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Supporting the Diagnosis of Childhood Brain Tumours through Structural Reports and Ontological Reasoning.

By

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ABSTRACT

After Leukaemia, childhood brain tumours are the second most common form of the disease. The most accurate way to diagnosis a tumour is via a biopsy, however this is not always possible. An alternative process is the use of Magnetic Resonance Spectroscopy (MRS), an imaging technique that works along side magnetic resonance imaging to analyse the chemical make up of the tissue being scanned. The MRS readings are then used to make a diagnosis.

An important aspect of a patient's treatment is their medical records and the reports that are used to communicate the findings from medical images. However, these notes are written using free text, which can be unclear and ambiguous which can lead to confusion and even errors in treatment. To avoid this, a proposed solution is to produce reports using Structured Reporting. This solution has been supported and incorporated into the Digital Communications in Medicine (DICOM) Standard for established imaging modalities, but not yet for MRS.

An ontology was modelled to produce DICOM supported Structured Reports for MRS. As well as this an algorithm to diagnosis of different types of childhood brain cancer using readings from MRS spectra was incorporated into the ontology to allow inferred reasoning to allow automated diagnostic support. Following this a prototype Structured Reporting application was designed based on the ontology to allow for usability testing. The ontology was able to produce Structured Reports that successfully diagnosed certain childhood brain tumours based on the MRS reading that were inputted. The usability testing garnered positive feedback and resulted in a stand alone system. The diagnostic

aspect of the ontology garnered positive feedback as at this time MRS data is only used to give a general diagnosis of whether the tissue is cancerous or not.

Future work would look at developing a working application that was able to integrate with systems within NHS hospitals and for the ontology to be extended to include more types of childhood brain tumours.

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List of Definitions and Abbreviations

CT: Computer Tomography

CSF: Cerebrospinal Fluid

DICOM: Digital Imaging and Communications

DICOMSR: Digital Imaging and Communications Structured Reporting

IOD: Information Object Definition

MRI: Magnetic Resonance Imaging

MRS: Magnetic Resonance Spectroscopy

MRSI: Magnetic Resonance Spectroscopy Imaging

No.: Number

NPfIT: National Programme for Information Technology

PACS: Picture Archiving and Communications System

SR: Structured Report/ Reporting

WHO: World Health Organisation

Chapter 1: Introduction

One of the biggest challenges faced in the medical field is the successful treatment of childhood cancer, with brain cancer being the second most common form after Leukaemia (Stiller & Nectoux 2004) (Cancer Research UK 2014). Research has led to more effective drugs and new treatments resulting in an increase in survival rates (Ward et al 2014) Cancer Research UK 2014). However, for treatment to be the most successful, an early diagnosis is a key factor (Hayat et al 2007) (Jemal et al 2008) (Jemal et al 2004) (Harrison 2011).

Doctors use several methods to make a diagnosis, including taking and testing tissue samples, medical imaging, and testing on blood and other samples (Cancer Research UK 2013). The most accurate way of making a cancer diagnosis is via a biopsy. This involves taking a sample of the tissue in question, analysing it and identifying any of the cells are malignant (Biopsy 2003). However this is not always possible, particularly with suspected tumours in the brain. Due to where they are situated, the process of taking a sample may be impossible or have too higher risk of damaging surrounding brain tissue (Cancer Research UK 2013).

As a consequence there is a high reliance on medical imaging to investigate and diagnose a suspected brain tumour. This is a specialised aspect of medicine that uses different modalities, or processes, such as x-ray radiographs and magnetic resonance imaging to produce images of the body that are used for investigative and diagnostics purposes (WHO 2014). A patient's medical notes are the main form of communication of the findings taken from these images. The reports radiologists produce for medical records

need to be easily accessible, clear and be easy to determine the required information (Kahn 2009). Although there have been changes in how the reports are produced, for example the introduction of dictation services, and more recently voice recognition software, the presentation of a report has not changed much since the first x-ray radiograph was taken over a hundred years ago years ago (Weiss Langotz 2008).

With the introduction of computer-based imaging modalities such as Computer Tomography (CT) Scanning in the 1970s and the development of medical informatics systems such as Picture Archiving and Communications Services (PACS) there was a need for a standardised imaging format. This finally came in the 1990's with the introduction of the Digital Imaging in medicine (DICOM) standard (OFFIS 2011).

Although DICOM standardises the production and storage of images it does not have an effect on the way radiological reports are created or their format. Medical reports are written and presented using natural language or free text (Structured Reporting 2002). Although clear to the author, the report may be unclear or ambiguous to another person reading it elsewhere. This is a significant issue as unclear information in the findings about a patient could lead to delays in treatment, or even incorrect treatment being given. It also makes it difficult to compare with different reports and track the progress of a patient's treatment (Clunie 2000) (Kahn 2009) (Structured Reporting 2002).

A solution that has been proposed to remove these issues is to use a method of reporting called Structured Reporting. This method means that the information in a report is presented in a clear organised manner, using a set lexicon (Clunie 2000) (Structured Reporting 2002). Support for this reporting method has meant that the DICOM format

has been extended to incorporate Structured Report Documents. This extension covers established imaging modalities, but doesn't cover newer ones such as Magnetic Resonance Spectroscopy Imaging, a type of imaging that works alongside Magnetic Resonance Imaging to analyse the chemical components within the tissue being scanned (Clunie 2000) (NEMA 2011).

The DICOM standard is a large and complex document which is difficult to navigate. If someone wishes to develop an application utilising it they have to manually locate and extracted the required sections. To try and make DICOM more accessible there have been attempts to model it as an ontology (Kahn et al 2011), an organizational framework of concepts and the relationships between the different classes and their instances. So far these DICOM ontologies have only been developed to encapsulate the standard itself in a human and machine readable way (Kahn et al 2011).

This body of work proposes modelling a DICOM-based ontology to support diagnosis of childhood brain tumours through structured reporting and Magnetic Resonance Spectroscopy Imaging.

The objectives of the project are:

- Propose, design and implement an ontology specifically for the Structured Reporting of Magnetic Resonance Spectroscopy to support childhood brain tumour diagnosis.
- Facilitate decision support for tumour diagnosis through ontological reasoning algorithms and user interface presentation.

- Evaluate the proposed system using technical performance metrics and usability testing.

Chapter 2: Literature Review

The patient's medical record is an important factor in determining their treatment. Its entries communicate observations, findings and recommendations to multiple hospital personnel within the many departments. It is reviewed by a group, or panel, of doctors to ensure that the correct treatment is given and review that a current treatment is being successful. Even with the technical advances that have occurred in certain areas such as radiology, many hospitals still rely on paper based records that are written using natural language, or free text.

There are several disadvantages with paper based records compared to computer based records which could lead to incorrect or delays in treatment. Paper based records are usually stored at the hospital and physically sent to the different hospital areas when needed. Many hospitals require excessive space to store the records and there is a risk of records being lost, e.g., a set of notes required for a clinic may not be returned to the medical records department in time for it to be sent to the correct department, or it may be sent to a consultant's secretary and not properly tracked. If a patient's paper medical record is required by another hospital it needs to be copied and sent. An aspect that is very important for clinical trials is the difficulty with paper-based records to track a patient's progress and to compare their progress against others undergoing the same treatment.

Many of these disadvantages are mitigated by scanning paper records. However, even if a hospital scans records there is still a reliance on paper as documents are scanned and correctly formatted to be stored on file, which in turn means that there is increase

demand for additional human resources (Goff 2014). Scanned records can also be less legible which leads to ambiguity. In addition, many written notes could be ambiguous due to the language used.

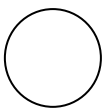
To try and combat these disadvantages, fully computerised notes have been introduced. The Electronic Patient Record (EPR) or Electronic Medical Record (EMR) is (Huang 2010) a global initiative to introduce electronic records to hospital trusts. Their purpose is to provide quicker and consequently better patient care, as they will make it easier for doctors and hospital trusts to communicate more effectively, without the worry about locating a physical record. Recent reviews have shown that these goals are being met (King et al 2011) report that 75% of those that adopted EMR reported an increase in the quality of patient care, stating that benefits included easily being able to view the needed section of the record, ensuring the correct tests required were ordered and that potential medical errors were easily identified and therefore avoided.

Although the EMR is expected to improve record accessibility, ambiguity concerns remain. Making the record completely digital may remove the legibility problems such as unclear scanning or unclear hand writing (Huang 2010), but the variation in language and style of writing still remains, making tracking a patient's progress and analysing it compared to others difficult. This has led to the idea that record storage not only needs to be revolutionised, but also how records are created. A proposed solution to using free text is to create reports using a process of capturing data called Structured Reporting (SR). This is a system of reporting that standardises the information being collected, presenting it a clear and organised manner (Weiss Langotz 2008).

2.1 Structured Reporting

Due to the importance of these records, they need to be clear, precise and easily accessible. This is especially important within Radiology, or Medical Imaging, as the reports produced by a Radiologist are usually the main form of communication of findings to other doctors. Although the technology to create medical images has evolved greatly since its conception, the way of reporting the findings from the images has not. The technologies to capture the notes have increased productivity, the most prominent change being the introduction of dictation services and more recently voice recognition transcribing software. However, this has not changed the format in which the reports have been written and stored (Weiss Langotz 2008). Currently, reports are produced using free text; either being written directly by the Radiologist or via voice-recognition transcription services. However, these methods have been described as ineffective, time -consuming and as being a risk of introducing errors. For example, time can be lost correcting errors after the transcription process or errors may not recognised by the radiologist when the report is being signed off (Zimmerman 2011) (Langlotz 2000).

Due to the nature of free text, reports in this format can be inconsistent and ambiguous, at times not even addressing the key clinical questions (Langlotz 2002). The ambiguity of the language used could lead to errors being made in diagnosis. This is due to the nature of free text because in any language there are multiple synonyms that can be used to describe something. For example, the shape below could be described in many different ways by a report author:



For example: “a circle,” “a ball” or “round.” However these descriptions could mean something different to those reading the report (Zimmerman 2011) (Langlotz 2000) (Hussein 2001).

It can be difficult to extract specific details from a free text report, and when attempted to obtain this information it can be excessively time consuming. This is again down to the nature of free text. There are numerous ways for a radiologist to describe the image they are viewing, even if using clinical terms. This means that when searching for specific information if only searching for “renal calculi” reports using an alternative term, in this case “kidney stones” may be missed (Weiss Langotz 2008) (Noumeir 2006) (Hall 2009). Having agreed terms, or codes, to represent the information in a report means that a search for specific information is going to return more accurate results.

SR would remove the ambiguity of free text. The standardisation would also to ensure reports are complete and all information is captured as the forms for creating the reports prompt the radiologist creating it for the necessary information (Structured Reporting 2002). Codes are used to capture the key concepts and information as well as having embedded references to link them to important supporting information such as the medical image being reported on. A SR is also able to provide context to the information being relayed, such as being linked to previous reports. It can also link the text with the images, waveforms etc. being described.

For a report to be created using SR it must have three attributes: a structured format, consistent organisation and a standard language or lexicon.

Having a structured format in a report, for example headings such as “Findings,” “Summary” and “Conclusion” make it easier to understand and ensure that all necessary information is captured. The different headings are also linked in a hierarchy to show the relationships between the information. For example a finding stating a diagnosis of Malignancy, that the tissue being reported on is cancerous, could be inferred from the properties of the connected components of the report.

Consistent organisation, itemised or standardised reporting will ensure report organisation. For example, the report for a chest scan would have specific sub headings such as Lungs, heart etc. Under which more specific information can be found. This again works to ensure that all the necessary information is captured in the report.

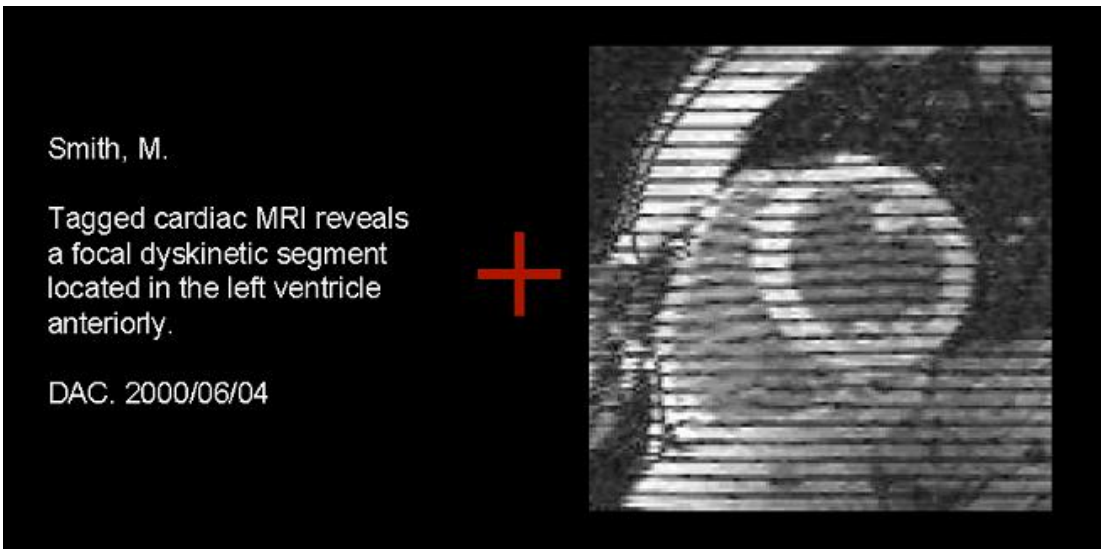
A standardised language or lexicon is possibly the key to a successful SR. By allowing only the use of specifically defined terms or coded entries the possibility of ambiguity and confusion is reduced, making the reports clearer and accessible. This is because one term or code is used to define a finding.

Using the previous example, the shape above could only be described as “round.” Any other entry attempted would be rejected. This may seem restrictive, but a possible solution is to allow the system to recognise synonyms and have these relate to the same code within the agreed lexicon. So if the term “circular” was used to describe the shape above it would have the same code as “round.” This could also be useful in helping reports be accessible to an international community and make a system usable globally. For example, if referring to the “Breast” anatomical region in a report, using the SNOMED lexicon, this would be coded as “T-4000,””SNM3.” The same code would be used for this

region whether the language to create the report was English, French or any other language. As a result a SR could be easily translated (Weiss Langotz 2008) (Structured Reporting 2002) (Clunie 2000).

As well as these attributes, a SR also creates a link to the images being discussed via embedded references (Clunie 2000). This gives context to the reports, helping to make the information being conveyed clear. Annotations, image mark up and graphics can be placed on an image to further highlight the findings being reported to provide further clarity (Zimmerman 2011) (Channing 2009). Figure 1 below shows a comparison of a 'free text' report against a structured report:

Free Text:



Structured Report:

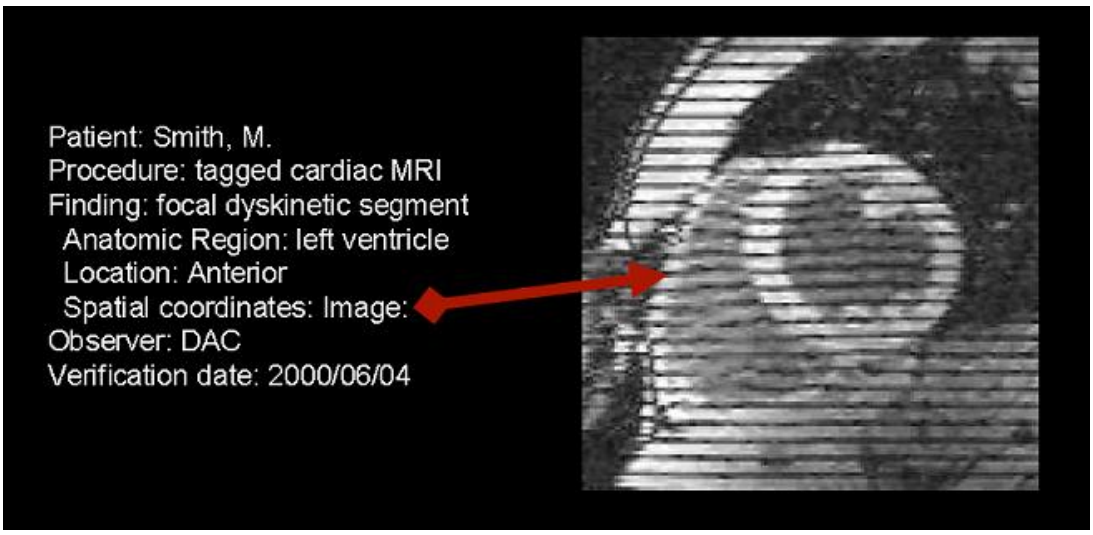


Figure 1: Comparison of a Free Text and a Structured Report (Syckle 2000).

From these examples it can be seen that the use of headings makes it much easier to identify the different information, such as the type of imaging used and findings being conveyed in the report. Also the use of the graphical annotation directly on the image makes it much easier to identify the area of interest than the vague description of “left ventricle anteriorly” in the free text report.

Although there are many arguments to support the use of SR, concerns remain. The use of the coded entries is a useless process if there is no lexicon to define their meaning. Since this type of reporting was introduced there have been several lexicons developed, such as the Systematized Nomenclature of Medicine (SNOMED) (International Health Terminology Standards Development Organisation 2014) and RadLex (RSNA (Unknown). However, at this time no standard lexicon has been agreed. This means that different SR applications can use different lexicons. As a result all application used to view the reports

would need to have access to the different lexicons to ensure correct interpretation (Weiss, Langlotz 2008) (Langlotz et al 2000) (Hall 2009).

Another concern is that practitioners completing reports in this manner would be required to use correct codes from the decided lexicon. As a result, if a user came across a finding they were not familiar with they would not be able to improvise and would have to take time to search for the appropriate code. Although it is possible to add to a lexicon this takes time as any addition need to be fully agreed upon and then inputted in to the system. This also leads to a concern that the amount of time a radiologist spends observing an image would be reduced as they now have to input details into a report via mouse and keyboard, instead of a dictation program. This could cause inaccuracies to occur in the reports as the radiologist is not observing the image whilst they are inputting the details (Weiss, Langlotz 2008) (Langlotz 2000) (Hall 2009). However, these issues may only be connected to unfamiliarity with the process, codes and the system. Once the user has become use to these the time taken to complete the reports would likely decrease.

2.2 Childhood Brain Tumours

One of the biggest challenges faced in medicine is the successful diagnosis and treatment of childhood cancer as it is the most common cause of death in children (Cancer Research UK 2014). With brain tumours being one of the most common and devastating forms of the disease in children (Siegel et al 2013) (Cancer research UK 2014) there is a large focus on finding a method of diagnosing a suspected tumour as early as possible to allow the best chance of successful treatment and recovery (Harrison 2011).

2.2.1 Types of Childhood Brain Tumours

There are many types of childhood brain tumours. They can either be primary or secondary. A primary tumour originates in the brain where as a secondary tumour develops when cancers cells that originated from another part of the body that have metastasised, or spread, to the brain. For this study only the different types of primary tumours will be discussed (Cancer Research UK 2013).

The different types of brain tumour are identified based on their location within the brain and/ or the types of cells they developed from.

The brain is made up of three main areas: the cerebrum, the cerebellum and the brain stem.

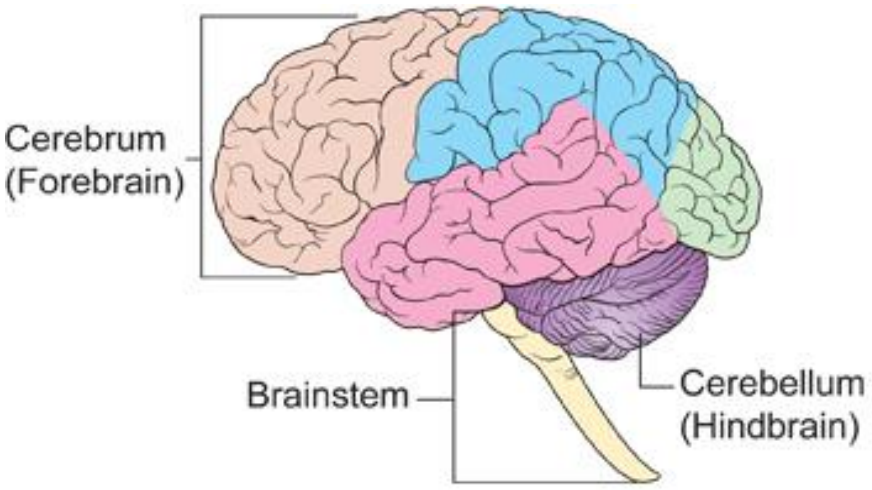


Figure 2: Diagram Showing the Main Areas of the Brain (Cancer research UK 2013).

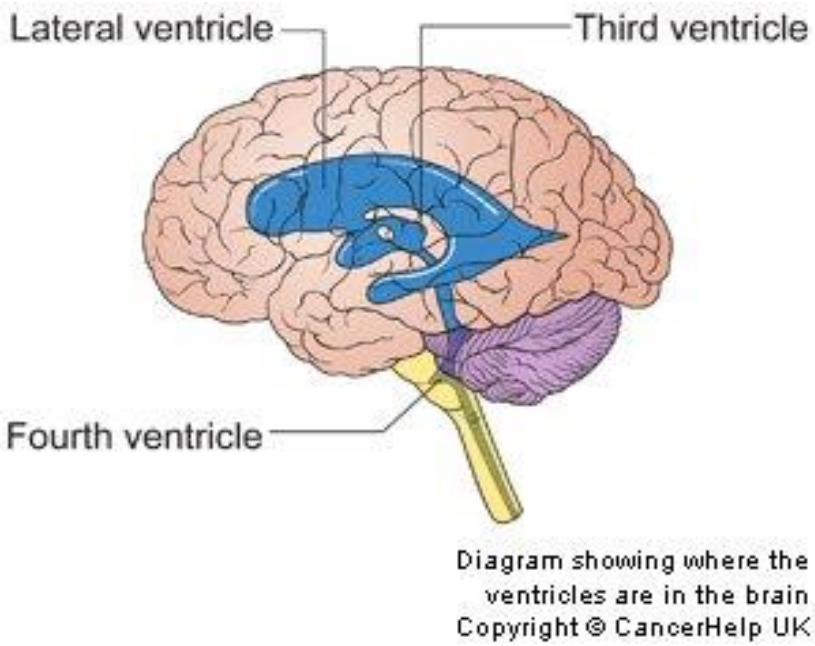


Figure 3: Diagram Showing the Ventricles within the Brain (Cancer research UK 2013).

The cerebrum is the largest part of the brain. It is broken down into two parts, the left and right hemispheres. These in turn are made up of four areas called the frontal lobe, parietal lobe, occipital lobe and temporal lobe. This area of the brain is involved with the control of movement, thinking, memories, emotions senses and speech. The cerebellum is the back area of the brain. It is in control of balance, posture and the timing and control of skilled movements such as walking. The brain stem connects the brain to the spinal cord and the nervous system throughout the body. It controls unconscious actions such as breathing and swallowing. Within the brain there are spaces filled with Cerebrospinal Fluid (CSF) called Ventricles. These connect with spaces in the centre the spinal cord and the meninges, the tissues that cover the brain (Cancer Research UK 2013).

The most common types of brain tumours are gliomas and medulloblastomas (American Cancer Society 2014). Gliomas can form in all the areas of the brain from the different

types of glial cells; they are named based on the cells they have developed from. There are two main types of gliomas: astrocytoma and ependyoma (Cancer research UK 2014). Astrocytomas develop from astrocyte glial cells and can occur in both cerebrum and cerebellum (American Cancer Society 2014). Ependyomas develop from ependymal glial cells, which line the ventricles and the spinal cord. Tumours of this type can form in all areas of the brain.

Medulloblastomas form in the cerebellum and are a type of primitive neuroectodermal tumour. These types of tumours develop from cells that have been left over from early development in the womb (Cancer research UK 2013).

2.2.2 Diagnosing Childhood Brain Cancer

The severity of a cancer is determined by the grade it is given. The grade given determines how likely and quickly the tumour will grow. This grading system was developed by the World Health Organisation (WHO) (Brain Tumour Grading System 2014). There are four tiers in the grading system going from grade I to grade IV. The lower grades the more slowly the tumour will develop. Low grade tumours, Grades I and II are regarded as benign and the higher grades as malignant. Astrocytomas can be graded from I to IV, and ependyomas from I to III. Medulloblastomas are always grade IV (Ohgaki et al 2007).

Grade I	Slow growing, Cells look normal under a microscope, Unlikely to spread to nearby tissue Unlikely to come back if removed Likely to only need removal by surgery to treat
Grade II	Relatively slow growing Cells look slightly abnormal under a microscope Sometimes spreads to nearby tissue Sometimes return after treatment Can progress to higher grades
Grade III	Relatively fast growing Cells look abnormal under a microscope Reproduces abnormal cells Spreads to other areas of the brain and spinal cord Tends to come back after treatment, often as a higher grade Needs to be treated with radiotherapy and chemotherapy as well as surgery
Grade IV	Fast growing Cells look abnormal under a microscope Reproduces abnormal cells Easily spreads to other areas of the brain and spinal cord Very likely to come back after treatment Tumours prone to form areas of dead cells at their centre (necrosis)

Figure 4: Table Showing the Different Levels of Tumor Grading (Brain Tumor Grading System 2014) (Cancer research UK 2013).

There are several ways to diagnose a tumour. The most accurate way is via a biopsy. This involves taking a physical sample of the tissue in question, analysing it and identifying any

of the cells are malignant or benign. As this is an invasive form of investigation it is not always possible for this to be used when trying to identify a brain tumour. Due to where the suspected tumour is located, it may be impossible to take a sample as it could be in a region that has too higher risk of damaging the surrounding brain tissue.

This means that there is a high reliance on medical imaging to investigate and diagnose a suspected tumour. Medical imaging is the use the production and use of images of the body for diagnostic purposes. There are many types of modalities and processes for producing these images (WHO 2014). The most common imaging techniques used in terms of brain cancer are Computer Tomography and Magnetic Resonance Imaging (MRI).

2.2.3 Computer Tomography (CT) Scanning

This a medical imaging technique developed in the 1970s (OFFIS 2011) that uses x-rays to produces tomographical, or cross sectional, images of the body. The images are taken from various angles and these are compiled in to a three dimensional (3D) image using a computer.

As with standard X-ray image, or radiographs, the X-rays are absorbed by the denser material in the body but passes through lower density materials, such as blood, creating monochrome images. A contrast, or dye, may be administered to make the images produced easier to view. This is mainly in cases where a certain low density tissue, such as a specific organ system, needs to be seen but would not normally appear in an x-ray based image. The most common contrasts used are iodine and barium (National Cancer Institute 2013.) Although the images are created in a similar manner to standard X-ray

images, they contain a lot more data that can easily be manipulate to enhance an image or see alternative views without needing the patient for further imaging (RSNA 2011).

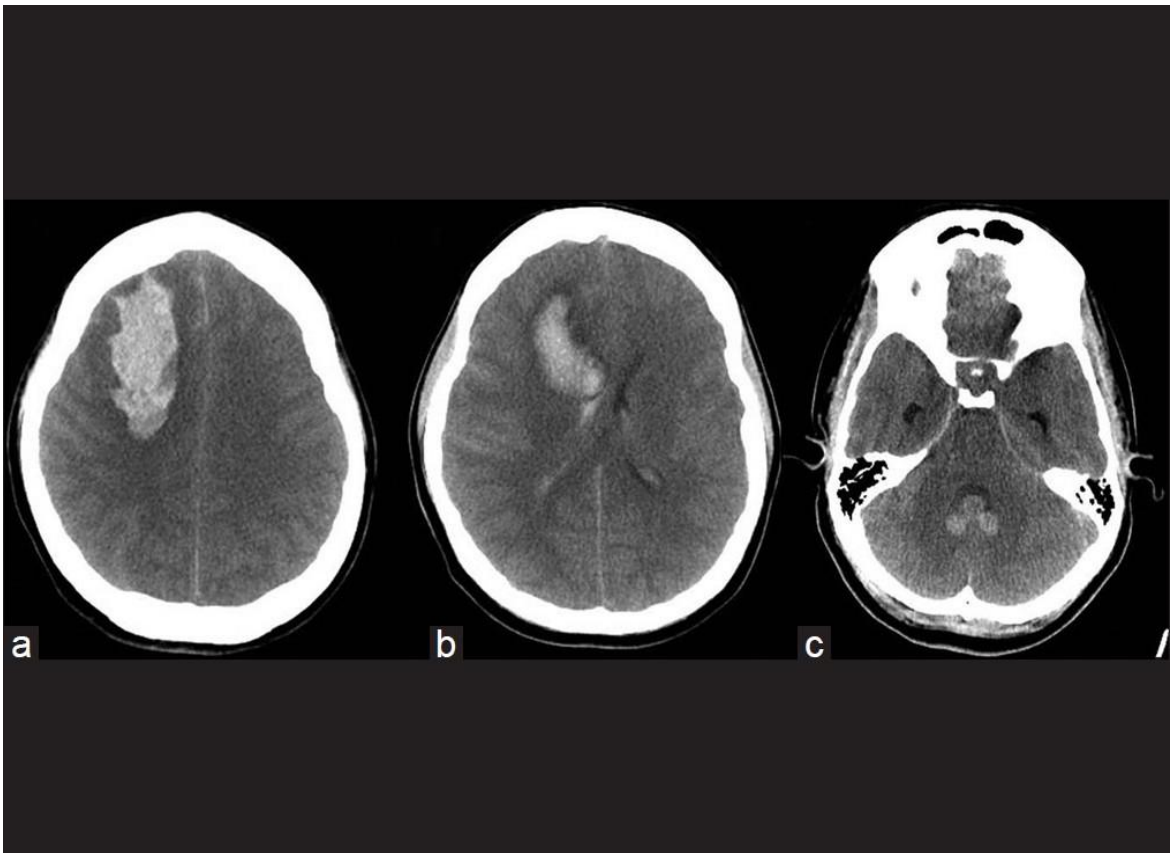


Figure 5: Example of a CT scan of the Brain (Ghaly et. al. 2012).

In regards to brain tumours, CT scanning is used to detect abnormal growth and diagnose the presence of the tumour. Once a tumour is identified the images are used to determine where to perform the biopsy procedure and where treatments such as radio therapy need to be directed (National Cancer Institute 2013).

2.2.4 Magnetic Resonance Imaging (MRI)

MRI is similar to CT scanning in that both scanning methods produce cross sectional images of the body. However, MRI used a very different process to do this. Instead of

using ionising radiation to produce an image, radiofrequencies emitted from nuclei of specific atoms in the body are measured and a shade of grey is assigned based on the strength of this signal. This is then used to compile a series of greyscale images of the section of the body being scanned. The images produced have a much higher amount of detail than those of a CT scan and soft tissue is much clearer without the use of a contrast.

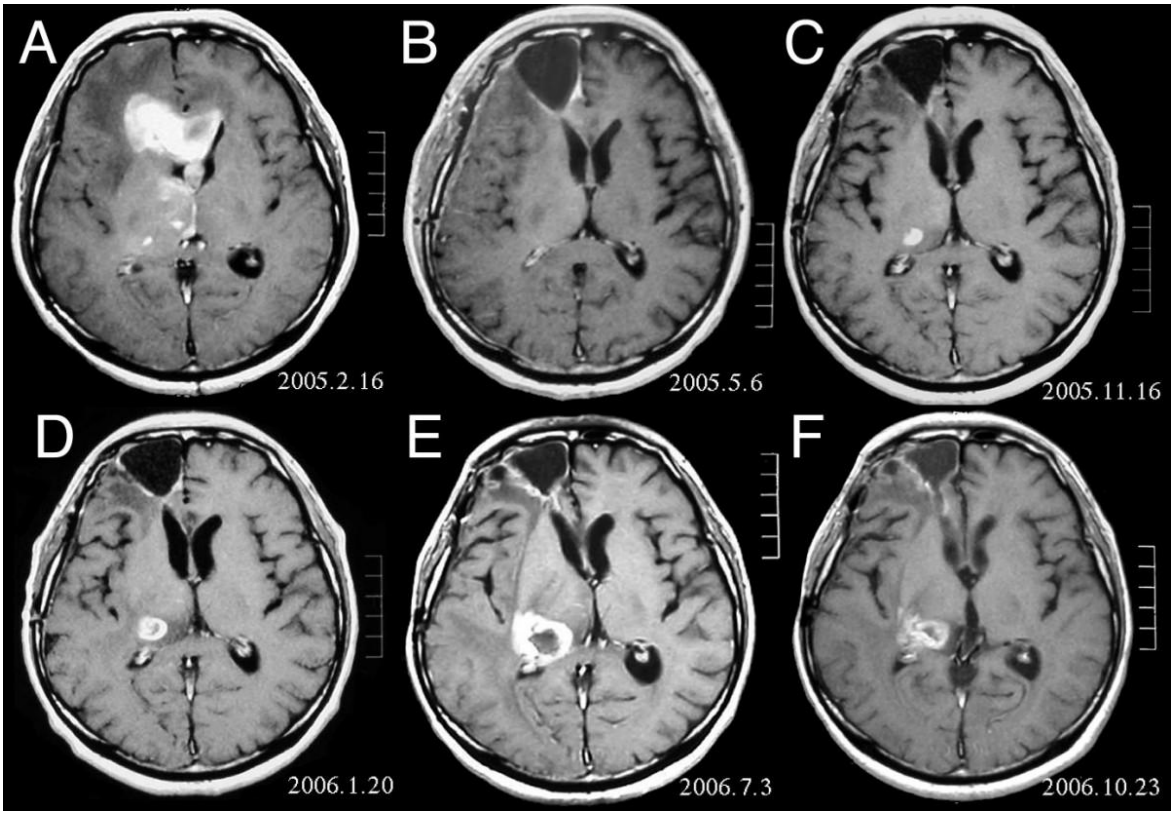


Figure 6: An Example Image of a MRI Scan of the Brain (Siegfried 2014)

Although the cross sectional images produced from both CT and MRI scan can give a very accurate picture of where a tumour is situated and how big it is, and this information is be useful when trying to make a diagnosis, it is still not as accurate taking a biopsy (Cancer Research UK 2013). As a result further techniques have been, and are being, developed based on MRI to try and avoid the used of invasive surgery. At the forefront of

these techniques are Magnetic Resonance Spectroscopy and Magnetic Resonance Spectroscopy Imaging.

2.2.5 Magnetic Resonance Spectroscopy and Magnetic Resonance Spectroscopic Imaging.

Magnetic Resonance Spectroscopy (MRS) and Magnetic Resonance Spectroscopic Imaging (MRSI) are techniques that are used to measure the concentrations of the different chemical compounds found within the different tissues of the body. Although the technique is based on that used to produce MRI images, where a radiofrequency emitted from nuclei of specific atoms are measured and a shade of grey is assigned based on the strength of the signal emitted; in the case of MRS and MRSI it is the chemical composition of the tissue that have been scanned that produces an image (NEMA 2011) (Kurhanewicz et al. 2000) (Bertholdo et al).

Unlike MRI which produces graphical images of the anatomy being scanned, MRS and MRSI produced a graphical representation with different peaks that identify the different metabolites present in the tissue within the area of interest. These new technique have been found to be more accurate than CT or MRI scanning for diagnosis and tracking the progress and response to the treatments being administered as the results give quantitative data that was easily by analysed (NEMA 2011) (Kurhanewicz et al.2000) (Bertholdo et al).

MRS and MRSI spectra are used alongside standard MRI, and can be created uses existing scanners with additional software and extra peripheral hardware. The MRI image is produced first from which the site of interest, either a single voxel or a range of voxels, is

selected. The signals from the molecules within this voxel(s) are used to create the MRS Spectra.

MRS is when the spectra is created using signals from only one voxel. It is also as Single Voxel Spectroscopy (SVS). MRSI is when the source of the signals is a group of voxels; also know as Multi Voxel Spectroscopy (MVS). The data from this type of Spectroscopy can be presented in either 2D or 3D images. The spectra data is stored as volumetric pixels (voxels), a unit of graphical information that defines a point in three-dimensional space (NEMA 2011) (Kurhanewicz et al.2000) (Bertholdo et al).

Each voxel represents an entire spectrum and is held in a frame. The number of voxels in a frame is described by rows and column. They are ordered from left to right, top to bottom. Spectroscopic data can be stored in three, two or one dimensional spectra. Within a two dimensional spectra, the location of a specific voxel is denoted using the value of the column and row. For a three dimensional spectra the number of the frame is used to specify which frame the column and row values are referencing.

Spectral data points within the voxel are ordered from high to low frequencies for a static magnetic field strength when the Signal Domain Column and Signal Domain Rows attributes contain the value Frequency. When these attributes contain the value Time, the order is determined by the sequence of increasing time. The Figure 7 below illustrates this organisation of the voxels.

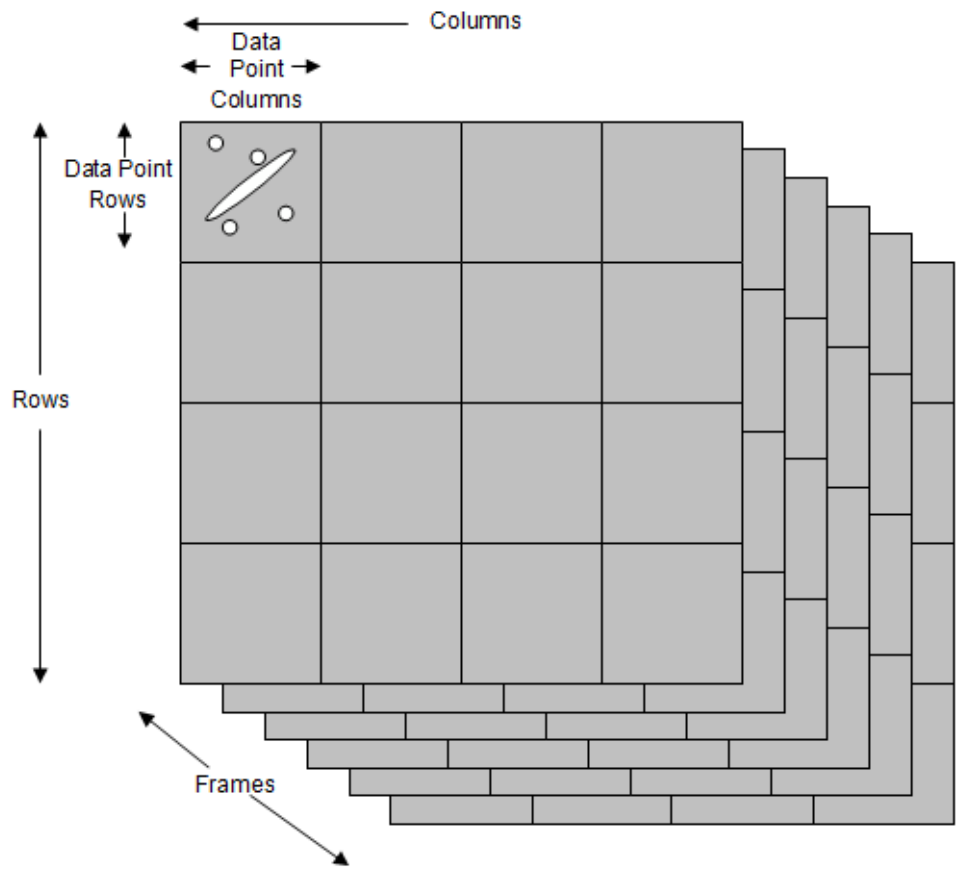


Figure 7: Diagram Illustrating the Structure of Voxels in MVS Spectra (NEMA 2011).

Once the reading has been taking from the area of interest, the chemical composition of the tissue within this area is analysed. With MRS the composition of the tissue held within the entire area of the single voxel is taken into account. Whereas with MRSI as the area of interest is broken down into multiple voxels the spectrums taken can show a change in the tissues composition and compare those of a suspected tumour against "normal" tissue. The figures 8 and 9 below show the different type of graphs created by the readings received from MRS and MRSI.

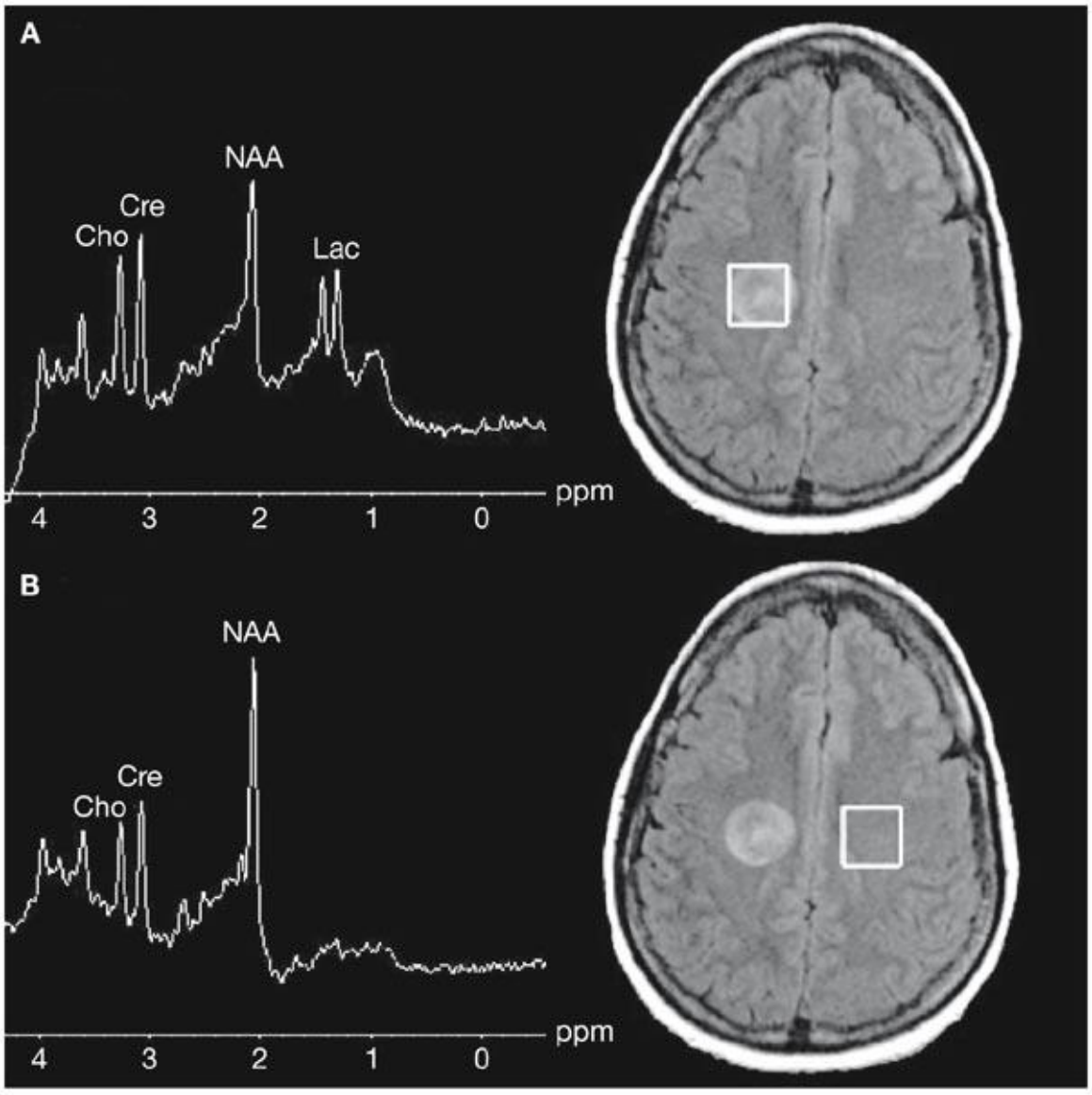


Figure 8: An example of single voxel Magnetic resonance Spectroscopy (MRS) (Nelson 2003)

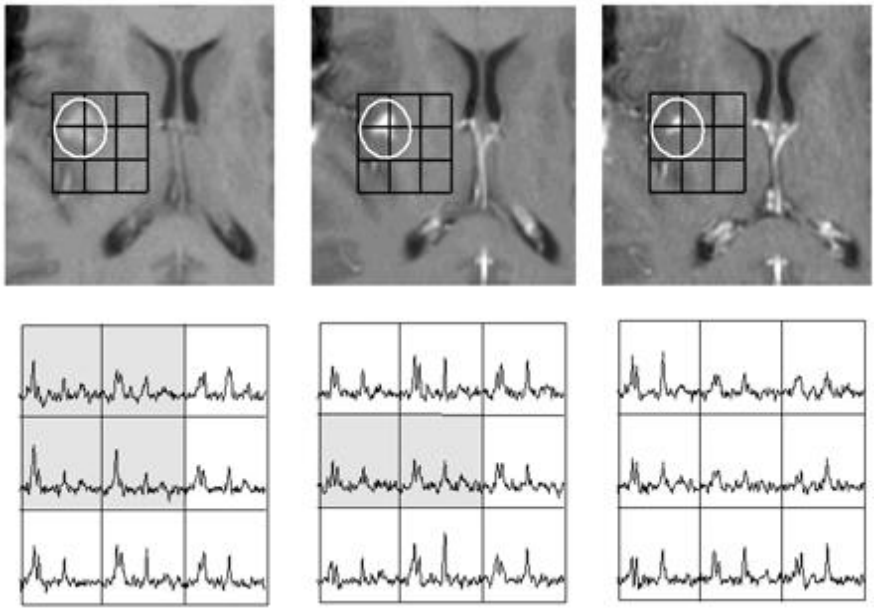


Figure 9: An example of Magnetic Resonance Spectroscopy Imaging (MRSI) (Nelson 2003)

Once the spectra have been obtained, radiologists use the peaks of the spectra to determine if the tissue being observed is malignant or benign without the need for taking a tissue sample.

2.3 The DICOM Standard.

With the proposal of introducing SR as a part of the reporting work flow, any software would need to be compatible with the existing hospital systems. At this time EMRs are not a global standard within hospitals (Aminpour, Farzaneh et al. 2014), albeit it there are those being developed and piloted in various countries. E.g. within the United Kingdom (UK) the National Programme for Information Technology (NPfIT) was launched in 2002. Since then various systems have been introduced in the National Health Service (NHS), such as the Lorenzo Regional Care system, to allow the introduction of EMRs in to British

Hospitals (CSC. 2014) as well as EMR systems being piloted in hospitals around the UK (NHS 2013). However, within Radiology there has been a global standard for medical images for several years, known as the Digital Image and Communications Standard.

As stated previously, medical imaging has been an integral part of diagnosis for many years. However, with the introduction of newer computerized technologies, it was found that viewing these images was still as time consuming as printing off and viewing films. This was because each scanner manufacture would use a different image format specific to them and could not be converted to another file type. Therefore, at times the only way to view the images was on the workstation connected to the scanner that has taken the images. This meant that films would have to be printed to view the images in another part of a hospital, let alone a different hospital site.

To combat this issue several standards where produced to allow on conformity and interoperability between devices. The most successful of these attempts was collaboration between the American College of Radiology and the Nation Electrical Manufacturers Association (ACR-NEMA) which led to the introduction of the ACR-NEMA Standard. This provides a set of standards to govern information exchange, interconnectivity and communications between medical imaging systems. Since its release in 1982 it has been through three iterations, the most recent was released in 1992 when it was renamed to the Digital Imaging and Communication in Medicine (DICOM) Standard.

In this version, a specific file format was introduced alongside the written aspect of the standard, which all medical devices are now required to recognise and use to save image

files. Previous to the introduction of the DICOM File format the image and patient data would have been stored in separate files, which would have taken up more data storage space. Also it meant that this information was at risk of being separated and therefore being unusable, e.g. An image without the patient details would be unidentifiable. Instead of this, each DICOM file contains a Header where the patient information and information such as the dimensions of the image, the scan details and scanner details are held. There is also an Instance which is used to hold used the image data. As well as this, the Instance can be used to hold other types of documents such as reports, waveforms (e.g. Electrocardiograms (ECG)) etc.

DICOM became the accepted global industry standard in 1996, meaning that all medical devices had to be compatible with the format. Since being accepted as the industry standard, any equipment found not compatible or using the standard has been phased out. This meant that the file could be easily accessed from any workstation within a hospital site without the concern of compatibility issues, thus saving the time and resources lost to printing films and transporting them around a hospital or to another site.

As a result of this, any ontology produced as part of this project will be required to model the DICOM standard. If this is not used any application developed using the ontology developed would not be practical. It would mean that any images viewed and stored via the application would need to be converted from the DICOM file format before they can be utilised. It would also mean that important patient information would have to be

extracted before this image conversion occurred due to the way that the DICOM file format stores the patient and image information.

2.3.1 The DICOM File Format

As mentioned above, DICOM is not just a document. It is also a file format utilised to store and transfer medical images in several fields including radiology and cardiology.

The format consists of two key components:

-The Information Object Class, which defines the contents of a set of images and their relationships.

-The Service Class, which describe what to do with these objects (Zimmerman 2011)

The building blocks of the file format are the DICOM Elements, which are also known as DICOM Attributes. These are clustered together to form modules, which in turn are grouped together to create Information Objects. The elements that are used to build specific Objects are defined in Part 6 of the DICOM standard (Hussein et. al 2004) (Oosterwijk 2008)

Each DICOM Element has a:

Tag– The tag is the unique identifier of the element that is made up of two short numbers. These are called Group and Element respectively. If the elements are related, for example are a part of the same sequence of images, the can have the same group. For example the image group is 0028 so the elements that hold the height and width of the image will both have the group 0028.

VR– This is a two character code that represents the data type of the element. In the example above the VR is CS which stands for Coded String. As the Tag defines the VR, this can be seen as redundant. However, it is standard practice to still include this.

Value– The value of the element. Strings are always printed in square brackets.

Value Length– Defines the length of the DICOM element. This is always an even value. If the value is odd this would be rounded up to an even amount, for example RGB with a length of 3 would be rounded up to 4.

VM– The Value Multiplicity is the number of values that can be held within the value field.

Tag Name– The name of the tag (DICOM Standards Committee 1999)

These can be seen when data from the file is printed out using specialised software. An example is shown in the diagram below.

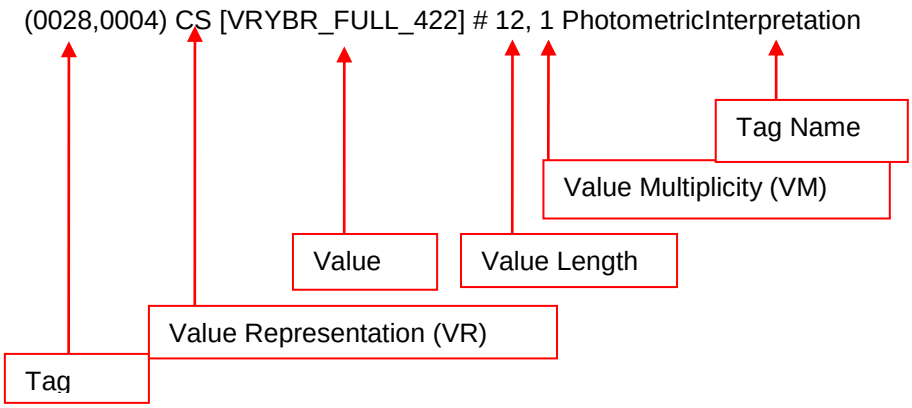


Figure 10: Printout of a DICOM Element

As mentioned above these elements are clustered together to form modules, which in turn, combine to form DICOM Information Objects. The structure of the objects is defined by the DICOM Information model. This is a hierarchical data structure that has four object levels or Information Entities (IEs): Patient, Study, Series/Equipment and Instance. Each of these levels can contain several sublevels. The instance level used to be called Image. However, this has been amended as it is now use to also store waveforms, SR etc. as well as images. The diagram below shows the relationship between these levels: (Zimmerman 2011) (Huang 2010) (DICOM Standards Committee 1999).

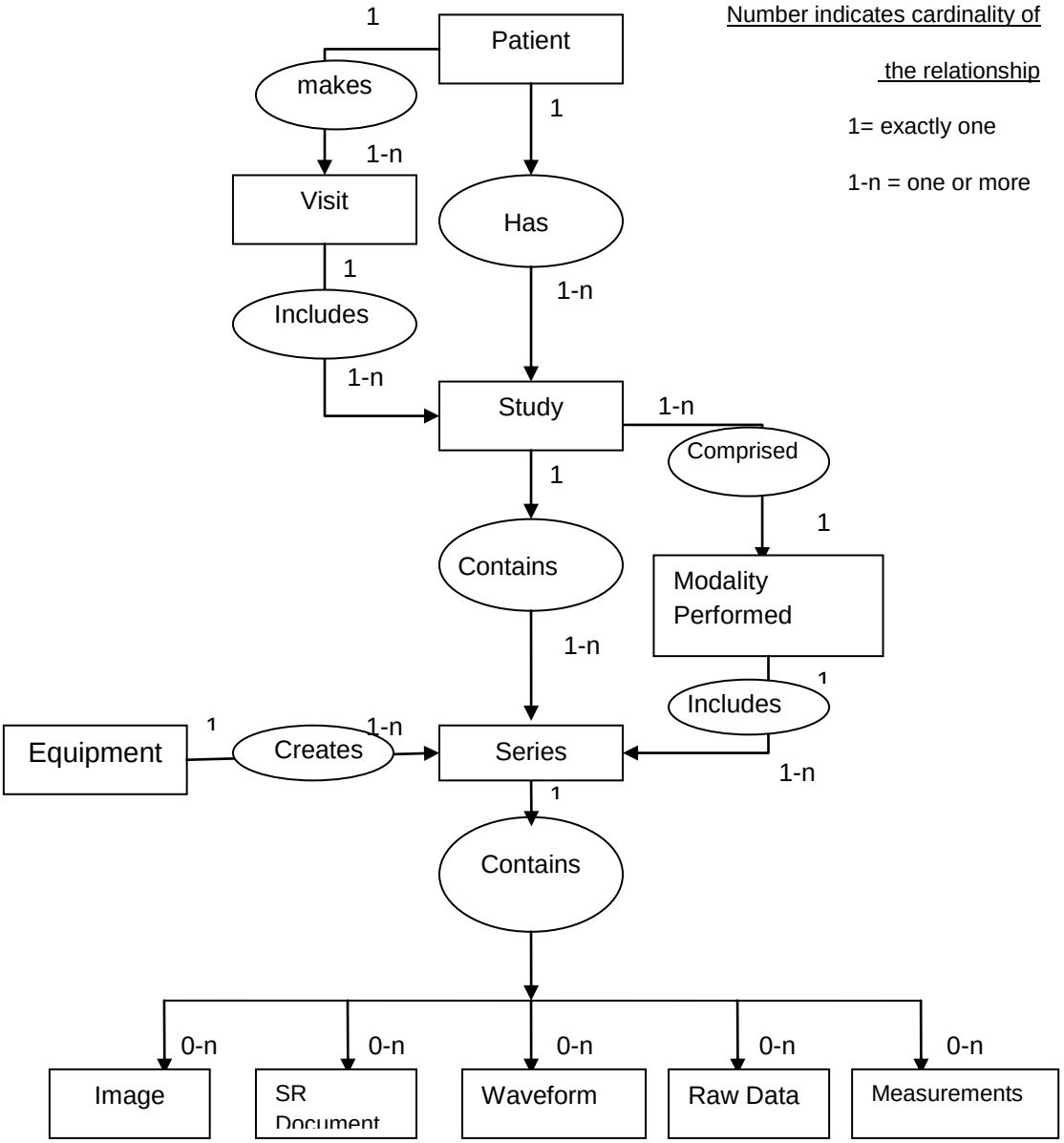


Figure 11: Relationship Diagram of DICOM Information Model (Kahn 2011).

The diagram shows the relationship between the entities of the DICOM Information Model. A Patient has one or more Studies, each of which contains one or more Series, which contains zero or more Instances such as an Image or Waveform (Oosterwijk 2008)

Patient - The person receiving or registering to receive a health care service. A patient may already have previous studies can register for further one. For example he or she may have a historic chest x-ray and is visiting for a chest MR.

Study - This can be a historic, current or future study. Within each layer several series and nested series can be stored.

Series– Is created by the equipment being used e.g. MRI scanner, CT scanner. This can hold several images, waveforms, documents etc.

Instance - An image from all types of equipment e.g. a CT Image, an ECG Waveform from an ECG device (Zimmerman 2011).

There are two types of DICOM object; Normalised and Composite. Normalised DICOM objects only contain elements inherent to the Information Entity (IE) from the DICOM data model that is being represented. For example: In a Study Object, study date and image time are attributes, but patient name is not. However, the patient name is an attribute of the Patient Object.

Composite DICOM Objects are formed using elements from several of the Information Model IEs. E.g. The Computed Radiography Object has attributes from the Study IE (study date, study time etc.) and the Patient IEs (patient's name, date of birth etc) (Zimmerman 2011).

As mentioned previously, the other key component of the DICOM file format is the Service Class or DICOM Message Service Elements (DIMSEs). DIMSEs are software programs written to perform specific functions and used for the communication of imaging information objects within a device. For example, displaying an image file, or storing it.

There are two types of DIMSEs; One for normalised objects and one for composite objects. For both types the services are paired. For example, a device will issue a command request and the receiver will respond accordingly. A device providing a service is known as a service class provider and a device using a service, as service class user (Zimmerman 2011).

The DICOM Objects and DIMSEs are combined to form Service Object Pairs (SOPs), the fundamental units of the DICOM (Zimmerman et al 2011) (Huang 2010) (DICOM Standards Committee 1999).

Even though we have the aspects of the DICOM objects and standards nailed down there can still be misrepresentation of the information from a clinical level. This can be due to the ambiguity of the natural language used in the report. It can also occur as a result of the specialist incorrectly diagnosing the results from the medical image. To avoid this, specialist techniques can be used to prevent ambiguity and to a lesser extent prevent incorrect diagnosis.

Since becoming a global standard in the mid 1990's, DICOM has been maintained by NEMA. This includes regular updates to incorporate approved changes and supplements. A new DICOM Standard Document is completed every couple of years to include all new

of these changes and additional content. However, due to the fact that changed and additions to the standard need to be vetted and agreed, it can take time for newer technologies to be incorporated. This can be seen with the DICOM Structured Reporting (DICOMSR) supplement.

2.3.2 DICOMSR

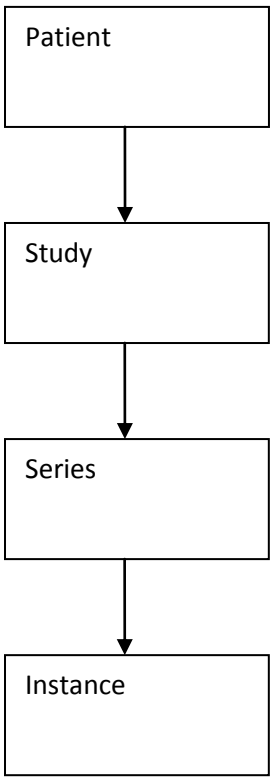
DICOMSR is a supplement that has been added to the DICOM Standard to support SR (Clunie 2000) This is a reporting method that is beginning to be utilized in the medical industry to make medical records clear in terms of the information they are conveying and also easier to search for specific information. At this time, DICOMSR includes technologies such as standard MRI and CT scanning but newer not images methods such as MRS and MRSI. As such this project will need to look into how the standard could be changed to allow for these imaging methods to be included.

Due to the fact that the SR offers a clearer, more easily searchable form of digital records there has been a push to use it. As a result of this a SR element has been added to the DICOM standard, called DICOM Structured Reporting or DICOMSR (Clunie 2000). Currently, this covers the conventional methods of medical imaging such as MRI (NEMA 2011). However, younger technologies such as MRS and MRSI have not yet been included in the DICOMSR standard and as such this needs to be extended.

To allow for this an understanding of the structure of the DICOM file format is required. The format consists of two components; the information Objects Class and the Service Class. These define the contents of set of images and the relationships between them, and what to do with these Information Objects respectively (Huang 2010).

A DICOM file is constructed out of DICOM Elements. Each element has a Tag a unique identifier made up of two numbers called the Group and the Element. These are used to identify the DICOM Element. Elements that are related, such as one holding the height and another holding the width of an image, will have the same group. As well as a Tag the DICOM Element also has a VR which is a two character code that represent the data type of the element; A Value and Value Length which define the value and the length of the element; a Value Multiplicity (VM) that defines the number of values that can be held within the value field and finally a Tag Name (Clunie 2000) (Langlotz 2002).

The DICOM elements are clustered into modules. The elements used to form these modules are defined in the standard by DICOM macros (Yu 2006). These modules are then combined to form DICOM Information Object Definitions (IODs). The modules used to form the IODs are defined in part 6 of the DICOM standard (Clunie 2013) (Langlotz 2002). The structure of an IOD is directed by the DICOM Information model, a hierarchical structure that consists of Information Entities (IEs): Patient, Study, Series and Instance. Each of these IEs can contain can contain several sublevels (Huang 2010) (Clunie 2000) (Langlotz 2002).



Patient - The person receiving or registering to receive a health care service.

Study -can be a historic, current or future. Several series and nested series can be stored in each level.

Series – Is created by the equipment being used e.g. MRI scanner. Several Series can be stored within a Study

Instance - An image from all types of equipment e.g. an MRI Scan

The different layers of the hierarchy are known as Information Entities (IE)

Figure 12: Diagram Showing the Hierarchy of a DICOM IOD (Roni 2012)

The DICOMSR information object definition (IOD) follows the same information structure/ hierarchy as other composite DICOM objects, e.g. an MRI Image. Therefore it is possible for a SR Document to be linked to and reference other instances, giving context to the information being conveyed in the report. As well as this, regions of interest can be annotated within the images being reference narrowing the opportunity of the report to be ambiguous.

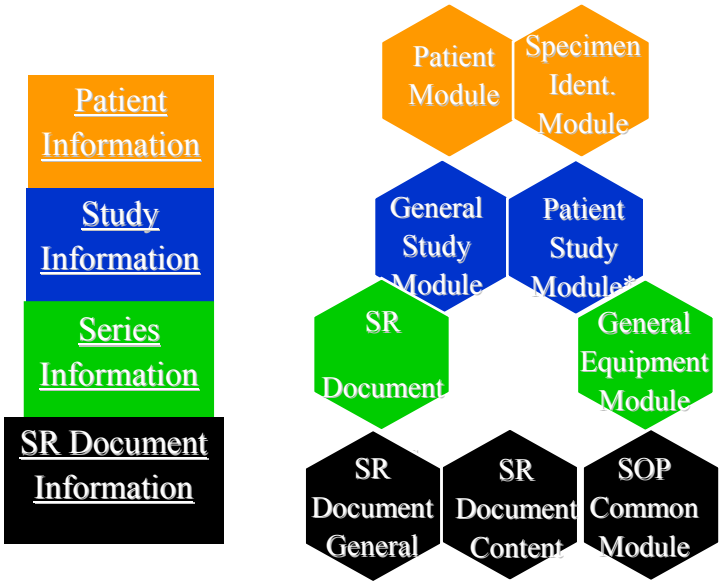


Figure 13: Diagram showing the structure of DICOMSR IOD (Syckle 2000) in comparison to Figure 12

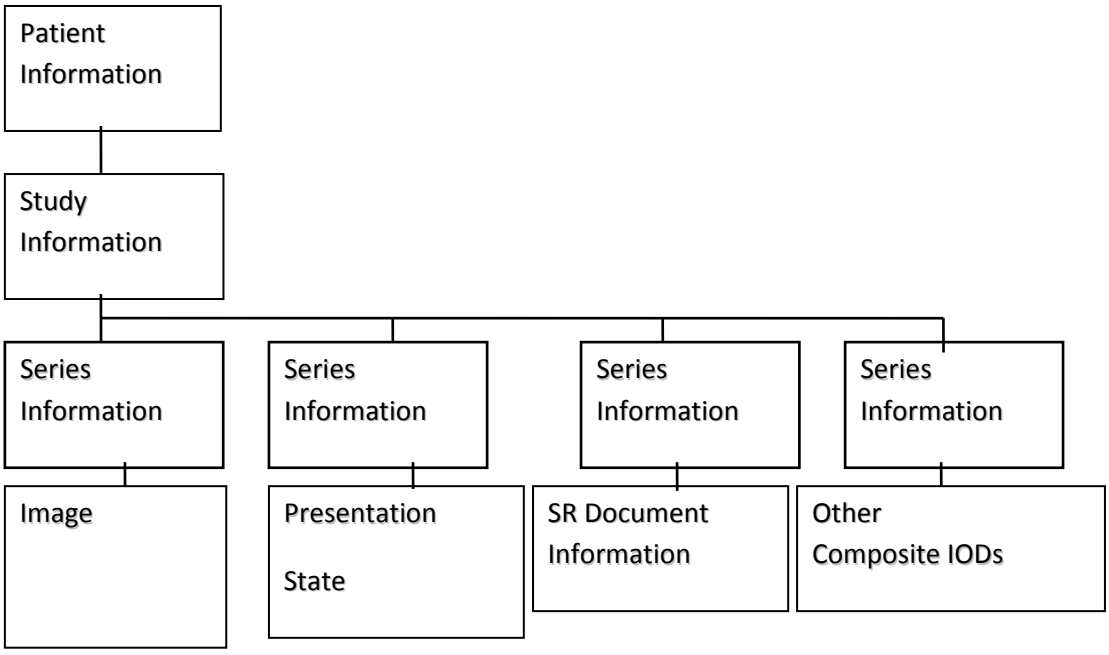


Figure 14: Diagram Showing DICOM SOP Instances Being Linked (Syckle 2000)

2.3.2 DICOMSR Documents

A DICOMSR Document is made up of Content Items and the relationships between these. There is always a single Root Content Item, which conveys the document's title. Within this further Content Items are nested.

There are many different types of Content Items such as CONTAINER, TEXT, PNAME, UIDREF and DATETIME. The Root Content Item is always a CONTAINER as these denote headings and sub headings. The Content items are encoded using a Concept Name Code Sequence. This sequence is encoded using Coded Entries Sequences, also known as Triplet Encoding, which are made up of three different attributes:

The **Code Value**: A unique computer readable code. This is unique within the chosen "Code Scheme Designator"

The **Code Scheme Designator**: Identifies the Lexicon being used to define the meaning of the Code Value

The **Code Meaning**: A human readable text entry that is a maximum of 64 characters. This is present in case an application receiving the report was not in possession of the lexicon being used (Syckle 2000) (Clunie 2000).

For example: To represent a PA and Lateral CT scan the below would be used:

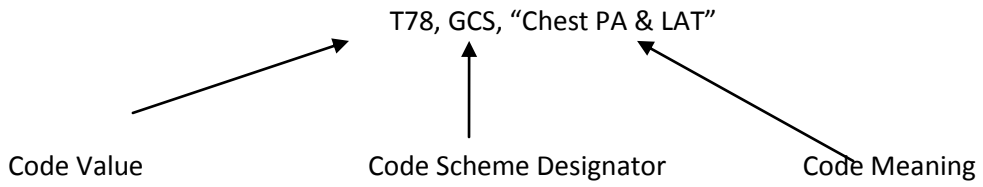


Figure 15: Example of a concept name code sequence

The content items of the document have a parent/ child relationship. For example:

“Source Content Item A” “has relationship B” with “Target Content Item C.” (Syckle 2000) (Clunie 2000).

The Source Content item is always the parent and target Content Item the child. As stated above, each document has a single Root Content Item. This can then have 1 or more Content Items nested within. These nested Content Items can in turn contain further Content Items. As a result of this the type of relationship between the Content Items is encoded with the child. This allows the parent to have a different relationship with each child.

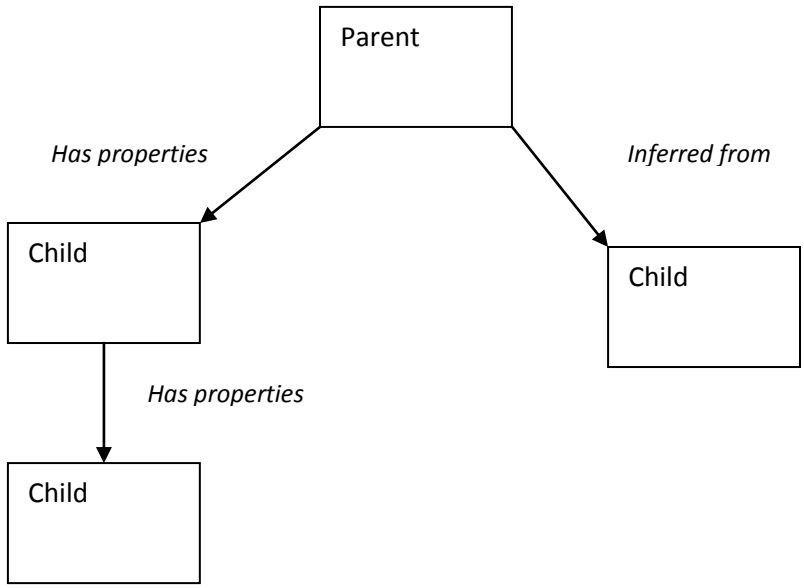


Figure 16: Diagram illustrating the Parent /Child Hierarchy (Syckle 2000) (Clunie 2000).

These relationships are encoded using the Relationship Type attribute (0040, AD10), which is found in every Content item that is a child of another. There are several different relationships utilized in the DICOMSR SOP classes, however the most prominent are:

Contains– specifies that the child and its descendants are a part of the parent. This relationship is usually used to convey headings and sub headings in the SR document.

Has Properties– specifies that the parent has characteristics or properties and the details of these are stored in the child and its descendants.

Inferred from– specifies that the parent is a conclusion, deduction or inference that was made from the information held in the child and its descendants (Syckle 2000) (Clunie 2000).

Like a standard DICOM object, SR is built using IODs defined in part 3 of the DICOM standard. These specify which modules are required to be present with in the different levels of the objects hierarchy. SR Templates are then used by the IODs to define the hierarchical structure of the different containers within the document. They also define the attributes of these containers and the values allowed. The templates are all detailed in Part 16 of the DICOM Standard (Clunie 2011).

2.4 Ontologies

The DICOM Standard is a large, complicated document split over many different parts that are currently accessed via PDF documents. It currently lacks a reference information model (Kahn et al 2011), which is description of all the information that is stored within the DICOM objects in regards to a medical image, and as such it is not computable and anyone wishing to develop an application to use or be DICOM compatible has to spend a lot of time manually extracting the required portions of the standard (Rubin et al. 2008)

If the DICOM standard was converted into an ontology the relationships between the various aspects of the standard would be defined in a way that is easily readable to both humans and computers. With the relations ships defined in this way the standard would be less ambiguous and much easier to interpret (Mhiri 2007). This would also allow for easier development and compatibility of new software and devices (Easton et al. 2011) As well as this, by converting the DICOM standard to ontology it will allow easy harmonization and combination with other ontology such as Radlex or SNOMED, two of the medical lexicons that have been developed.

The term Ontology has its origins in philosophy and can be dated back over 2000 years to Aristotle. However, in recent times it has been utilised in computer science and engineering (Bodenreider et. a 2003).

An ontology is an organizational framework of concepts and the relationships between the different classes and their instances. These are organised into a hierarchy with the attributes usually connected by an “is - a” or a “part - of” relationship (Kahn et al 2011).

For example the diagram below shows the relationship of a Serum Glucose Test to its parent. The solid line represent the “is-a” relation between the different instances. So the Serum Glucose Test “is a” part of the Laboratory test, and this with a Laboratory Procedure, “is a” part of a Diagnostic Procedure, which is an Event in Medical Entity.

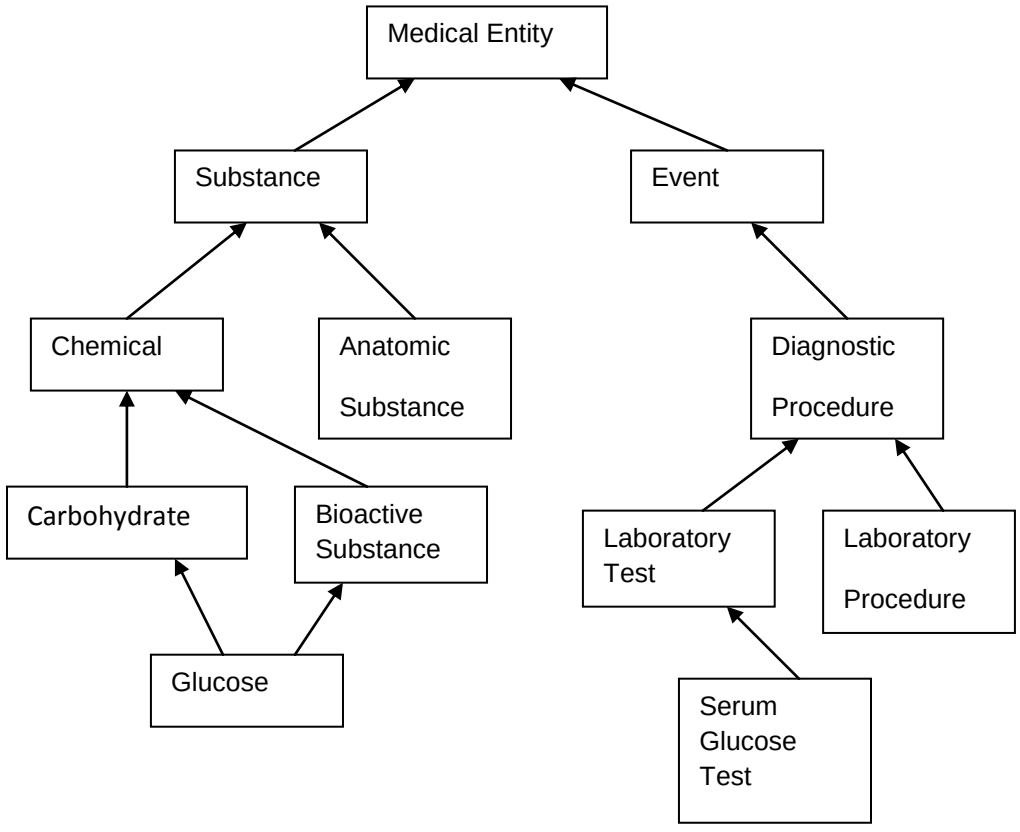


Figure 17: Ontology Diagram of the Relation of a Serum Glucose Test to its Parents (Yu 2006).

In view of software design, ontologies usually take form of controlled vocabularies that enable natural language processing, interoperability, knowledge sharing and reuse. This is particularly useful in medical research and the health care industry (Yu 2006) (Bodenreider et al 2003). An important aspect of ontologies is that they are readable to by both human and computer. This means that converting the DICOM standard in this format could facilitate easier development for DICOM based systems.

With information evolving rapidly, particularly in fields like Bioinformatics, it can be difficult to keep track of changes and updates to procedures. Through the use of ontologies, the knowledge can be broken down and therefore is easier to assimilate and integrate with existing information. The controlled vocabulary of the ontologies, like SR, reduces the ambiguities in the information being presented.

Although the use of ontologies is increasing, there are still issue with the quality and coverage of those available. Systems being developed may depend on several different ontologies. At this time there is no set standard for the process of creating ontologies and formats used for storing and reading them. As a result, if different ontologies are being used for a project several different programs may be required to allow them to be viewed. This could cause interoperability issues within a project.

2.4.1 OWL Ontologies

Even though the processes of creating an ontology have not yet been standardised, several languages have been created to encode ontologies. The Web Ontology Language is one of these, and it has been endorsed by the World Wide Web Consortium (W3C) , the main international standard of the World Wide Web, as the standard language for

creating ontologies, causing it become a prominent ontology language used for academic and research purposes. As such, it will be being used to create the ontology within this project.

2.4.3 Components of an OWL Ontology

OWL ontologies are structured using three main components: Classes, Individuals and Properties. These are described in the following subsections.

2.4.4 Classes

Classes are used to define the concepts within a knowledge base. (Noy 2000) They form a hierarchy and can have subclasses to represent more specific concepts, also known as a taxonomy (Introduction to Ontologies with Protégé 2012) Classes can also been interpreted as sets that contain individuals. The class specifies the conditions that an individual must meet to be a member of that particular class (Horridge 2011). For example, if an ontology is constructed about different types of glioma tumours, the root class "Gliomas" could have subclasses "Astrocytoma" and "Ependyoma." From this is could be inferred that: All Astrocytomas and Ependyomas are Gliomas, all members of the class Astrocytoma, or Ependyoma, are members of that class Gliomas and something being either an Astrocytoma or a Ependyoma implies it is a Glioma Tumour. Whilst using OWL the relationships between these Classes and Subclasses can be computed by a reasoner based on the properties that have been assigned (Horridge 2011).

It is assumed by reasoners that OWL classes overlap. To ensure that certain classes are separated, they must be made "disjoint." For example, a tumour cannot be both Grade I

and Grade III. Therefore classes describing these grades would have to be disjoint from each other.

2.4.5 Individuals

Individuals are the object instances of the classes within an ontology. In OWL ontologies a class is defined as a set of individuals; however an individual can belong to more than one class. They linked together by Object properties. Also they can have values assigned using Data type Properties (Horridge 2011) (Tutorial 4: Introducing RDFS & OWL 2009).

In this ontology the individuals are the structured reports. One uses enumerated individuals to assign values such as patient name, and findings ratio.

2.4.6 Properties

Properties represent the relationships that link the classes and individuals within an ontology. There are two types of properties in OWL: Object Properties and Data type Properties.

Object properties are the relationships between the instances of two classes.

Data type properties are the relationship between instances of classes and XML Schema Data type value or an RDF Literal such as an integer (Horridge 2011) (W3C 2004).

2.5 Summary

Medical records are very important factor in a patient's treatment. Without them it would be nearly impossible to easily communicate information about the patient around the hospital and make correct decision about their treatment. However, even with changes to how they are stored, with the introduction of the Electronic Medical Record, the reports within are still written using free text. As a result they can be ambiguous, which could lead could lead to incorrect diagnosis and treatment.

A proposed solution is for this is to introduce a type of reporting called Structured Reporting, which would standardise the format in which the reports are created, stored and displayed. By using a structured format, consistent organisation, and a standard lexicon, ambiguity within the reports would be removed as only set terms and layout would be allowed. This standardisation would also mean that reports would be complete, with all required information included.

This would be a useful development for the diagnosis of childhood brain tumours due to the reliance on medical imaging in diagnosis. A more accurate method to gain a diagnosis is biopsy, a surgical procedure to remove a sample from the tissue suspected of being a tumour. This sample is then tested and observed under a microscope to identify if the cells are cancerous. However, this is not always possible in terms of a brain tumour. The suspected tumour may be inaccessible or the risk of causing damage to surrounding brain tissue is too high. As a result medical imaging as become integral to brain tumour diagnosis.

With imaging techniques such as CT and MRI a diagnosis is made based on what can be seen within the images but this doesn't give a definite indication if an anomaly is malignant. MRS, a newer scanning technique that works along side MRI, is able to show the chemical composition of the tissue being scanned. The result form these scans can be used to identify if the suspect tissue is cancerous, and even the type of tumour, without the need for gaining a sample of the tissue.

Due to the complicated nature of the DICOM standard, it has been suggested that an ontology be created to model the standard making it more accessible for those wanting to develop DICOM compatible software. Ontologies are hierarchical frameworks that are used to represent knowledge. They use relationships to between classes and their instances to represent a knowledge base in a computer and human readable manner.

Though the process of constructing an ontology has not been standardised there have been languages developed to construct them. OWL is a language that has been endorsed by W3C and has become widely used for research and medical ontology projects.

For on SR Diagnostic Ontology to be constructed several factors will need to be considered. Any tool developed will need to be compatible with the DICOM standard to allow interoperability with the medical informatics systems, such as PACS, that are already in place in a hospital. As well as this the DICOM compatibility will allow for certain patient information to be automatically extracted from the images produced by a scan. This means that the required sections of the DICOM standard need to be modelled within the ontology.

The ontology will also need to contain sections that that define the different types of Childhood Brain Tumours, identifying them by their location, originating cells and the grades they can be.

Using these sections a structured report and diagnosis section of the ontology will then be developed to allow for the diagnosis of a brain tumour based on the reading that have been taken from an MRS Image.

Chapter 3: An Ontology for Structured Reporting and Diagnosis of Childhood Brain Tumours

3.1 Introduction:

For this project, the aim is to design an ontology that will create a SR for MRS and MSRI that is DICOM compatible and is able to support the diagnosis of childhood brain cancer. As such, the ontology would need to model three key aspects: The DICOM standard, a SR and the types of Childhood Brain Cancer.

Based on this the ontology itself will be broken down into these three parts. One part to model the DICOM standard to cover MRS data and basic SR report objects as represented within the Standard. The second parts models the different types of childhood brain cancer and the third the SR and Diagnosis aspect.

To develop an ontology to reach the aims of the this project, there are three key aspects that need to be modelled: the DICOM format section, an SR and Diagnosis section and a section that models the types of Brain tumours that are prevalent in children. To complete this, each aspect will be developed individually and then linked to each other by the relationships of the connecting classes. For example, the SR and Diagnosis aspect will have sections that required classes from both the DICOM Ontology and the Brain Tumour Ontology. The ontology will then be able to produce Individuals that are structured reports for a specific patient, and provide a diagnosis based on the MRS ratio readings that have been inputted.

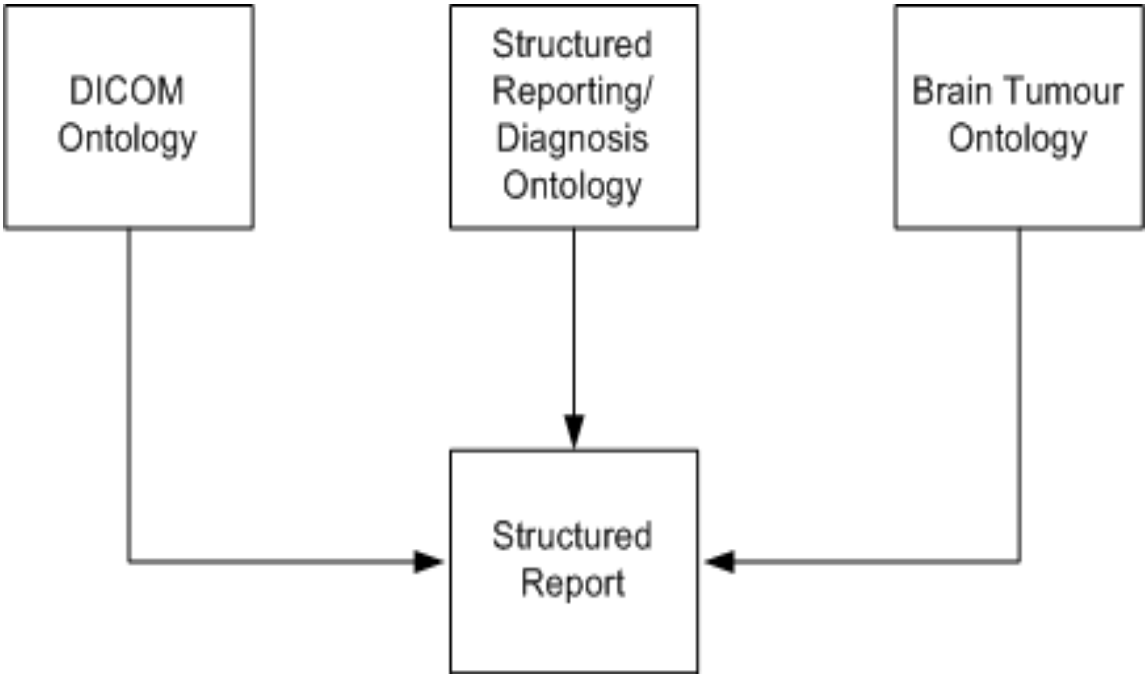


Figure 18: Showing the proposed architecture of the SR ontology

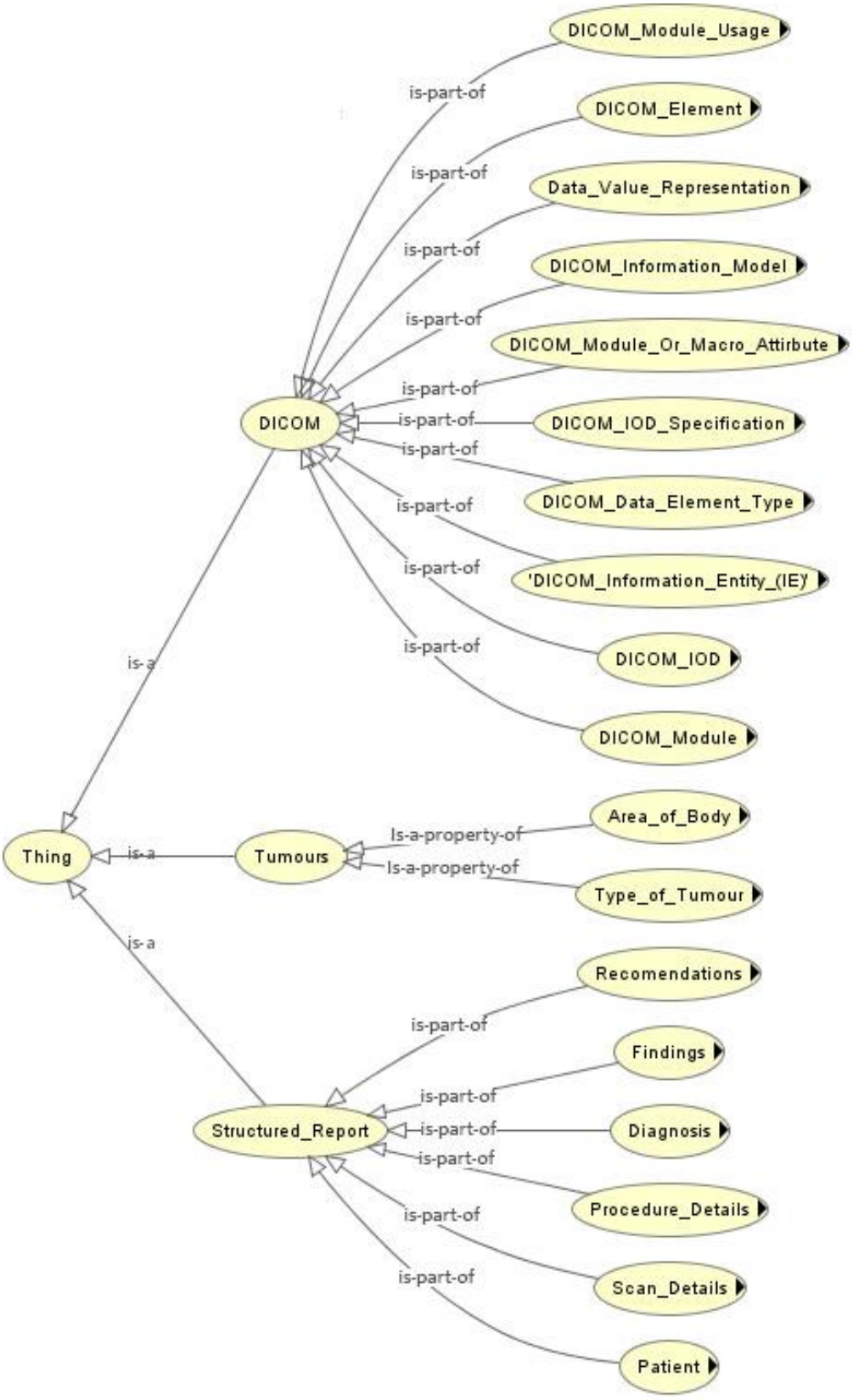


Figure 19: Showing a part of the ontology, focusing on the key sections of the ontology.

The ontology is modelled with the Web Ontology Language 2(OWL 2). This is the most recent standard ontology language endorsed by the World Wide Web Consortium (Horridge 2011) (W3C 2004). OWL uses a logic model that makes it possible for concepts to be defined as well as described. The logical model also allows a reasoner to be used to ensure that the concepts and definitions within an ontology are consistent and that the hierarchy of the ontology has been correctly maintained (Horridge 2011).

To model the ontology the software Protégé is used. This is an open source ontology editor and framework developed at the Stanford Centre for Biomedical Research at Stanford University. The version used will be Protégé Desktop 4.1 (Stanford University 2014) This version has been chosen as it was the current version available at the beginning of the project. Also this version supports plug-ins that allows an ontology to be evaluated that are no longer supported in more recent versions. This is due to them being free software that then developers have not updated to be compatible to never versions of Protégé.

3.1 DICOM Ontology

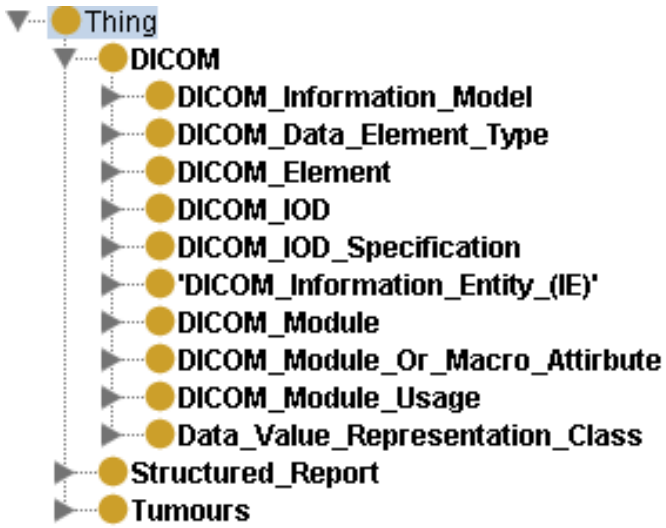


Figure 20: Showing Ontology within Protégé

The DICOM standard section of the ontology was modelled using the guidelines from the UK National Cancer Institute (NCI) (Wiley 2012) who have been working on modelling the standard as an ontology. For the DICOM standard to be modelled the MRS and the Basic Text Structured Reporting (SR) Information Object Definition (IOD) module tables were located within the standard (NEMA 2011).

These were then used to break down the IODs into the key components to make up the standard as an ontology. Figure 21 below show the Basic Text SR IOD. This was used to describe how the IOD was modelled. The same process was used for the MRS IOD.

A subclass called DICOM_IOD was created within the DICOM class. Within this class, further subclasses to group the IOD that were connected to specific Information Entities (IEs) were created. As the Basic Text SR documents and MSR data are held within the Image/Instance IE, two subclasses were created within this class to represent their IODs.

Table A.35.1-1
BASIC TEXT SR IOD MODULES

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
	Clinical Trial Subject	C.7.1.3	U
Study	General Study	C.7.2.1	M
	Patient Study	C.7.2.2	U
	Clinical Trial Study	C.7.2.3	U
Series	SR Document Series	C.17.1	M
	Clinical Trial Series	C.7.3.2	U
Equipment	General Equipment	C.7.5.1	M
Document	SR Document General	C.17.2	M
	SR Document Content	C.17.3	M
	SOP Common	C.12.1	M

Figure 21: Basic Text SR IOD Module Table as Found in DICOM Standard Document Part 3 (16 Page 230)

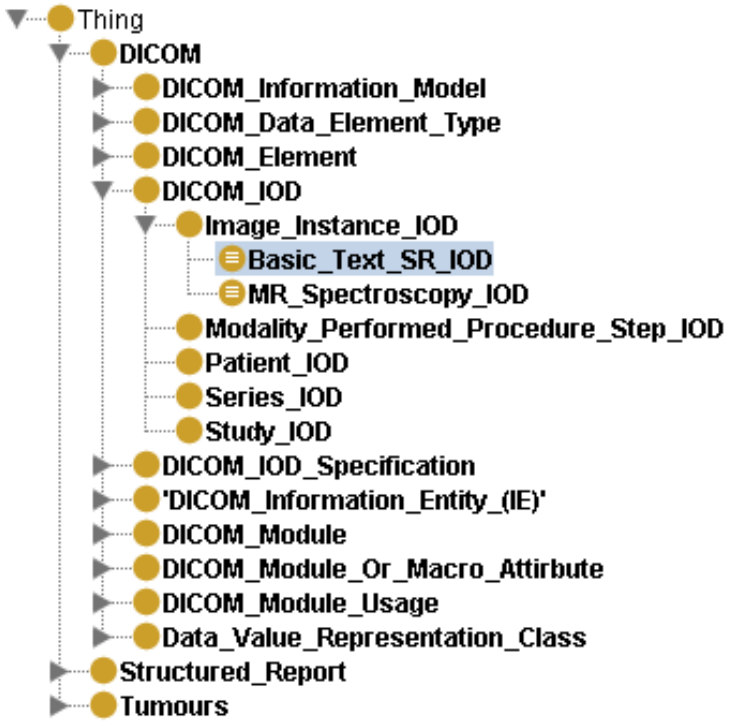


Figure 22: Showing creation of Basic_Test _SR_IOD Class

Each table was constructed as a DICOM IOD, e.g. Basic_ Text_SR_IOD. A class called "DICOM_IOD_Specification" was created. A subclass within this was made to represent the Basic_Text_SR_IOD_Specification. Subclasses were then created in this class to represent each row within the table and were numbered accordingly. This was then used to identify and define the different DICOM IOD Modules and their usages that were being used to construct the IOD in question.

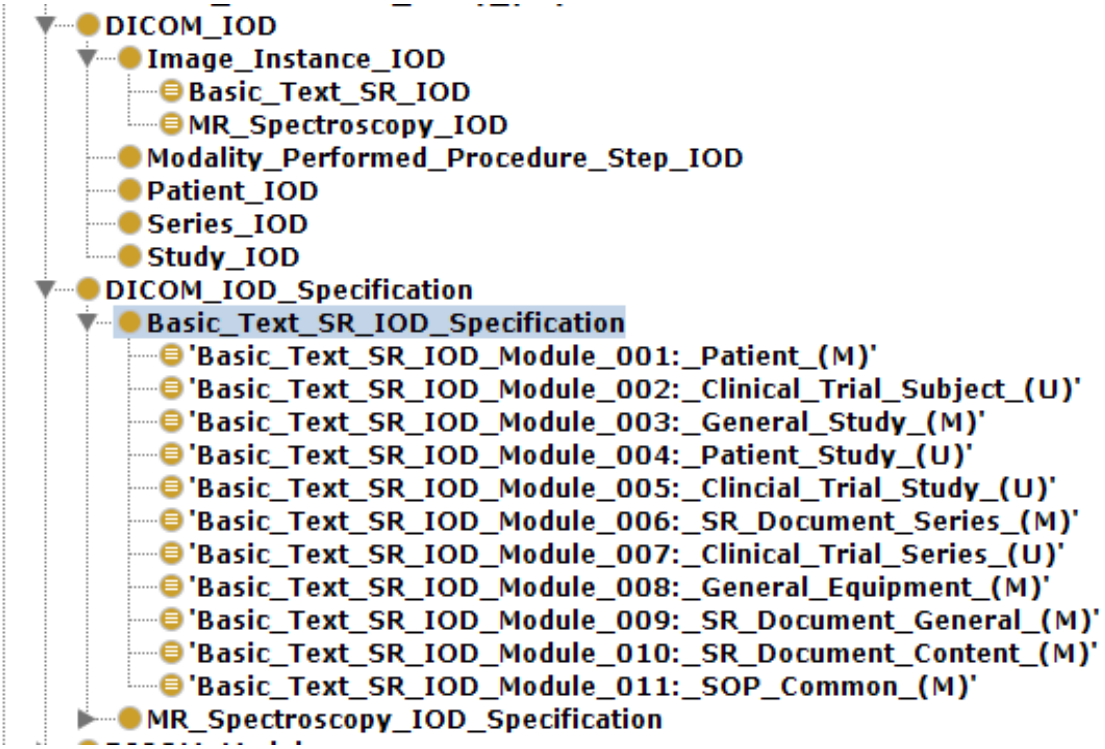


Figure 23: Showing Modeling of IOD Specification Attributes

Each Module identified was then modelled to be a child of a parent class called DICOM_Module. In this example the Basic_Text_SR_IOD_Module_001:_Patient_ (M) is a child of the Patient Module.

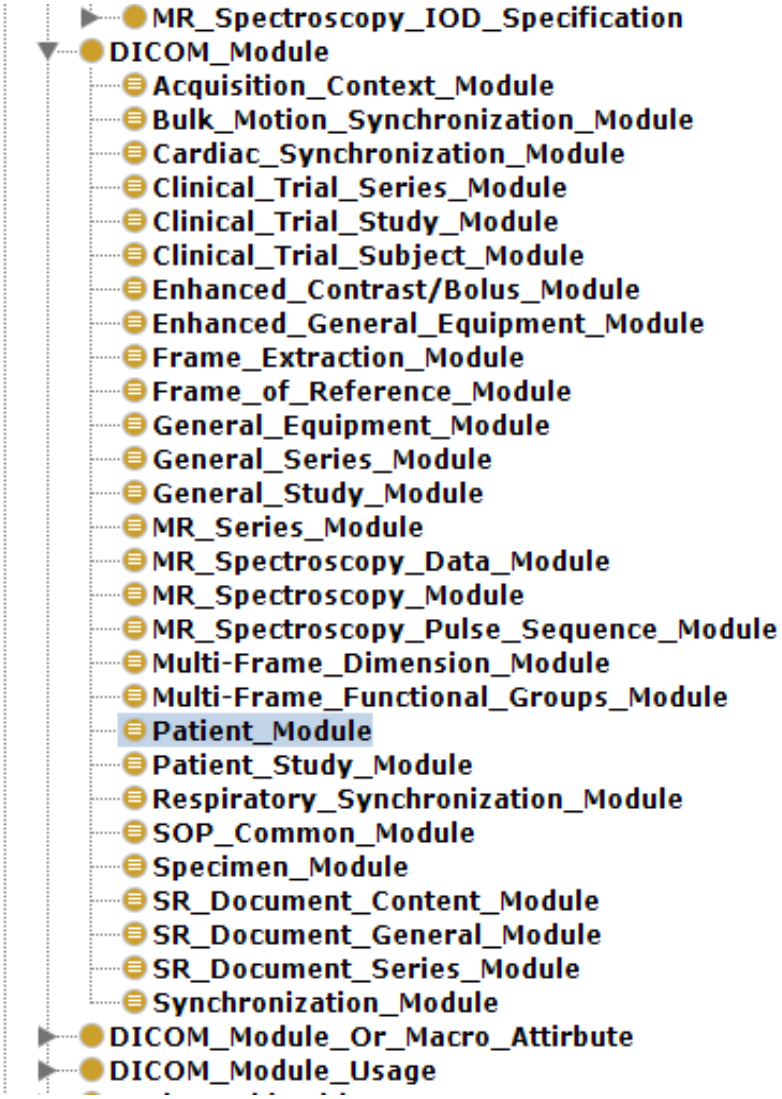


Figure 24: Showing the Modeling of the Patient Module

Each module also required a second parent, the DICOM Information Entity (IE) they were a part of. For example the Patient Module would be a child of DICOM_Module and Patient_IE. Each module would also have a property that sets the module reference and a table reference taken from the DICOM Standard e.g. the Patient Module would have the module reference C.7.1.1 and the table reference C.7-1.

Once this was completed, attributes were then assigned to each of the Basic_Text_SR_IOD_Specification subclasses. Each class had a property that contains the

module which it references and the usage it has. For example, the first subclass within the Basic_Text_SR_IOD_Specification class is:

Basic_Text_SR_IOD_Module001:_Patient(M)

This subclass will there have a slot that states it is a part of the Patient_Module and a further slot that states is have the usage “M.” With both the IOD Class and IOD Specification being created it was possible to then link them together using properties. In this case the properties “hasIODModule” “hasIODModuleUsage” and “hasLineNumber” were created to join the different classes.

With the IODs modelled, the modules they referenced now needed to be constructed within the ontology.

Table C.7-1
PATIENT MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Patient's Name	(0010,0010)	2	Patient's full name.
Patient ID	(0010,0020)	2	Primary hospital identification number or code for the patient.
Include Issuer of Patient ID Macro Table 10-18			
Patient's Birth Date	(0010,0030)	2	Birth date of the patient.
Patient's Sex	(0010,0040)	2	Sex of the named patient. Enumerated Values: M = male F = female O = other
Referenced Patient Sequence	(0008,1120)	3	A sequence that provides reference to a Patient SOP Class/Instance pair. Only a single Item is permitted in this Sequence.
>Include SOP Instance Reference Macro Table 10-11			
Patient's Birth Time	(0010,0032)	3	Birth time of the Patient.
Other Patient IDs	(0010,1000)	3	Other identification numbers or codes used to identify the patient.
Other Patient IDs Sequence	(0010,1002)	3	A sequence of identification numbers or codes used to identify the patient, which may or may not be human readable, and may or may not have been obtained from an implanted or attached device such as an RFID or barcode. One or more Items are permitted in this sequence.
>Patient ID	(0010,0020)	1	An identification number or code used to identify the patient.
>Include Issuer of Patient ID Macro Table 10-18			
>Type of Patient ID	(0010,0022)	1	The type of identifier in this item. Defined Terms: TEXT RFID BARCODE Note: The identifier is coded as a string regardless of the type, not as a binary value.
Other Patient Names	(0010,1001)	3	Other names used to identify the patient.
Ethnic Group	(0010,2160)	3	Ethnic group or race of the patient

Figure 25: A Section of the DICOM Patient Module Table (16 pages 373 -375)

A DICOM module is constructed using specific DICOM Elements. Within the DICOM Standard, each module is defined using a Module table, which has a reference for identification. In the case of the Patient Module, it has a reference of C.7-1 (16 Page 373)

In most cases, each row in these tables represents a DICOM element. When a row is

preceded with a ">" symbol, it denotes a DICOM Macro, a collection of DICOM Elements. Macros are used to these groups of Elements and can be reused in different modules (Wiley 2012).

To model a DICOM Module, a class named "DICOM_Module_or_Macro_Attribute" was created. Within this, two subclasses, "DICOM_Module_Attribute" and "DICOM_Marco_Attribute" were also created. Within the DICOM_Module_Attribtue class, further subclasses were created to represent each DICOM Module being modelled. Within each of these classes a class was created for each row within the Module table.

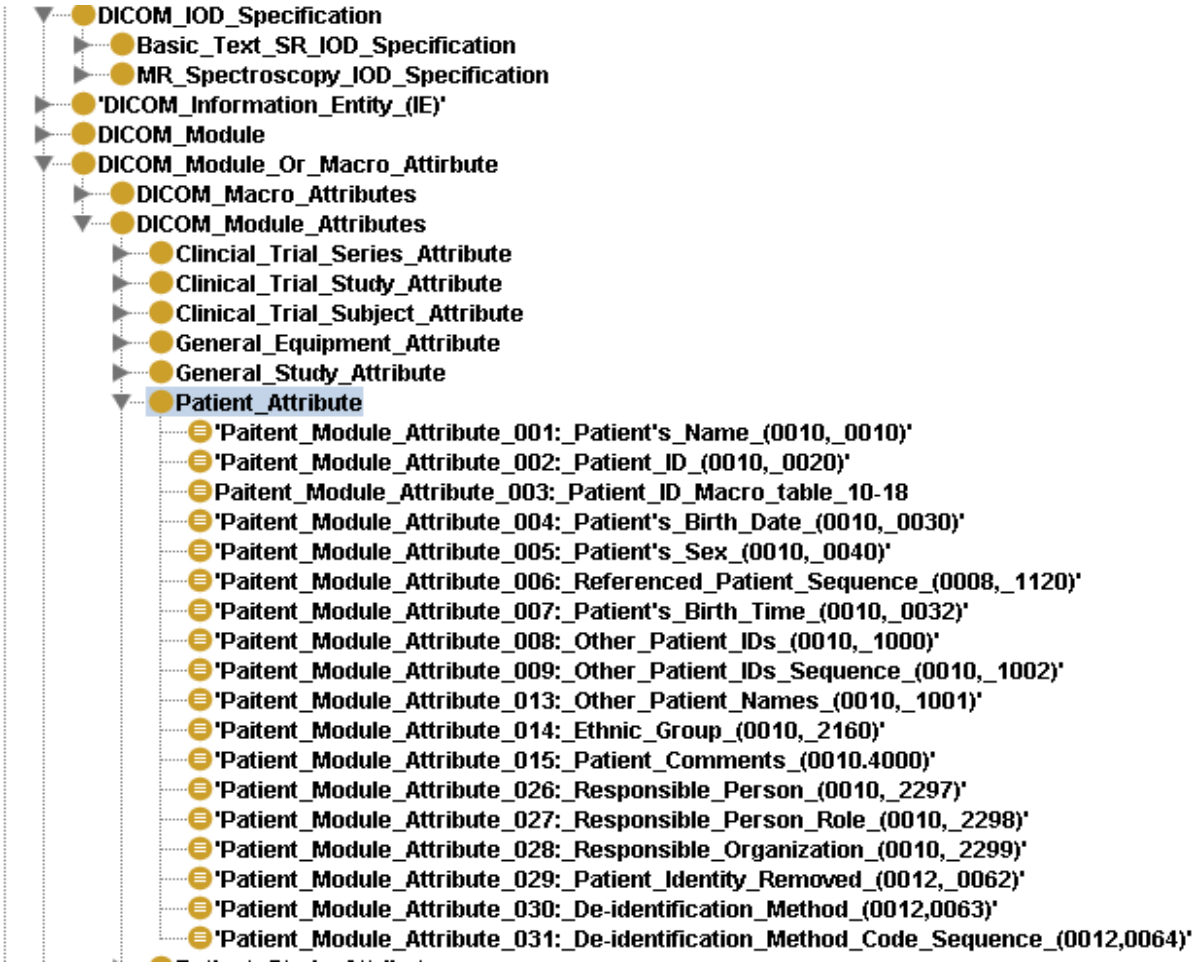


Figure 26: Showing the Modeling of the Patient Module Attributes

Each Module Attribute class had three attributes: "Line Number", "Attribute Data Element or Macro" and "Attribute Data Element Type." These are assigned using the Data property "hasLineNumber," and the Object Properties "hasDICOMDataElement" and "hasType." respectively.

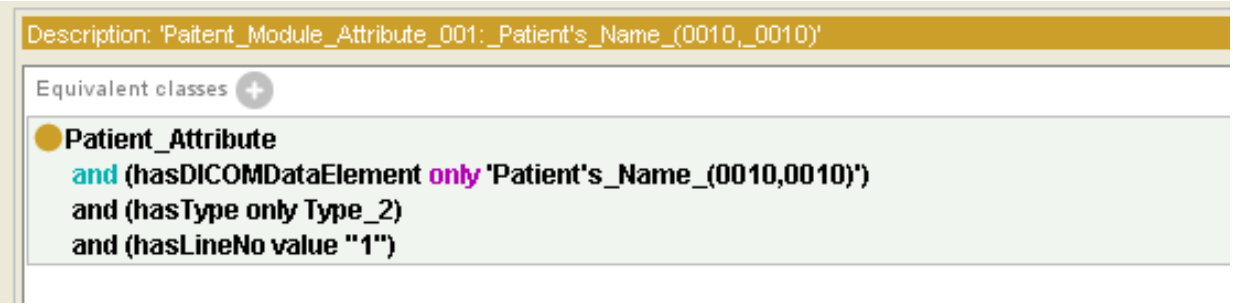


Figure 27: Example of the Attributes Assigned to Each Patient Module Attribute

For a Data Element to be assigned it needs to be modelled. As with the DICOM Module a class was created to represent the DICOM Elements called "DICOM_Data_Element." Subclasses representing the different groups that the elements are a part of were also modelled. This is denoted by the element's Tag, in which the four first four digits represent the group an element is a part of. In the case of the Patient Name element seen in Figure 27, it is a part of the 0010 group. The group subclass "Patient's_Name_ (0010, 0010)" was assigned a group value using the "hasGroup" Data Property. This will then be inherited by any subclass.

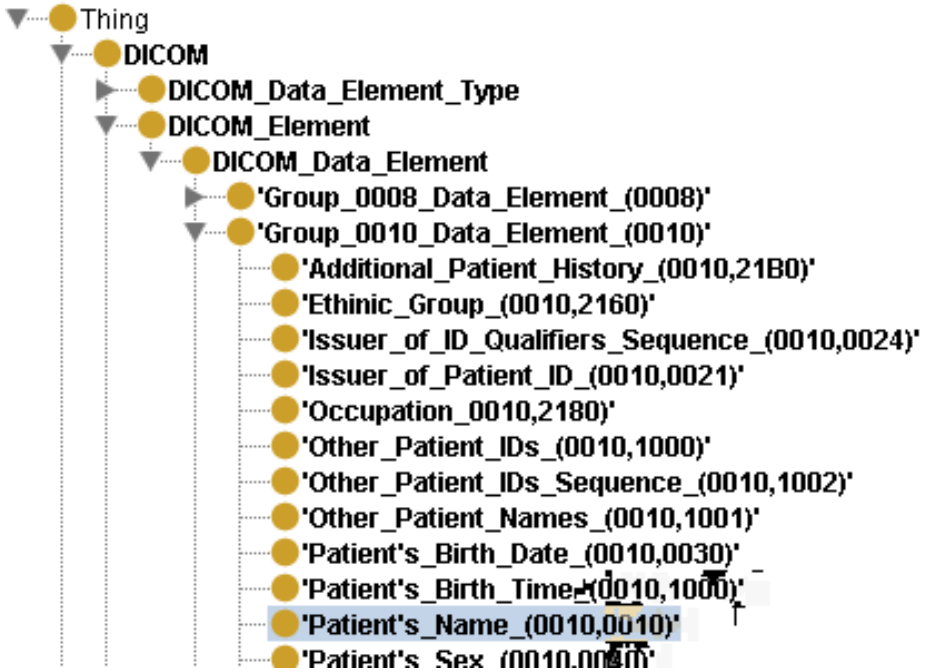


Figure 28: Showing the DICOM Data Element Patient's Name within the Ontology

Each element has five attributes: Data Element Name, Element Reference, Data Element VM Min, Data Element VM Max and VR. These were assigned using the DataProperties "hasDataElementName", "hasElement", "hasMaxVM", "hasMinVM" and the Object property "hasVR" respectively. Each element utilised within this ontology was modelled in the same manner.

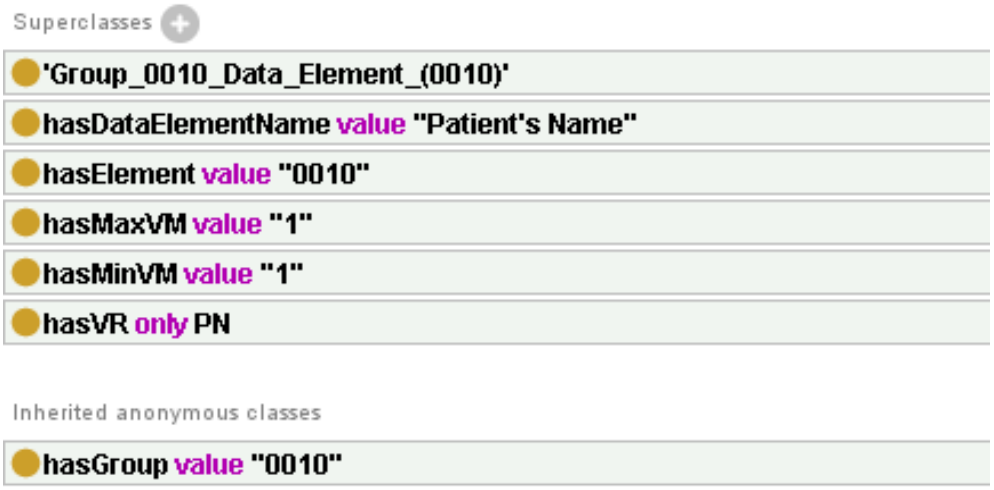


Figure 29: An Example of the Attributes Assigned to a DICOM Data Element

Once the required elements had been modelled they were linked to the corresponding Module Attribute. Continuing the example of the Patient Module, the element "Patient's_Name_(0010, 0010)" was assigned to the "Paitent_Module_Attribute_001:_Patient's_Name_(0010,_0010)" class using the "hasDICOMDataElement" Object property.

Following modelling the singular DICOM elements used within the module, the macros required were then constructed. There are two types of macros: inline and enumerated. Inline macros are contained within the Module table were they are being used. Each inline Macro has a starting, or header, row which contains the name of the macro followed by the word "Sequence." When modelled in Protégé it is the convention to replace this with "Macro." e.g. in Figure 30 "Other Patient IDs Sequence" would be created as a class named "Other Patient IDs Macro." This would then have the following rows with a preceding ">" Symbols as subclasses. Enumerated Macros are referenced

from a separate table. An example of this is found In Figure 22. The thirteenth row states "include Issuer of Patient ID Macro Table 10-18."

Both types of macros are modelled in the same way, which is also the same as modelling an attribute. In the case of macros they are constructed as a subclass of the "DICOM_Macro_Attribute" instead of the "DICOM Module Attribute."

Figure 30: Showing a DICOM Macro within the Ontology

Each macro class was assigned a corresponding table reference taken form the DICOM standard using the data property "hasTableRef." This would be inherited by any subclasses representing the element that form the macro. Each element that was used to

model the macro had the attributes Element and Type, assigned using the "hasDICOMDataElement" and "hasType" Object Properties. With the module attributes modelled, the DICOM Module Attribute class was then linked to the corresponding DICOM Module within the ontology using the object property "hasModuleAttributesorMacros."

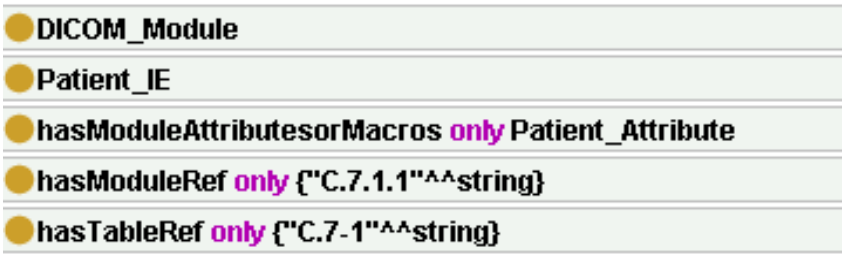


Figure 31: An Example of the Attributes Assigned to DICOM Macro

The processes described above were used to model all the required DICOM Modules.

Once modelling of the required parts of the standard was completed, the final step was to connect the DICOM IODs to the classes within the DICOM Information Model. To do this each subclass within the DICOM_Information_Model class was linked with the corresponding IE using the object property "hasDICOMIE." For example the Patient class in the DICOM_Information_Model is linked to the Patient IE.

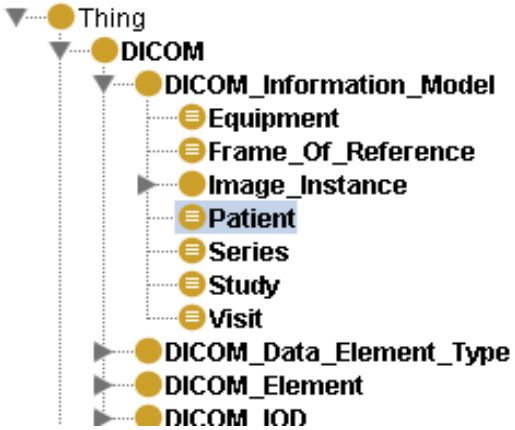


Figure 32: Showing the DICOM Information Model within the Ontology

The classes within the DICOM_Information_Model are linked to each other by object properties. E.g the Patient class is linked to the Study class via the "has_Study" property.

Figure 33: An Example of the Properties Assigned to the Classes within the DICOM Information Model.

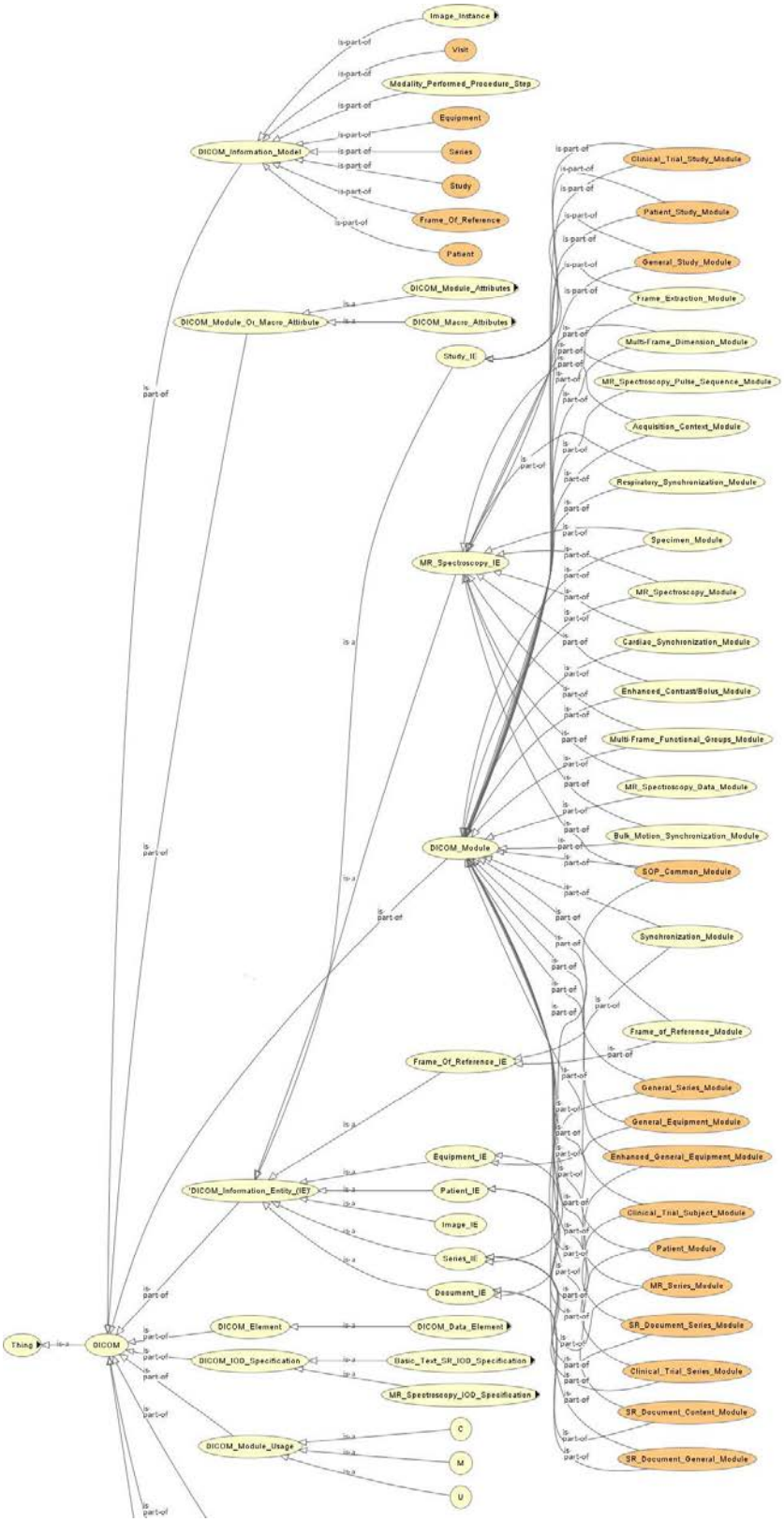


Figure 34: Showing a graphical visualization of part 1 of the DICOM section of the ontology.

Name: Amy Morgan
Student Number: 129570

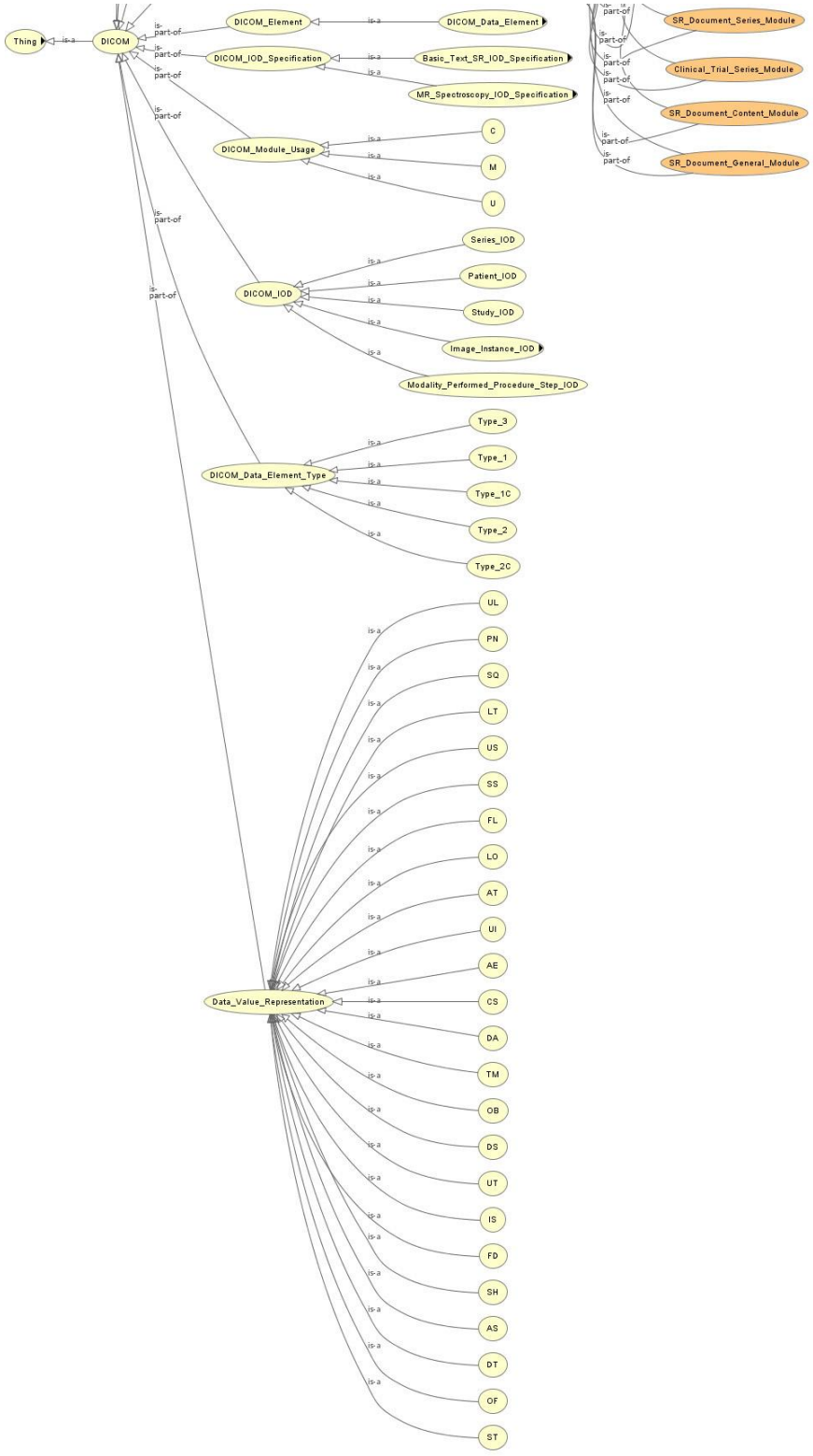


Figure 35: Showing a graphical visualization of part 2 of the DICOM section of the ontology.

With the modelling of the DICOM standard completed, development of the Structure Reporting and Brain Tumour aspects of the ontology could be started.

3.2 Brain Tumour Ontology

As the SR ontology will require elements from the DICOM ontology and the Brain Tumour ontology, The Brain Tumour ontology was the next aspect of the Ontology to be modelled.

There are several elements used to identify a tumour (Cancer Research 2013). A core factor is the area of the body that the tumour has been located, the cells that the tumour has developed from and the grade of tumour.

Two classes named "Area_of_Body" and "Type of Tumour" were created.

Within the "Type of Tumour" class the subclasses "Malignant", "Benign" and "Grade" were created. As it is not possible for a tumour to be both malignant and benign, these two classes were made disjoint of each other. Four subclasses were created in "Grade" to represent the four grades of cancer: Grade I, Grade II, Grade III and Grade IV. Cancers that are Grades I and Grades II are benign and Grade III and Grade IV as Malignant. As a tumour cannot be more than one grade, these classes were made disjoint of each other. To represent this in the ontology the classes corresponding to the Grades were linked to the classes "Malignant" and "Benign" using the Object property "hasGrade."

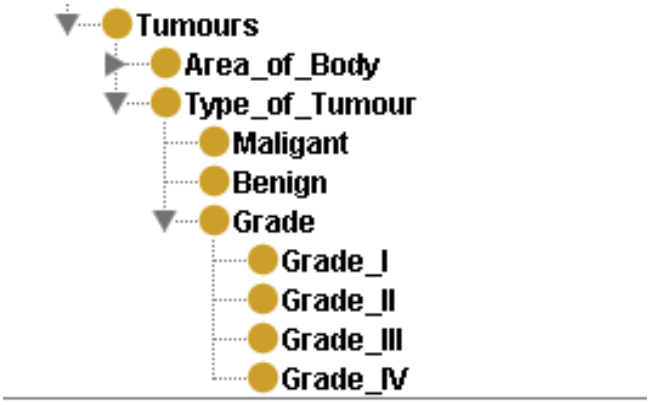


Figure 36: Showing the 'Type of Tumor' section of the Brain Tumors Ontology.

Within the "Area of Body" class, a subclass called "Brain_and_Spinal_Cord" was created. As this study is focusing on childhood brain tumours, this is the only location that was modelled. Different areas of the body could easily be modelled and added in the future. As stated previously, the MRS data obtained only refers to readings taken for Astrocytomas, Ependyoma and Medulloblastomas. As such they will be the only tumours modelled.

As seen in Chapter Two, brain tumours are diagnosed based on the cells from which they originate and area of the brain they have formed. As a result three subclasses called "Types Brain Tumour," "Areas of the Brain" and "Origin Cells" were created within the "Brain and Spinal Cord" class.

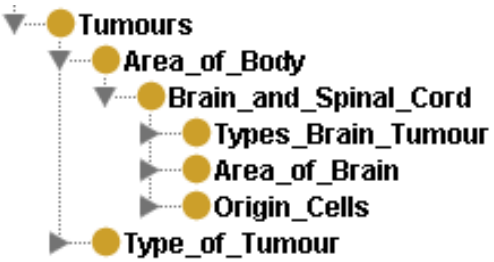


Figure 37: Showing the 'Area of Body' section of the Brain Tumors Ontology.

The "Areas of the Brain" class was given four subclasses to represent the four areas of the brain: the brain stem, cerebellum, cerebrum and spinal cord. Within the "Origin Cells" class, subclasses were created to represent the origin cells for the types of tumour mentioned above: Glial, Ependymal and Embryonal respectively.

Within the "Types Brain Tumour" class the subclasses "Medulloblastoma" and "Gliomas" were created. The Gliomas class also contained two subclasses, Astrocytoma and Ependyoma. These classes were made disjoint of each other as it is not possible for a tumour to be diagnoses as more than one type.

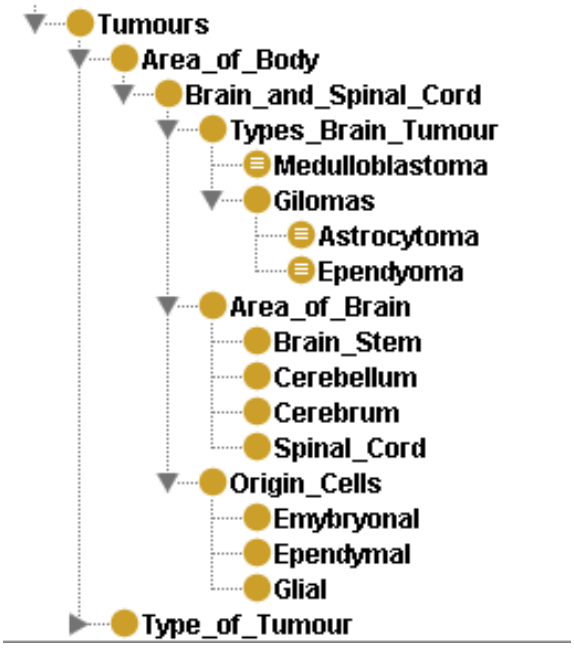


Figure 38: Showing the Brain Tumors Ontology in Protégé

Each of the subclasses representing a type of tumour was assigned four attributes using the Object Properties "hasTumourType," "hasTumourGrade," "hasTumourLocation" and "hasTumourOrigin Cells." to link the types of tumours to the attributes that differentiate them.

Figure 39: Showing the attributes of a medulloblastoma tumor.

Figure 40: Showing the attributes of an astrocytoma tumor.

Medulloblastoma are always Grade IV, are malignant, located in the Cerebellum and develop from Embryonal Cells. However, an Astrocytoma, which always develops from Glial can be classed as any of the Grades, and therefore be either benign or malignant. They can also be located in the Cerebellum or the Cerebrum. This means that the Object properties had to be set to recognise these variations. Once set, the Brain Tumour section of the ontology was completed and could then be used, with elements of the DICOM ontology to construct the Structured Reporting and Diagnosis ontology.

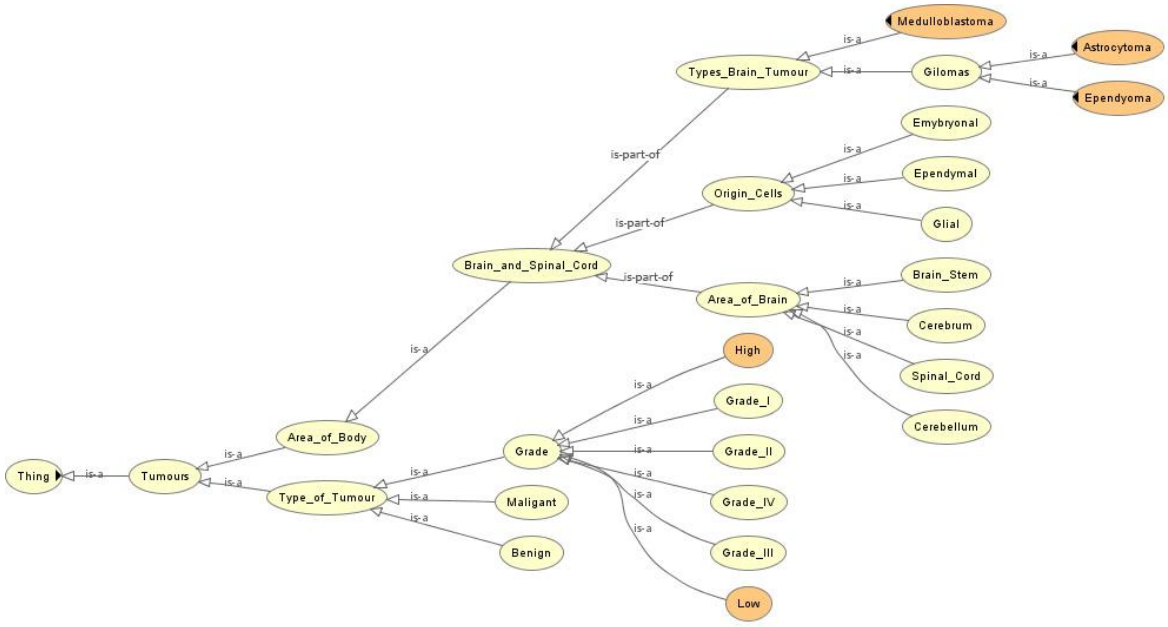


Figure 41: Showing a graphical representation of the Brain tumor section of the ontology

3.3 Structured Report and Diagnosis Ontology

With the both the Tumour and DICOM sections of the ontology completed it was possible to model the SR section. For this section to be modelled the information that was required within a medical report had to be considered. The graphical example of a Text SR shown below in Figure 42 was used for the basic structure of the report, were as Figure 43 was used to determine the type of information expected to be held within a report.

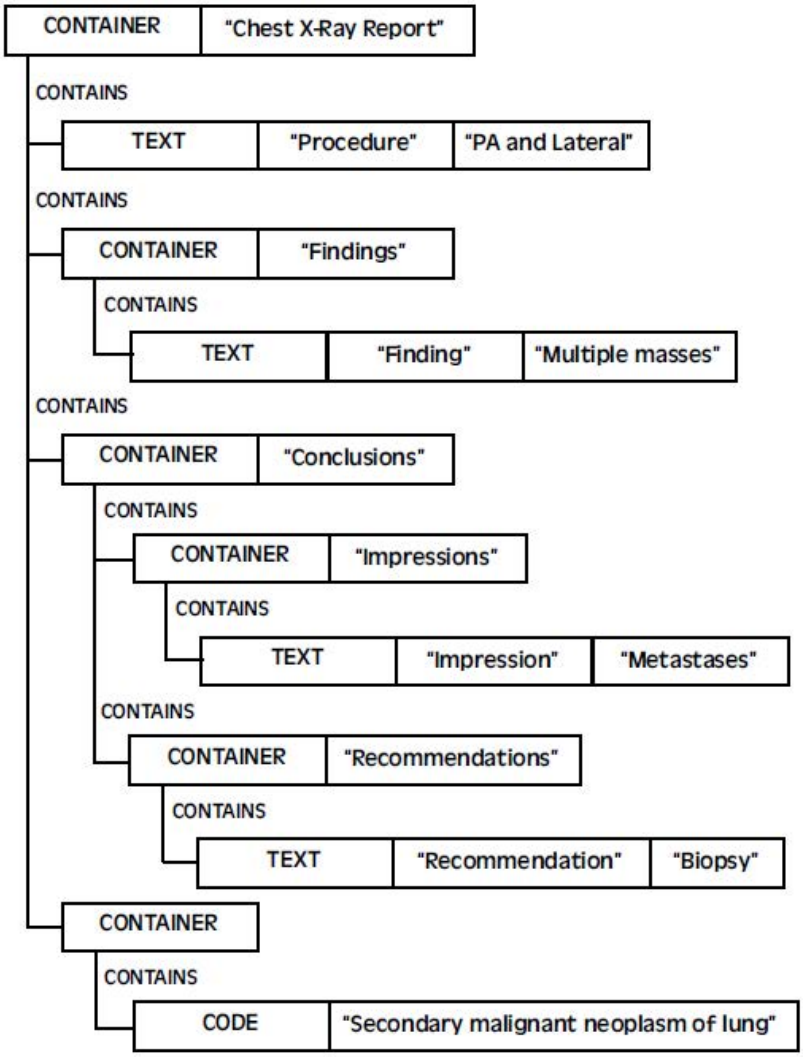


Figure 42: A Graphic Representation of a DICOM Text SR (Clunie 2000)

Report Section	Contents
Administrative information	Imaging facility Referring provider Date of service Time of service
Patient identification	Name Identifier (e.g., medical record number or Social Security Number) Date of birth Gender
Clinical history	Medical history Risk factors Allergies, if relevant Reason for exam, including medical necessity
Imaging technique	Time of image acquisition Imaging device Image acquisition parameters, such as device settings, patient positioning, interventions (e.g., Valsalva maneuver) Contrast materials and other medications administered (including name, dose, route, and time of administration) Radiation dose
Comparison	Date and type of previous exams reviewed, if applicable
Observations	Narrative description or itemization of findings, including measurements, image annotations, and identification of key images
Summary or Impression	Key observations, inferences, and conclusions, including any recommendations.
Signature	The date and time of electronic signature for each responsible provider, including attestation statement for physicians supervising trainees, if applicable

Figure 43: Table Showing the Components of a Radiological Report (Kahn 2009)

Six classes were created: "Patient," "Procedure_Details," "Scan_Details," "Findings," "Diagnosis" and "Recommendations." and were made disjoint of each other.

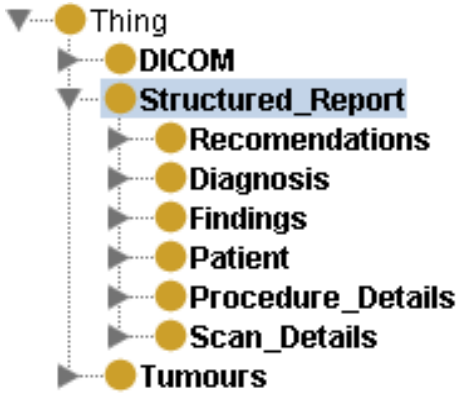


Figure 44: Showing the Structure Reporting Section of the Ontology

Using the table in Figure 43 the subclasses of each of these classes was created and defined. Some of the contents from the table in Figure 43 were not placed in the corresponding classes. For example, the "Patient" Class was an amalgamation of the Patient Identification and Clinical History Report Sections. As well as this, some of the Contents were left out as they were not required e.g. Radiation Dose and Contrast. MRS imaging doesn't use radiation and doesn't require use of a contrast. Both the "Patient," "Recommendations" and "Scan Details" were modelled in a similar manner.

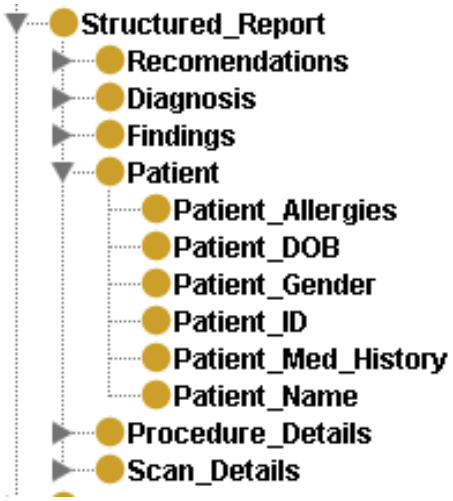


Figure 45: Showing the Subclasses of the "Patient" Class.

Once the subclasses were created, they were then connected to the DICOM Section of the ontology via the corresponding DICOM Data Element that would contain the required information. This was accomplished by using the object property, "hasDICOMElement."

The "Prodecure_Details" class was broken down to further subclasses. "Date," "Location", "Physician," Procedure_Type and "Time." All except "Procedure Type" were linked to the corresponding DICOM Data Elements as shown above. For the "Procedure Type" class it was given a subclass of "MRS." This was also linked to the DICOM Ontology, but instead of being linked to a DICOM Data Element, it was linked as being equivalent the "MR_Spectroscopy_IOD_ Specification" class as this represents the procedure within the DICOM standard.

The "Findings" class was modelled with three subclasses. "CR:CHO_Ratio," "Ins:Naa_Ratio" and "Naa:CR_Ratio." MRS imaging creates a graph that shows the chemical composition of the tissue being scanned. The ratios between those peaks are then used to make a diagnosis. These three subclasses reflect the ratios observed to diagnose the tumour types that are the focus of the study: astrocytoma, ependyoma and medulloblastoma. Each of the subclasses has an integer based attribute assigned using the Data Property "has'X:Y'_Ratio" where the X:Y is the ratio reflected in the subclass. For example the subclass "Naa:Cr_Ratio" uses the Data property "hasNaa:CR_Ratio."

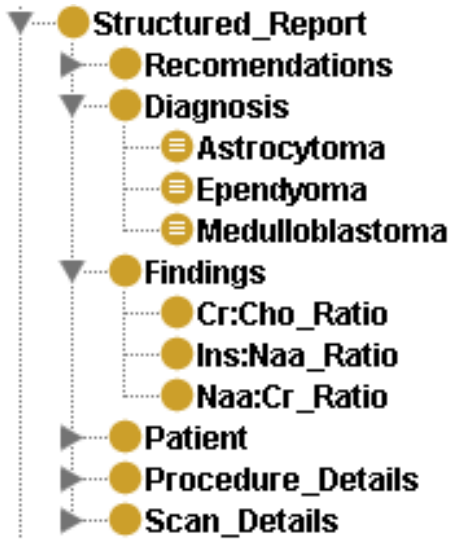


Figure 46: Showing the Subclasses of Diagnosis and Findings Classes.

For the"Diagnosis" class, the subclasses are equivalent to the classes of the same name within the "Types_Brain_Tumour." As these subclasses would be equivalent to each other, with the same attributes they were also linked. This was accomplished in a different manner to before, by making them subclasses of both "Diagnosis" and the corresponding subclass in "Types_Brain_Tumour." e.g. "Astrocytoma" and "Ependyoma" subclasses of both the "Gliomas" and "Diagnosis" classes and they both inherited the same attributes from each other. With these classes linked, the ontology was now fully modelled.

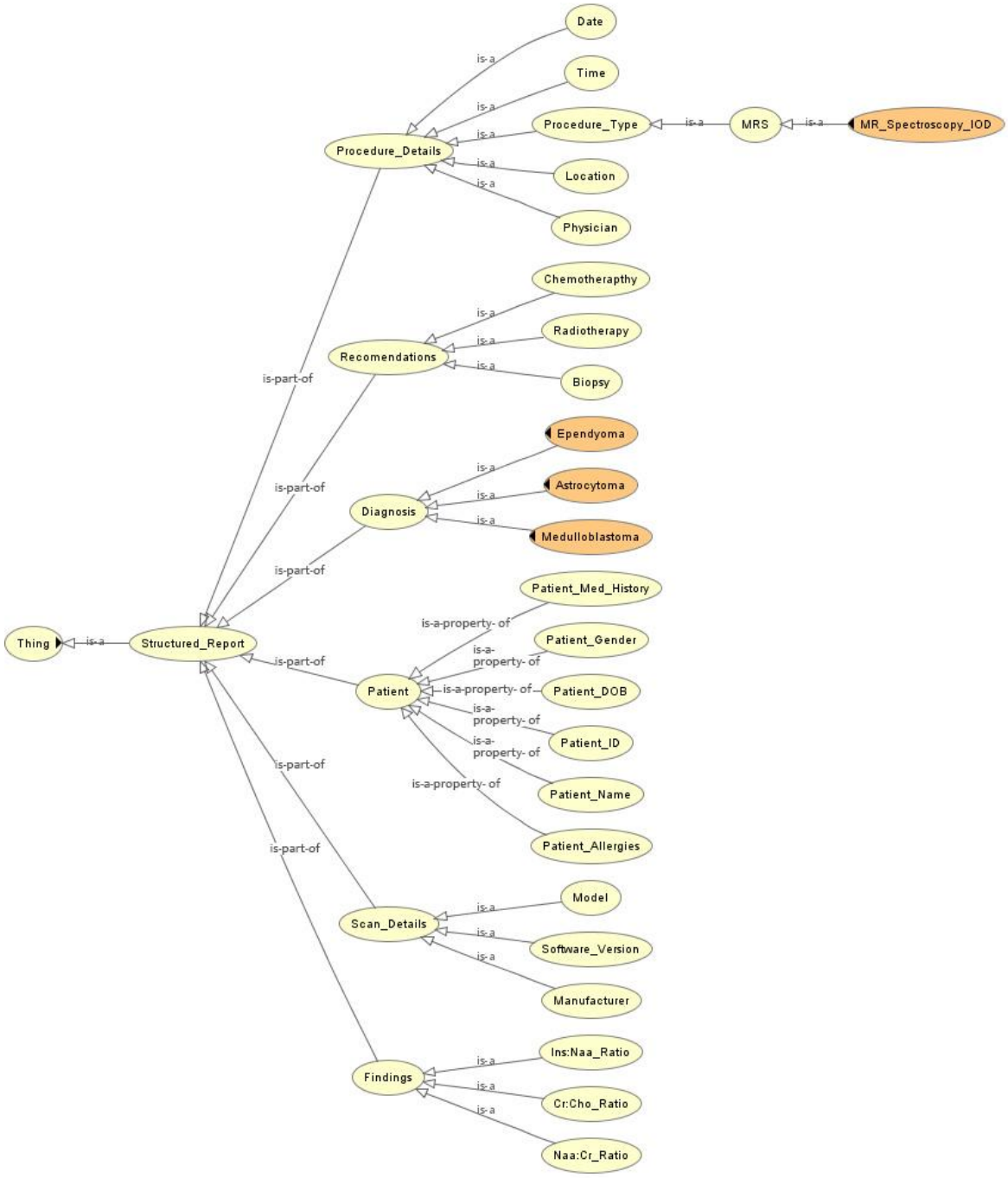


Figure 47: Showing a graphical representation of the SR and Diagnosis Section of the ontology.

3.4 Diagnosis Support

Although the ontology has been modelled, it so far only provides a knowledge base and structure for creating a SR. To meet the objectives of this project, it is also required to help facilitate diagnosis. To allow this, the ability of an ontology to infer knowledge via a reasoner will be used.

It has been found that the ratio readings for Cr:CHo, Ins:Naa and Naa:Cr produced by an MRS scan has ranges that are specific to different types of brain tumour (Harris 2009).

The table below (Harris 2009) shows the readings that have been taken from MRS scans and the diagnosis made from these ratios.

	QC???	PEAK HEIGHTS				RATIOS			DIAGNOSIS FROM RATIOS	COMMENTS
Spectra	Passes?	Ins	Cho	Cr	NAA	NAA/Cr	Ins/NAA	Cr/Cho		
1	Pass	1.76	2.24	1.64	0.90	0.55	1.96	0.73	MEDULLOBLASTOMA	
2	Pass	0.67	3.64	0.83	0.70	0.84	0.96	0.23	MEDULLOBLASTOMA	
3	Pass	0.33	1.28	0.33	0.77	2.33	0.43	0.26	MEDULLOBLASTOMA	
4	Pass	2.05	5.30	2.03	1.65	0.81	1.24	0.38	MEDULLOBLASTOMA	
5	Pass	2.93	2.35	2.23	1.08	0.48	2.73	0.95	EPENDYMOMA	
6	Fail	0.28	0.89	0.16	0.80	5.00	0.35	0.18	GRADE 1 ASTROCYTOMA	
7	Fail	0.35	2.42	0.95	3.20	3.37	0.11	0.39	MEDULLOBLASTOMA	
8	Fail	0.08	0.88	0.26	1.10	4.31	0.07	0.29	GRADE 1 ASTROCYTOMA	
9	Fail	2.44	4.69	2.28	3.10	1.36	0.79	0.49	MEDULLOBLASTOMA	
10	Fail	0.80	4.55	0.75	1.90	2.53	0.42	0.16	MEDULLOBLASTOMA	
11	Pass	5.30	3.00	4.00	1.90	0.48	2.79	1.33	EPENDYMOMA	
12	Fail	3.40	6.58	1.00	2.98	2.98	1.14	0.15	MEDULLOBLASTOMA	
13	Pass	0.38	1.85	1.16	0.44	0.38	0.86	0.63	MEDULLOBLASTOMA	
14	Pass	0.44	2.08	0.82	0.77	0.94	0.57	0.39	MEDULLOBLASTOMA	
15	Pass	0.62	2.31	0.40	1.84	4.60	0.34	0.17	GRADE 1 ASTROCYTOMA	
16	Pass	1.43	4.80	1.60	1.05	0.66	1.36	0.33	MEDULLOBLASTOMA	
17	Pass	0.77	2.67	0.33	1.88	5.68	0.41	0.12	GRADE 1 ASTROCYTOMA	
18	Fail	0.29	0.60	0.00	0.84	0.00	0.34	0.00	MEDULLOBLASTOMA	
19	Pass	0.25	2.08	0.59	0.67	1.15	0.37	0.28	MEDULLOBLASTOMA	
20	Fail	0.23	0.50	0.09	1.06	12.41	0.22	0.17	GRADE 1 ASTROCYTOMA	

Figure 48: Table showing "Gold Standard" MRS readings and the Diagnosis that was determined (Harris 2009)

It can be seen that the ratios of Cr:Cho and Ins:Naa are integral to this distinguishing the type of brain Tumour . Using these values an algorithm has been created and detailed below (Harris 2009)

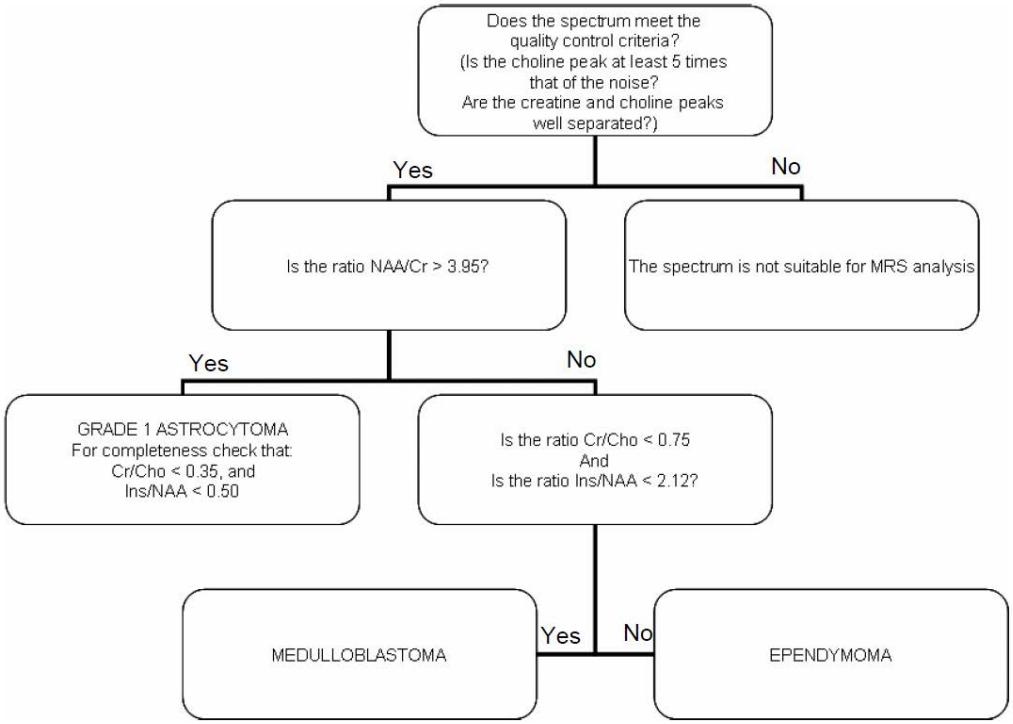


Figure 49: Algorithm to Diagnose Brain Tumor using MRS Data (Harris 2009).

This algorithm can be translated into an ontology, by assigning Data Type properties to the classes that represent the tumours. For example, in Figure 49 it can been seen that MRS data that has a CR/Cho Ratio that is less than 0.35 and an Ins:Naa ratio less than 0.50 will be from an astrocytoma.

To translate this into the ontology data properties were assigned to the astrocytoma class with on the Structured Reporting section of the ontology.

This was done using the data properties: "hasCr:ChoRatio", "hasIns:NAARatio", "hasNAA:Cr_Ratio." Each data property was set to only recognise integers as an input value and was defined using the operators ">" or "<."Integers had to be used as Protégé would not recognise the input as floats. As a result test readings from the table in appendix A were multiplied by 100. For example:

hasCr:ChoRatio some integer[< 35]

hasIns:NAARatio some integer[< 50]

hasNAA:Cr_Ratio some integer[> 395]

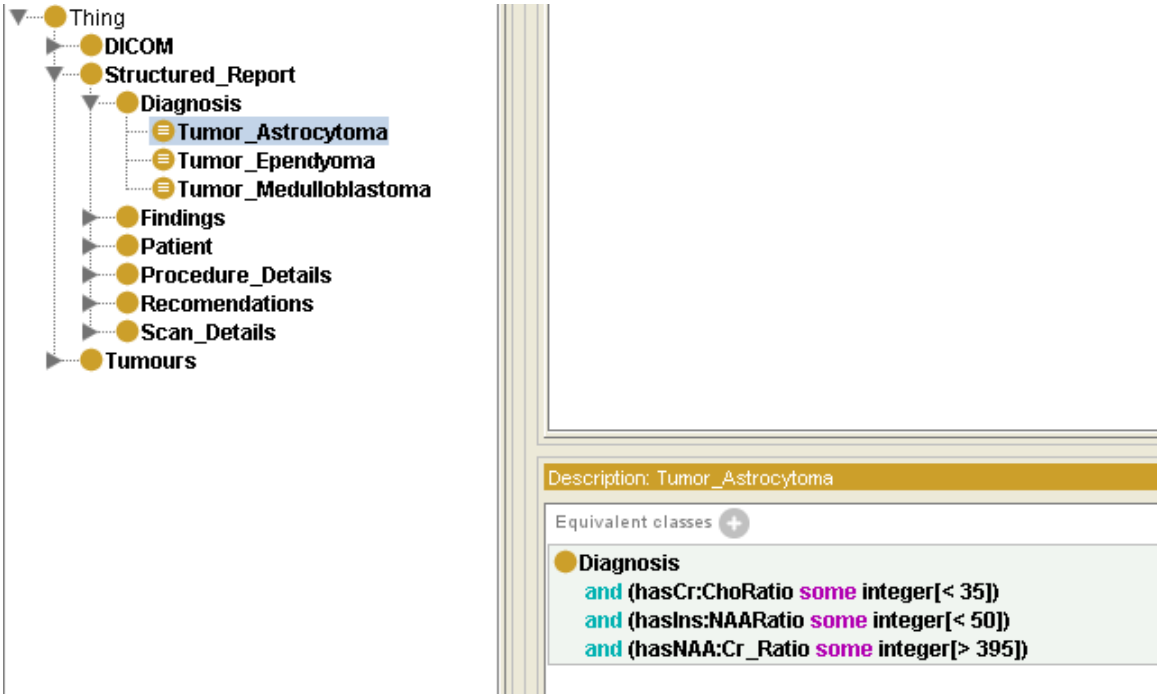


Figure 50: Showing the Data Properties assigned in OWL Ontology.

This process was repeated for both the medulloblastoma and ependyoma Classes.

3.5 Evaluation

Once the ontology was completed it was processed using the reasoner built into Protégé called FaCT++. No inconsistencies were highlighted and after comparing the asserted hierarchy to the inferred hierarchy it was found that no classes had been misplaced in the latter.

Following this, individuals were created to represents the SR of a patient. These individuals were assigned integer values using the data properties hasCr:ChoRatio, hasIns:NAARatio, hasNAA:Cr_Ratio. Once assigned, the reasoner was restarted and the newly appointed values where processed against the corresponding data properties within the sub classes of the Diagnosis class. After the values are processed the reasoner determines which Diagnosis subclass the individual is a member of. For the purposes of validation the ontology is presented with 20 individuals and it correctly determined the diagnosis for each individual. For the purposes of validation, it can be said that the ontology has been successful.

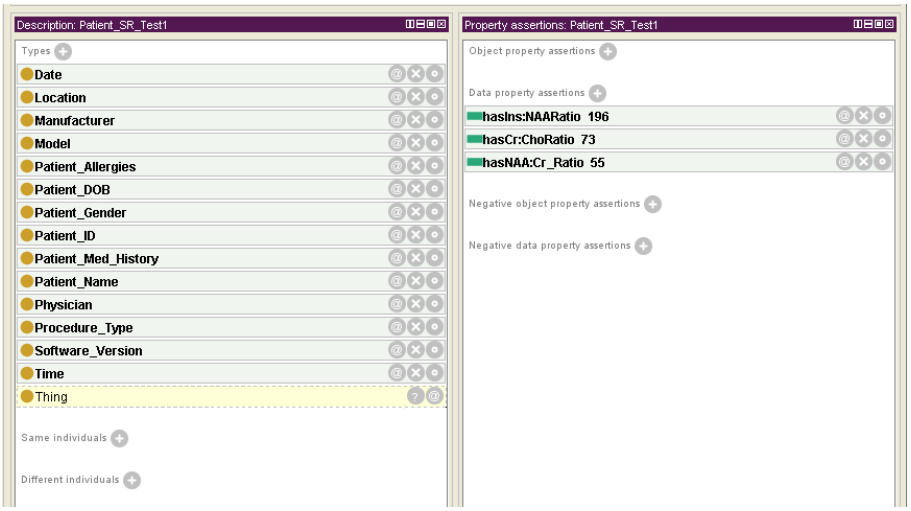


Figure 51: Showing the individual being set with the values that indicate a medulloblastoma tumor.

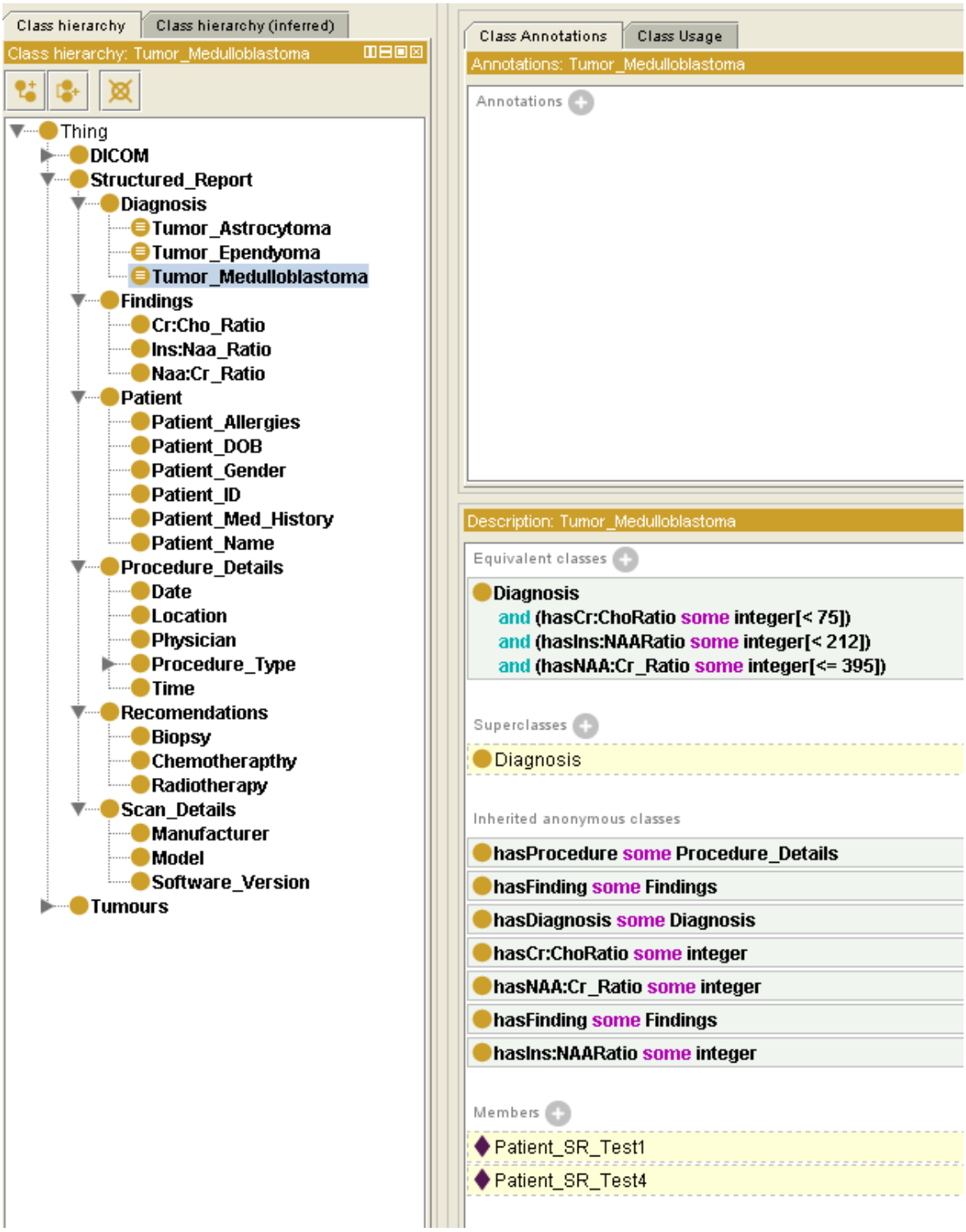


Figure 52: Showing the individual Patient_SR_Test 1 as a member of the medulloblastoma diagnosis class indicating it has been diagnosed correctly.

However the verification of the ontology cannot be so easily ascertained, for this we need to look into different evaluation methods for ontologies. With the increase in ontology development there has been a growing need to evaluate whether an ontology is suitable for its proposed need. At this time no global approach to this has been agreed upon (Gangemi et al 2006) Despite this there are three main evaluation approaches that have been developed:

Gold Standard Evaluation -An approach were an ontology is compared against another that is seen as a bench mark. It uses measures to determine the accuracy of relationships within the proposed ontology by comparing it with an already existing one (Yu et al 2007)

Criteria Based Evaluation - An approach that evaluates an ontology based on proposed criteria that includes, but not limited to, consistency, completeness, conciseness and expandability. A criteria evaluation only focuses on the ontology itself, not on any application area. As such an ontology may meet the criteria, but may still not satisfy the needs of an application (Yu et al 2007)

Task- Based Evaluation - An approach that evaluated the ontology based on its competency in completing tasks. It is a good method to use to judge whether an ontology is suitable for an application. This is done measuring the ontology's performance within the context of an application. However, it can be difficult to compare the evaluation of two different tasks. Therefore a separate evaluation would be needed to be taken for each task considered (Yu et al 2007)

At this time there is no DICOM based diagnostics support ontology that can be used as a “Gold Standard” to evaluate this project. The task-based approach is also not possible as

there has been no application developed to allow tasks to be completed.

The criteria based method is the only method that is viable for this project as it uses metrics taken from the ontology. These metrics are used evaluate certain aspects of the ontology. The results evaluate the ontology's design and its ability for rich knowledge representation (Tartir et al 2005).

Determining if the ontology models the knowledge it represents correctly and completely is not possible. It is possible to demonstrate these aspects, but it is not to prove them (Yu et al 2007). However, the following metrics can be used to indicate the richness, width, depth and inheritance of an ontology (Tartir et al 2005).

Relationship Richness shows the diversity of the relations and the placement of these relationships within the ontology. It is defined as the ratio of the total number of relationships within an ontology divided by the sum of the number of subclasses and the number of relationships. The result produces a percentage that indicated the number of rich relationships. These are relationships other than a class-subclass relationship (Tartir et al 2005) (Yu et al 2007).

Relationship Richness = No. Relationships/ (No. Subclasses + No. Relationships)

= 98 / (698 +98)

=0.123

= 12.3%

As the score is low, closer to zero, this indicates that relationships within the ontology are

mainly class-subclass (Tartir et al 2005). This is expected as the DICOM standard is a large complex document that defines many different data elements that use a class-subclass hierarchy. The richer relationships are then used to link these elements to construct the modules that form the DICOM documents.

Attribute Richness is the average number properties that have been defined to each class within the ontology. It is generally viewed that the more properties that have been defined to a class the more knowledge is conveyed by the ontology (Tartir et al 2005). Attribute Richness is calculated as the total number of attributes divided by the number of classes (Tartir et al 2005) (Yu et al 2007).

Attribute Richness = No. of Attributes in all Classes/ No. Classes

=2959/1000

=2.96

The value for the Attribute Richness is low, which indicates that the ontology that less information is provided by each class. However, this could be affected by the modelling of the ontology. Some classes have been used to represent certain aspects of DICOM, such as the Data Value Representation or Module Usage, where a value could have been used. As such these do not have any attributes assigned. An example of this is the Value Representation of the DICOM elements. The "Data_Value_Representation" contains 24 subclasses to represent the different Value Representation values that can be assigned to the DICOM Data Elements. None of these have properties assigned. These could have been assigned to the DICOM Elements as a value instead of a relationship to another

class.

Class Richness measures the number of classes that have individuals attributed to them (Yu et al 2007) (Tartir et al 2005). It is calculated to as a percentage of the number of classes that have individuals divided by the number of classes within the ontology (Tartir et al 2005) (Yu et al 2007). If the score is high, e.g. close to 100%, this would indicate that most of the information in the ontology is represented.

Class Richness = No. of Classes with Individuals/ Total Number of Classes.

= 23/1000

= 2.3%

The score for Class Richness is very low. However for this ontology the individuals are the Structured Reports that are produced by the ontology. As such the only classes that have individuals are those within the SR section of the ontology. As this section is much smaller than the DICOM section this low score is not unexpected.

Inheritance Richness, or Fan-out, measures the distribution of information across the different levels of the ontologies. This gives an indication of how well the knowledge within the ontology has been organised in to categories and subcategories. If the result is high it indicates that the ontology structure is horizontal in nature, represents a wide range of knowledge. A low result indicates that the ontology structure is more vertical in nature which indicates that the ontology represents a very detailed and specific knowledge (Tartir et al 2005) (Yu et al 2007).

Inheritance Richness = No. Leaf Classes/ No. Classes.

=943/1000

= 0.943

This low score indicates that the ontology is vertical in structure as such is very specific in regards to the knowledge it holds. This is expected due to the subject of the ontology being focused on the representation of the diagnosis of childhood brain tumours using MRS (Tartir et al 2005) (Yu et al 2007). If expanded to include using other imaging modalities for diagnosis, or using it for diagnosis of other types of tumours in other parts of the body the ontology is likely to become more horizontal in nature.

Chapter 4: Structured Report Interface Prototype Application

4.1 Introduction

With the ontology complete and being able to produce Structure Reports as individuals, it was apparent that although correct in terms of the information contained, the reports are not easily readable in this format. As a result an interface is required to present a report to a user. In this chapter a paper prototype of the user interface is presented and a user evaluation conducted.

As the name suggests, paper prototyping is a method of designing, testing and refining user interfaces where users perform tasks by interacting with a paper version of the interface or product that is being tested. The interface is manipulated by a person "playing" the computer and simulated how it behaves. The "computer" only interacts with the user based on their instructions via the interface, they do not explain how to use the system or assist the user.

It should be noted that paper prototyping is not the same as compositions or storyboards. Although they may seem similar both compositions- images used to show the design and look of an interface- and storyboards- a series of drawings used to represent how an interface would be used to complete a task - are only visual representations of an interface, they cannot be interacted with. Similarly, paper prototypes are not to be confused with wire frames. These are used to define the layout and navigation of websites and applications, however they do not contain any realistic content, so cannot be used to test to determine a user's understanding of the system (Snyder 2003) (Snyder 2003).

The benefit of this type of prototyping is that it is a fast way to mock up an application, no coding is required. Coding doesn't take place until after the interface has been refined. Therefore, no time is wasted developing an application, only to find it needs to be significantly reworked after usability testing. Using the paper prototype also allows experimentation with many ideas and for suggested changes to be implemented straight away, even being presented to the user who suggested the change within the same testing session (Klee 2000).

However, there are possible downsides to using this type of prototyping. An obvious one is that it doesn't produce any code. Once the interface has been defined it is then required to be fully implemented. This could cause issues in development is it is found that features in the refined interface are not possible to implement. As well as this it can affect how the users react to the product. Some may feel that it is unprofessional and therefore not take the testing seriously. However this can work from a positive angle as well. As the prototype is obviously a work in progress, the user may be more amenable to the testing and when be more constructive with feedback when an issue is discovered (Snyder 2003) (Snyder 2003) (Klee 2000).

4.1.1 Considerations

Once this method of prototyping was decided upon, an application was designed. It was identified that a user would use the system to complete several key processes:

- User login
- Creating a report

- Viewing a report
- Editing a report
- Searching database for reports

It was also consider that an ability to view the user's history for easy access to recently completed or viewed reports would be useful. For the paper prototype is has been assumed that a database to store the records has been set up and the application is able to communicate with it.

To design the application, the actions that the user and system would need to take to complete a process were considered and activity diagrams completed to illustrate the steps taken.

4.1.2 User Login

Any application developed to view a patient's medical images and report the findings would store sensitive personal information. As such it is import that unauthorised users do not have access, or are able to amend the information store. As such a user would be required to login into the system to verify they have been assigned the correct privileges to access the information. Figure 53 shows the method used by a user to login and verify their details. If the incorrect details are provided, access to the system is not granted and an error messaged displayed.

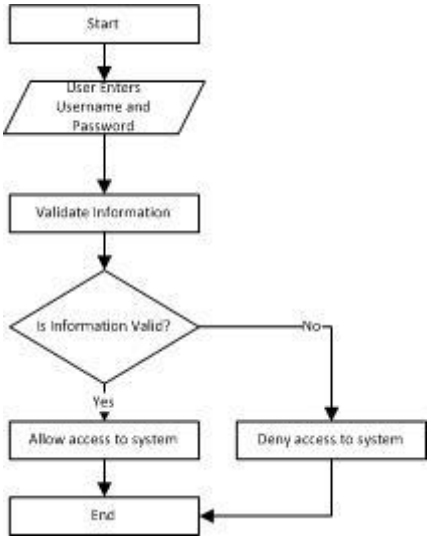


Figure 53: Activity Diagram showing the process of a User Logging into the System

4.1.3 Creating a Report

To create a record, a user would have to have the correct permissions to again protect the personal information stored within the database and the medical images. This would also protect any database connected to the application form being abused, for example a malicious user trying to create numerous records to clog to the system.

The user requests to create a report. They complete the form that load and upload the medical images. Once the report is completed, the system verifies that all compulsory fields have been filled. If the form has been completed correctly the record will be saved to the database and its version number set to a default value of 1. If the fields have not been completed an error message will be given and the user will have to add the missing

details before being able to save the report.

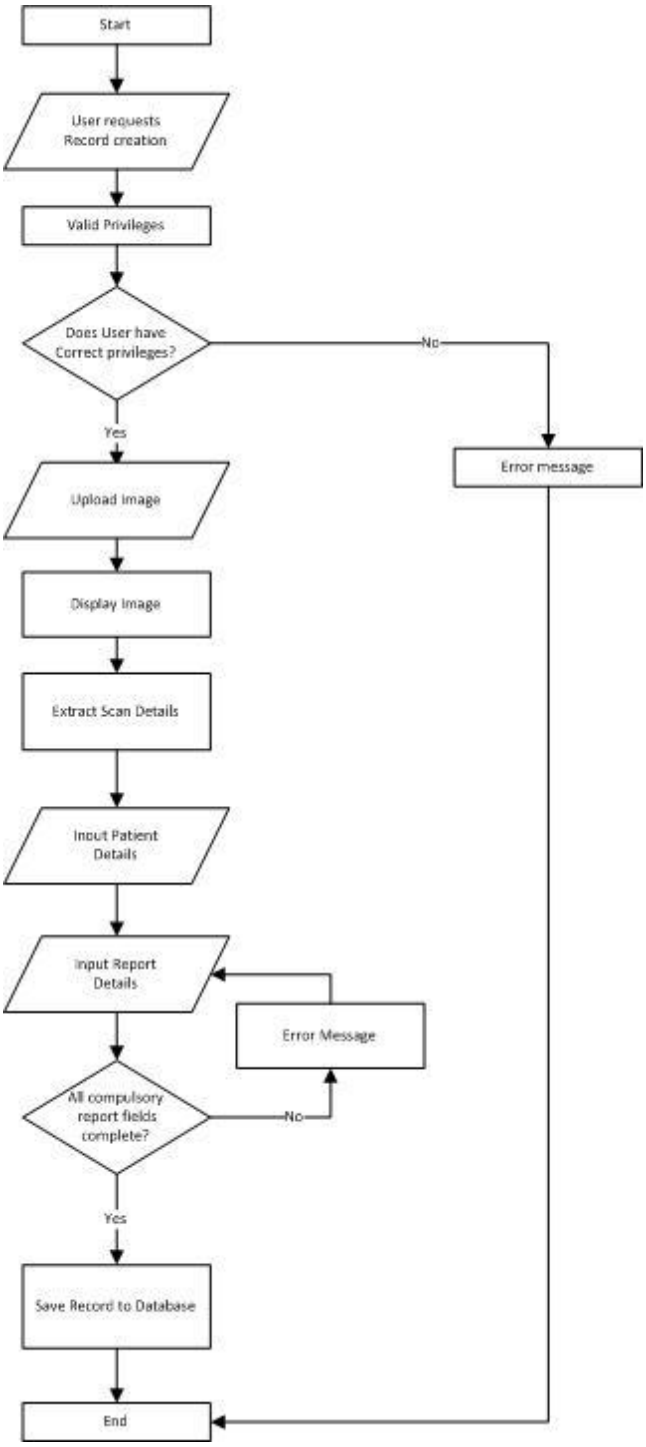


Figure 54: Activity Diagram showing the process of creating a Report

4.1.4 Viewing/ Retrieving a Report

As with accessing the system in general, a user must have correct privileges to be able to view a report. As a result their privileges are again verified. If the user's privileges do not allow them to view a record, access will be deigned. If a user has the correct privileges the record will be loaded from the database.

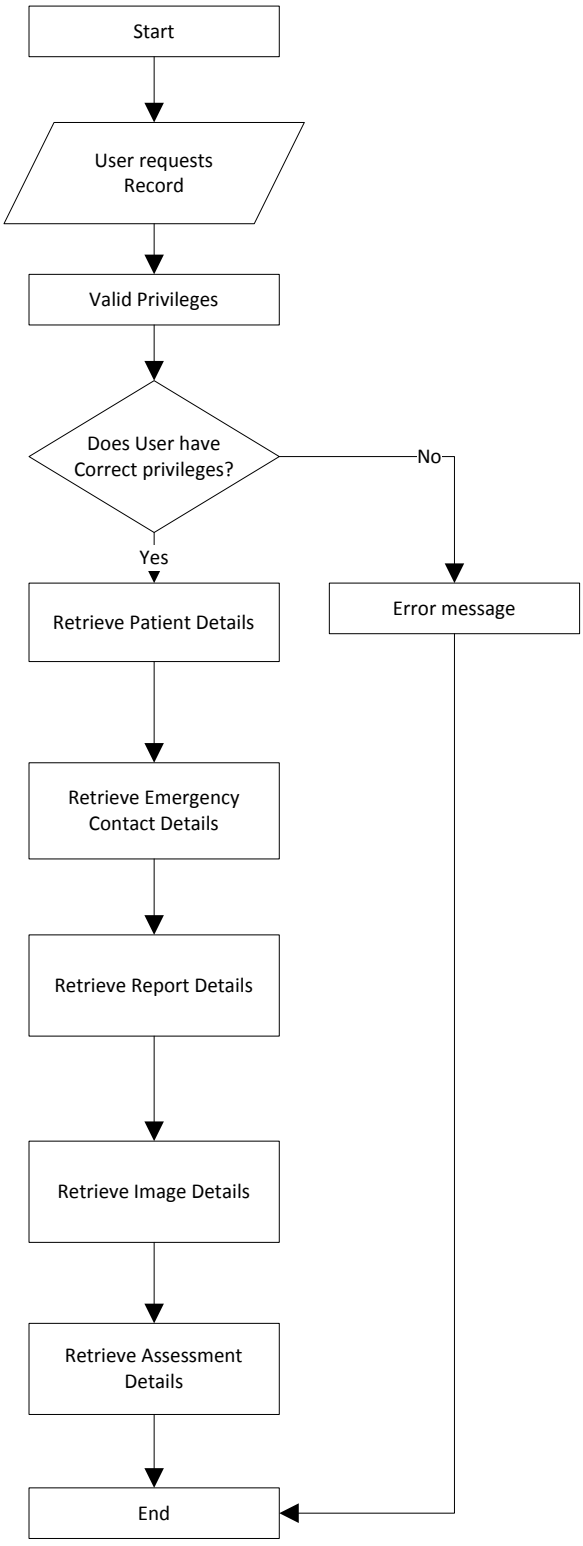


Figure 55: Activity diagram showing the process for retrieving a record.

4.1.5 Editing a Record

To ensure that that the reports are not changed incorrectly, any user wishing to use this function much have the correct privileges to view and then append the information sorted. If a report is edited, the new version will be saved to the data base as a new report. The author of the new report will also be stored. By default the most recent version will be loaded when a user requests to view a report, however there will be an option to view previous versions. This will allow any changes to be tracked and traced to the user. This is to protect the report from being maliciously amended.

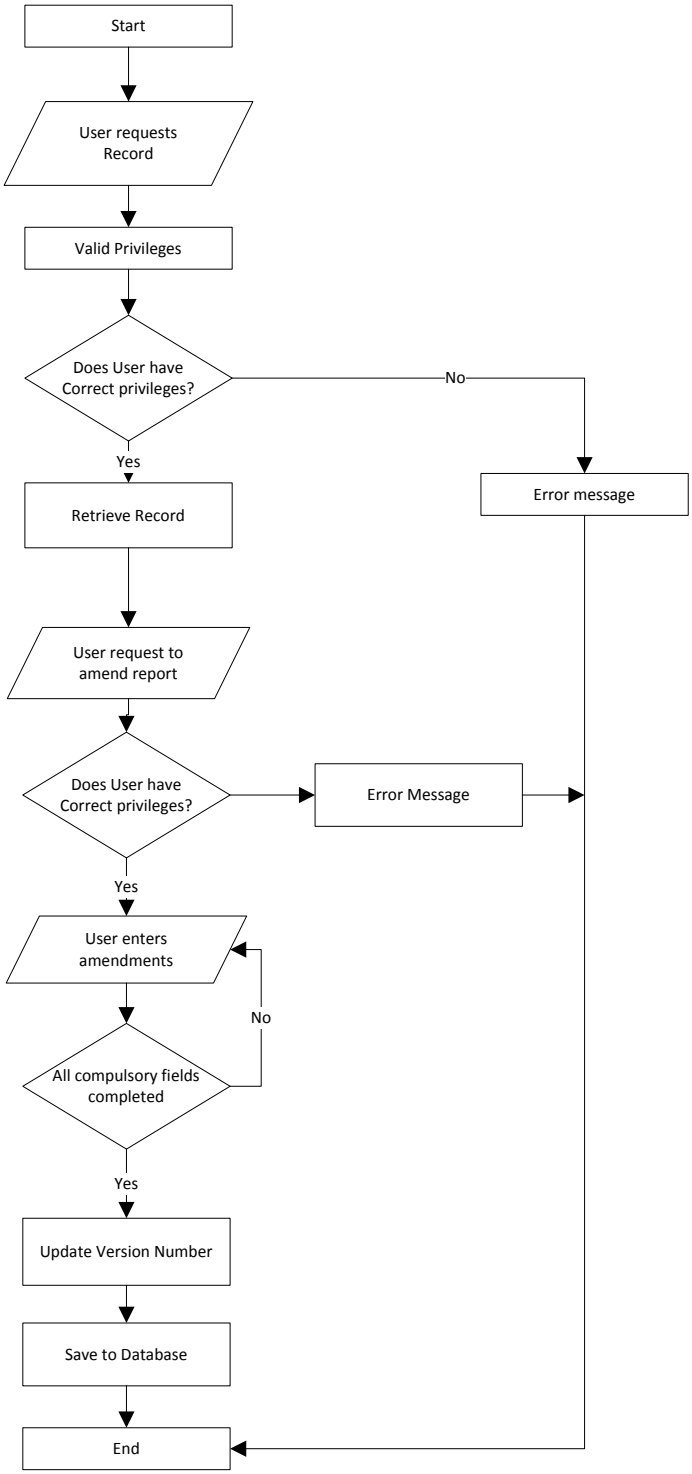


Figure 56: Activity diagram showing the process of editing a record.

A main concern that has been identified about introducing SR is the risk that productivity could be affected and that time taken looking at an image could be reduced due to the

radiologist now having to take time to fill in a form, which could lead to mistakes being made in diagnosis. This means that the entry of the clinical data needs to be intuitive so that the Doctors using the software are able to easily learn how to use the system so that their productivity is not adversely affect as they are spending time trying to work the system or contacting someone for technical support (Weiss Langotz 2008).

The input needs to also be easy so they are not spending too much time focusing on data inputting instead of the image they are reviewing. It would also intuitive and simple to use as for some time radiological reporting has been completed using dictation services and more recently voice recognition (Weiss Langotz 2008). A possible way to combat this is to have the fields within the SR form be navigate-able via the keyboard as well as or instead of the mouse.

Taking these aspects into consideration, the architecture of the prototype was designed and is shown in the diagram below.

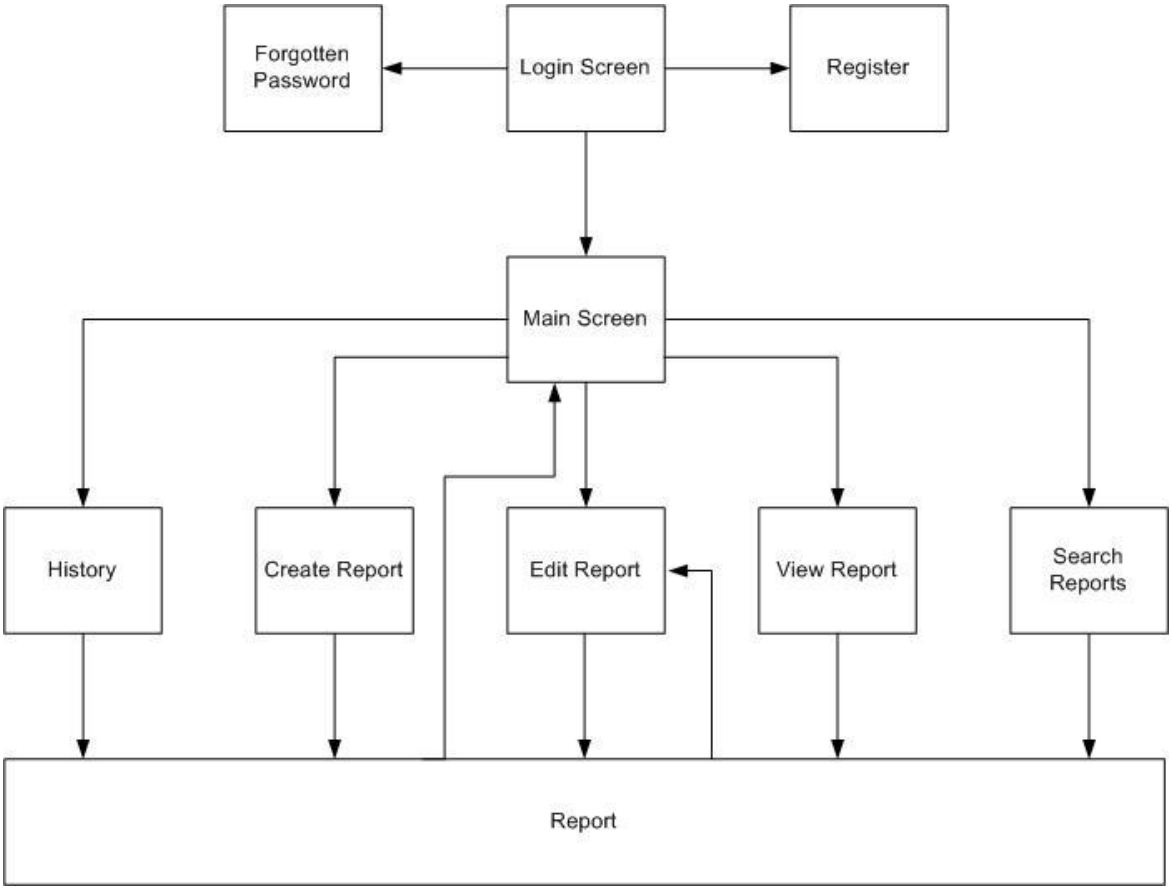


Figure 57: Diagram showing the architecture of the prototype

For some features of the prototype, namely the search and the report creation tool, there were two different versions designed. For the search function, one version used a multiple drop down fields to filter the arguments being inputted. In the second version, there was only on field within which to input the arguments. However, multiple types of information could be entered at once. As long as they were separated by a semi colon the multiple inputs would be identified.

For the report generation tool, the initial version that the users would be tested on would be a standard form, with multiple drop down menus with present options to eliminate the need for free text. Any readings from the MRS data would be entered into the specified fields and the user from these would then need to deduce a diagnosis, which

would then be entered along with a recommendation based on this. In the second version a diagnosis support tool was included. This was a visual graphic of the section of the body, in this case the brain, being reported on. Before any readings had been entered the user would be able to interact with this to gain general information about the sections of the brain and what types of cancer could be found within certain regions.

Once the user began to input readings into the specified fields in the reporting tool the graphic would begin to suggest a possible diagnosis. This would narrow down was the fields of the MRS data ratios where completed. The user completing the report could then use this to help support their diagnosis and recommendations for treatment.

As previously discussed, one of the three aspects of a SR is the use of a standardised lexicon. Due to the nature of the paper based prototyping is not possible to incorporate into the prototype and therefore be tested. As a result, whilst using the prototype it will be assumed that system is using an agreed lexicon to create the reports.

With these considerations in mind architecture for the prototype was developed. This was then used along side the SR section of the ontology to build the paper based prototype. The architecture was used to dictate which screens would be accessible to the screen being displayed at the time and where a user could navigate from that point. The SR section of the ontology dictates what information needs to be captured to create a complete structured report. Therefore, the form to create the reports was modelled based on this. For example Figure 58 below showing the SR section of the ontology illustrates that a patient's allergies, date of birth, gender, ID number, medical history and

name are required to be captured. As a result the form has fields to record this information, as seen in the images on pages 113 to 116.

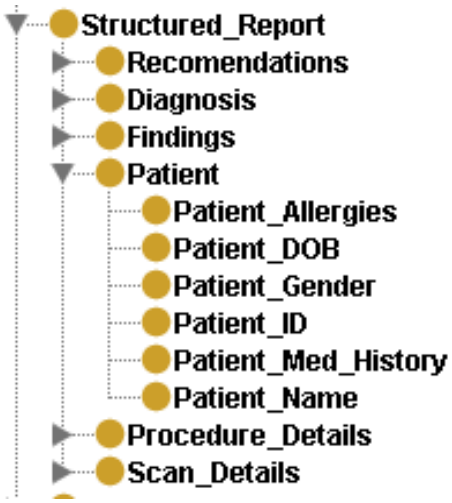


Figure 58: Showing the Structured Reporting part of the ontology

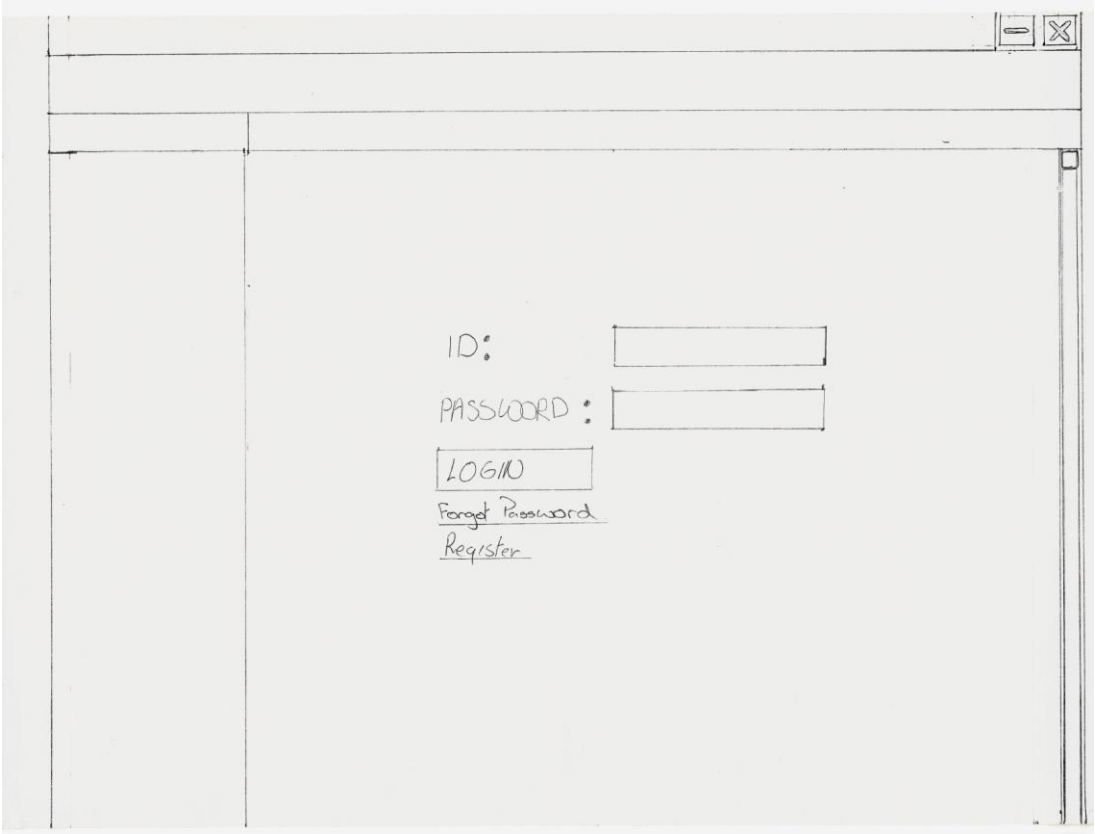


Figure 59: Prototype "login" screen. Once a user logged on the screen would be overlaid with new screens.

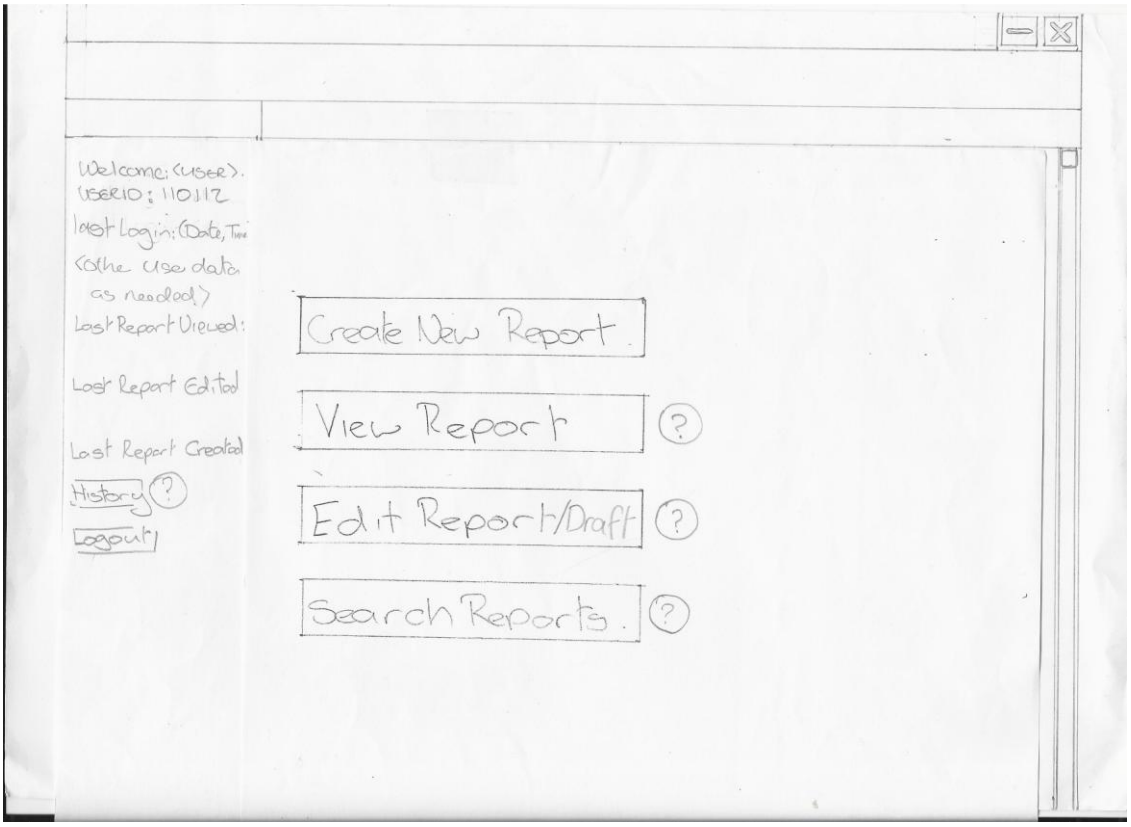


Figure 60: Prototype main screen after user has logged in. Report menu and side bar have been laid over the log in screen.

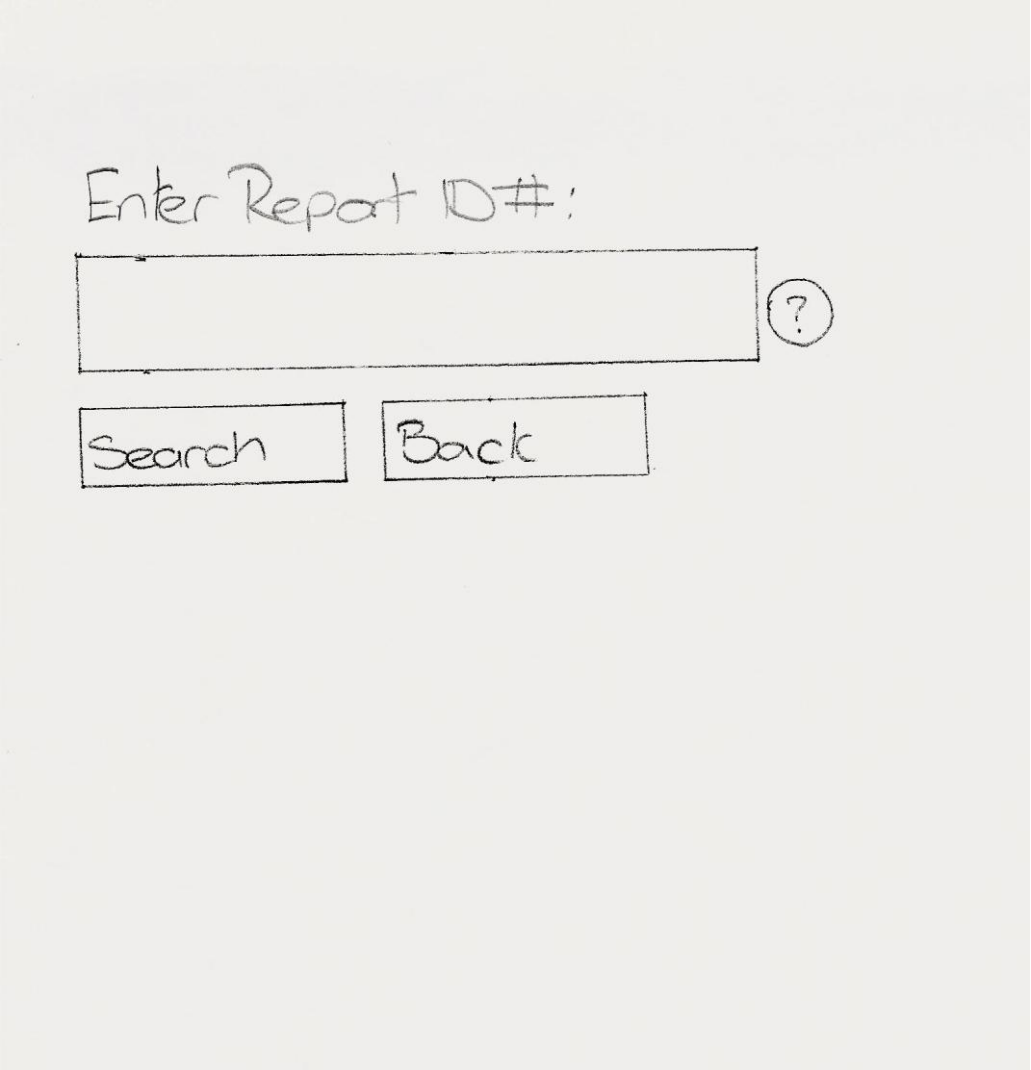


Figure 61: Edit and View Report "Search" screen.

Name: Amy Morgan
Student Number: 129570

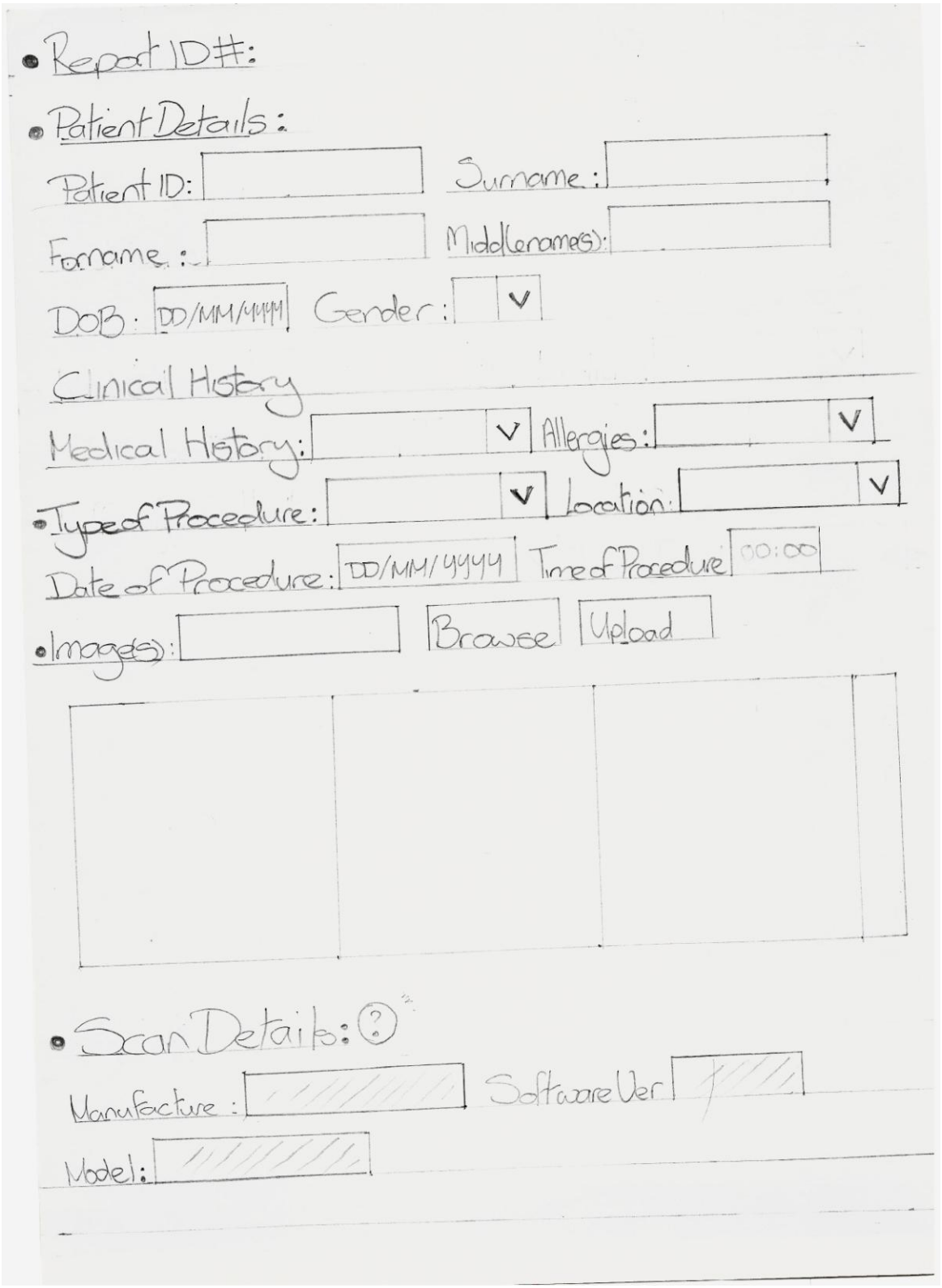


Figure 62: Report Creation Part 1

.

Name: Amy Morgan
Student Number: 129570

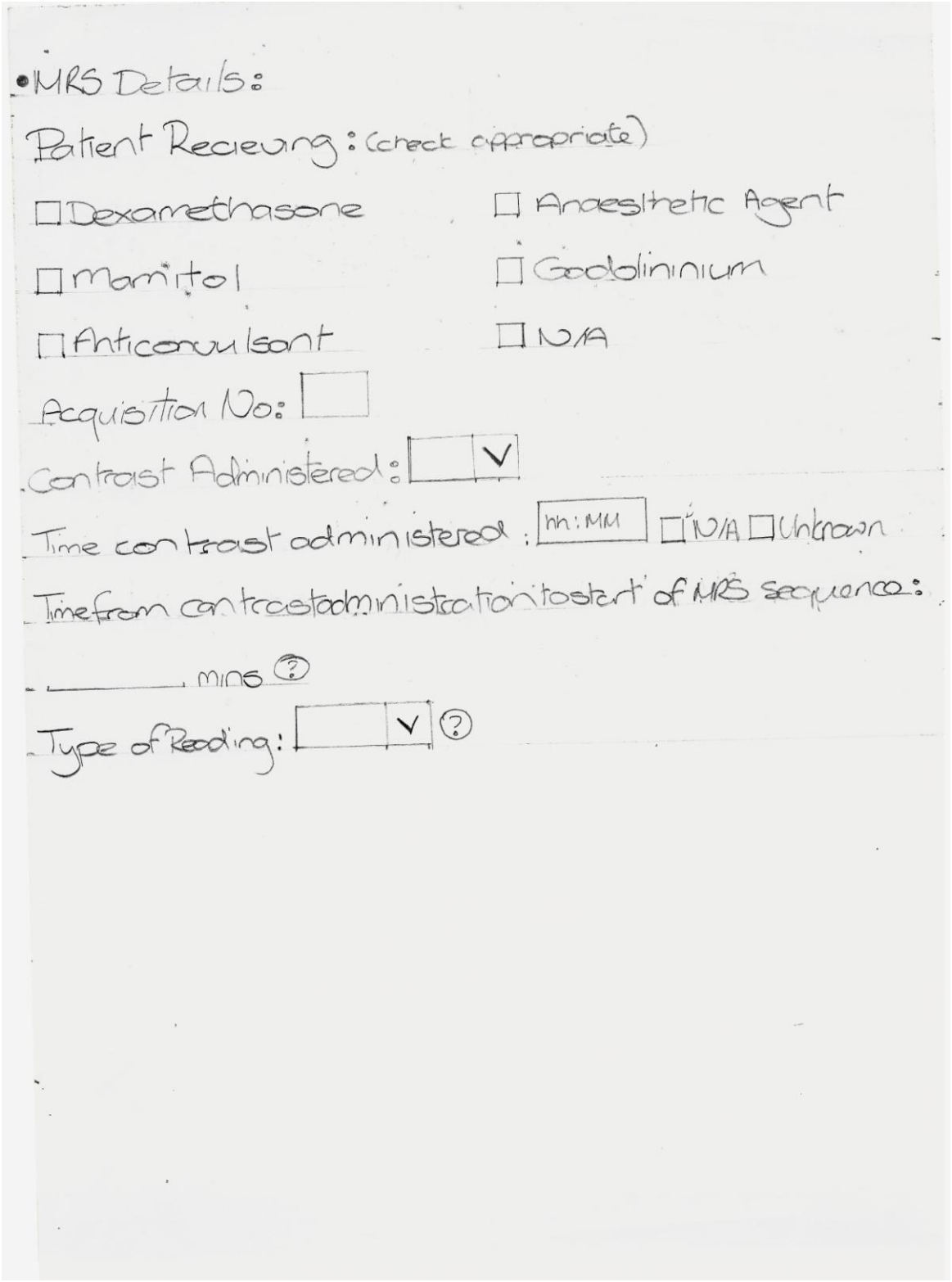


Figure 63: Report creation part 2

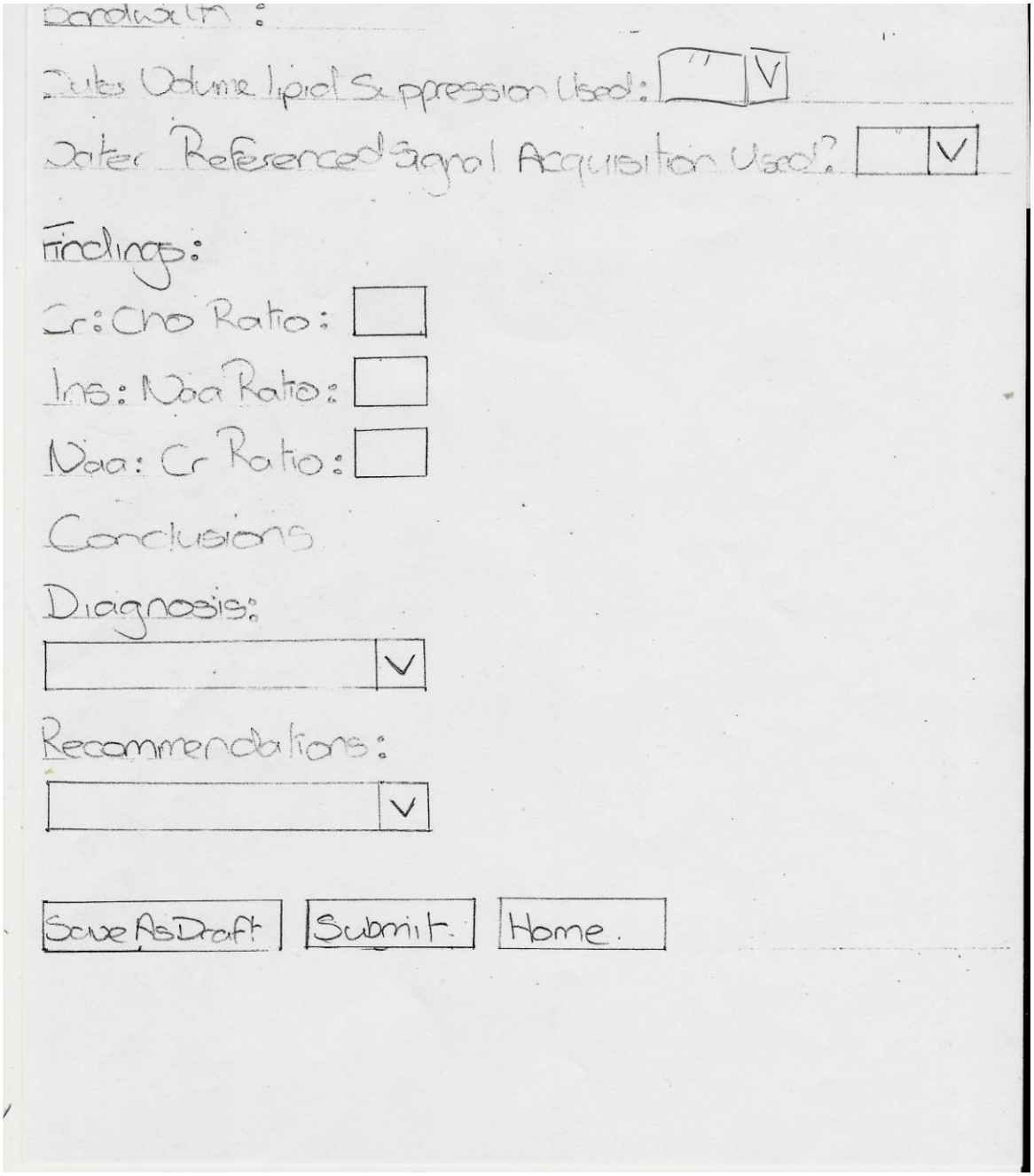


Figure 64: Report creation part 3 (standard version).

This is overlaid the blank half of the report creation image part 2.

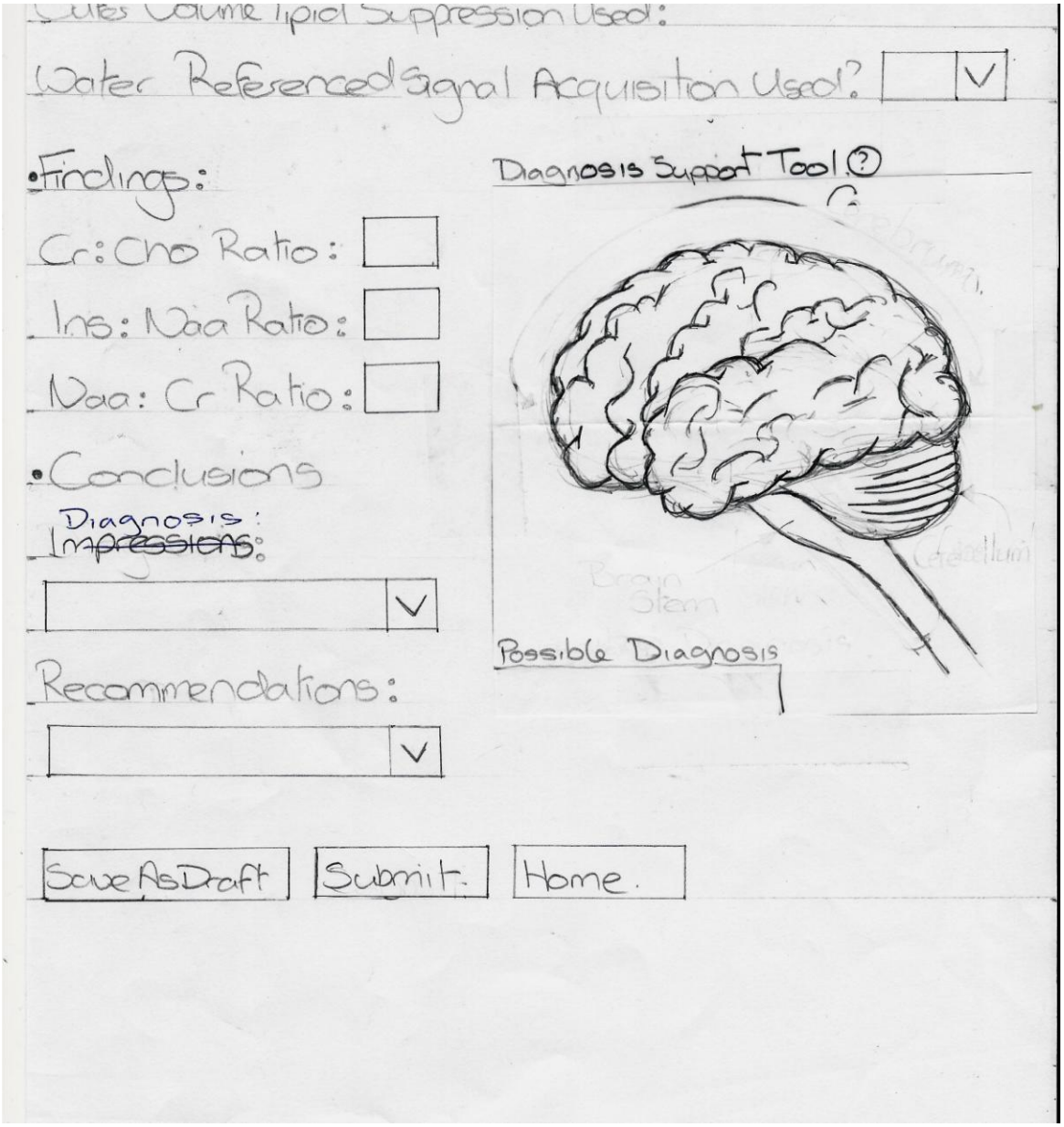


Figure 65: Report creation part 3 (advanced version).

This is an alternative version of the final section for the report creation form. Unlike the standard version it has an image of the brain. As a user inputs the MRS reading into the findings section the corresponding area of the brain was highlighted and possible diagnosis was displayed. This is to implement the diagnostic aspect of the ontology, on which the application would be based.

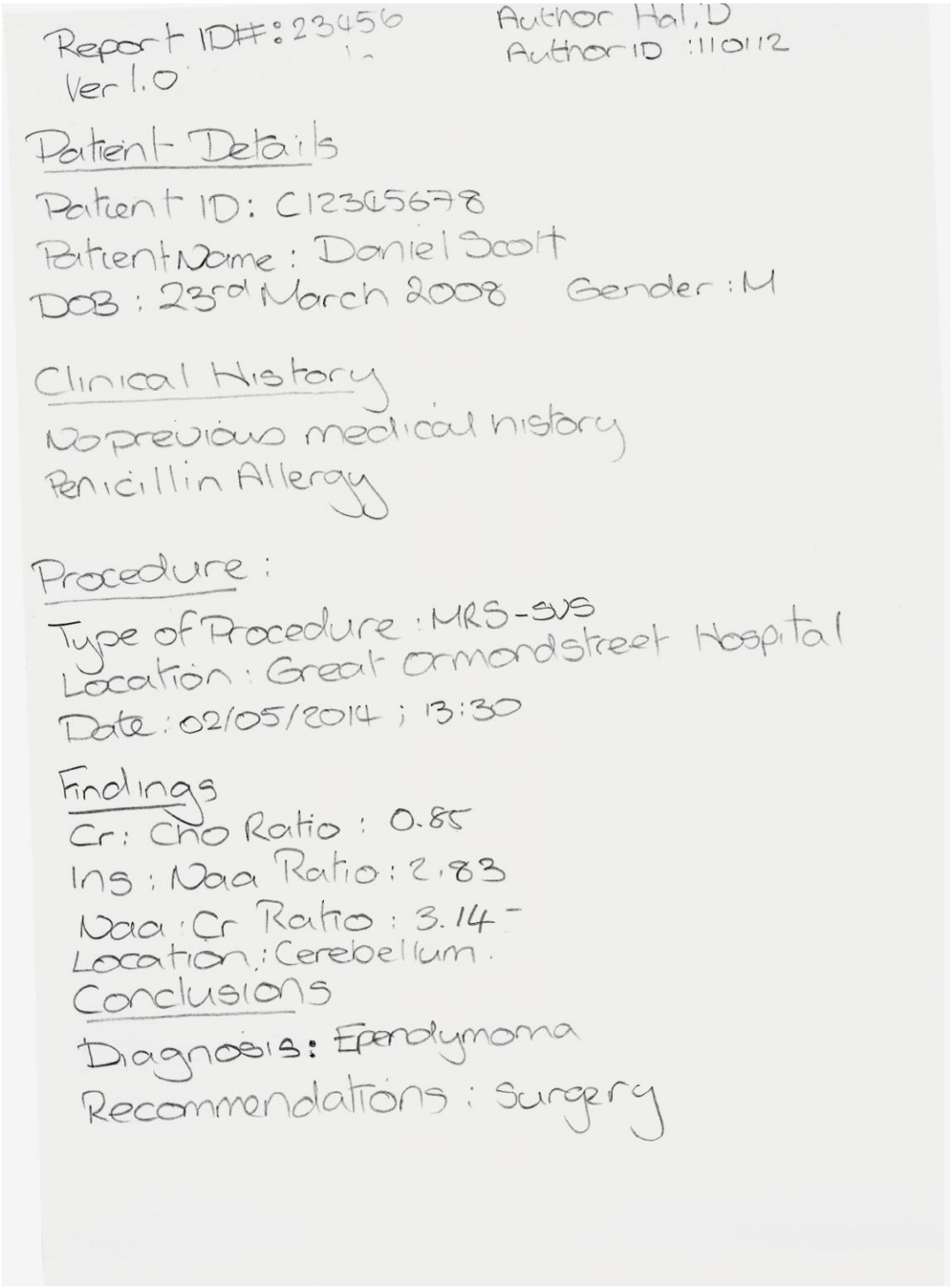


Figure 66: Example of a structured report created by the tool.

Once the paper prototype had been developed it was evaluated in regards to usability.

4.2 Prototype Usability Evaluation

Objective:

The objective of this evaluation is to test the usability of a proposed Structured Reporting tool based on the ontology that has been developed**.**

Method:

To test the application a task based evaluation was used. The participants of the test were given a set of tasks to complete and then answered a Usability questionnaire. This questionnaire has been developed using the QUIS testing system, which assesses the user's subjective satisfaction with specific aspects of the prototype (Norman & Shnriderman) (Norman & Shnriderman). As well as QUIS other usability testing systems, such as the System Usability Scale (SUS) and Software Usability Measurement Inventory (SUMI) (Kirakowski (Unknown) were also reviewed (System Usability Scale (SUS) 2014) (Brooke 2005). After reviewing these different usability testing systems, it was felt that they were too generic for these evaluations. As such a questionnaire was designed to give specific feedback on this particular prototype.

The questionnaire was comprised of 17 questions. Screen shots of the questionnaire are shown below. All the answers provided were done so using a scale of 1 to 5, 1 being "Strongly Disagree" and 5 "Strongly Agree" responses. These results where recorded into a spread sheet and then an evaluation was completed.

Name: Amy Morgan
Student Number: 129570

Prototype Usability Survey

1. Given the correct line of work, how frequently would you use this system:

	1	2	3	4	5	
Not at all	○	○	○	○	○	Always

2. How intuitive did you find the system:

	1	2	3	4	5	
Complex	○	○	○	○	○	Easy to Use

3. How would you rate the complexity of the system:

	1	2	3	4	5	
Very Hard	○	○	○	○	○	Very Easy

4. I think that I would need the support of a technical person to be able to use this system:

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

5. I found the various functions in this system were well integrated:

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

6. I thought there was too much inconsistency in this system.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

7. I learnt to use this system very quickly

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

8. I found the system very cumbersome to use.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

9. I found myself drawing on past experience to use this system

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

10. I needed to learn a lot of things before I could get going with this system.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

11. I found the filter search method the user friendly

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

12. I found the single field search method user friendly

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

13. I found entering in data for a clinical review easy

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

14. I found using this software to review a clinical report made it clear to understand

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

15. I found reviewing a free text clinical report easy to understand

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

16. I found the diagnosis tool intuitive to use

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Figure 67: Showing the survey participants were asked to complete.

Testing took place with an individual subject over a 20 minute period. A total of 20 people took part in the study in three separate groups. 19 of the participants were students at the university with no medical background. A consultant Radiologist from North Staffordshire University also took part in the testing. At the beginning of each session the subject was informed of the paper prototyping method and what would occur in the session and what was expected of them. Before using the prototype they were presented with a free text version of a medical report to review. Once they had done this they completed the tasks they had been set using the paper prototype and then completed the usability questionnaire. The tasks to be completed are shown in Figure 68 below. Where any privileges would have needed to be validated it was assumed the user details provided in the testing has the correct user privileges assigned.

Name: Amy Morgan
Student Number: 129570

Usability Test Tasks

1. Login using the provided details.

User Name: DaveHal
Password: 1234

2. Find and view record id# 12345.

3. Create a record using the notes provided below:

Paitient ID#: c12345678
Patients' name: Daniel Scott.
Date of Birth: 23rd March 2008.
Gender: Male
Medical History: None Known
Allergies: Penicillin
Type of Procedure: MRS
Location: Great Ormond Street Hospital
Date: 2nd May 2014
Time 13:30
Upload: .dicom image
Patient Receiving: Anaesthetic Agent
Acquisition number: 2
No contrast Administered
Types of Reading: SVS
Outer Volume Lipid Suppression used?: No
Water Referenced Signal Acquisition used?: No
Findings:
Cr: Cho ratio: 0.85
Ins: Naa ratio: 2.83
Naa: Cr ratio: 3.14
Diagnosis: Ependymoma
Recommendation: Surgery
Submit record

4. Complete record ID# 54321. Make a diagnosis using the diagnosis support field.

Record Id# 54321 has been saved as a draft and needs completing. Open the draft and complete the diagnosis using the following readings:
Cr: Cho ratio: 0.26
Ins: Naa ratio: 0.43
Naa: Cr ratio: 2.33

Recommendation will be for the patient to have a biopsy.

5. Amend a record:

There was an error in the Cr:Cho ration readings in report ID# 23456 created in task 3. Amend this to 0.95.

7. Search for a record using the information below:

Locate the report by Dr. David Hal for patient Kimberly Cranston. Her Date of Birth is 14th November 2007. She had an MRS scan on 17th April 2014.

Figure 68: Showing the Usability Questionnaire.

Once the tasks were completed, the participant filled out the Usability questionnaire to record their experience using the system. They were also asked for any feedback and suggestions regarding the prototype and these were recorded.

4.3 Results

With the usability testing completed the results from the questionnaires were processed. The results for each question have been detailed below. The questions are assessed with a score of three being neutral, below three considered as low and above three as high. For questions 4, 6, 8, and 10 the x-axis has been flipped so that the desired outcome is giving a high score instead of low, matching the other questions results to allow for them to be easily assessed.

Question 1

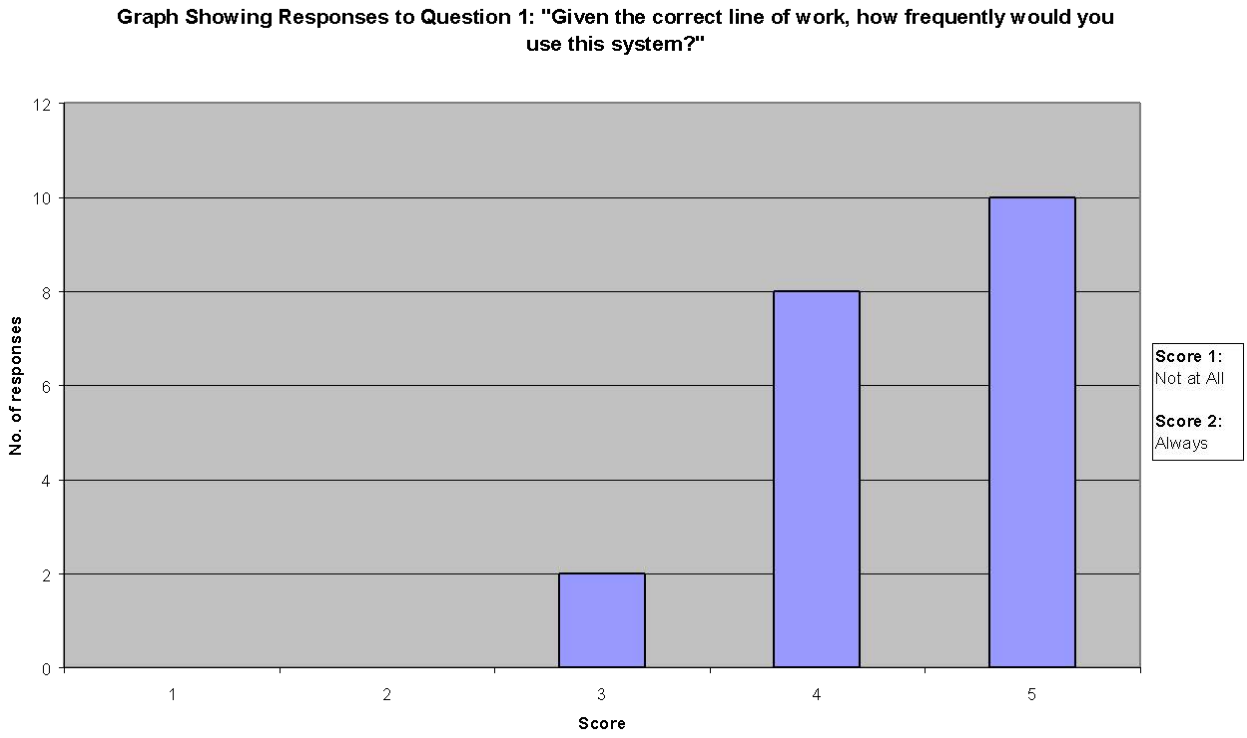


Figure 69: Graph showing the results for Question 1.

Mean: 4.40

Standard Deviation: 0.68

Question 1 was asking the participants if they would choose to use the prototype if they were someone reviewing medical images and the reports that had been made by a radiologist. From Figure 69 above it can be seen that 18 of the 20 participants (90%) gave a positive score and 2 (10%) were neutral, with an overall mean of 4.40 and a standard deviation of 0.68 it can be considered that the participants would choose to use this system frequently.

Question 2

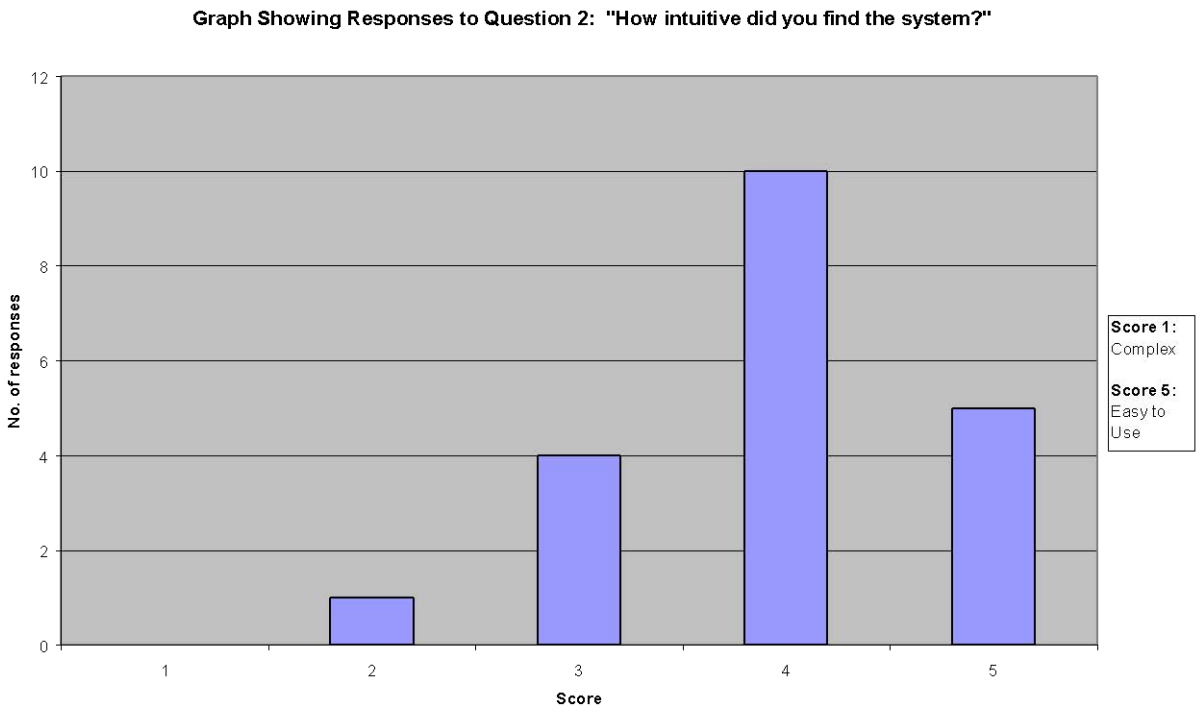


Figure 70: Graph showing the results for Question 2.

Mean: 3.95

Standard Deviation: 0.83

The purpose of Question 2 was to see if the participants found the prototype intuitive to use and navigate. The standard deviation of 0.83 reflects that the scores where not as

closely grouped and that the participants had a wide range of opinions for prototype. From the result it can be seen that 15 of the 20 participants (75%) scored it positively, 4 (20%) were neutral and 1 (5%) gave a low score, with mean of score 3.95. With this mean along with a standard deviation of 0.83 to can be consider that participants found the system intuitive.

Question 3

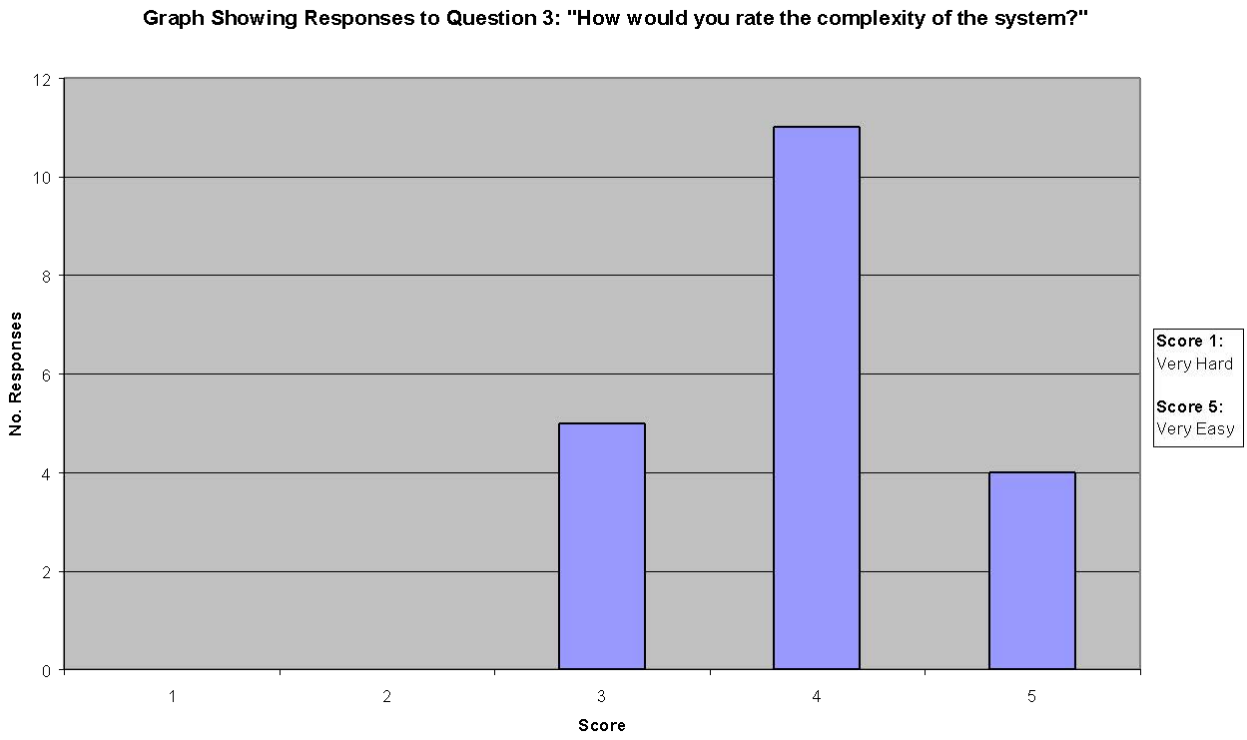


Figure 71: Graph showing the results for Question 3.

Mean: 3.95

Standard Deviation: 0.69

Question 3 asked participants how easy they found using the prototype. 15 of the 20 participants (75%) scored the prototype highly; stating that they found the system easy to

use and 5 (25%) scored it neutrally with a mean of 3.95 reflecting the positive response, which is supported by the standard deviation of 0.69.

Question 4

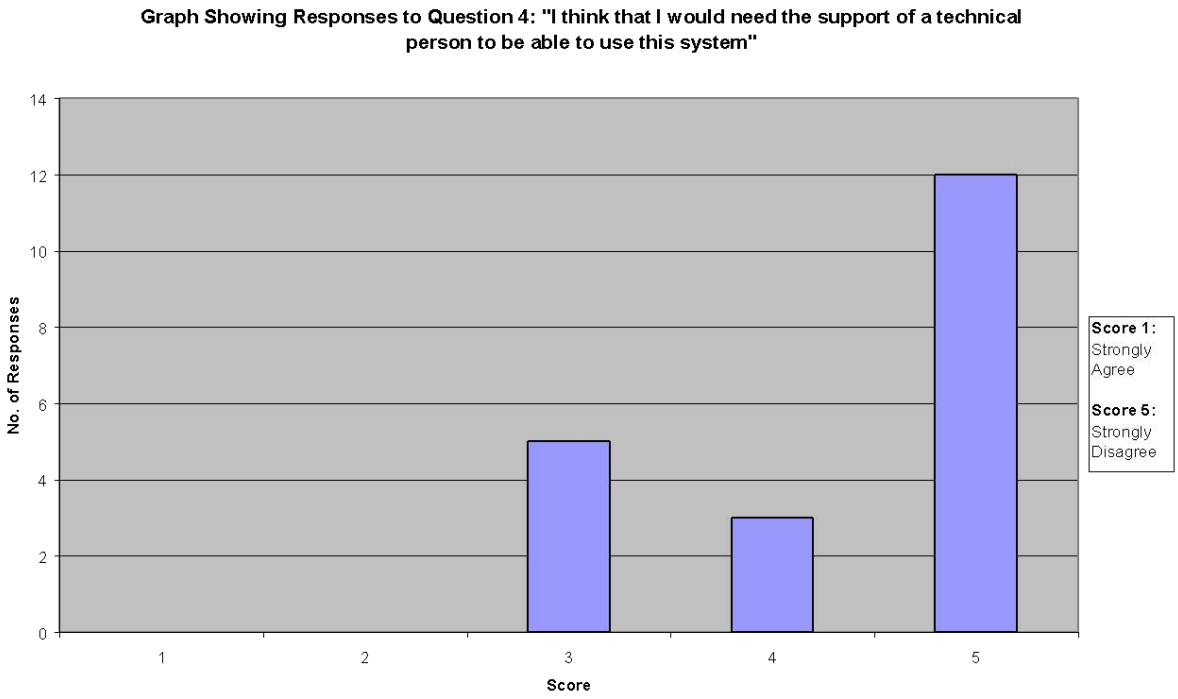


Figure 72: Graph showing the results for Question 4.

Mean: 4.35

Standard Deviation: 0.88

With Question 4 the participants were asked if they thought they would need the support of another person more specialised in using the system to help them complete the tasks they had been set. 15 of the participants (75%) scored this high, saying they did not think they would need any further support and 5 (25%) scored a neutral response with a mean of 4.35 and a standard deviation of 0.88. It can therefore be considered that the participants would not require specialised support to use the system.

Question 5

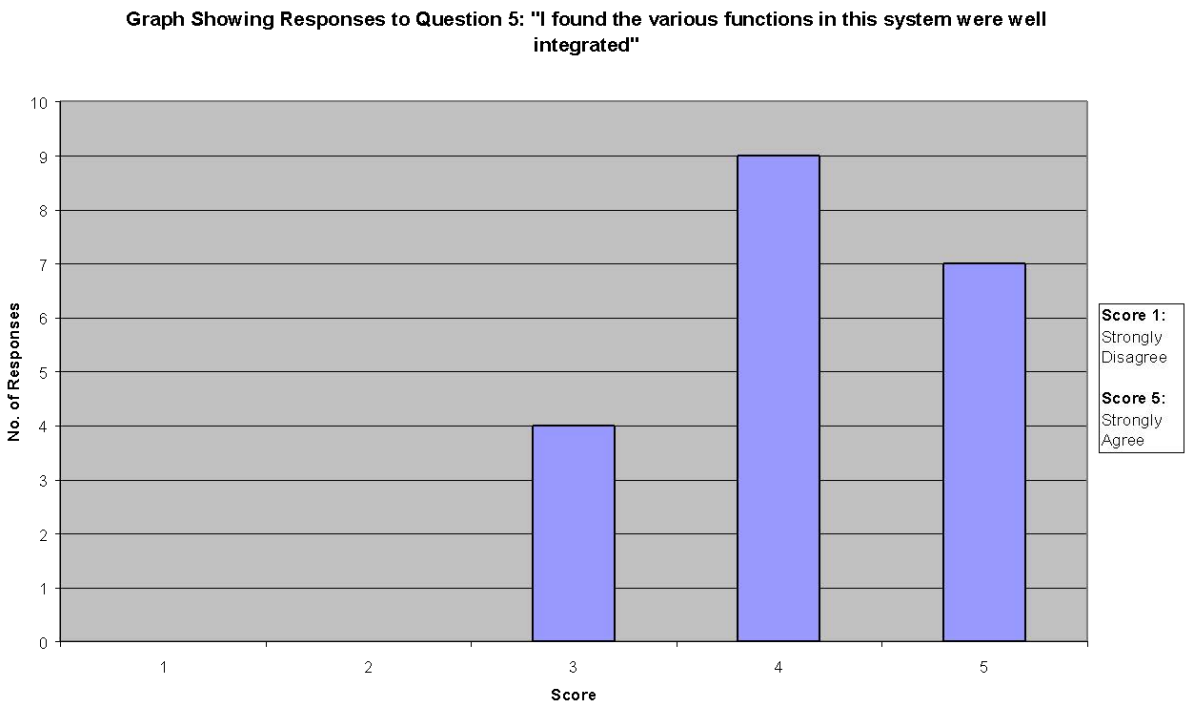


Figure 73: Graph showing the results for Question 5.

Mean: 4.15

Standard Deviation: 0.75

Question 5 asked the participants if they felt that the functions of the system were well integrated and therefore easy to use. 16 of the 20 of the participants (80%) gave a high score and 4 (20%) gave a neutral response with a mean score of 4.15 and a standard deviation of 0.75 it can be considered that the participants found the functions of the system were well integrated.

Question 6

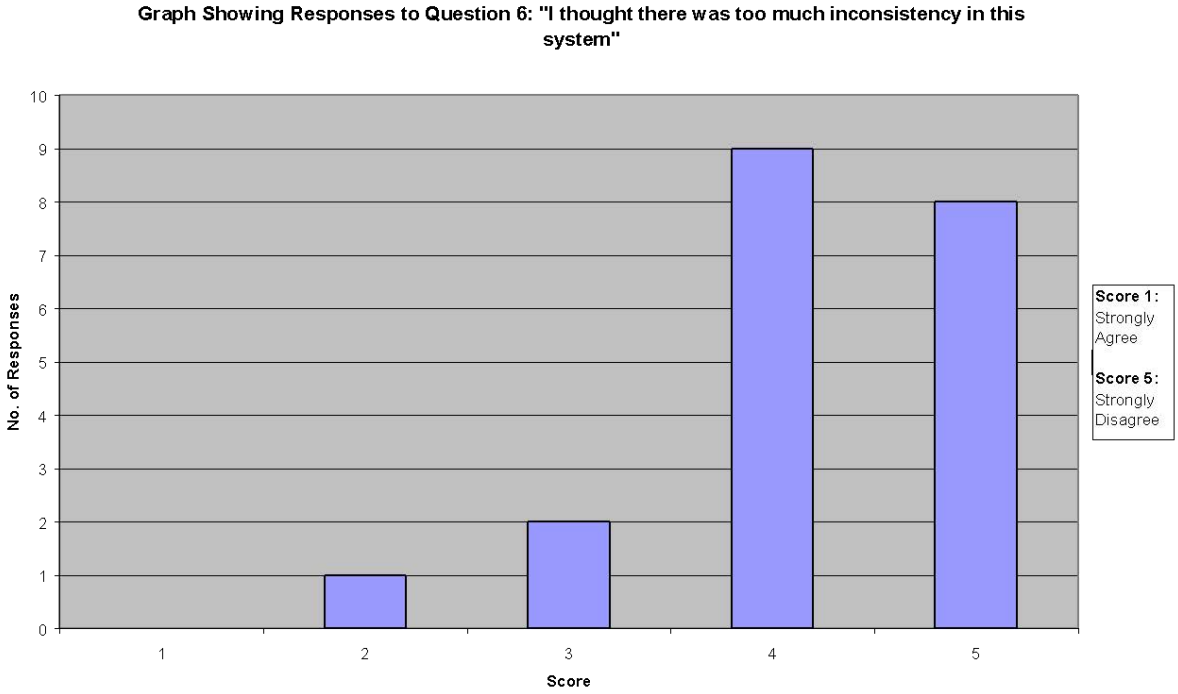


Figure 74: Graph showing the results for Question 6.

Mean: 4.20

Standard Deviation: 0.83

Question 6 was asked to find out if the participants felt the prototype was consistent in how its functions worked and the navigation of the prototype. 17 of the 20 participants (85%) scored the prototype low in regards to inconsistencies, showing that that they found the system consistent making it easy to use and navigate. 3 (15%) participants gave a neutral score. However 1 (5%) participant gave a score of 2, saying that they felt there was too much inconsistency in the prototype. With a mean score 4.20 and a standard deviation of 0.83 it can be considered that the participants found the system consistent.

Question 7

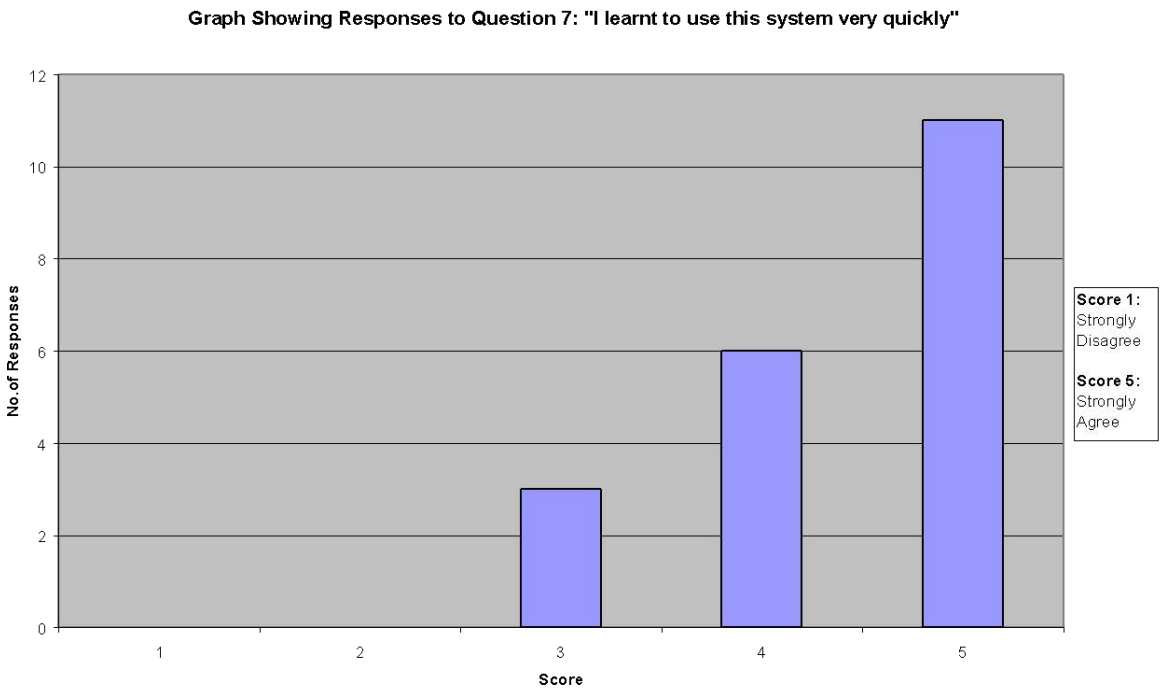


Figure 75: Graph showing the results for Question 7.

Mean: 4.40

Standard Deviation: 0.75

The purpose of Question 7 was to see how quickly the participants learnt to use the system. 17 of the participants (85%) score this highly with 3 (15%) giving a neutral result, with a mean score of 4.40 and a standard deviation of 0.75 showing that the participants felt they were able to quickly and easily learn to use and navigate the prototype.

Question 8

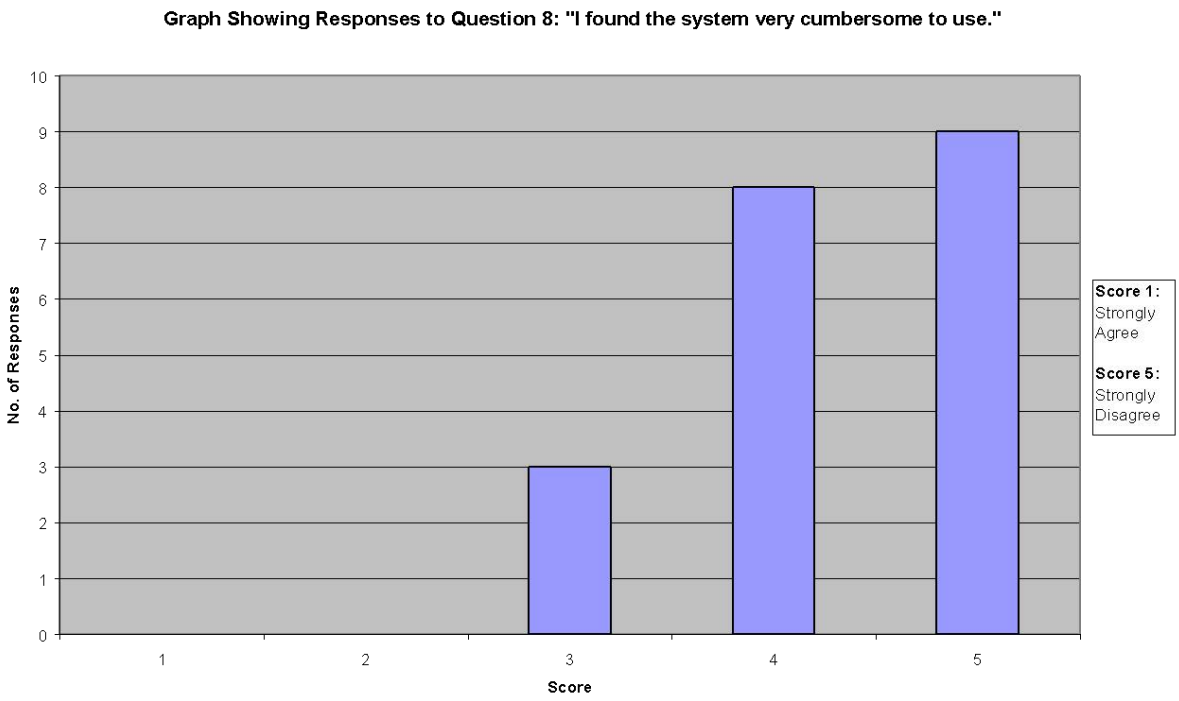


Figure 76: Graph showing the results for Question 8.

Mean: 4.30

Standard Deviation: 0.73

Question 8 was asked to determine how easy the participants found the prototype to use and navigate. 17 of the participants (85%) gave a high score, stating they found it easy to use and navigate and 3 (15%) gave a neutral score. With a mean score 4.30 and a standard deviation of 0.73 it can be considered that the participants did not find the system cumbersome to use.

Question 9

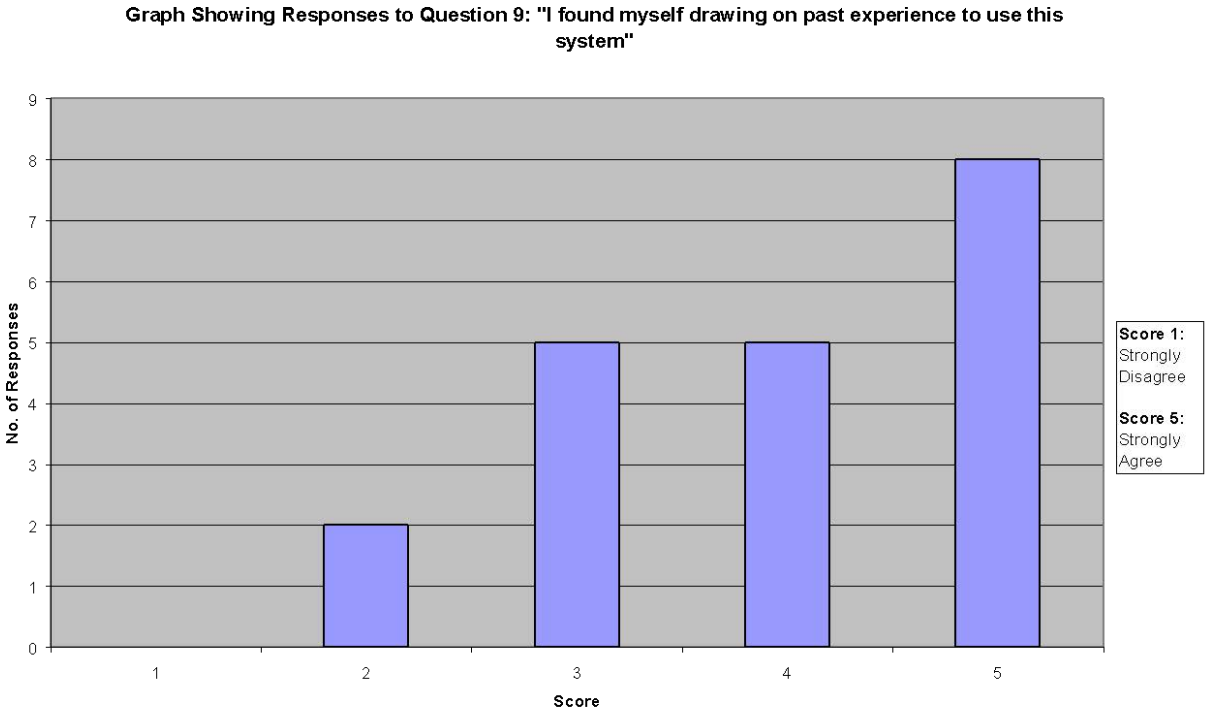


Figure 77: Graph showing the results for Question 9.

Mean: 3.95

Standard Deviation: 1.05

The purpose of question 9 was to see if the prototype was similar to systems that the participants had used before. If this was the case it would mean that they would be able to transfer their experiences with other systems to allow them to easily use and navigate the prototype. 13 of the participants (65%) gave high scores, 5 (25%) gave neutral results and 2 (10%) gave low with a mean score of 3.95 and standard deviation of 1.05. This mean and standard deviation reflects that no definitive statement can be can be made on whether the participants used past experience to use the prototype.

Question 10

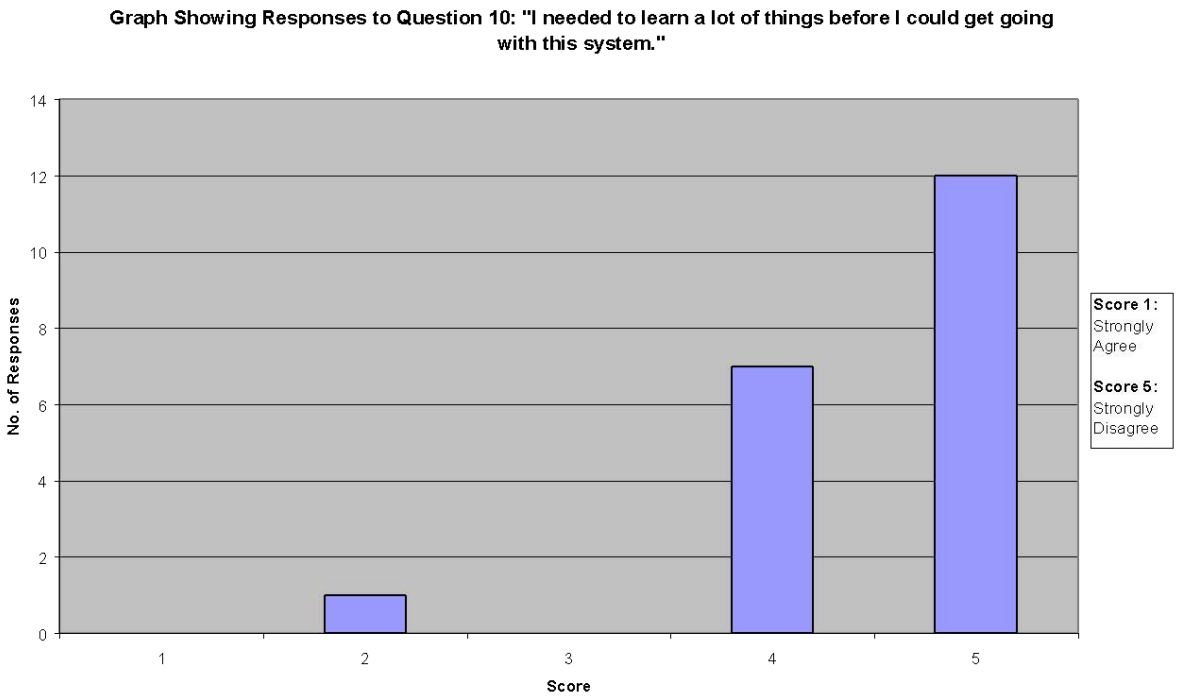


Figure 78: Graph showing the results for Question 10.

Mean: 4.50

Standard Deviation: 0.76

The purpose of Question 10 was to find out if the participants felt they needed to learn a lot about the prototype before being able to use it. The mean score of 4.50 suggest that most participants felt that they didn't need to learn a lot and could just start using the system with little to no previous training. However, it can be seen that, whilst 19 of the participants (95%) gave a positive score, 1 participant score a low score saying they felt that they did need to learn a lot. With the mean score of 4.50 and the standard deviation

of 0.76 it can be considered that the participants did not have to learn a lot to be able to use the system.

Question 11

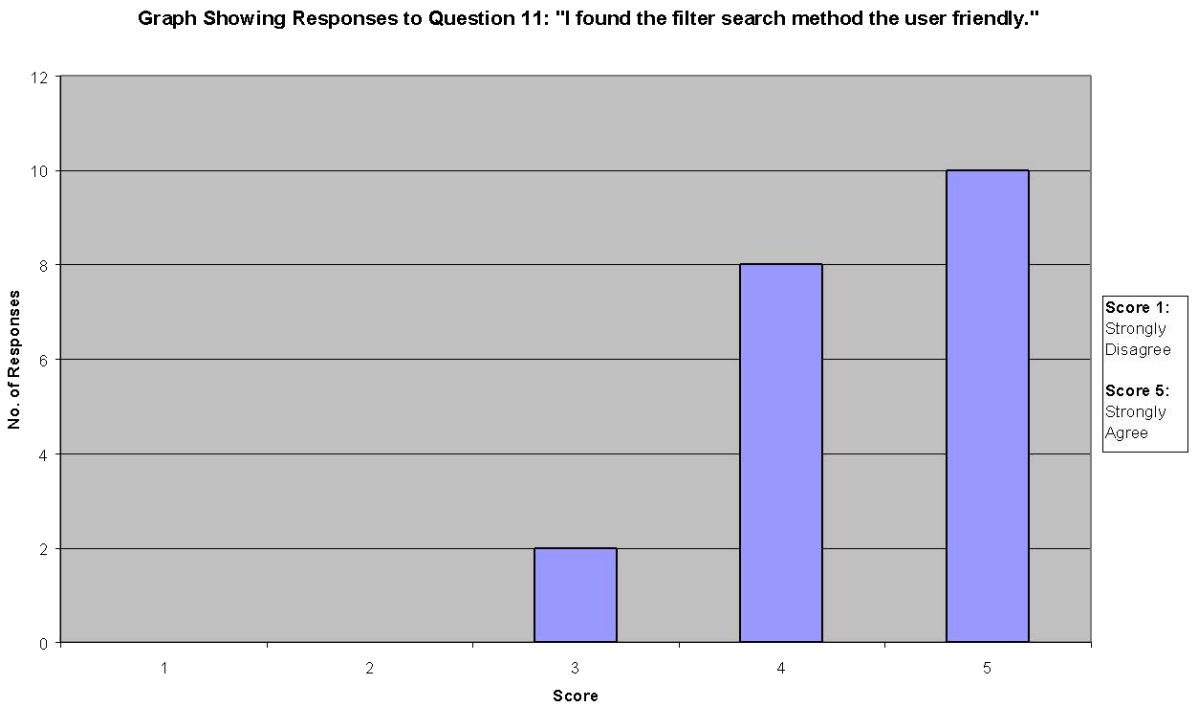


Figure 79: Graph showing the results for Question 11.

Mean: 4.40

Standard Deviation: 0.68

During the usability testing the participants were asked to use two different styles of Search function. One used a filter search method with several different fields for different type of information, where a user could enter information for the search into a specific field. E.g. if a user wanted to search for a record using their patient ID there was a patient ID field to enter the number into. The other used a single field that could be used search for different types of information i.e. a user could input a patient ID or their name into

the field and the search function would be able to discern the type of information inputted to search for the desired information.

Question 11 asked the participants if they found the filter version of the search easy to use. 18 of the participants (90%) scored highly stating they found it easy to use, 2 (10%) participants score it neutrally with a mean score of 4.40 and a standard deviation of 0.68. This mean and standard deviation it can be considered that the participants found the filter search method user friendly.

Question 12

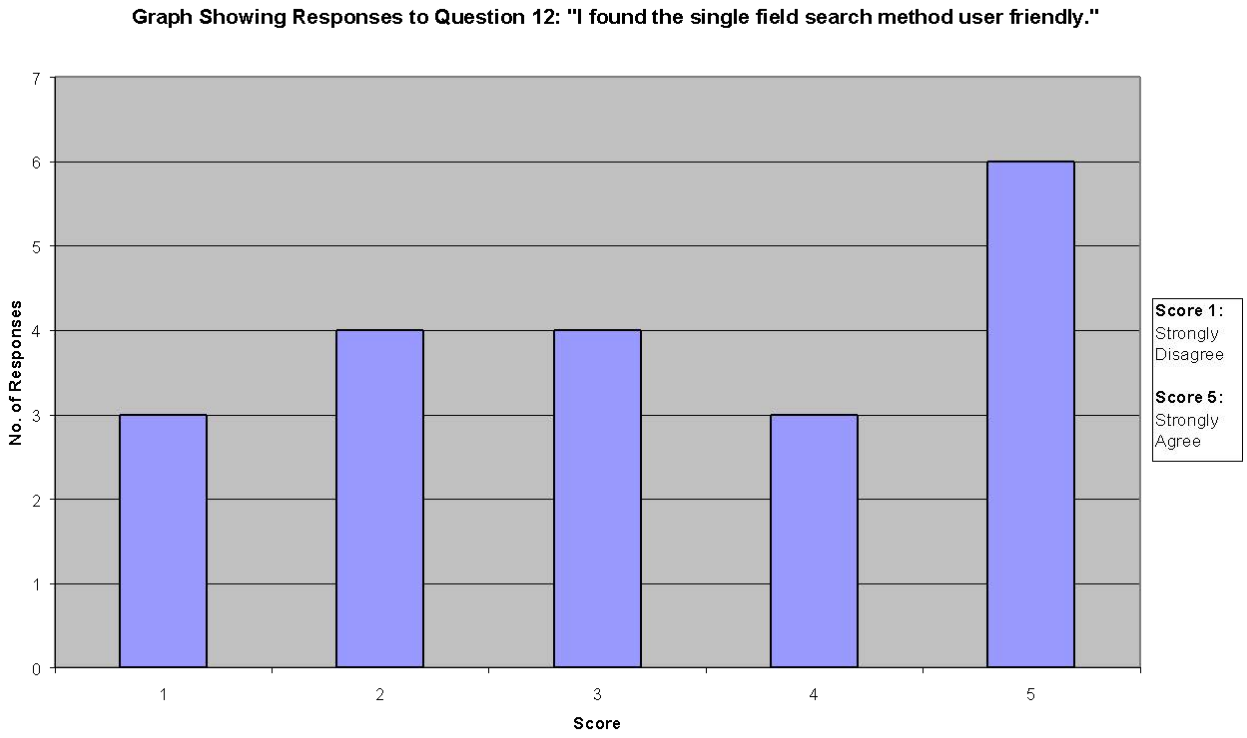


Figure 80: Graph showing the results for Question 12.

Mean: 3.25

Standard Deviation: 1.48

Question 12 asked participants if they found the single field version of the search function easy to use. 9 of the participants (45%) score it highly stating they found it easy to use, with 4 (20%) giving a neutral score. However, 7 (35%) participants gave a low score. With a mean score of 3.25 and a standard deviation of 1.48 no definitive statement can be made on whether the participants found the single field search user friendly.

Question 13

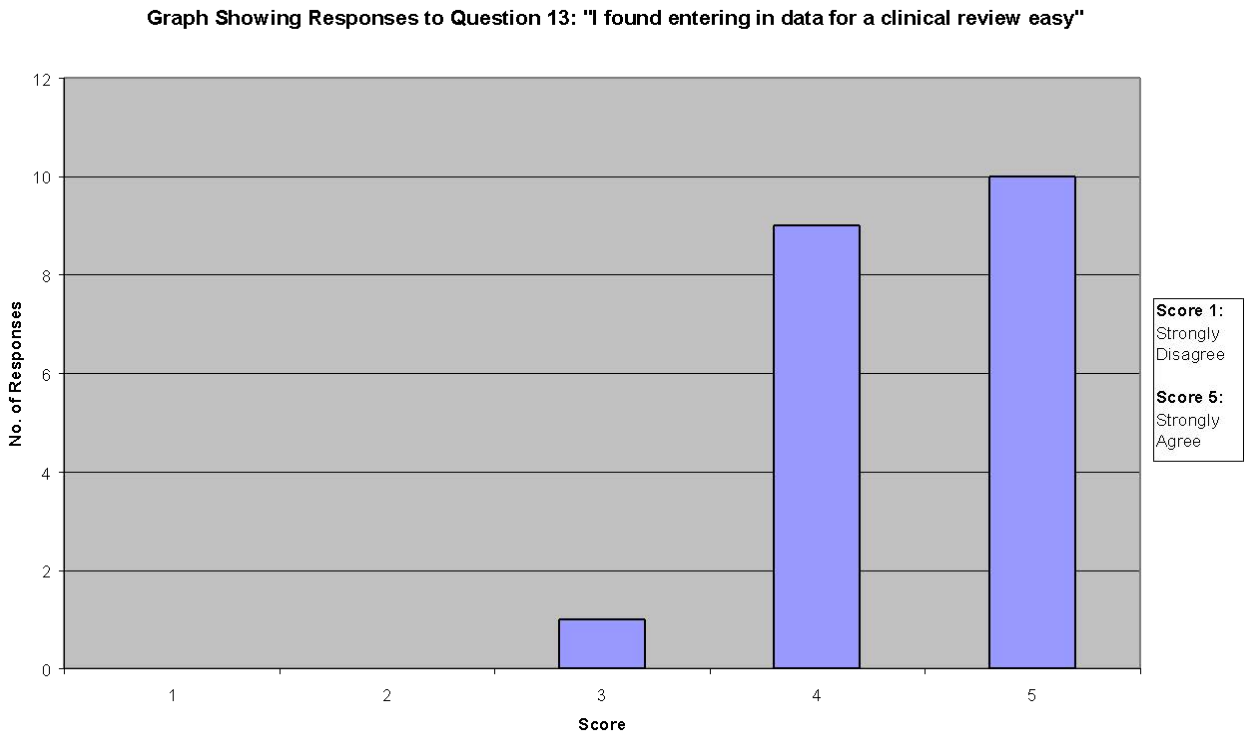


Figure 81: Graph showing the results for Question 13.

Mean: 4.45

Standard Deviation: 0.61

The purpose of Question 13 was to see if the participants found it easy to enter data into the report section of the system. 19 of the participants (95%) gave a high score and 1

(5%) gave a neutral score. With a mean score of 4.45 and a standard deviation of 0.61 it can be considered that the participants found entering data for a clinical report easy.

Question 14

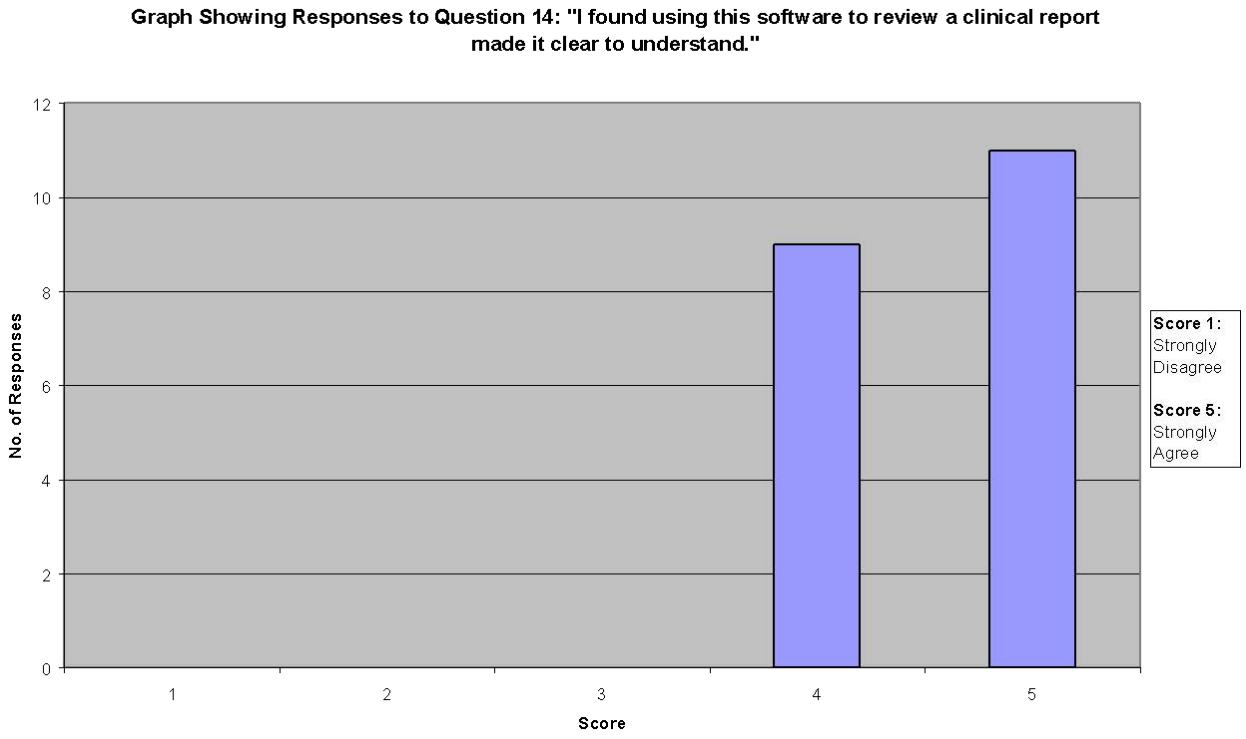


Figure 82: Graph showing the results for Question 14.

Mean: 4.55

Standard Deviation: 0.51

Question 14 asked the participant how easy they found viewing and reading a medical report created by the system. The mean score of 4.55 shows a positive response, with 20 of the participants (100%) giving a high score. With a standard deviation of 0.51 it can be considered that the participants found it easy to review a clinical report using this system.

Question 15

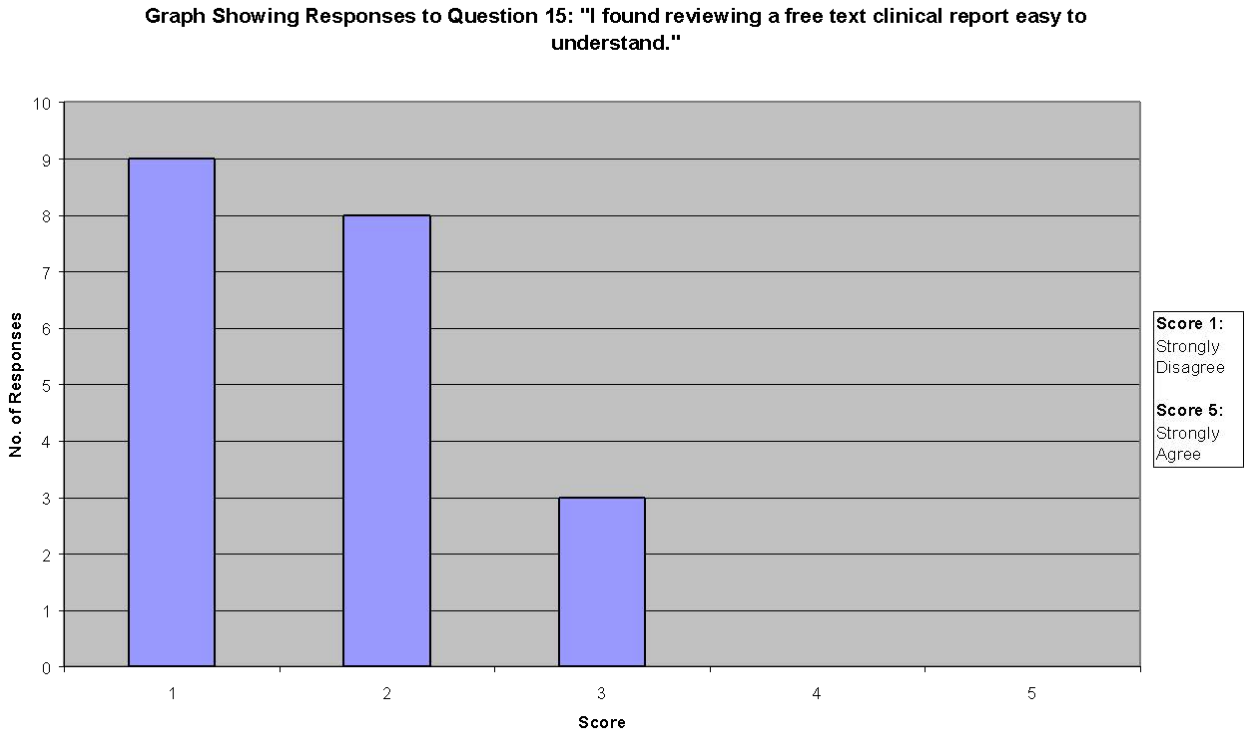


Figure 83: Graph showing the results for Question 15.

Mean: 1.70

Standard Deviation: 0.73

With Question 15 the participants were asked how easy they found viewing and reading a report that had been created using free text. 17 of the participants (85%) gave a low score and 3 (15%) gave a neutral score, with a mean of 1.70 and standard deviation of 0.73. This mean and standard deviation reflects that a high proportion of the participants found reading a free text report difficult.

Question 16

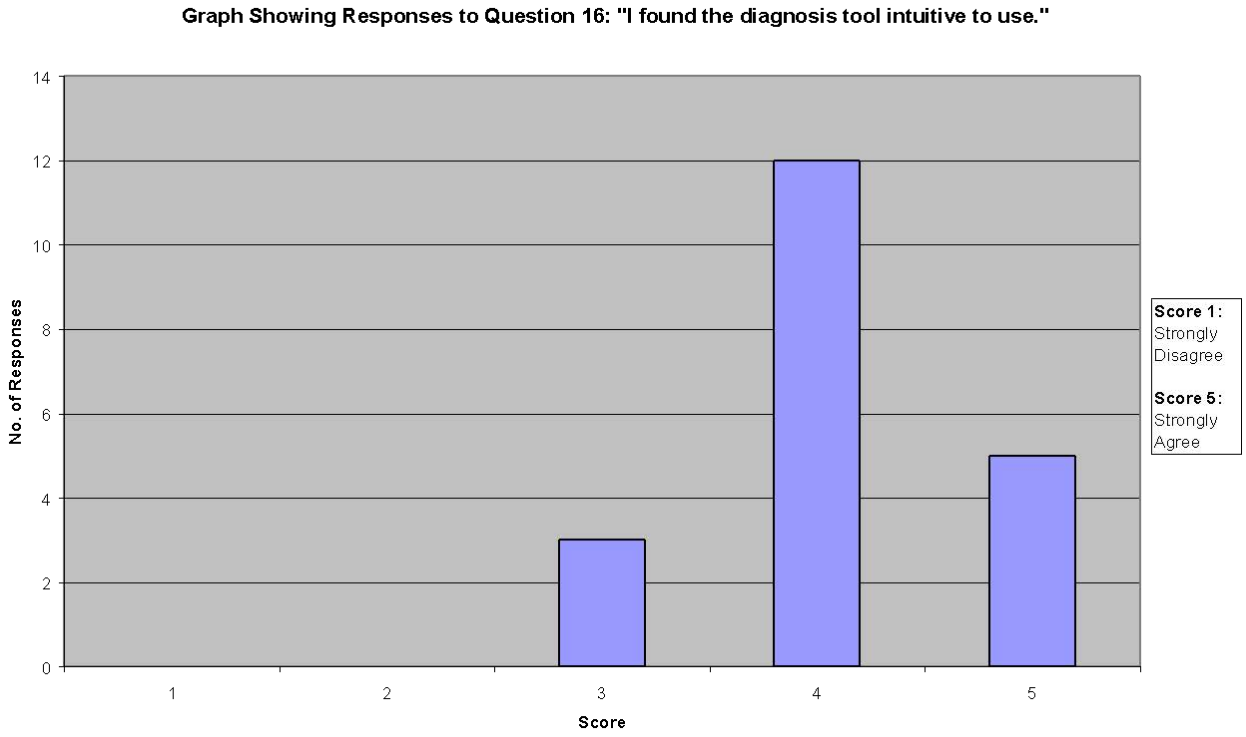


Figure 84: Graph showing the results for Question 16.

Mean: 4.10

Standard Deviation: 0.64

When taking part in the testing the participants were asked to use two versions of the report creation tool. Question 16 was asked to see how easy to use and understand the participants found the version of the tool that utilized a diagnosis tool. 17 of the participants (85%) gave a high score and 3 (15%) gave a neutral score. With a mean of 4.10 and standard deviation of 0.64 it can be considered that the participants found the diagnosis tool intuitive to use.

Question 17

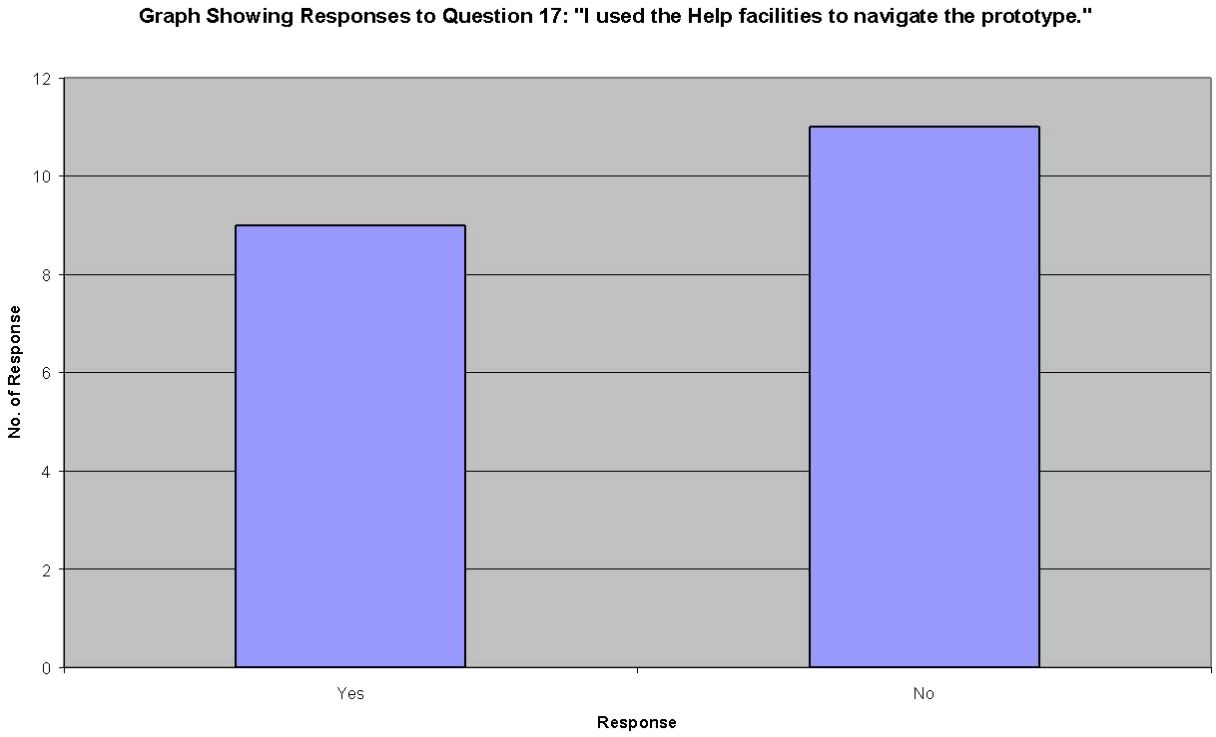


Figure 85: Graph showing the results for Question 17.

Through out the prototype a 'Help' function was available to those taking part in the testing. Question 17 was asked to ascertain how many of the participants utilised this function. 11 of the participants (55%) did not, whilst 9 (45%) did.

System Usability

Questions 1 to Question 12 were asked to find how intuitive and easy to use the participants found the prototype system. From the graphs showing the results of these questions it can be discerned that the overall response to the prototypes usability was positive with most participants feeling that the prototype was easy to learn and use, giving a high score.

A help function was provided through out the prototype to provide extra details on using a function in the system if the participants required it. 45% of the participants did make use of this function. However, the usage of this function did not affect the participant's opinions on the ease of use of the prototype.

Several of the responses given that were neutral. It is not possible to tell if these neutral scores have been given due to the participants having a mixed opinion to the prototype or if they do have not opinion. For future testing the usability survey could have an option to allow participants to state if they have no opinion to allow the actual neutral response to be easily analysed.

Although the trend for the results is overall positive, the results for Question 9 have a high standard deviation of 1.05. This is the maximum standard deviation that would be possible for this set of results. This indicates that the results within the first standard deviation are either positive or slightly less than neutral. As a result no definitive statement can be made as to whether the participants did use past experience to help them navigate and use the system and therefore if they found it easy to use the prototype as a result.

Another discrepancy of note is that in Question 2 "How intuitive did you find the system?" one participant gave a low score of 2 saying that they did not find the system intuitive. They also gave scores that said they felt the system was too inconsistent. However, they have also scored the system highly saying they didn't find it complex or cumbersome to use and felt the functions of the system were well integrated. This suggests that they found the system intuitive and easy to use, contradicting the low

scores they had given when asked about this previously. These contradictory scores could be due to the participant not understanding what questions being asked or due to the design of the questionnaire did not select the response they actually wanted to reflect.

Search Function

Two different styles of Search function were tested by the participants. Questions 11: “I found the filter search method the user friendly.” and Question 12: “"I found the single field search method user friendly.” focused specifically on these different styles of the function.

The filter search method was scored highly by 90% of the participants, stating they found it easy to use. The response to Question 12, in regards to the single field search function was not definitive.

With a mean score of 3.25 the trend is leaning towards a positive result. However, the standard deviation is 1.48. Compared against a maximum standard deviation of 1.75, this shows that the results are varied with a substantial proportion being low. As a result of this is not possible to have a definitive answer as to how successful this feature was based on these results.

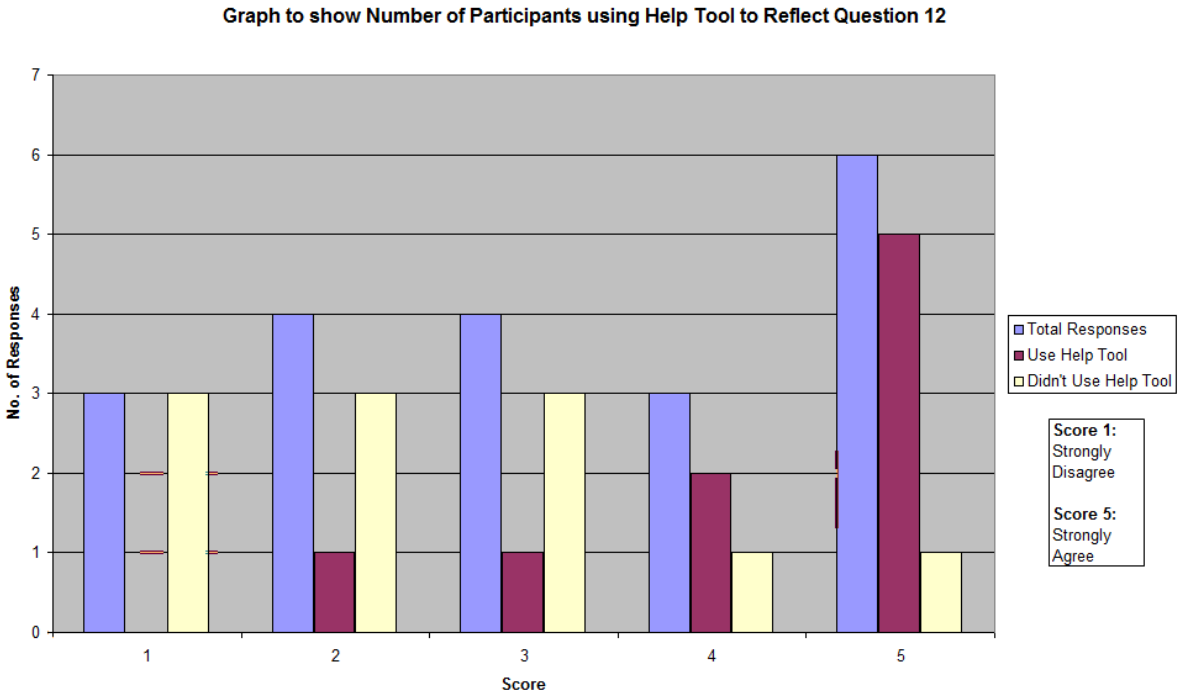


Figure 86: Showing a comparison of the participants that use the Help function for Question 12.

It is possible to compare the usage of the help function (Question 17) with the scores for Question 12. Figure 86 above shows that of the nine participants that that gave a high score of greater than 3, seven of them utilized the help function whilst using the prototype. Comparatively, of the seven participants that gave the single field search a low score of less than 3, 1 of them did use the help function. This suggests that single field search feature is not intuitive enough to allow easy use for a first time user with no support but with the aid of the help function this feature is a viable tool.

However, when comparing the scores that the seven high scoring participants who used the help function with the scores they gave when asked how intuitive they found the system (Question 2) it was found that six of them scored highly, stating they found the prototype intuitive. In fact eight of the nine participants that used the help function

whilst using the prototype in its entirety scored the system as being intuitive and easy to use. This suggests that they found the inclusion of a Help function a part of what made the prototype intuitive.

Creating and Reviewing Reports

Whilst Questions 1 to 12 were asked in the general usability of the system, Question 13: “I found entering in data for a clinical review easy” and Question 16: “I found the diagnosis tool intuitive to use" focused on the creation of the reports. As with the Search function the participants were asked to use two versions of the report creation tool. One was a standard form and the second had an integrated diagnosis support tool that would suggest a diagnosis based on the MRS ratio values that had been inputted.

The participants scored Question 13 highly, saying that they found entering the data to create a report easy. As well as this they scored gave high scores for Question 16 saying that they found the diagnosis support tool intuitive to use. This addresses the concern that a radiologist using the system would be less productive as they are trying to work the system and taking time to enter the details they need to complete report, reducing the time viewing an image.

Whilst Questions 13 and Question 16 focused on creating the reports, Question 14 “I found using this software to review a clinical report made it clear to understand” and Question 15 “I found reviewing a free text clinical report easy to understand” focused on viewing and reading a report. The participants were asked to view a report that was created using free text and another report which contained the same information but was in a structured format. For Question 14, 100% of the participants gave a high score of

either 4 or 5 stating that they found the structured report easy to view and understand. Comparatively, for Question 15 85% of the participants gave a low score of 1 or 2. This shows that the participants found reading the SR easier than the free text version, supporting the theory that the Structure Reports is a more effective way of communicating the information in the reports over using free text.

4.4 Feedback

After completing the usability testing, the participants where asked if they had any feedback. A large proportion of the participants did not have a medical background but were able to provide feedback regarding the usability of the system.

Overall, no major issues with the design of the system where identified, however minor changes were suggested. The first group of users identified minor design flaws, such as missing “Back” and “Home” buttons, which were corrected whilst the testing took place. Another suggestion made was regarding the input fields for “Medical History”, “Allergies” and “Location.” Initially, these were drop down boxes where as user would have to scroll and find the entry they wanted to input. It was requested that these be converted to combo boxes, so that a user could type into the box to quickly locate the required entry if they already knew the entry needed. Similarly, it was suggested that any drop down boxes for fields that required a Yes or No answer be converted to check boxes as it a faster input method that selecting from a drop down menu.

A larger change was suggested by several participants in the first group. This was in regards to the history function. In the first design, if the history page was accessed to locate a record the user would be present with links to fifteen records, the last five that

had been created, viewed and edited. This was found to not be a useful feature as a record a user wanted to access could quickly be removed. It was suggested that history page list off records that had been accessed by the user, but there be a filter system to make it easier to locate the wanted file.

The changes that were suggested from the first test group were implemented in time for the testing of the second. In their feedback no further improvements on these changes were proposed. A change to the input of the date and time fields was recommended so that it was auto filled, with the ability to edit if needs, or as well as having a field to type the date there is a calendar pop up. Further feedback from this group suggested that an option to add further medical history and allergies be introduced, in case a patient had more than one, would be beneficial. As before these changed were implemented before the next testing session.

As well as the recommendations this group made, they also raised a concern about the diagnosis system. Although they found it easy to use and useful for someone with no medical knowledge, they had a concern that a medical specialist would find it patronising and as such be reluctant to use. In response to this concern it was arranged for a Radiologist to test the usability of the prototype and provide feedback.

4.5 Subject Matter Expert Feedback

In response to the concerns raised by the participants of the usability testing, a final testing session took place with a Consultant Radiology at the North Staffordshire Hospital NHS Trust. This testing session followed the same procedures as the previous ones. Results from Usability questionnaire completed in this session where included as part of

the overall results. Once they had completed the tasks and questionnaire they were asked for feedback.

Their comments were positive in regards to the application being a standalone system. A change was advised in regards the terminology of the options on the main page, specifically changing “Edit Record.” To them seemed as though this would mean that the original record would be changed and it would not be possible to compare different versions. They demonstrated the reporting system that they used within the hospital and showed that there was an option to add an “Addendum” to a report. This would add a new section to the already created report with an identifier and time stamp along side the changes made, so it was easy to see the changes.

To compare, it was explained that if a report was edited using the application, the original version would still be stored but a new version, indicated by a change in version number, would also be saved. The older version would be visible by a user clicking on the version number and selecting an older version. It was agreed that it would be easier to identify changes if the amendments could be seen on the same screen. From this, the terminology on the main screen was amended whist in testing so the option to “Edit a Record” became “Add Addendum”. Future work on the application would mean that any changes made to a report would be visible on the one screen with a time stamp and identifier.

Whilst comparing the application with the current system in the hospital it was showed that there were in fact two systems that ran along side each other to create a report, a work queue and reporting system based on a windows machine and then a Picture

Archive and Communications System (PACS). The radiologist who was creating a report would select a patient's procedure from a work queue, which would then load up the reporting template, with all the patient's and scan's information pre loaded on the screen for the Windows based system and the images connected to this procedure would auto load on the PACS screens. The only information that the Radiologist was required to fill out would be their observations, conclusions and recommendations.

Contrary to the feedback from the second group of test participants, the feedback in regards to the Diagnosis Tool was very positive, saying it would be a very useful addition. At this time, using MRS for diagnosis is generalised. A radiologist will review the graph readings and be able to tell whether the tissue being analysed is malignant or not, but not able to refine this any further. As seen previously, when the graph for the MRS readings are produced the ratios between the key chemicals are also produced. As such it would be easy for a radiologist to enter these into the system. It could even be possible to have these entered automatically when then image is loaded. With the introduction of the diagnosis tool, it could help speed diagnosis as it would give an indication of the type of cancer that has developed.

4.6 Summary

A paper based prototype was created based off the ontology that has been developed. This was then tested by a group of 20 people to test the design usability. Overall the response to the usability of the prototype was positive with most participants find the tool easy to navigate and to complete the tasks set. It was found that the reports that

would be created by the prototype were cleared and easier to read than when presented with a report written in free text.

The prototype was also tested by a subject matter expert; a Radiologist from the North Staffordshire NHS Trust. The feedback received from them was positive and they were able to provide feedback that can be considered for future work. The also found the diagnostic tool and innovative idea and thought it would be useful in the medical field as at this time MRS data is only just to state if the tissue scanned is malignant or not. By using the specified readings from the MSR scans it would be possible to narrow down or diagnose a tumour with out the need for biopsy.

Chapter 5: Conclusions and Discussion

Having completed the ontology development and testing the following chapter will be discussing the contributions that have been made, the limitations faced, future work and the conclusions that can be made.

5.1 Contributions

Through this body of work an ontology has been designed and created to produce Structured Reports that support the diagnosis of certain types of childhood brain tumours. The ontology has been successful in diagnosing the type of brain tumour, either Astrocytoma, Ependyoma or Medulloblastoma based on the MRS data ratio provided. The diagnosis has been compared against and validated by data that was correlated by Lisa Harris (Harris 2009).

The ontology's fitness of purpose and structural integrity is demonstrated through the criteria based evaluation metrics for the proved that the ontology itself was structurally sound, the inability to associate the metrics to the criteria made the evaluation inconclusive. An important factor for development of the structured reporting was intuitively and clarity.

Twenty individuals were requested to test the paper based proto-type and asked to complete a number of set tasks. This was to determine if the proto-type was intuitive and in conclusion all the users were able to complete the tasks set before them. Afterwards the users were requested to complete feedback forms and in only a few cases did any of the users find it difficult to use a single feature of the proto-type; however this did not

inhibit any of them from completing their tasks in a timely manner.

Within the twenty users a consultant radiologist from North Staffordshire Hospital NHS Trust was requested to perform the same tasks as the other users, as such they reported that the proto-type was fit for purpose as a standalone system.

5.2 Limitations

For this project there was only MRS data available for 3 types of Glioma brain tumours. As there are many types of Childhood Brain Tumours, this means that only a small number have been shown to diagnosable using MRS data.

It was found that evaluating the ontology via associating the metrics to the criteria is very difficult. Assessing the ontology with an application means it is able to yield worth while results. As a result, this allows for a better assessment of the performance of the ontology (Yu et al 2007.) Because of the lack of associated application for the project it is too difficult to associate the values of the metrics to the criteria of a Criteria Based Evaluation. If an application was available to the project then the Criteria Based Evaluation would be more conclusive.

Further limitation to the evaluation was, that due to time constraints, only one subject matter expect (SME) was able to take part in the paper based prototype usability testing. As a result the feedback received, although positive, cannot be seen as a representation of the overall views of radiologists, the target users of the application.

5.3 Future Work

In regards to the ontology, future work would be develop further MRS diagnosis algorithms to allow more types of brain tumours and for these to be incorporated in to the ontology. Also, as well as diagnosis of the type of brain tumour, the ontology could also be expended to provide recommendations on what action to take in regards to treatment, for example the patient to under go a biopsy procedure.

The feedback received from the radiologist who took part in the usability testing stated that the prototype would be successful as a standalone. However, it was advised that wouldn't be feasible to use it within an NHS hospital trust as they depend on a Picture and Archiving Communications System (PACS) access and load patient images and data as well as dictate their work queues.

Future aspirations for this project would see would the development of a software component to integrate with the ontology instead of the use of a paper base proto-type. This would allow the tool to be fully test for usability and would also make it easier to evaluate the ontology.

Additionally because of the feedback given by the consultant radiologist, the work towards improving analysis of brain tumours can be further looked into by incorporating the system within to a PACS to allow use within the NHS. As well as this,

A possible improvement would be the addition of a dictation input system as this is the what is expected within NHS trust.

5.4 Conclusion

Based on the results of the evaluation of the ontology and the usability testing the objectives of the research project have been met. It can be seen that using MRS data to support the diagnosis of Childhood Brain Tumours. By using Structure Reporting software built in conjunction with a diagnosis ontology would allow for a very powerful tool to support diagnosis and allow for clear communication of the findings and recommendations that have been recorded.

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Appendix A

Data from Paper Prototype Usability Testing

	1.Given the correct line of work, how frequently would you use this	2.How intuitive did you find the system:	3.How would you rate the complexity of the system:	4.I think that I would need the support of a technical person to be able to use	5.I found the various functions in this system were well integrated:	6.I thought there was too much inconsistency in this system.	7.I learnt to use this system very quickly	8.I found the system very cumbersome to use:	9.I found myself drawing on past experience to use this system	10.I needed to learn a lot of things before I could get going with this	11. I found the filter search method the user friendly	12. I found the single field search method user friendly	13. I found entering in data for a clinical review easy	14. I found using this software to review a clinical report made it	15. I found reviewing a free text clinical report easy to understand	16. I found the diagnosis tool intuitive to use	17. I used the Help facilities to navigate the prototype
	4	3	4	5	3	4	4	4	5	5	4	1	5	5	2	4	No
	3	2	4	3	5	2	3	4	5	2	4	2	5	5	1	3	No
	3	4	5	5	4	4	4	3	5	5	5	2	4	5	2	4	No
	5	3	3	4	4	4	4	4	3	4	5	1	4	4	1	5	No
	5	4	5	5	4	4	5	4	2	4	5	5	5	5	2	5	Yes
	4	4	4	5	5	5	5	5	5	5	5	3	5	5	3	4	No
	5	3	3	3	3	3	4	4	4	4	4	4	4	4	1	4	Yes
	5	5	4	5	5	5	5	5	5	4	5	5	5	5	1	4	Yes
	4	4	4	3	4	3	3	4	4	5	4	4	5	4	3	3	No
	4	4	4	3	5	4	3	5	3	4	4	3	5	5	2	4	Yes
	5	5	4	5	5	5	5	5	2	5	5	5	5	5	2	3	No
	5	4	4	5	5	5	5	5	4	4	5	5	5	5	1	4	Yes
	4	5	3	5	5	5	5	5	3	5	4	4	4	4	2	4	Yes
	5	4	4	4	4	4	5	5	5	5	4	5	4	4	1	5	Yes
	4	4	3	3	3	4	5	5	3	5	3	5	4	4	1	5	Yes
	4	4	3	5	4	4	5	4	4	5	3	3	4	4	2	4	No
	5	4	4	4	4	5	4	3	4	5	5	3	4	4	1	4	No
	5	5	5	5	4	5	5	5	5	5	5	2	4	5	3	5	Yes
	4	3	4	5	3	4	4	3	3	4	4	1	3	4	1	4	No
	5	5	5	5	4	5	5	4	5	5	5	2	5	5	2	4	No
Mean	4.4	3.95	3.95	4.35	4.15	4.2	4.4	4.3	3.95	4.5	4.4	3.25	4.45	4.55	1.7	4.1	
Median	4.5	4	4	5	4	4	5	4	4	5	4.5	3	4.5	5	2	4	
Mode	5	4	4	5	4	4	5	5	5	5	5	5	5	5	1	4	
ST Dev	0.681	0.826	0.686	0.875	0.745	0.834	0.754	0.733	1.050	0.761	0.681	1.482	0.605	0.510	0.733	0.641	
Score																	
1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	9	0	Yes
2	0	1	0	0	0	1	0	0	2	1	0	4	0	0	8	0	9
3	2	4	5	5	4	2	3	3	5	0	2	4	1	0	3	3	No
4	8	10	11	3	9	9	6	8	5	7	8	3	9	9	0	12	11
5	10	5	4	12	7	8	11	9	8	12	10	6	10	11	0	5	
Total	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	

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