United Kingdom** where effective access to medical imaging data is currently not commonly provided. By default, once an exam is performed, only the medical report (a written interpretation of the imaging findings provided by a radiologist) will be send to the referenced general practitioner (GP) or other referring clinician. The patient will then need to make an appointment, with that clinician, in order to get the information concerning his medical condition. More precisely, he will get the clinical report communicated by his clinician. No medical images would necessarely be shared, or even shown at any time of the process, neither to the medical expert, nor to the patient. On demand, and provided payment of a defined amount, a patient can get his medical data on a CD or DVD, supplied with a default software reader built to deal with the special DICOM format. However, the kind of software that are provided on CDs or DVDs were initially made for clinician and may not be adapted for an average person.

Consequently, as patient desire to access their imaging data is growing, the idea to provide them with a suitable interface has become pretinent. By **suitable** is implied an interface that would only contains relevant and useful features, that would be instinctive, and contain information that are reliable for the user. Indeed, it is more than easy nowadays to find a wealth of erroneous or misleading informations and explanations all over the Internet. The goal is to offer the patient a safe environment where he could explore his data and understand his medical condition without any drift. Such interfaces are commonly called **"patient portal"** and some have already been created and experimented locally on a sample of patient in Los Angeles [5]. However, this has only been part of an internal study and haven't reached the outside of it's location.

Nevertheless, for the above reasons, building an interface for sharing medical diagnosis with imaging patients is not an trivial task. Medical images are sensitive pieces of information and a misunderstanding can be significant. What would then be the **risks and the benefits** of creating a patient portal? These questions have been subject to several literature reviews [1] and especially to the realisation of a **PhD** by one of my supervisors **William Cox**.

2.2 Related Work

Before we started to actually discuss the project goal, Will provided me with several documents, either literature reviews or articles already referenced above, concerning works and researches directly related to the project. Among those, he also provided me with the late stage report of his PhD, containing the state of play of his work at that stage. Those papers have allowed me to understand the background of the project and to identify the related issues and challenges.

The goal of Will's PhD is to identify the **risks and benefits** related to the creation of a patient-oriented interface. To be more precise I would cite directly from this report:

"Intuitively, there are benefits available from sharing images with patients. Indeed, there is a wealth of research available which assesses how visualisation aids increased understanding, or promotes communication. However, little research assesses the value of radiological images in this context. Moreover, no work assesses the risks associated with sharing patients images with them. This is the gap which this PhD will address. The research questions for this PhD are, therefore:

- *Is there additional benefit that can be extracted from diagnostic images?*
- *If so, what are the requirements to enable the realisation of this benefit?"*

Specifically, to lead his researche, he has divided benefits in two categories:

- *"Primary benefits benefits related to the rationale for acquiring the image, e.g. diagnosis, assessment, interventional guidance*
- *Secondary benefits benefits unrelated to the rationale for acquiring the image, e.g. education, communication, empowerment"*

At the moment, Will has achieved a significant work, he has completed a literature review, to set up the background and understand the issues related to the creation of a patient portal. Precisely, the aim was "to ensure that this was a suitable subject for research and to identify any pertinent gaps in the existing knowledge.". He also carried out a survey, questioning medical experts, supplemented with 8 semi-structured interviews in order identify and scale the related risks and benefits from a clinician point of view. the results of those works are available for consultation on

2.3 Goal definition

Once familiar with the project background, it has been easier for me to understand the main **issues and challenges** and to have a precise idea of the goal to achieve. The objective of this project is not to simply copy and create another standard DICOM viewer but to create an interface that can be **progressively adapted to fit patient needs**. Challenges consist in buildging an interface that could be sufficient and valuable, meaning it could provide enough information to guide the patient on the right track without any simultaneous external contribution. Moreover, designing this interface should allow to identify the benefit to be realised through providing people with their imaging data, whilst also minimising the identified risks of this process.

It has been agreed that we would together with Fernando and William, define project specifications (in terms of design and content) and that all information relative to benefits and content would be discussed mainly with William. They, also advised me to install some already existing DICOM viewer made for clinicians. They wanted me to get an idea of the kind of interface that I could produce, while keeping in mind that the goal is not to create a copy of those readers, but to produce my own patient-oriented interface.

In the following part, I will develop the project specifications that have been produced in the early stage of the project, following multiple discussion with my tutors. Moreover, considering that I have been given complete freedom in the choice of the tools and languages to use for building the interface, I will explain the choices I have made before starting to implement my project.

3 Early Specifications and Implementation Methods

3.1 Early specifications

Based on my previous experiences concerning the development of a project for a third person, it was really important for me to clearly define the specifications and limits of the project, before starting the implementation. This was, on one hand, to be sure that I would produce an interface that would suit my supervisors needs, and on the other hand, to avoid time being wasted in the future. Specifications concerning the graphical interface have been divided into five parts: the basic requirements, the content, the design, the features and completed with further precisions.

During the early stage of the project we had several meetings with my two supervisors in order to define those specifications. These following specifications correspond to those agreed by the time of writing the **background and progress report**. Eventually, those specifications have evolved during the implementation of the project, adjusting tasks to the the achieved work and encountered issues. Precisely, concerning the design of the interface, specifications have evolved while discovering the interface designer. Further precision concerning the design of the interface has been provided by Will approaching mid July. He gave me a well detailed drawing of what he was expected supplement with more precisions concerning the features he was expecting. Those specifications were given as a reference to start the implementation of the interface architecture and are available on ***Appendix 4***.

- **Basic requirement - main criteria of success:**
  - Patient should be able to understand the provided images
  - Patient could explore the data in different ways/ different images orientation
  - Patient should have the possibility to ask questions to doctors/ specific assigned people
  - At some point the interface should be evaluated by a panel of experts and laypersons that would be asked to use it and provide feedbacks.
- **Interface content:**
  - The interface should display patient images - images will be provided in DICOM format, and translated so that the patient can read them.
  - The interface must contain the clinical report and the simplified version.
  - A link to NHS website will be given, so that patient could find general information about their condition
  - Patient could get flag informations - to be filled by doctors - while exploring the images, for example, the image which best demonstrates any abnormality can be pulled out from the broader study dataset
  - Any other relevant information related to what the DICOM files provides could be added
- **Interface functionalities:**
  The interface should provide:
  - One doctor-oriented window: so, they can fill in the relevant data (images, report) and add a flag to appropriate images at their convenience.

  - One patient-oriented window: read only data (no modification allowed) and the possibility for patient to chat with doctors.

  My main concern - in the context of this project - is to focus on the patient-oriented side and see how far I can lead this project. This part can be really time consuming as it might need to be frequently readapted following the needs of my tutors.

  Also, Will gave me, back at the time, detailed general specifications concerning the patient-oriented interface content/functions that are available on ***Appendix 2 and 3***.

- **Interface design:**
  - Imaging display will depend on the provided images (MRI, CT) but not on the part of the body. Will also gave me on demand description concerning images to be display and the way to deal with it - Appendix XX -.
  - Provide a side by side or other relevant organization that would allow the patient to get the images and the report together in a relevant way
- **Further precisions:**
  - No access to any database will be provided for the current project (security and data protection issues)
  - Access to the interface will be local, patient would be given (upon request) a CD with their images loaded on the interface; this wont change patient access to data but should make them want to access meaningful
  - Interface should include user specifications/precisions for patient
  - Benefits/specifications will have to be defined before starting implementation
  - Interface should be Microsoft Windows portable

3.2 Choosing tools- C++ and Qt

A lot of tools are available on the Internet to manage the creation of Graphical User Interfaces (GUI). These kinds of software provide classes, function and usually a “designer” mode to facilitate the creation of an interface. The most famous I discovered on the Internet are Qt, WxWidget, GTK+, FLTK, FOX. If necessary, I would have been ready to learn any programming language to achieve my project, luckily for me most of the available tools are develop in C++. During this year of Computing Science master at Imperial College of London I learned a lot on the C++ languages, firstly through lectures and lab session, and also through my group project. Hence, it was really time saving for me not to look for other tools.

In order to be sure to use a widget library that will suit me I have decided to compare the provided one before picking one. I couldn’t compare all of them, so I have decided to focus on Qt, WxWidget GTK+.I looked across the Internet to get some testimonies about the different tools and I tried to distinguish them following several criteria - see grid below. According to these criteria and considering that Qt is highly recommended for beginners, I have finally decided to use Qt for this project.

Criterias\Interface	Qt	WxWidget	GtK+
Chat doc	+++	+	++
Cross-Platform	Yes	Yes	Yes
Open Source	Yes	Yes	Yes
Langage	C++	C++	C++
Flexibility	High	Low	Medium
Performance	High	High	High
Documentation	+++	++	++

Figure 1: Qt, WxWidget, GTK+ comparison table

In order to get used to Qt, which was new to me, I have decided to complete Openclassroom tutorials [6]. Those tutorials have helped me to install QtCreator and to get familiar with Qt beginning with some basic exercices.

4 The Imaging File Format: DICOM standard

DICOM standard is a special software integrated format dedicated to **ease data storage and communication** between different facilities in the **medical imaging field**. This standard has been defined by the **American College of Radiology** (ACR) and the **National Electrical Manufactural Association** (NEMA) in 1985. DICOM defines a specific data model structure, a file format and data dictionary, it also comes with a TCP/IP protocol to facilitate data transfer. Before the creation of this standard, it was challenging for distinct services to exchange imaging information, currently DICOM format is widely use among the medical imaging area.

DICOM standard is a well-structured but also hard to reach software. Even if its website [7] provides a wide documentation, it remains challenging to fully understand it. The aim of the following subsection is to give a basic overview of DICOM standard structures. In the scope of my project I will mainly focus on the data storage and treatment, TCP/IP protocol has not been part of my concern. Moreover, as complete the DICOM standard website could be, I used several websites [8] & [9], to build my understanding on the DICOM file format.

4.1 DICOM Information Model structure

DICOM has been created to facilitate information exchange in **the real world of patient healthcare services**, according to the medical imaging field. Hence, all information that are processed with DICOM are related to **real world elements**, that could be patient, location, studies, images etc. DICOM standard defines its own terminology to descibe the context and relationships between those element in his **DICOM Model of the Real World**, available in

4.2 DICOM File Structure

The **DICOM File Format** decribes how the information, encapsulated in an **SOP instance**, should be stored in a byte stream, in a file on a physical medium. Each DICOM file is composed of two instance: a **Header** followed by a **Data Set**.

- **The Header** contains 128 bytes preamble (which are all set to zero if it is not used) followed by 4 byte DICOM prefix (DICM). The header is not necessary included in the file but is useful to make access to data easier, indeed the prefix allows to quickly acknowledge DICOM format. Besides, no structure is required for the preamble.
- **The Data Set** is organised as consecutive **DICOM Data Element** (or Data Attribute), referenced in the DICOM standard [10]. Those Data Element can represent various information, from the patient name and birth to theimage pixels. More precisely one **DICOM Data Element** is *one unit of information* corresponding to one encoded **Information Object Definition (IOD) Attribute**, defined above. Figure 4 gives a representation of the DICOM File structure.

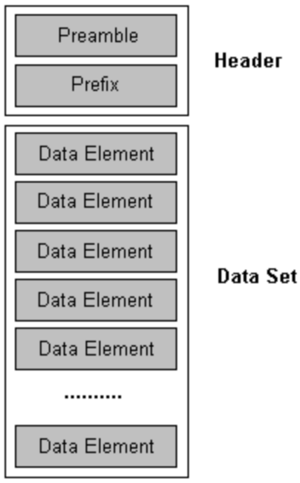


Figure 2: Basic DICOM File Structure

DICOM Data Element are *Tag Element*, therefore DICOM can be said to be a tag file format, this mean that each element is referenced by a unique **Tag Number** defining the element and its properties. In the Data Set, Data Elements are ordered by increasing Tag Number. Each Data Element is made of the same range of consecutive fields:

- **Tag Number**: it consists in an ordered pair of 16 bits unsigned integer of the form (gggg,eeee) representing the *Group Number* - defining the Information Entity - followed by the *Element Number* - defining the attribute. For example, in the tag (0028,0010), the Group Number is 0028 and correspond to the Image group, the Element Number is 0010 and correspond to the row (especially to the length of the image in pixels).
- **Value Representation**: it defines the data type of the element. As the Tag Number already implies the data type, the value representation can be omitted.
- **Value Length**: either 16 or 32 bits element, this defines the length of the following value.

- **Value Field**: consists in an even number of bytes containing the value of the element; this field can contain the Value Multiplicity, which would specified the number of values that can be encoded in the field.

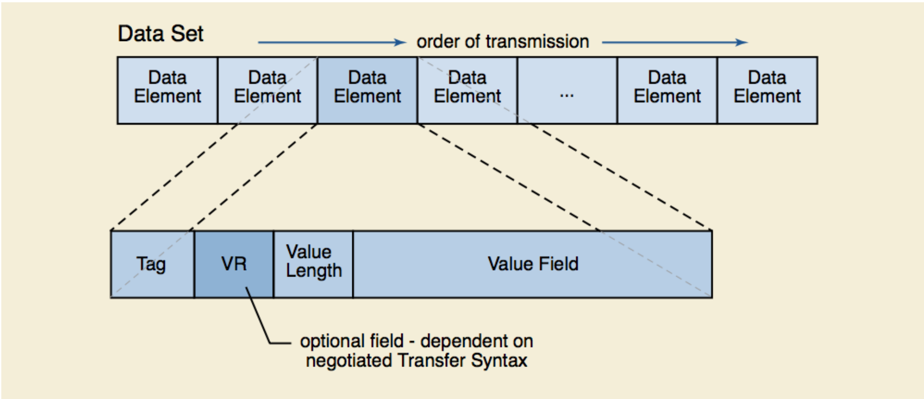


Figure 3: Data Set and Data Element structure

4.3 DICOM Folder - Patient level

While asking for their medical imaging data, patients will be given a **DICOM Folder** containing all relevant information. Every basic DICOM folder should contain one DICOM element called **DICOMDIR** and a folder named **DICOMDAT** leading path to the images.

- From the DICOMDAT folder, the hierachical structure will be as follow:

```
DICOMDAT
├─ SDY00000
│  ├─ SRS00000
│  │  ├─ IMG00000
│  │  ├─ ...
│  │  └─ IMG0000N
│  ├─ SRS00001
│  │  ├─ IMG00000
│  │  ├─ ...
│  │  └─ IMG0000N
│  └─ SRS00002
└─ SDY00001
   └─ SRS00000
```

  - **SDY0000** folder represents a unique study for a given patient. One study correspond to one set of exams, on request of the patient to explore on part of the body at a given time. A study can be made of one or more series.
  - **SRS0000** stands for a unique serie. One serie correspond to a specific exam organisation (patient orientation, duration, etc.) used to capture the image(s). A serie can be made of one or more images.
  - **IMG00000** are DICOM Images Element, corresponding to the propper "Medical Images". Those elements contain all the relevant information that should be used to render the images on a screen.

- The **DICOMDIR** is a **DICOM File Object** containing the tree structure described above. This will allow to automatically get the path to each element. It also contains the general information according the the exam (patient information, study ID, date).

The folder might contain other non DICOM element (e.g the report) that won't be recorded by the DICOMDIR. During the creation of my interface, this DICOMDIR has allow me to browse through all the folder element and to automatically find path to images.

5 Classes and File Structure

5.1 DCMTK Library and Qt

DCMTK is an **open-source** collection of libraries and scripts that has been made to deals with **DICOM Objects**. This toolkit is widely used by hospitals, companies or private individuals, that aim at creating DICOM-related desktop software. DCMTK provides already built **DICOM-related classes** suitabely made to treat, construct, and convert DICOM objects; it also provides an internal worklist server in order store, send or receive images. DCMTK source code repository is available on Github and free for downloading and is available for both Windows and Unix operating systems.

What I want to tell:
1. Why I choose dcmtk: obviously I coudln't unwrap dicom element by myself dcmtk provided me a way to access tag element easily sound's widely used on the internet –¿ lot's of prebuild readers were using dcmtk

2. Building dcmtk: issues solutions –¿ explain how to link
3. Dcmtk classes
As I said DCMTK provides well-formed classes
had to go through dcmtk documentation to find the relevant function I will use !
Dcmtk provides a lot a classes to deal with dicom format
Developp the one I used:
- DicomImages - Dealing with tag element -¿ file and get bordel - DICOM bordel going though the tree

5.2 Classes and UML Diagram

Explain the code file structure
UML diagramm of the class (without all attribute for serie and maine window)
Explain the approach
Class definition
screenshot for serie and Mainwindow.h in appendix Serie Class Definition and MainWindow Class definition

6 Implementation

6.1 Rendering DICOM Images

The first challenge of this project was to render a set of DICOM Images or at least one DICOM Image.
As I already explained, in part 4.4, the DICOM folder tree structure blablabla
However IMG0000 file are not of only one type, this file can be either:

- One single frame DICOM Image
- Several single frame DICOM Images
- One multiframe DICOM Image

Objectively, single and multi frame images only differ by the size of the file.

1. Display one image:

The DCMTK library that I installed contains several classes that should make DICOM Images treatment easier. The class I used to deal with DICOM Images files is called DicomImage, the class structure and related functions are available on DCMTK website [8888]. The class is provided with four different constructors and depending on the given parameters this class allows to deal with single frame and multiframe images. Information about the constructor I choosed are available on Appendix XXX figure YYY

- Display single frame DICOM Image:

  *DicomImage *DcmImg = new DicomImage(path)*

- Display multiframe DICOM Image:

  *DicomImage *DcmImg = new DicomImage(path,0,index,1)*

  index being the index of the frame to display

The variable *path* is a string and contains the absolut path to the DICOM Image file.

Once I got the DicomImage object, I need to get the pixels in order to have the opportunity to use QImage class thereafter. Here again DCMTK provide me with the function *getOutputData()* - see Appendix XX figure ZZ -. The corresponding line of code is:

$uint8_t * pixelData = DcmImg- > getOutputData(8)$

Explain what is uint8_t
Finally I only need to use two classes provided by Qt to render the DICOM Image on my application:

$uint8_t * pixelData = DcmImg- > getOutputData(8)$

QIMage only takes pixel and a scene can only display QPixmap element see appendix

2. Store and display successive images of the serie

6.2 Building 3D plan

7 Results

As specified at the begining of this report, the main goal of my project was to build a Graphical User Interface, suitably made for medical imaging patient in order to help them view their medical images. The final result of my project consist consequently in a Windows runnable application, that can be used by anyone, in order to view imaging data. The following section will present the finale output of the interface in terms of content and features. The first part intend to give a general overview of the interface, describing the different steps from the launching of the app to the effective display of one medical image. The second part will focus more precicesly on the features that I have developped and are available through the interface.

7.1 Interface Overview - General Content

From the launch of the app through the effective display of the *MainWindow*, the user will first have to come accross several steps/windows that are described below:

- **Welcome page and Disclaimer**:

  The first contact with the interface consist in a *Welcoming Page* explaining the utility of the interface. User will get indication about the way of accessing his images and will be given a disclaimer, as follow:

  “ **Welcome**
  This interface is designed for patients to view their medical images.
  Please select the file corresponding to the study you wish to view (select folder SDY00XXX).
  Your images are protected by PIN.
  Your pin is your date of birth in the following format: YYYY/MM/JJ

  Disclaimer:

  – These images are for information only
  – Do not try to interpret your images
  – For any queries, please contact your healthcare professional
  – Some people may find seeing images of themselves upsetting, please consider whether you want to view them
  – Be aware that these images constitute your personal medical data - please be mindful of who you share them with

  ”

  An overview of this **Welcome Page** is available in ***Appendix 9***. This page is supported by a button *Select File* to allow the user to choose the study he wish to display on the screen. By default the first image displayed will be the first image of the first serie.

- **PIN Access**:

  As the interface is dealing with sentitive medical data, images won't show automatically once selected. Indeed, data are protected by a PIN access, which correspond, as described in the disclaimer, to the patient date of birth in the format YYYY/MM/JJ; an overview of this window is available on ***Appendix 10 figure 18***. If the PIN provided is not right, the user will be informed on his screen and have the right to write another code, see ***Appendix 10, figure 19***. If no PIN in provided and the window is closed by the user, the application will close automatically. However, if the user provide the right PIN, he will have access to his images and the Main Window will pop up.

- **Main Window**:

  The *MainWindow* is the heart of the interface, this is the window that will allow the user to view his images and select options. An overview of the screen is available on ***Appendix 11***, displaying the CT-scan of an abdomen. The architecture of this interface has been realized taking inspiration on the Interface Design Specification (Appendix 4) mentionned in part 3.1. All the available features concerning images treatment and information access will be described in the following part.

7.2 Available features

- **Zoom in/out**:

  User can choose to Zoom in/out on the current selected image in order to reach more details, or simply to adapt the image to the window.

- **Display Flagged Image(s)**:

  The Flagged Image(s) of a serie correspond to the most “relevant” one and is supposed to give more precision about the condition of the patient - see appendix XXX. This kind of Image has to be directly inserted in the DICOM file, at the right place corresponding the the serie within a study. Path will be of the form “FLAGGED/SDY00000/SRS00000/FLAG1.png”. There can be one or more Flagged Images and the path will be directly found by the app.

- **Display one or more window**:

  Interface-user can choose to display one, two or four window on the screen depending on the number of serie he wants to watch.

- **Choose the serie(s) to display**:

  One can choose which serie to display in which window. For the moment he can only display several series from the same study. See appendix XX.

- **Choose the plan to display**:

  As described in the section 5.2, for series where the set of images is large enough, and the algorithm has been able to define the default plan of the images, the algorithm is able to recreate the two other corresponding plan of the serie. When enabled, the patient can choose which plan to display in the current window.

- **Scroll Images**:

  For series containing more thant one image, by default while using the mouse wheel, the interface will display successively the images of the serie.

- **Link Scrolling**:

  If the algorithm has been able to construct all the 3 plan from the given serie (section 5.2) and the user has choosen to display at least two plan on the same serie, it is possible for him to link the scroll of images. Linking scroll meaning display a red line that will inform about the position on the current image in the other plan, result is available on appendix XX. By default, window displaying the same plan of the same serie will scroll all at once.

- **Display different contrast**:

  DICOM provides 3 already made level of contrast call in their term “Windowing”, “Min-Max”, and “Histogram”. I replace the terms in Default, Darker and Brighter contrast.

By clicking on the corresponding button, one can choose to display the serie in a different contrast, the appendix XX show an exemple of the several contrast that can be displayed. I also add the possibility for each of this contrast, to invert the grayscale of the image. At the moment, for multiplan series, changing the contrast on one of the plan will change it for all of the corresponding plan (storrage concern).

- **Compare to “Normal” Images**:

  If the result of the exam show that the patient is not in a “normal” condition, example of normal images will be provided in the given file. On the same principe as Flagged Images, these images need to be inserted by a clinician, using a path of the form “REFERENCES/SDY00000/SRS00000/REF1.png”

- **Access to reports**

  Clicking on the relative button, user will be given access to his both *clinical* and *simplified* report. Those report have to be filled by a clinician and given to a jpeg format (for the moment), using a path of the form “REPORTS/SDY00000/CLINICALREPORT.jpeg”. The reports will appear in a distinct designated window, the patient can decide wether he want’s to display only on of those reports or both at the same time. An overview of this window in available on ***Appendix 12***.

8 Evaluation

8.1 Lay person evaluation

8.2 Ethic and LSEPI checklist

8.3 Personal evaluation

–¿ explain some choice
–¿ show calcul for different plan output

9 Conclusions and Future work

Remaining tasks

- reset button
- anonymize and share
- possibility to open another study
- take comments into consideration

10 Appendix

10.1 Appendix 1 - Expert Questionnaire Results from William PhD

Expert questionnaire

The questionnaire (APPENDIX II) was distributed to clinical imaging experts and 131 responses were received. Of these, 121 were valid responses. The questionnaire assessed:

- Participants' professional background and length of experience (Questions 1 & 2)
- Attitudes to potential benefits and risks of images sharing (Question 3)
- Support for image sharing (Question 4)

The findings from the questionnaire were as follows:

- Participants confirmed agreement by majority with the benefits/risks identified through the literature review
- Participants demonstrated support for sharing images with patients (79% (n=95) agree/strongly agree that image sharing is a 'good idea')
- Acknowledgement of the importance of context in image sharing to enable benefit realisation/mitigate risk

The questionnaire did not provide information on the following:

- Specific contextual factors necessary for safe and successful image sharing
- Information on how to manage safe and successful image sharing

Expert interviews

8 semi-structured interviews were subsequently undertaken with expert clinicians. The interviews were designed to confirm and expand on the findings from the questionnaire as well as to consider the requirements for enabling patients to extract benefits from access to images whilst mitigating the associated risks. The interviews were transcribed and subjected to thematic analysis utilising a constructive grounded theory approach (Charmaz 2006).

Results from the interviews included:

- Confirmation of the benefits and risks of image sharing identified through the preceding study
- Identification of key considerations for supervised image sharing:
    - Why share?
        - The importance of rationale
    - Who shares?
        - Clinician type
        - Patient type
    - What is shared?
        - +ive/-ive findings
        - Supporting information
    - When should sharing occur?
        - Supervised/independent?
        - On demand?
- Key requirements for benefit realisation via independent access to images
    - An explanatory layer
        - Clarity regarding user responsibilities
        - Understandable/accessible/trusted supporting information
    - Interactivity
    - Support mechanism availability
    - Data security

The data from these interviews will be further analysed in the context of data gathered from the planned patient interviews. This will involve checking that codes remain 'fit' and 'relevant' and will enable the identification of agreement and difference between the two groups.

Figure 4: Expert Questionnaire Results

10.2 Appendix 2 - General Specification

General requirements:

Initial interface (before opening imaging)

- Password control
- Disclaimer
  - For information only
  - Do not try to interpret
  - Any queries contact your healthcare professional
  - Some people may find seeing images of themselves upsetting, please consider whether you want to view them
  - Be aware that these images constitute your personal medical data – please be mindful of who you share them with
- ... any further which may be identified/emerge over course of the project
- Will need to be some thought given to how to make the functionality designed for clinicians accessible/useful to end user

Accompanying information

- Relevant abnormality information (from patient.info)
- Report – could terms be linked to definitions?
- Simplified report
- Normal comparator/diagram
- FAQs
- ... any further which may be identified
- Ability to display:
  - Multiple studies. E.g. interval studies.
    - This is when an X-ray of a broken wrist is taken at the time of the accident and then another X-ray is taken 6 weeks later to see if it has healed
      - Helpful if these could be viewed side by side
  - Multiple images side-by-side (e.g. axial view (top to bottom view) & sagittal view (side to side view)
    - See diagram below for the imaging planes:

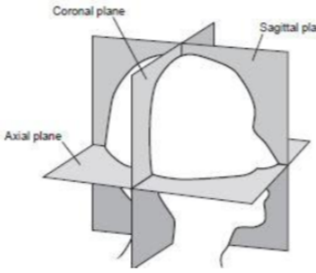


Figure 5: General Specification 1

- Flagged image from a series opens first
  - It would be helpful to know how many times the user accesses the more detailed imaging vs how many times they only review the flagged image
- Highlight abnormality
  - Can be toggled on and off
- Hover over labels (anatomy)
- Annotations made by clinician
  - Can be toggled on and off
- Ability to remove any personal information/annotations (for users who want to share their image without revealing information)
- Ability to share image onwards (e.g. via email)
- ... any further which may be identified

Basic manipulations:

- Zoom
- Adjust contrast/brightness
- Invert greyscale
- Measure
- Ability to reset to original image appearance/undo manipulations
- ... any further which may be identified
  - Useful to have an explanation for each of these
  - Pop up box?
    - What they do/how they may affect the image appearance
    - Disclaimer/warning that changing the image appearance may make it look artificially abnormal

Interactivity

Contact information for queries

Chat functionality

Figure 6: General Specification 1

10.3 Appendix 3 - Imaging Specification

Specific requirements by imaging modality:

Conventional X-ray

- The most common form of imaging
- Usually 2 images per body part imaged
  - e.g. Dorsi-palmar (DP) wrist (axial plane - top to bottom view) & lateral wrist (sagittal lane - side to side view)
    - DP wrist :

    - Lateral wrist:

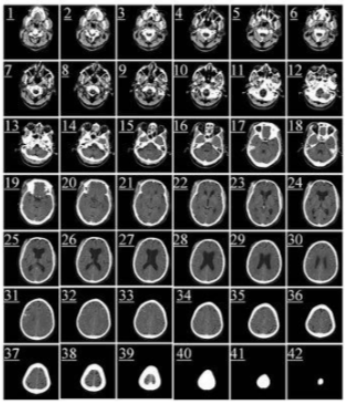
- May be more than one body part imaged
  - e.g. hand (2 images) & elbow (2 images)
- May occasionally contain more than 2 images, if initial 2 don't display all the information –
  - e.g. if a leg is longer than the image size, need 1 image for top of leg, 1 image for bottom of leg

Computed tomography (CT)

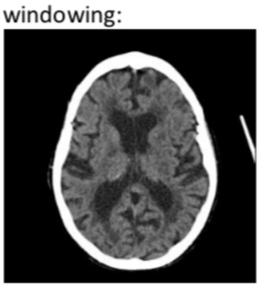
Format information

- Multiple images in series with sequential slices to cover all relevant anatomy
  - e.g. brain scan:

Figure 7: Imaging Specification 1



- May contain imaging in more than one plane/utilising windowing to highlight anatomical structures of different density
    - e.g. brain images in axial/sagittal/coronal plane
    - E.g. brain images which have been 'windowed' to show only the bone of the skull in order to make it easier to identify fractures
        - Normal windowing:



        - Bone windowing:

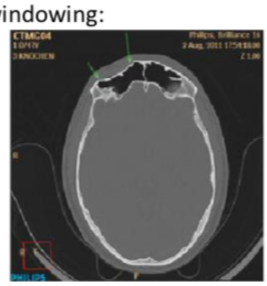


Figure 8: Imaging Specification 2

Requirements for display

- Should be able to open the study with the 'flagged' image first. User can then view further imaging if necessary
- It would be helpful to know how many times the user accesses the more detailed imaging vs how many times they only review the flagged image

Magnetic resonance imaging (MRI)

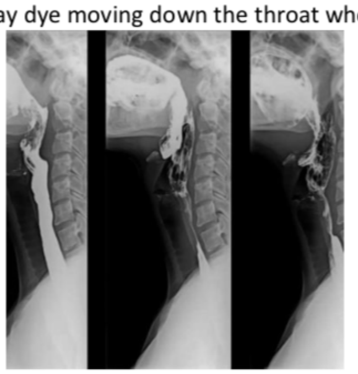
- Similar to CT
  - Can contain a lot of images which are arranged in sequences
  - Can have images displayed in different imaging planes
  - Different sequences show different parts of the anatomy by demonstrating different types of tissue (similar to windowing in CT)

Ultrasound (U/S)

- Similar to CT
  - Can contain a lot of images, although sometimes only 1 or 2
  - All images will be acquired in the same imaging plane

Fluoroscopy

- Similar to CT
- Can contain a lot of images
  - Images may be acquired in multiple anatomical planes
  - Images sequences may demonstrate time-lapse movement (similar to a video)
    - E.g. X-ray dye moving down the throat when swallowed



    - Helpful to be able to present these images like a slideshow so that they look like a video

Other points:

I have access to limited DICOM datasets but I do have some CT studies and fluoroscopy

These are quite large files and come on a CD bundled with an existing DICOM viewer – do you have a preferred secure method for me to transfer this data to you?

I also have a large bank of conventional X-ray images which are in fw.png format. These should be easier to transfer. It would be good to use these, too.

Figure 9: Imaging Specification 3

10.4 Appendix 4 - Interface Design Specification

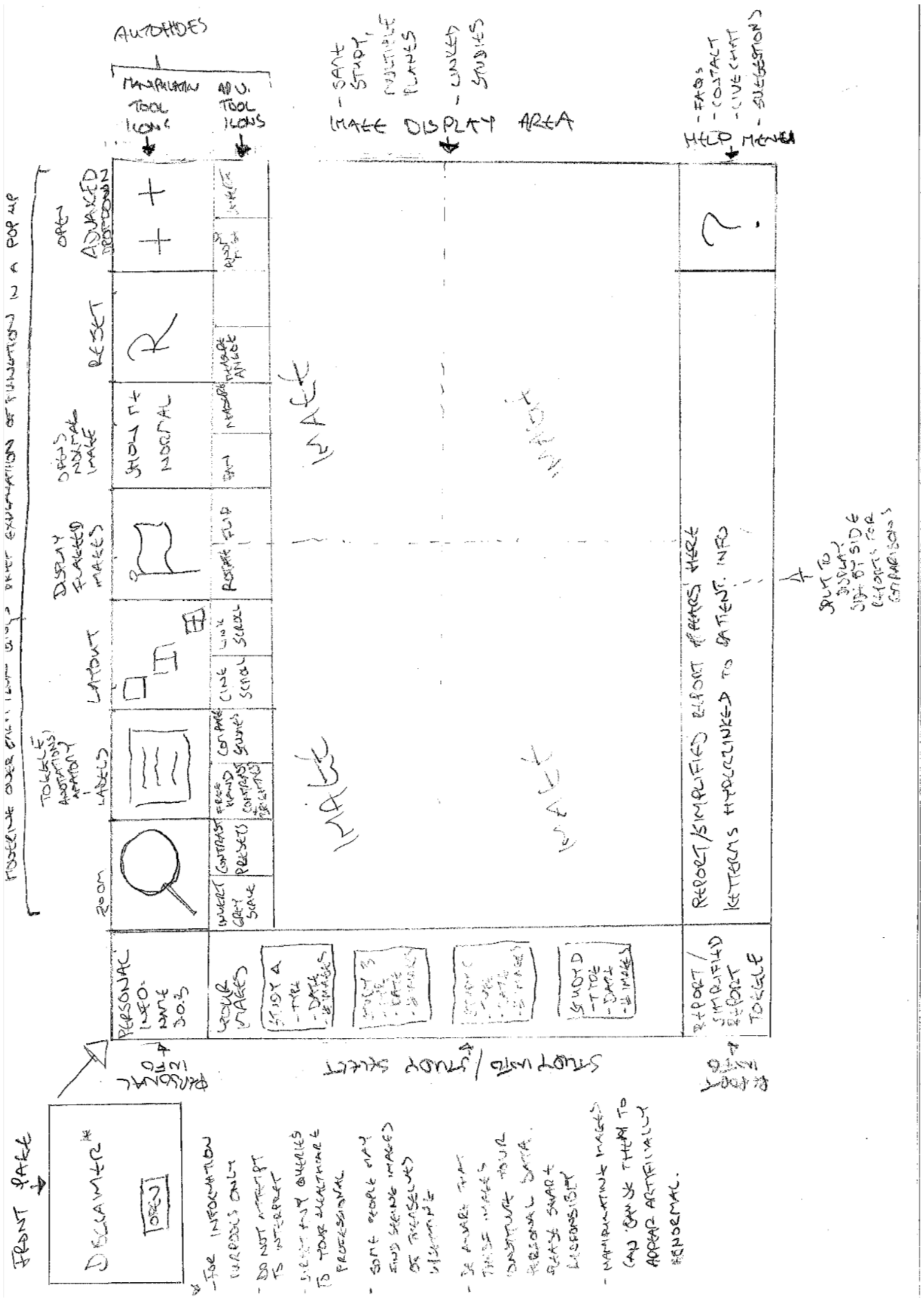


Figure 10: Interface Design - Drawing Specification

The basic icons on this toolbar include:

- Zoom
- Labels: Toggles annotations/anatomy lables on and off
- Layout: Determines how many images are shown at once
- Display flagged images: Calls up any flagged images
- Show me normal: Opens a normal image of the same type, e.g. a normal chest xray
- Reset: Returns image to original display format
- Advanced: Opens further icons in a dropdown toolbar inferiorly. e.g.:
    - Measurement tool
    - Measure angle
    - Contrast presets
    - Contrast and brightness manipulation
    - Invert greyscale
    - Annotate
    - Rotate
    - Flip
    - Pan
    - Cine scroll
    - Link scroll
    - Compare studies
    - Save
    - Anonymise image
    - Share image

Hovering over each icon should pop up some information regarding the function which each icon opens. e.g. for 'Reset' - 'This will return your image to its original appearance and any changes made will be discarded.'

In the superior left corner, I think it would be helpful to have the patient's personal information, name, date of birth, etc.

Left lateral edge:
Along the left lateral edge, we can situate buttons for each study the patient has. Any flagged image can be the thumbnail image for these. Hovering over them will provide the study type, e.g. chest Xay, the study date, and the number of images in the series.

Inferior edge:
in the Inferior left corner is the toggle for displaying the report or the simplified report. This is then displayed along the inferior edge of the display. This can be split into two if multiple studies/multiple reports are being reviewed.

This report toolbar should be resizeable so that the user can drag it up to take up more of the screen.

In the inferior right corner is the 'help' icon which can allow the user to:

- Access FAQs
- Contact their clinician
- Enter a live chat
- Make a suggestion for improving the interface, e.g. additional functionality

Figure 11: Interface Design - Features Specification

10.5 Appendix 5 - DICOM model of the Real World

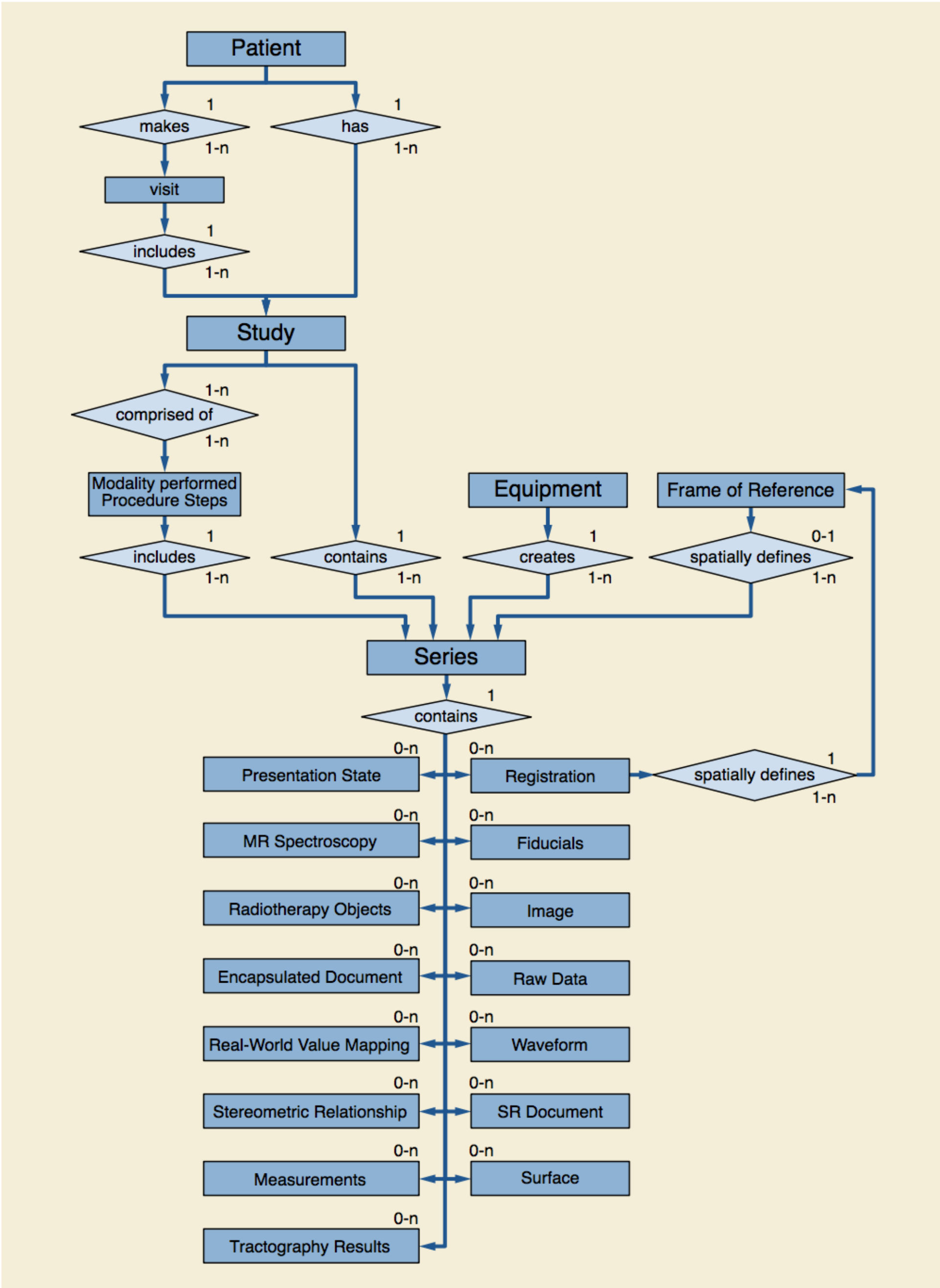
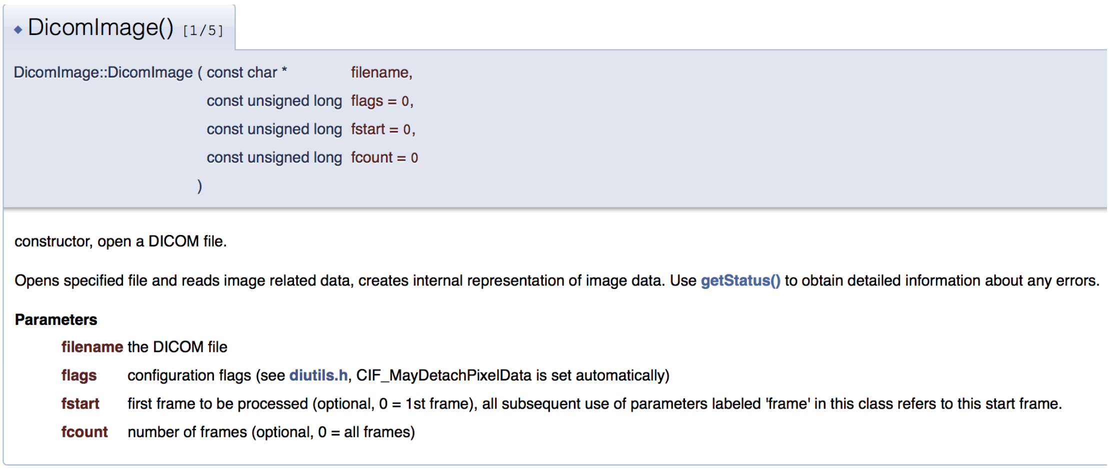


Figure 12: DICOM Model of the Real World

10.6 Appendix 6 - UML Diagram

10.7 Appendix 7 - DCMTK: Relevant classes and functions declarations



◆ DicomImage() [1/5]

```
DicomImage::DicomImage ( const char *          filename,
                         const unsigned long   flags = 0,
                         const unsigned long   fstart = 0,
                         const unsigned long   fcount = 0
                       )
```

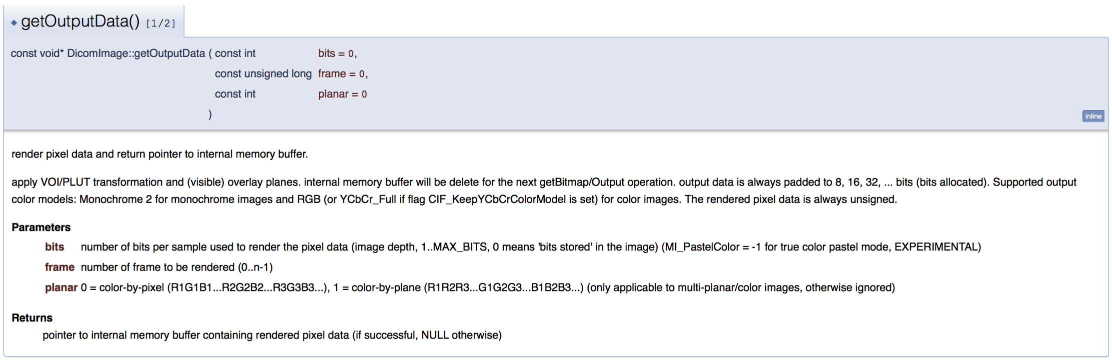
constructor, open a DICOM file.

Opens specified file and reads image related data, creates internal representation of image data. Use getStatus() to obtain detailed information about any errors.

Parameters

- **filename** the DICOM file
- **flags** configuration flags (see diutils.h, CIF_MayDetachPixelData is set automatically)
- **fstart** first frame to be processed (optional, 0 = 1st frame), all subsequent use of parameters labeled 'frame' in this class refers to this start frame.
- **fcount** number of frames (optional, 0 = all frames)

Figure 13: DicomImage Class Constructor



◆ getOutputData() [1/2]

```
const void* DicomImage::getOutputData ( const int             bits = 0,
                                        const unsigned long   frame = 0,
                                        const int             planar = 0
                                      )
```

inline

render pixel data and return pointer to internal memory buffer.

apply VOI/PLUT transformation and (visible) overlay planes. internal memory buffer will be delete for the next getBitmap/Output operation. output data is always padded to 8, 16, 32, ... bits (bits allocated). Supported output color models: Monochrome 2 for monochrome images and RGB (or YCbCr_Full if flag CIF_KeepYCbCrColorModel is set) for color images. The rendered pixel data is always unsigned.

Parameters

- **bits** number of bits per sample used to render the pixel data (image depth, 1..MAX_BITS, 0 means 'bits stored' in the image) (MI_PastelColor = -1 for true color pastel mode, EXPERIMENTAL)
- **frame** number of frame to be rendered (0..n-1)
- **planar** 0 = color-by-pixel (R1G1B1...R2G2B2...R3G3B3...), 1 = color-by-plane (R1R2R3...G1G2G3...B1B2B3...) (only applicable to multi-planar/color images, otherwise ignored)

Returns

pointer to internal memory buffer containing rendered pixel data (if successful, NULL otherwise)

Figure 14: DicomImage getOutputData Function Definition

10.8 Appendix 8 - Qt: Relevant classes and functions declarations

QImage::QImage(int *width*, int *height*, QImage::Format *format*)

Constructs an image with the given *width*, *height* and *format*.

A null image will be returned if memory cannot be allocated.

Warning: This will create a QImage with uninitialized data. Call fill() to fill the image with an appropriate pixel value before drawing onto it with QPainter.

Figure 15: QImage contructor

QPixmap QPixmap::fromImage(const QImage &*image*, Qt::ImageConversionFlags *flags* = Qt::AutoColor) `[static]`

Converts the given *image* to a pixmap using the specified *flags* to control the conversion. The *flags* argument is a bitwise-OR of the Qt::ImageConversionFlags. Passing 0 for *flags* sets all the default options.

In case of monochrome and 8-bit images, the image is first converted to a 32-bit pixmap and then filled with the colors in the color table. If this is too expensive an operation, you can use QBitmap::fromImage() instead.

Figure 16: QPixmap static function

10.9 Appendix 9 - Disclaimer

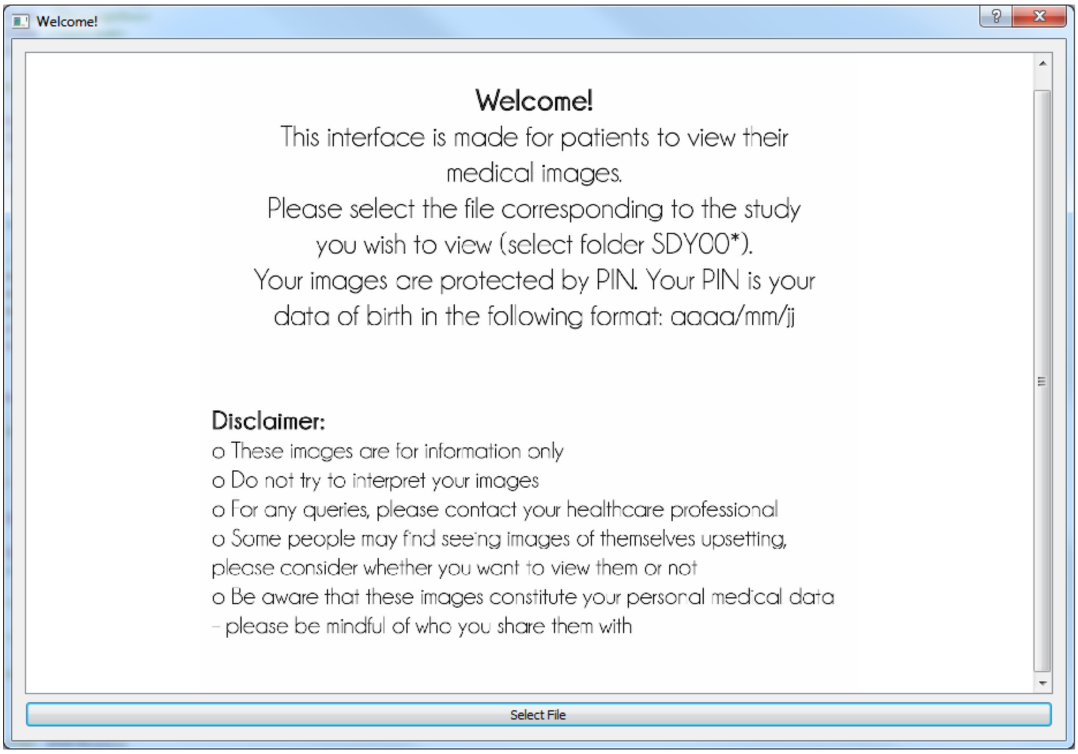


Figure 17: Welcome Window and Disclaimer

10.10 Appendix 10 - Pin Access

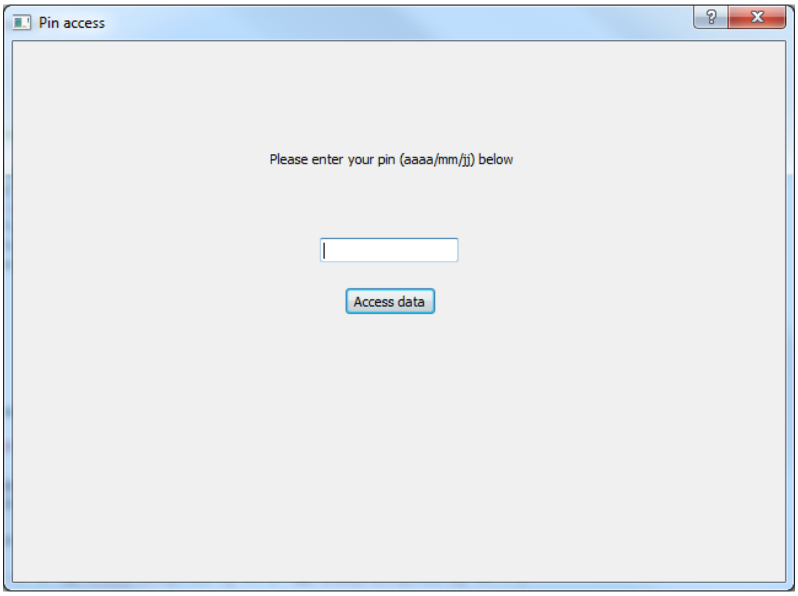


Figure 18: PIN Access Window

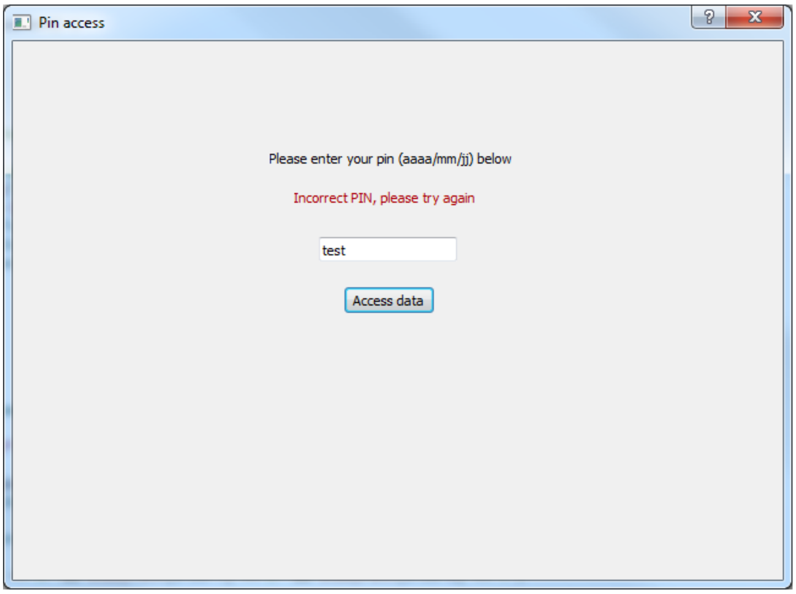


Figure 19: PIN Access Window in case of wrong provided PIN

10.11 Appendix 11 - Main Window Overview

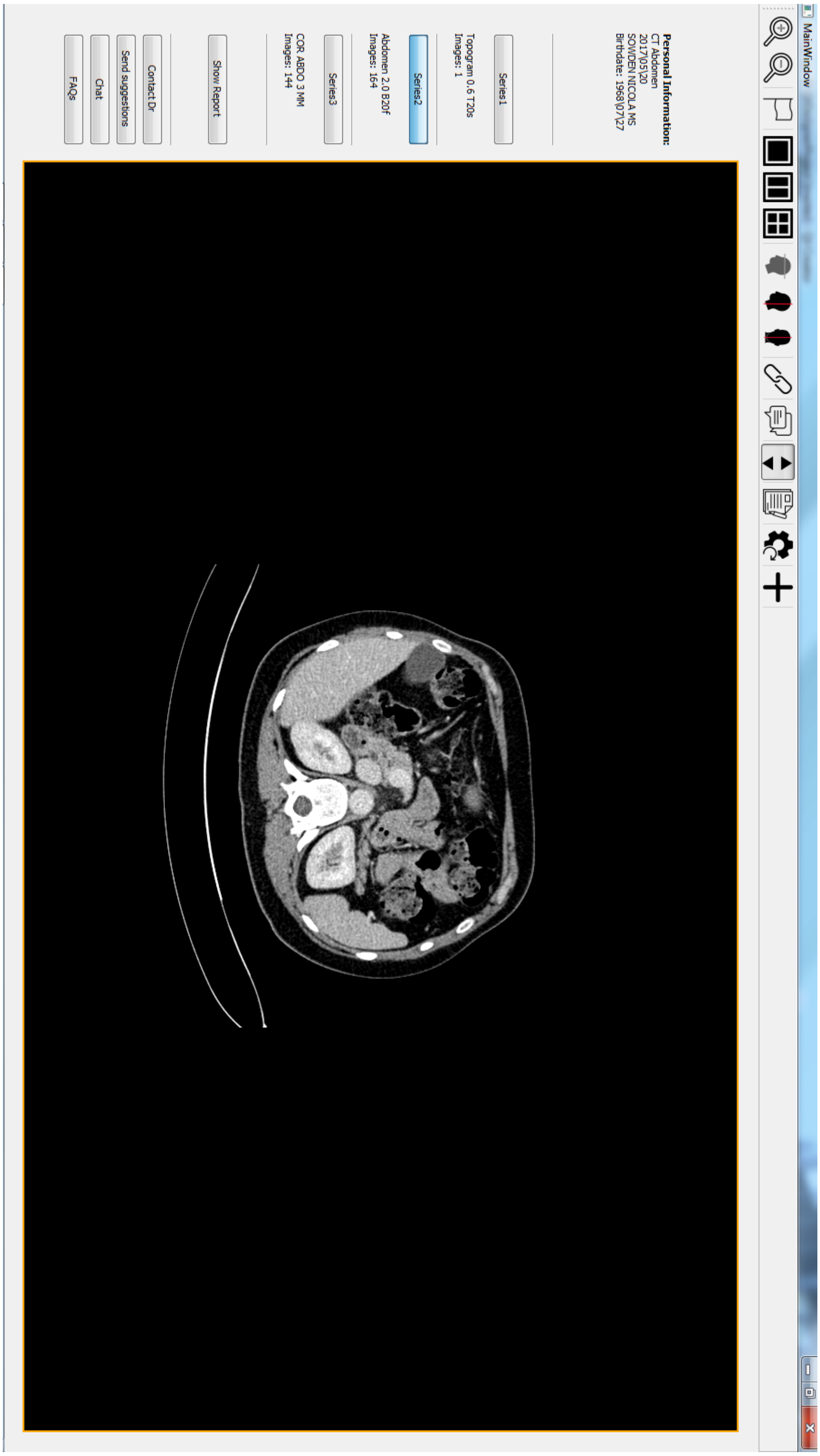


Figure 20: Main Window Displaying CT Abdomen

10.12 Appendix 12 - Reports Window

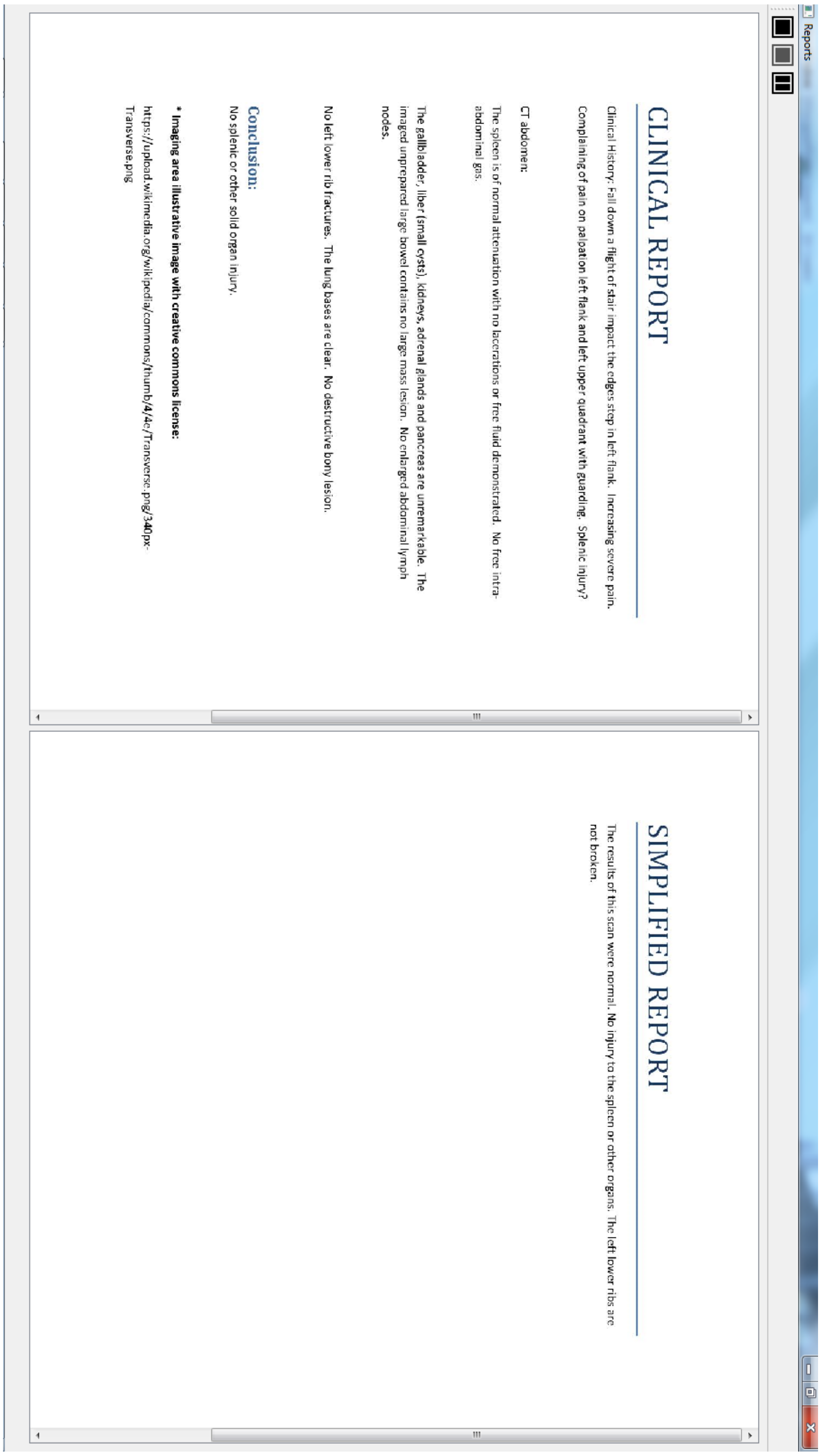


Figure 21: Overview of the Reports Window