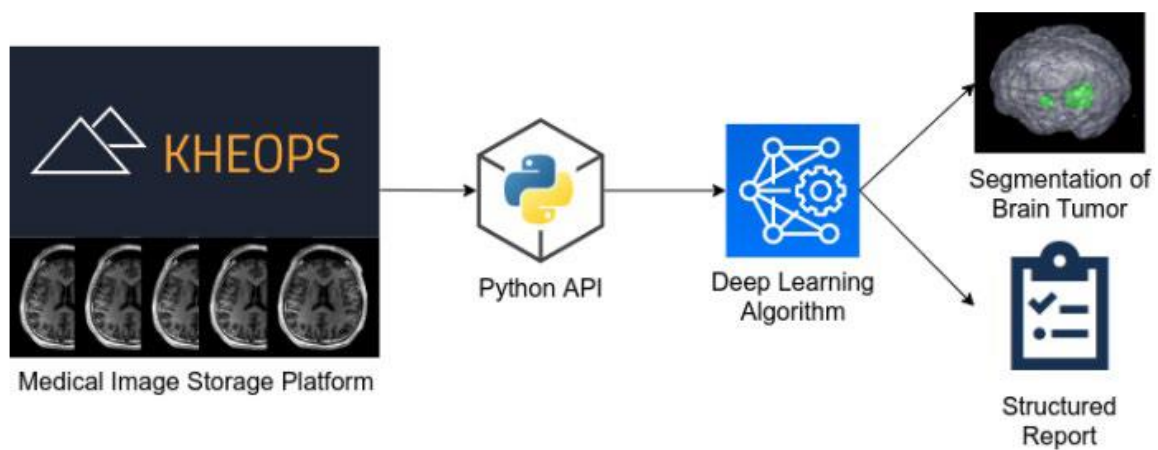


Travail de Bachelor 2023

Automatic reporting for Multiple Sclerosis based on medical imaging and Deep Learning



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www.hevs.ch

Source of illustration on title page: Adrien Depeursinge, MSxplain project

Abstract

Context: The field of medical imaging has progressed considerably with the integration of artificial intelligence. Today, many algorithms are on par with human experts, particularly for tasks such as organ analysis and segmentation. Despite these remarkable achievements, a crucial challenge persists in effectively translating the outputs generated by algorithms into easily comprehensible radiology reports.

Objectives: Firstly, it aims to explore the possibilities offered by the DICOM SR standard format, and to understand how a structured report can be generated and visualized. Secondly, it seeks to determine the most appropriate format and technology for generating structured reports that summarize the outputs of AI tools. Finally, the project aims to implement an end-to-end pipeline for report generation, seamlessly integrating this mechanism into existing medical systems.

Result: The outcome of this project is a fully functional report generation mechanism tailored to MRI images of Multiple Sclerosis. The generated reports adhere to the DICOM SR standard format, ensuring compatibility with various medical systems including the PACS, and are presented in a clear, user-friendly format.

Conclusion: This project represents an important step towards bridging the gap between AI-generated outputs and radiology reports. By leveraging the DICOM SR standard and using an end-to-end pipeline, it enables the production of Structured Reports that improve the quality and accessibility of crucial medical information. Also, future research challenges are identified to encourage further improvements of the methods.

Key words: Multiple Sclerosis, Medical Imaging, DICOM, Structured Report, Deep Learning

Foreword

This project concludes a training at the HES-SO Valais leading to a Bachelor's degree in Business Informatics. It was carried out during the final semester of a three-year full-time course. The aim is to assess the skills acquired by future graduates during their training.

The subject of this work was submitted by the Professor Adrien Depeursinge in collaboration with the HES-SO Valais IT Research Institute. The mission is to discover and learn about the DICOM SR standard format. A large part of the research consisted of positioning ourselves in relation to the standard in order to determine whether it was suitable for this project.

This report is written on the basis of the APA 6 (American Psychological Association) formatting standard for scientific reports. This concerns writing, layout, figures and illustrations, references, etc.

To make this document easier to read, the masculine form will be the only one used in the texts.

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I would like to express my sincere gratitude to everyone who helped and supported me during my training and the completion of this Bachelor's thesis. More specifically, I would like to thank:

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Abbreviations

AI	Artificial Intelligence
CHUV	Centre Hospitalier Universitaire Vaudois University Hospital of Lausanne
CNS	Central Nervous System
CSF	Cerebrospinal Fluid
DICOM	Digital Imaging and COmmunication in Medicine
DL	Deep Learning
FLAIR	Fluid Attenuated Inverse Recovery
HTML	HyperText Markup Language
IOD	Information Object Definition
JPEG	Joint Photographic Experts Group
MS	Multiple Sclerosis
MRI	Magnetic Resonance Imaging
NIFTI	Neuroimaging Informatics Technology Initiative
PACS	Picture Archiving and Communication System
PDF	Portable Document Format
PHP	Hypertext Preprocessor
SR	Structured Report
TIFF	Tag Image File Format
UML	Unified Modeling Language
USB	Universitätsspital Basel University Hospital of Basel
XML	eXtensible Markup Language

1. Introduction

1.1. Context

The field of medical imaging has advanced significantly with the integration of artificial intelligence (AI). Today, many algorithms are now on par with human experts, particularly for tasks such as organ analysis and segmentation. However, despite these remarkable achievements, a crucial challenge remains in effectively translating the outputs generated by AI algorithms into comprehensible radiology reports. Currently, it is difficult to present AI-generated results in a way that is easily understood by radiologists. This is a barrier to the integration of AI into the healthcare sector and limits its ability to contribute effectively to patient care.

One of the objectives of this project is to develop a solution to facilitate this translation of AI decisions into terms that radiologists can understand. For these outputs to be fully exploitable and useful to radiologists, it is important to translate them into their language. Radiological reports are essential documents that summarise the observations, conclusions, and recommendations of radiologists, enabling clear and precise communication with other healthcare professionals. This involves developing methods and tools that enable the results of the algorithms to be summarised in a structured way, focusing on medically significant information.

Moreover, another goal is to generate accurate, structured radiology reports that can be stored in the Picture Archiving and Communication System (PACS). This approach will enable AI results to be integrated into the existing radiology workflow, while improving communication and understanding of the decisions made by the algorithms.

In this introduction, we will clarify the problem we wish to solve through this project. It will lay the foundations for the rest of the report, where we will detail the various stages of implementation and the results obtained.

1.2. Project “MSxplain”

This work is part of a Hasler Foundation project called “MSxplain”¹, the objective of which is to work on the integration of AI and Deep Learning (DL) to the diagnosis and treatment planning of Multiple Sclerosis (MS) with an explainable AI decision in the field of personalized healthcare. In this context, a web-based platform is developed jointly with the University Hospital of Lausanne (CHUV) and the University Hospital of Basel (USB) to allow the execution of DL analysis algorithms on Magnetic Resonance Images (MRI) of the brain to help physicians identify and diagnose potential MS patients.

The platform is developed from existing software components for storing, organizing, sharing, and viewing medical images, as well as running DL algorithms on the available data. The outputs of DL algorithms, as currently implemented in the project, can be complex and difficult to understand/interpret. An important project need is to create clear, concise, and easy to understand reports that summarize the results of the AI tools. This report can contain the total volume of MS lesions, their distribution in the anatomy of the brain, etc.

These reports can be generated using a standard format called Digital Imaging and COmmunication in Medicine (DICOM) Structured Reporting (SR), which aims to use standardized values for all contents of a report, rather than having the traditional report that is simply dictated by a physician and then transcribed into free text.

1.3. Objectives of the thesis

The objective of the project is to explore the possibilities offered by the DICOM SR standard and to understand how they can be generated and visualized. A large part of the research consisted of positioning ourselves in relation to the standard in order to determine whether it was suitable for this project, or whether it was far too cumbersome to put in place.

Additionally, integrating report generation into an end-to-end pipeline by viewing images, triggering the DL algorithm, generating the report, and viewing the report, would be very useful for future integration of the work done in the existing platform.

¹ <https://wp.unil.ch/mial/research/projects/msxplain/>

1.4. Methods

This report is structured to provide a clear and thorough understanding of the research and development activities. The structure is defined as follows:

The first section delves into the various formats of medical imagery, with a specific focus on the DICOM format and its Structured Reporting capabilities. A comparative analysis will be conducted to assess the suitability of DICOM SR in comparison to alternative report formats for our project's needs. We will identify and justify the selection criteria based on technical feasibility.

Then, we will present a detailed description of the selected report generation method and its integration into the existing MSxplain platform. The process of selecting development technologies will be elaborated upon, along with the reasoning behind each choice. The implementation steps will be outlined.

Finally, we will share the results obtained from the tests conducted to assess the efficiency and reliability of the generated reports. A comprehensive analysis of the outcomes will be presented. The conclusion will summarize the findings, underscore the contributions made by this bachelor's thesis, and discuss the potential future improvements for the MSxplain project.

1.5. Available resources

In the initial stages of our project, we had access to the resources of Kheops. As described on their website: “Kheops offers a simple solution for storing, sharing and viewing medical images” (KHEOPS | Manage and share your DICOM easily). Developed at Campus Biotech in Geneva, the platform aims to provide scientists and researchers with a flexible and open image archiving solution. This platform served as the foundation and offered essential features necessary for the project's success. Its primary focus is to offer secure and reliable storage of data, particularly excelling in the handling of DICOM images (KHEOPS | Manage and share your DICOM easily).

In addition, we were provided with an algorithm that was useful for adding information when generating a report. This algorithm served as the fundamental basis, and we were able to exploit its potential to achieve our objectives effectively. We therefore had access to a reliable platform and an algorithm for setting up our project.

2. Medical Imaging

2.1. Definition

A medical image is the representation of the internal structure or function of an anatomic region (Michele (M.) Larobina, 2013, pp. 200-206). In the medical domain, medical images are essential for the diagnosis of many pathologies, the treatment and follow-up care of patients. They provide healthcare professionals with valuable information about anatomical structures, functions, and pathological abnormalities. Technological advances in the field have considerably improved medical imaging capabilities, with more detailed data and with better visualisation techniques.

Medical images are used in all fields of medicine (radiology, cardiology, neurology, and many others) and play a central role in doctors' decision-making for better and more accurate diagnoses. Medical images allow visualising internal human body structures, such as organs, tissues, blood, bones, to detect anomalies, tumours, lesions, and other medical conditions (Dossier/imagerie médicale, 2016).

There are many ways to obtain medical images. Here are the three most common techniques that are used worldwide.

Computed Tomography Scan (CT-scan) is one of the most traditional methods to obtain medical images. It uses X-rays to create three-dimensional images of the patient's body by analysing the body in thin slices. It is used to detect trauma and diagnose cardiovascular disease, abdominal disease, or lung lesions. Soft tissues are sometimes difficult to distinguish (Dossier/imagerie médicale, 2016).

Positron Emission Tomography (PET) is used to visualise metabolism by injecting a molecule with a radioactive atom into the patient. It is then captured by a specialized scanner to produce three-dimensional images. By repeating the operation over time, we can even measure the trajectories of the substance. This technique is widely used to localize tumours (Dossier/imagerie médicale, 2016).

Magnetic Resonance Imaging (MRI) uses a powerful magnetic field and computer-generated radio waves to create detailed images of the organs and tissues in the body. It exploits the spin of particles, particularly protons, to locate atoms precisely under the effect of a magnetic field. Excellent for detecting soft tissue and neurological structures, but less suitable for hard parts such as bone. One of the great advantages of this technique is that it is non-invasive and non-irradiating (Dossier/imagerie médicale, 2016) (Ivory, 2023).

MRI is the most frequently used imaging test of the brain and spinal cord. It is often performed to help diagnose Multiple Sclerosis and other known diseases. This technique will concern us more for this report (MRI - Mayo Clinic, 2021).

2.2. Multiple Sclerosis

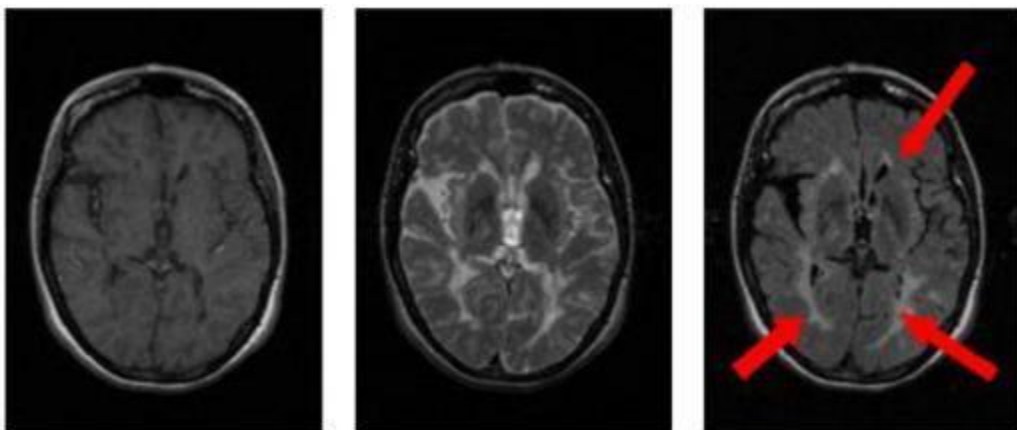
Multiple Sclerosis (MS) is a complex autoimmune and inflammatory neurological disease affecting the Central Nervous System (CNS). Its course can vary greatly and remains unpredictable for most patients. Initially, individuals may experience episodes of reversible neurological deficits, followed by progressive neurological deterioration over time (Goldenberg, 2012).

To diagnose MS, clinical findings and supporting evidence from auxiliary tests, such as brain MRIs and cerebrospinal fluid (CSF) analyses, are crucial. There is no single diagnostic procedure, but it is supported by evidence of at least two distinct lesions² in the CNS's white matter. (Goldenberg, 2012).

Each MRI scan can be obtained in different formats, referred to as sequences, similar to filters in photography. Each sequence offers unique advantages and disadvantages for visualising different aspects of the brain and spinal cord (Michele (M.) Larobina, 2013, pp. 200-206).

Kevin (K.) C MA and al. explains that the purpose of an MRI scan is to visually locate lesions in the CNS. MS lesions appear “hypointense” or “isointense” in a T1-weighted scan and “hyperintense” in T2-weighted and Fluid Attenuated Inverse Recovery (FLAIR) scans. Location and morphology of lesions are also used to identify lesions caused by MS (Kevin (K.) C MA, 2015).

Figure 1: Slice of patient's brain with MS



Source: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4936902/bin/nihms796391f1.jpg>

This figure shows the three aforementioned axial slices of a patient's brain with MS. The left image is “T1-weighted”, the middle image is “T2-weighted”, and the right image is “FLAIR”. White regions in the FLAIR image (as pointed by arrows) indicate MS lesions in white matter.

² Plaques or scars

In our project, we aim to implement an algorithm that utilizes T1 and T2 images, also known as sequences, to detect specific brain structures and abnormalities. T1 images are essential for visualising the detailed anatomy of the brain and spinal cord, aiding in the identification of “black holes” that represent areas of atrophied or previously injured brain tissue. On the other hand, T2 sequences play a vital role in highlighting areas of demyelination caused by MS activity. These sequences are useful for counting the total number of MS lesions, depicted as bright white spots on T2-weighted and fluid attenuated inverse recovery (FLAIR) scans (Kevin (K.) C MA, 2015).

The algorithm for the MSxplain project will primarily focus on T2 sequences for white matter segmentation with White Matter Lesions (WML), since T2 provides more information relevant to our specific objectives. While T1 is also useful in MS, it contributes less to the quantification and interpretability required. By implementing this algorithm, we aim to enhance the identification and analysis of MS-related abnormalities in brain images, ultimately contributing to improved diagnostic accuracy and patient care.

2.3. Image file formats

In the field of medical imaging, it is important that doctors can easily exchange and share images and related information with each other. This helps them work together and make the right decisions for their patients. To facilitate this exchange of information, various rules, named standards, have been developed and adopted in the medical imaging community. These standards make sure that different medical imaging systems can work together and read each other's pictures easily, so that different healthcare institutions can share important medical pictures between hospitals and clinics (Michele (M.) Larobina, 2013, pp. 200-206).

One such widely recognized standard is the Digital Imaging and Communications in Medicine (DICOM) standard. DICOM provides a comprehensive framework for creating, storing, transmitting, and displaying medical images along with critical patient details and acquisition information. This standardized language allows different machines, software, and healthcare systems to communicate effectively, ensuring interoperability (Clunie D. A., DICOM STANDARDIZATION OF WSI DATA, 2020).

In addition to DICOM, the Neuroimaging Informatics Technology Initiative (NIfTI) format plays a crucial role, particularly in neuroimaging data analysis. NIfTI stands out for its simplicity and minimalist approach, specifically designed to meet the needs of research and analysis. Its straightforward structure enables efficient data processing and analysis in neuroimaging studies.

2.3.1. DICOM

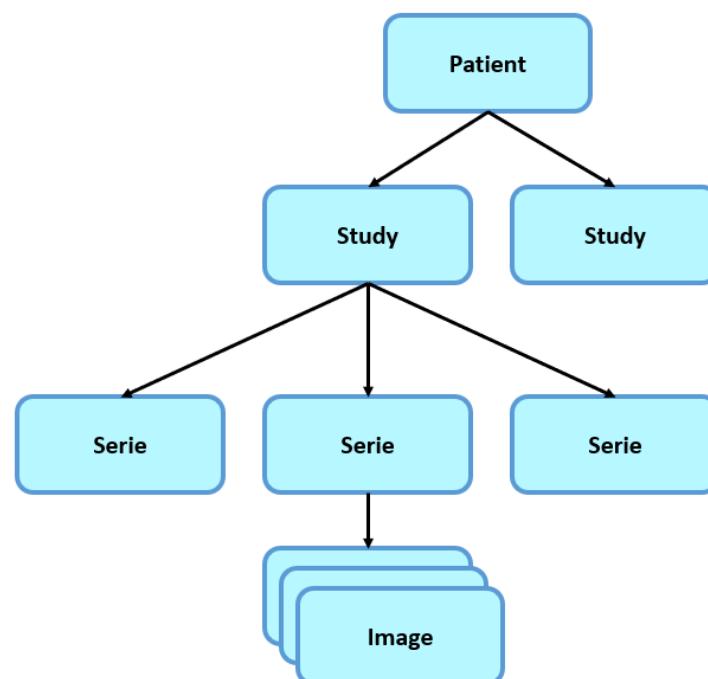
According to the official website of DICOM, it is the international standard for medical images. It establishes the formats for medical images that may be exchanged with data and quality for the medical application (About DICOM- Overview, 2023).

This norm is used in nearly every radiology, cardiology, radiotherapy equipment (X-ray, CT, MRI, ultrasound, and so on), as well as in devices in other medical domains such as ophthalmology and dentistry. DICOM is one of the most used healthcare communications standards in the world, with hundreds of thousands of medical imaging equipment in use. There are also billions of DICOM pictures around the planet used for clinical treatment (About DICOM- Overview, 2023).

The DICOM standard proves to be highly valuable for integration of a wide array of modern imaging equipment, including the PACS. Its user-friendly integration capabilities and consistent updates have led to widespread acceptance by vendors in the radiological equipment industry, making it an almost universal communication standard over the years (Varma, 2012, pp. 4-13).

DICOM organizes data following this hierarchy:

Figure 2: DICOM Hierarchy



Source: Adapted from: <https://www.researchgate.net/publication/260374716/figure/fig1/AS:613853259898896@1523365430690/DICOM-Information-Hierarchy-one-patient-may-have-multiple-studies-each-study-may.png>

According to the figure above, here are some explanations:

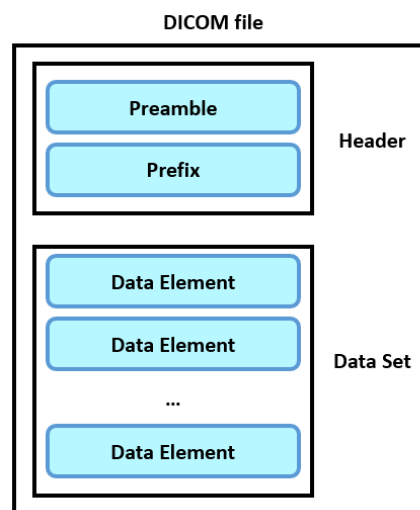
- The “Patient” is the person that receives the exam.
- The “Study” means an imaging study performed at a specific date and time.
- The “Serie” is the representation of the patient being physically scanned multiple times (for example with an MRI or CT exam).
- The “Image” is an instance of the 3D image, it can be interpreted as a slice of the image.
(Alexander (A.) Weston PhD, 2021).

In simple terms, DICOM provides a standardized way to represent real-world data in healthcare, such as patients and medical tools. This standardisation is achieved through Information Object Definitions (IODs), which are like lists describing each piece of information. For example, a patient's IOD would include their name, medical record number, sex, age, weight, and other relevant details. This ensures that doctors have all the essential information about the patient when providing treatment (How does DICOM work?, 2008).

To maintain consistency, DICOM has a comprehensive “data dictionary” with over two thousand standard names. This ensures that everyone uses the same names for objects and handles them in a uniform manner. For instance, information about a patient's name, birthdate, gender, and other details can be found in the DICOM Data Dictionary. This common vocabulary promotes interoperability and communication between different medical systems and healthcare professionals (How does DICOM work?, 2008).

DICOM files are stored with the file extension “.dcm”. They are different from other image formats because they organize information into sets of data. A DICOM file contains a “Header” and image “Data Sets”, but all information is stored in one single file.

Figure 3: DICOM file structure



Source: Adapted from (Overview: Basic DICOM File structure | An overview of the DICOM file format | DICOM C++ Class Library help, n.d.)

The initial segments of data in a DICOM image file are referred to as the “Header.” This section contains essential information about the patient, image acquisition parameters, and specific details about the image itself. The computer relies on this header data to properly display the image. These data are stored as a sequence of 0s and 1s, which can be reconstructed as an image by using the information from the header. Depending on the modality that generated the image, this attribute may encompass information for a single image or multiple frames of a study (Varma, 2012, pp. 4-13).

The header data in a DICOM file is encoded to ensure it remains connected to the image data and cannot be accidentally separated. This link between the header and image data is essential for the computer to correctly identify the imaging study and the patient to whom it belongs. If the header is detached from the image data, it could lead to a misinterpretation of the image and a potential medicolegal situation (Varma, 2012, pp. 4-13).

The information is organized as a constant and standardized series of tags. These tags are organized into groups of “Data Elements”. For example, the tag “0010-0010” is the patient’s name, and the tag “0010-0020” is the patient’s identification number (Varma, 2012, pp. 4-13).

Using the DICOM Browser³ application, it is possible to open a DICOM file and see such elements on the following figure.

Figure 4: DICOM tags

Tag	Name	Value
(0008,0005)	Specific Character Set	ISO_IR 100
(0008,0008)	Image Type	DERIVED/SECONDARY
(0008,0012)	Instance Creation Date	20230704
(0008,0013)	Instance Creation Time	135109.292306
(0008,0014)	Instance Creator UID	
(0008,0016)	SOP Class UID	1.2.840.10008.5.1.4.1.1.4
(0008,0018)	SOP Instance UID	2.25.49459130277490158505573449694010849562
(0008,0020)	Study Date	20230704
(0008,0021)	Series Date	20230704
(0008,0022)	Acquisition Date	20230704
(0008,0023)	Content Date	20230704
(0008,0030)	Study Time	135109.292306
(0008,0031)	Series Time	135109.292306
(0008,0032)	Acquisition Time	135109.292306
(0008,0033)	Content Time	135109.292306
(0008,0050)	Accession Number	ABCKYZ
(0008,0060)	Modality	MR
(0008,0070)	Manufacturer	
(0008,0080)	Institution Name	INSTITUTION_NAME_NONE
(0008,1030)	Study Description	Slightly Processed/Coregistered Data
(0008,103E)	Series Description	Flair
(0008,1090)	Manufacturer’s Model Name	
(0010,0010)	Patient’s Name	Patient01
(0010,0020)	Patient ID	01

Author’s source

Based on this figure, we can see starting from the left the tag identifier, the name of the tag, and the value. DICOM Browser also offers the possibility to modify the value or add a new tag-value.

³ <https://www.xnat.org/download/dicombrowser/>

2.3.2. NIfTI

As observed, the DICOM standard has achieved significant success by providing a comprehensive and unified framework for transferring, storing, and printing medical data. However, implementing DICOM transparently requires substantial effort and expense, making it challenging for research environments with limited resources. Additionally, the rapid advancements in analysis methods and data create further complexities. As a result, researchers often opt for simpler image formats that enable faster progress. These formats retain a focused and relevant set of the images' metadata (Xiangrui (X.) Li, 2016, pp. 47-56).

In contrast to DICOM, the Neuroimaging Informatics Technology Initiative (NIfTI) format is exceptionally straightforward and minimalistic. NIfTI is a format specifically developed for neuroimaging data analysis. NIfTI files primarily store volumetric data, such as 3D brain images, along with relevant metadata. The format is widely used in neuroimaging research and software tools due to its simplicity, flexibility, and compatibility with popular neuroimaging analysis packages. It has gained widespread adoption in neuroimaging research, allowing scientists to seamlessly integrate image processing and analysis tools developed by different teams. This convenience and efficiency make NIfTI an attractive choice for researchers in the field (Xiangrui (X.) Li, 2016, pp. 47-56).

The NIfTI format brought about another significant improvement by enabling the use of a single file, unlike the ANALYZE⁴ format, which requires two separate files: a header file “.hdr” extension and the image data file itself “.img”. The requirement of identical names before the extension (e.g., “brain_image.hdr” and “brain_image.img”) effectively doubled the number of files in an image directory, resulting in unnecessary clutter (Working with NIFTI Images – data science for psychology and neuroscience – in Python, n.d.).

In contrast, NIfTI simplifies this process by defining a single image file with a “.nii” extension. This not only streamlines file management but also offers the option to compress NIfTI images using the widely adopted, open source “Gzip”⁵ algorithm, with “.nii.gz” extension. This compression capability significantly reduces file sizes, making it especially valuable for large neuroimaging data files that require substantial storage space. By incorporating these improvements, the NIfTI format has enhanced the efficiency and practicality of managing neuroimaging data (Working with NIFTI Images – data science for psychology and neuroscience – in Python, n.d.).

⁴ Another medical imaging format

⁵ <https://www.gzip.org/>

2.4. Conclusion

In summary, while DICOM serves as the universal standard for medical imaging across different modalities, NIfTI specifically focuses to the needs of neuroimaging research and analysis. Both formats play crucial roles in advancing medical imaging and neuroscience, enabling clinicians and researchers to gain valuable insights into the human body and brain.

Although other file formats may be practical, clinical practice relies primarily on the DICOM format. Its unambiguous nature stems from the fact that each file contains a header that comprehensively documents essential information, including hospital, patient, scanner details and image data (Weston, 2021). Therefore, the DICOM format remains the preferred choice for information exchange and comprehensive documentation in medical imaging.

Unfortunately, unlike other image file formats such as Joint Photographic Experts Group (JPEG) or Tag Image File Format (TIFF) files, the individual DICOM files are not readily recognized by Windows as so. It is not possible to directly view the contents of the image by simply double clicking on them (Varma, 2012, pp. 4-13). To do so we have to use a medical imaging viewer. We will delve into this aspect later in this paper for a more comprehensive discussion.

3. Reporting

3.1. Radiological reports

According to the National Cancer Institute, a radiological report is a “*a detailed report that describes the results of an imaging test*” (National Cancer Institute, 2023). They also specify that the radiological report contains various aspects, such as the type of imaging test conducted and its methodology. Additionally, it includes a concise medical history of the individual having the test, including any symptoms, or known medical conditions that necessitated the examination. Furthermore, the radiology report describes the observed findings in the scanned areas of the body and may compare them to previous imaging tests, if available. A summary of all the identified findings, which may be used to make a diagnosis of a disease, as well as recommendations for additional testing, are also incorporated into the report. (National Cancer Institute, 2023).

This section aims to analyse different reporting templates commonly used in the medical field. These templates help to standardise reporting practices to improve efficiency and quality of diagnosis. It is widely acknowledged that clinical reports are important tools for radiologists to communicate with patients effectively. An ideal report should adhere to principles of uniformity, comprehensiveness, ease of understanding, and readability for both humans and machines (RadReport Reporting Templates, 2023).

The analysis of the different reporting templates commonly used in the medical field is of great importance to our project. These models play an essential role in standardising reporting practices, which in turn improves the efficiency and accuracy of the diagnostic process. As radiology reports play a crucial role in communicating medical information, it is essential to understand the structure and content of these templates to ensure that our system is aligned with established standards and practices (RadReport Reporting Templates, 2023).

By studying these models, we gain valuable insights into the specific fields and data points that medical professionals consider important for effective communication and decision-making. Radiologists rely heavily on these reports to provide comprehensive information on the results of imaging examinations, medical histories, observed findings and potential diagnoses (RadReport Reporting Templates, 2023).

3.1.1. Swiss Society of Radiology

The website of the Swiss Society of Radiology is a valuable repository of various documents pertaining to the field. In particular, our focus will be on Neuroradiology, which can be found at their website⁶. Within this section, we will explore the document titled “M-NEURO-HEAD-F” (French version), specifically designed for General cerebral MRI. The document can be found in [Appendix I](#).

This comprehensive resource is conveniently condensed into a single page, encompassing essential fields that are necessary for radiologists in their diagnostic processes.

The radiology report entitled “MRI Multiple Sclerosis first assessment [native / with contrast] of [date]” contains essential information concerning the MRI examination for the evaluation of MS. The report provides a detailed analysis of T2/FLAIR hyperintense lesions, classifying them according to their location in the brain (including periventricular, cortical, juxtacortical, infratentorial, subcortical and spinal). In addition, the presence of contrast-enhancing lesions is examined in detail, covering similar locations with the distinction of contrast enhancement.

The report also evaluates specific regions and other relevant findings. Each region is carefully assessed for any abnormalities or peculiarities. The conclusion allows the radiologist to summarize his findings and assessments and is an essential element in clear and effective communication with other healthcare professionals involved in the patient's care.

While some of these fields hold potential value for our project, it is essential to acknowledge that our algorithm may not be capable of filling all of them. These aspects involve highly specific details that require additional resources and expertise. Nevertheless, incorporating these fields could serve as a valuable complement to our outputs, enhancing the diagnostic process and providing a more comprehensive evaluation for medical professionals.

3.1.2. RSNA Radiology Society of North America

RadReport templates serve as valuable resources showing best practices for diagnostic reporting. They offer the opportunity to download the available templates and even create personalized templates. Among the extensive collection of templates available for different applications and languages, one particularly relevant for our project is titled “MR Brain - Multiple Sclerosis Screening”⁷, authored by Mark Mamlouk (RadReport, n.d.). The document can be found in [Appendix II](#). It is

⁶ <https://sgr-ssr.ch/fr/neuro-radiologie/>

⁷ <https://radreport.org/home/50644/2019-03-20%2015:53:28>

important to note that as of December 2022, RSNA is not actively reviewing submitted reporting templates nor publishing new ones (RadReport Reporting Templates, 2023).

Regarding the structure of the document, patient information such as name is filled in the “History” section, and the image acquisition technique is explicitly mentioned as “MRI images of the brain were acquired without intravenous contrast”.

The “Findings” section systematically assesses different regions of the brain parenchyma for T2 hyperintense white matter lesions associated with MS. Radiologists have the option of selecting “None”, “1-2” or “3 or more” lesions for the “Periventricular” region using a drop-down list. For other fields such as the regions of the brain, radiologists can indicate “No” or “Present” to indicate lesions.

In addition, the report includes fields for measuring the “atrophy” where they can choose between “None”, “Mild”, “Moderate” or “Severe” using drop-down lists. Atrophy is used to describe the shrinkage or loss of brain tissue. This is an important aspect to assess in brain imaging reports, as it can provide valuable information about the progression and severity of certain neurological conditions (Maria A. (M. A.) Rocca, 2016). However, in the context of our project, our algorithm does not extract this information, so it does not concern us too much.

The “Other” section allows to indicate any other relevant results. The “Impression” section concludes the report with “Brain MRI normal” indicating the absence of MS-related abnormalities in the brain images or “Multiple white matter lesions that are consistent with demyelinating disease”.

The reference to the 2016 MAGNIMS MRI criteria establishes the standards for disease dissemination in space in Multiple Sclerosis (Lancet Neurology, 2016). According to these criteria, disease dissemination requires involvement in at least two of the five specific areas of the Central Nervous System, as outlined in the report.

3.1.3. University Hospital of Basel

The documents provided are medical reports from Basel University Hospital (USB) and are specifically focused on the diagnosis and follow-up of patients with MS. The two documents can be found in [Appendix III](#).

The “diagnostic report” includes a detailed analysis of MRI images of the brain, evaluating various regions for T2 hyperintense white matter lesions. The report also assesses compliance with the McDonald criteria, which are widely used diagnostic criteria for MS. In addition, the report provides an assessment of brain atrophy and any other abnormalities seen on the MRI images. As mentioned earlier, atrophy is not relevant to us in this project. Concerning the McDonald criteria, it is a set of diagnostic guidelines used for the diagnosis of MS. It was first introduced in 2001 and has been updated

over the years to improve the accuracy and efficiency of diagnosing the disease. The latest version, the McDonald 2017 criteria, represents the most recent and widely accepted guidelines for diagnosing MS (Marisa (M.) Wexler, 2023).

The McDonald criteria play a crucial role in determining the distribution of lesions, helping to ascertain whether they are localized in the same area or spread across different parts of the brain. Unfortunately, for the scope of this project, the absence of an atlas limits our ability to achieve this level of analysis, much like the assessment of atrophy. As a result, these specific aspects will not be feasible to explore at this stage.

In addition, the “follow-up report” contains information on subsequent brain MRI scans to monitor the course of MS in patients with a known diagnosis. The report assesses the presence and distribution of T2 lesions, and any new or progressive lesions compared with previous examinations. It also assesses the presence of T1 lesions.

3.2. Structured Reports

According to J. Martijn and al.: *“Structured Reporting is advocated as a means of improving reporting in radiology to the ultimate benefit of both radiological and clinical practice”*. However, with numerous characterizations of the term in circulation, “Structured Reporting” has become ambiguous and is often confused with “standardisation” (J. Martijn (J. M.) Nobel, 2020).

Beyond the realm of clinical trials, there are many reasons to encode structured, quantitative, and coded information related to images. Indeed, the ordinary human-readable radiology report, authored by radiologists for the consumption by an ordering physician, is often implicitly structured, by section headings, may contain quantitative information that has been measured and recorded manually, and frequently contains codes or keywords, for reimbursement purposes as well as for automated text generation from macros. One of the initial goals for the development of the DICOM Structured Report (SR) capability was to encode such reports, in a form that would allow information to be extracted more readily than from a paper printed report, or unstructured plain text (Clunie D. A., 2007).

3.3. DICOM Structured Reporting

Definition and adoption

According to Rada Hussein and al, Structured Reporting was added to the DICOM standard to provide an efficient mechanism for the generation, distribution, and management of medical reports. SRs can be used to exchange almost any sort of structured text data, including observations and reports (Rada (R.) Hussein, 2004).

David Clunie explains that the term “Structured Reporting” can be interpreted in many ways. It is important to understand that a structured document is defined more by **how** it is constructed rather than **what** it contains. He also explains that the word “report” in the name is actually a mistake, as a DICOM SR can carry any type of structured content, not just Structured Reports. SR documents can be used wherever there is a need for lists or hierarchically structured content, or a need for coded concepts or numerical values, or references to images, or other composite objects (Clunie, DICOM Structured Reporting, 2000).

Human-readable radiology reports often have an implicit structure with section headings, quantitative measurements, and codes for reimbursement and automation. The initial goal was to encode such reports for easier indexing and retrieval, but challenges like additional authoring effort and limited dissemination beyond the radiology environment hindered progress (Clunie D. A., 2007).

Despite these challenges, DICOM SR found success in encoding machine-generated structured content, such as measurements from imaging equipment and computer-assisted detection/diagnosis (CAD/CADx). The framework proved ideal for creating evidence documents, with both acquisition and reporting equipment supporting DICOM encoding for exchanging images (Clunie D. A., 2007).

For encoding structured, quantitative, and coded information derived from images, DICOM SR offers a reliable and efficient solution, particularly in clinical trials and medical imaging applications. It is increasingly replacing proprietary exchange mechanisms, not only in radiology but also in cardiology. The following sections will delve into how such information is encoded, and the additional steps required for reliable interchange between clinical trials systems (Charles E. Kahn Jr, 2007).

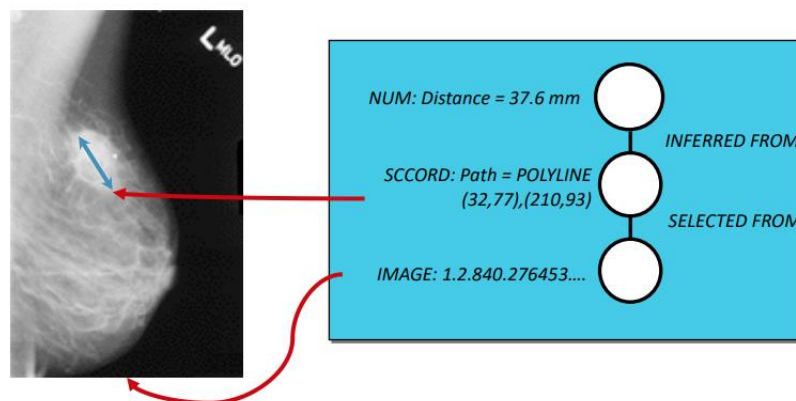
Content

A DICOM SR consists of a tree structure rooted at a single node, representing the report's title, like “Brain MRI Report”. Each node is referred to as a “content item”, and they have different types such as “CONTAINER”, “CODE”, “SCoord”, and “IMAGE”. CONTAINER serves as a section heading and contains child nodes, while CODE describes a coded concept with a value. SCoord defines spatial

coordinates on the corresponding image, and IMAGE references a specific image using its unique identifier.

DICOM SR enables efficient encoding, storage, and interchange of structured content, making it ideal for clinical trials and evidence documents. Along with other value types like “NUM”, “TEXT”, “DATE”, and “TIME”, DICOM SR provides a comprehensive framework for encoding diverse medical information.

Figure 5: DICOM SR Content example



Source: https://www.dclunie.com/papers/DICOM_2018_StructuredReports.pdf

In a DICOM SR document, crucial information is conveyed through individual “content items”, each representing a “name-value” pair. The precise identification of the “name” is known as the “concept name”, which is consistently defined using a code rather than free text. This approach enhances the document's organization, indexing, and searchability. Moreover, concept names serve as headings for containers and provide context for image and waveform references (Clunie D. A., DICOM Structured Reporting, 2000).

Every content item includes a corresponding “value”, which can take on various formats such as plain text, coded values, numeric values with units, person names, dates, times, and references to DICOM images. This flexibility ensures that diverse types of information can be effectively represented within the DICOM SR document (Clunie D. A., DICOM Structured Reporting, 2000).

In the DICOM SR standard, each document focuses only on conveying its intended meaning, without specifying how it should be displayed, printed, or presented. The emphasis is on maintaining unambiguous and independent meaning, free from any assumptions about its presentation (Clunie D. A., DICOM Structured Reporting, 2000).

To draw a comparison, DICOM SR can be compared to eXtensible Markup Language (XML), which carries meaningful tags but lacks explicit or implied presentation details, unlike HyperText Markup

Language (HTML) which incorporates both meaning and explicit presentation information. Just as an XML document may require a separate presentation tool, such as an eXtensible Stylesheet Language (XSL) or Cascading Style Sheets (CSS) file, to be rendered properly, the DICOM SR content also requires an application capable of transforming it into an appropriate format. This separation of content and presentation ensures the flexibility and adaptability of DICOM SR in diverse medical imaging applications and environments (Clunie D. A., DICOM Structured Reporting, 2000).

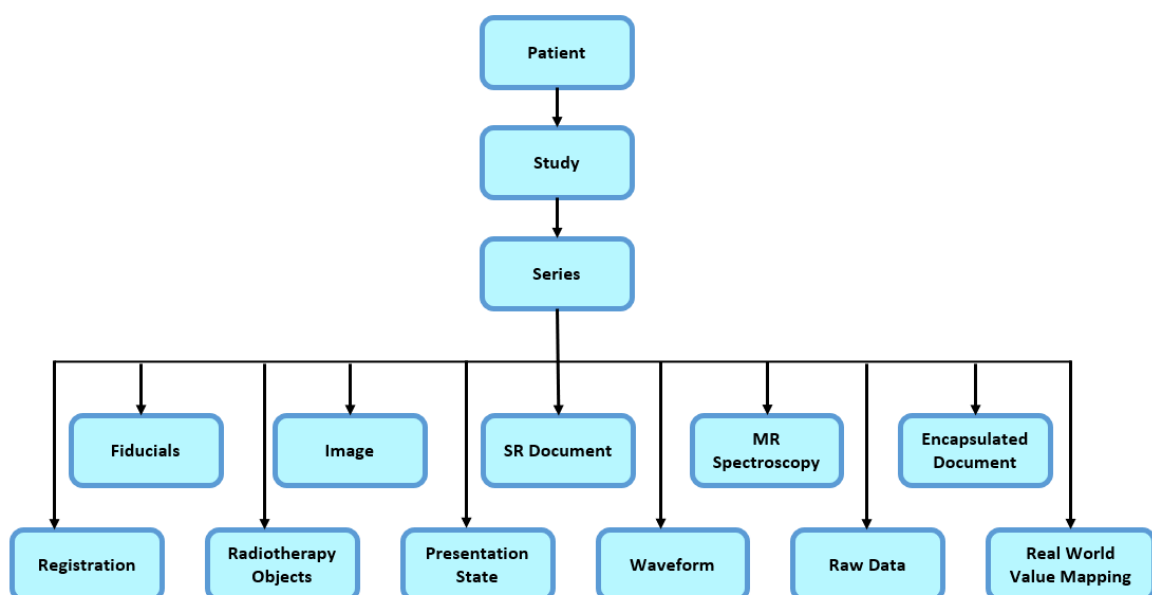
Coded terminology

DICOM SR utilizes coded terminologies from controlled vocabularies, allowing information extraction from DICOM documents for broader use in healthcare domains. When coding with controlled vocabularies, DICOM requires including a human-readable meaning “display name” for each code. This ensures that recipients can interpret the code without access to external dictionaries or services. Codes consist of a triplet, including the “coding scheme designator”, “code value”, and human-readable “code meaning”. For example, (F-01766, SRT, “Punctate Calcification”).

Structure

SR uses the DICOM Patient/Study/Series information model (header), plus a hierarchical tree of “Content Items” (Solomon, 2013, p. 5). The following figure represents where the SR document is located in the DICOM data module and shows how the DICOM SR structure fits in a real-world model.

Figure 6: DICOM SR Hierarchy



Source: Adapted from <https://link.springer.com/article/10.1007/s11548-009-0297-y>

3.3.1. Benefits and applications

In this section, we focus on its benefits. We believe they are significant, and understanding their importance helps to overcome any resistance to change in the interpretation process. Benefits of SRs include:

- **Better communication with the referring physician:** Referring physicians greatly value SR due to their concise and comprehensive nature. The clear organization of information in Structured Reports enhances readability, allowing for quicker assimilation of crucial details. Key elements within the structure can be effectively highlighted, ensuring that important findings are easily noticeable and not overlooked (Noumeir, 2006).
- **Direct referencing of DICOM objects:** One of the significant advantages of DICOM SR is its capability to directly reference other DICOM objects, such as medical images. This linkage enhances the contextual understanding of the reported information, providing a more comprehensive view of the patient's condition (Rada (R.) Hussein, 2004).
- **Template-based structure:** DICOM SR allows for structured data representation, enabling efficient data exploration and precise measurement of results. The standardized structure facilitates uniformity and consistency in reporting (OTpedia, 2023).
- **Header information consistency:** The SR shares the same header as the images, the header information is copied from the image by the application that generates the SR. This ensures the correctness and consistency of the patient and study information (Noumeir, 2006).
- **Integration:** The integration with external applications and the creation or processing of structured information are simplified (OTpedia, 2023).
- **Enhanced quality of reports:** Disease-specific report templates in DICOM SR can significantly improve the clarity and quality of radiology reports. Standardized templates ensure consistent use of terminology across practices, reducing ambiguity and enhancing communication between healthcare professionals (Noumeir, 2006).
- **Reduced diagnostic errors:** DICOM SR supports checklist-style reports that help reduce diagnostic errors. By following standardized reporting templates, radiologists can avoid oversight and ensure critical findings are not missed, leading to improved patient care and safety (Noumeir, 2006).

3.3.2. Success stories

In this section, we will explore projects that have successfully implemented the DICOM SR standard for Structured Reports, providing valuable insights and success stories.

“Design and development of an ethnically diverse imaging informatics-based eFolder system for Multiple Sclerosis patients”, conducted by Kevin (K.) C MA, James W. (J. W.) Fernandez, Lilyana (L.) Amezcua, Alexander (A.) Lerner, Mark S. (M. S.) Shiroishi and Brent J. (B. J.) Liu.

This first study shares a similar context with our MSxplain project, which also focuses on Multiple Sclerosis. This project offers comprehensive details, enriching our understanding of the process. The outcomes align closely with our objectives, making it an essential and intriguing reference. Notably, they have developed an algorithm for calculating the volume of brain lesions. To leverage the DICOM SR standard, they utilized MATLAB to convert the algorithm outputs into an XML document. Subsequently, a “dcmstk”⁸ open-source toolkit was employed to transform the XML data into an SR document. Finally, a Hypertext Preprocessor (PHP) script facilitated the conversion into an HTML table, presenting the SR in a web-friendly format. The approach taken by this project serves as a valuable source of inspiration and guidance for our own project (Kevin (K.) C MA, 2015).

“Implementing DICOM Structured Reporting in a Large-Scale telemedicine network”, conducted by: Aldo (A.) Von Wangenheim, Cloves Langendorf (C. L.) Barcellos Junior, Rafael S. (R. S.) Andrade, Isabela (I.) De Carlos Back Giuliano, Andriano Ferreti (A. F.) Borgatto and Dalton Francisco (D. F.) De Andrade.

This article discusses the integration of medical reports using the DICOM SR standard in large-scale telemedicine networks. The approach is to use structured vocabularies beyond radiology and focuses on a telecardiology case study. The study examined possible associations between cardiac risk factors and diagnoses using DICOM SR. The application developed, named “Cyclops SR (CSR)”, allows physicians to write SR using vocabularies and link descriptors to the report, resulting in standardized reports. The CSR application works as a library in an HTTP server, allowing physicians to access information from DICOM studies and structured vocabularies. The research demonstrates the feasibility and effectiveness of the DICOM SR standard in telemedicine networks, facilitating data exploration. The approach has been successfully applied in a large-scale telemedicine network, generating thousands of Structured Reports per day. Future work includes extending the methodology

⁸ <https://github.com/DCMTK/dcmstk>

to teleradiology services, integrating a specific vocabulary for radiology-specific Structured Reports named “RadLex” (Aldo (A.) Von Wangenheim, 2013).

“**Structured Reporting in Multiple Sclerosis Reduces Interpretation Time**”, conducted by Jonathan R. (J. R.) Lee, Robert A. (R. A.) Bermel, Jennifer (J.) Bullen, Paul (P.) Ruggieri and Stephen E. (S. E.) Jones.

This study does not directly concern DICOM SR, rather simply Structured Reports. One interesting result is the following: *“over the study period, 5824 MS MRI reports were completed with SR, and 1034 were completed without SR. Mean and median interpretation times before the implementation of SR for MS were 11.0 and 8.0 minutes, respectively, versus 8.5 and 6.0 minutes, respectively, after the implementation of SR”*. (Jonathan R. (J. R.) Lee, 2021)

This reduction in interpretation times indicates the efficiency and impact of using Structured Reports for MS MRI examinations. With SR, radiologists could complete their evaluations more quickly, potentially leading to improved workflow and patient management. The adoption of SR seems to have positively influenced the diagnostic process, allowing for faster access to critical information, and potentially enhancing patient care. Even if it does not directly concern DICOM SR, the findings offer valuable insights into the advantages of using standardized reporting systems in medical imaging, which can be crucial for optimizing radiological practices and overall healthcare outcomes (Jonathan R. (J. R.) Lee, 2021).

3.3.3. Limitations

- **Limited adoption outside radiology:** While DICOM SR fulfils imaging document encoding and archiving needs within radiology departments, its adoption outside of radiology has been limited. This is because the DICOM standard historically focused on encoding and communication of images, and other departments within healthcare may not be fully equipped to handle DICOM SR data (Noumeir, 2006).
- **Structured input challenges:** One of the significant challenges in the wide adoption of DICOM SR is the requirement for structured input during the interpretation process by radiologists. Transforming narrative reports into Structured Reports using natural language processing can be complex and may not capture all essential information accurately (Noumeir, 2006).

- **Resistance to change:** This is not a technical point but a personal one, introducing structured input by radiologists to generate DICOM SR reports may face resistance due to changes in the interpretation process. Radiologists and other healthcare professionals may need to adjust their reporting practices, which can take time and effort (Dhakshinamoorthy (D.) Ganeshan, 2018).

3.4. Alternative formats

DICOM SR, as discussed earlier, offers a structured format for encoding imaging diagnostic reports, providing semantic understanding. However, due to certain limitations and the historical focus on radiology, alternative formats are worth considering meeting the needs of various healthcare departments and institutions. In our analysis, we explored previously existing templates in neuroradiology. We found that two commonly used alternative formats could be used to generate Structured Reports are HTML and Word/PDF format.

3.4.1. HTML

Hypertext Markup Language is a widely used format for creating web pages and documents that are easily viewable on web browsers. Healthcare institutions, including the Swiss Society of Radiology, have adopted HTML as an alternative format for their Structured Reports for several reasons:

- **Web accessibility:** HTML-based reports can be easily accessed and viewed on various devices with internet connectivity, making it convenient for healthcare professionals to access reports remotely on any devices (Singhal, 2022).
- **Simple structure:** HTML is known for its straightforward and fixed structure, comprising predefined tags and attributes. The consistency in its syntax allows developers to quickly grasp the language and build web pages efficiently (Vatsal, 2022).
- **Flexibility in presentation:** HTML allows for flexible and customizable report presentation, enabling healthcare institutions to design their report templates according to their specific requirements and branding guidelines (HTML report: How to develop it efficiently?, 2023).
- **Lightweight and quick:** HTML is a lightweight markup language, which significantly reduces loading times for clients. This means that web pages built with HTML load quickly, allowing users to access content and information more efficiently ((P.), 2022).

- **Data linking:** HTML documents can include hyperlinks to other related data, such as images or additional information, enhancing the overall accessibility and richness of the report (Singhal, 2022).

3.4.2. Word/PDF

Word or Portable Document Format (PDF) are file formats that can be used to create detailed reports. They are well-known and can be applicable for the presentation of medical imaging results in a visually attractive and readily shareable way since they support the inclusion of text, photos, annotations, and formatting choices.

- **Familiarity and user-friendly interface:** Many healthcare professionals are familiar with using Microsoft Word, making it easier for them to create, edit, and share Structured Reports in this format (Vaibhav, n.d.).
- **Customization:** Word documents allow for extensive customization with respect to report templates, formatting, and layout, allowing healthcare institutions to tailor the reports to their specific needs (Vaibhav, n.d.).
- **Rich text content:** Word format supports rich text content, including images, tables, and graphs, which can be valuable for conveying complex medical information effectively (FREE 5+ Medical Report Forms in MS Word | PDF, n.d.).
- **Interoperability:** Microsoft Word and PDF format are widely recognized and utilized, making it easy to share reports with colleagues, referring physicians, and other healthcare providers.

While HTML and Word format offer advantages for Structured Reporting outside of radiology, it's essential to consider certain challenges. These formats lack the strict constraints and standardized vocabulary of DICOM SR, potentially leading to variability in how data is represented, interpreted, and exchanged.

3.5. Comparison of formats

Each format offers unique advantages and comes with its set of limitations, which must be carefully considered when selecting the most suitable format for Structured Reporting. Let's explore the key points raised in the comparison, highlighting the strengths and weaknesses of each format.

Table 1: Comparison SR formats advantages and limitations

Format	Advantages	Limitations
DICOM SR	<ul style="list-style-type: none"> • Structured format. • Standardized vocabulary and constraints. 	<ul style="list-style-type: none"> • Limited flexibility in presentation and layout. • Limited adoption outside radiology.
HTML	<ul style="list-style-type: none"> • Web accessibility, easily viewable on various devices. • Flexible and customizable report. • Data linking. 	<ul style="list-style-type: none"> • Lack of strict constraints • Lack of standardized vocabulary.
Word/PDF	<ul style="list-style-type: none"> • Visually attractive. • Supports inclusion of text, photos, annotations, and formatting choices. 	<ul style="list-style-type: none"> • Lack of strict constraints and standardized vocabulary.

Author's source

In this second comparison matrix, we will evaluate the three formats for Structured Reporting based on several critical criteria that hold particular significance for this project. These criteria include the medical context, data structure, interoperability with DICOM and Kheops, report efficiency, visualisation capabilities and ease of implementation. Understanding how each format performs in these aspects will help in deciding about the most suitable format for SR.

Table 2: Comparison SR formats with criteria

Criteria	DICOM SR	HTML	Word/PDF
Medical Context	Specifically designed for medical imaging and clinical data with standardized terminologies.	Lacks specific medical context and specialized terminologies.	General-purpose format, lacking medical context and specialized terminologies.
Data structure	Structured format with predefined templates and hierarchies.	Semi-structured format allowing some organization of data using HTML tags.	Unstructured format, requiring manual organization and interpretation of data.
Interoperability with DICOM images	High interoperability within medical systems that support DICOM standard.	Limited interoperability.	Limited interoperability.
Report efficiency	Efficient reporting with structured data entry, reducing the need for manual typing.	Efficient reporting but manual editing.	Efficient reporting but manual editing.
Visualisation	Supports the inclusion of medical images and annotations with structured data.	Limited image support, mostly for embedded images with annotations.	Limited image support, mostly for embedded images with annotations.
Ease of implementation	Requires expertise in DICOM and Structured Reporting.	Most straightforward and easy to implement.	Relatively easy, familiarity with Word and PDF creation tools.

Author's source

3.6. Conclusion

For the generation of SRs in our project, we have chosen to use the DICOM SR format, and there are several reasons for this decision.

Firstly, DICOM SR is specifically designed for medical imaging and clinical data, making it very suitable for encoding diagnostic reports generated from our medical images. It provides a standardised terminology that ensures a clear and unambiguous representation of medical information, which is essential for accurate communication and interpretation.

Secondly, DICOM SR offers a structured and hierarchical data format with predefined templates, allowing specific encoding of medical data. This structured approach enables consistent and organised reporting, reducing the need for manual data entry and minimising the risk of errors or misinterpretation. The use of templates ensures that essential information is included, improving the completeness and reliability of our reports.

DICOM SR is also highly interoperable with medical systems that support the DICOM standard. This integration enables efficient communication and exchange of Structured Reports between different healthcare facilities, facilitating collaborative working and improving the overall efficiency of the diagnostic process.

In addition, DICOM SR allows medical images and annotations to be included alongside the structured data. This feature is particularly valuable as it provides a comprehensive and visually rich representation of our results, enhancing the diagnostic value of the reports generated.

Although implementing DICOM SR may require expertise in DICOM and Structured Reporting, we believe that the benefits it offers outweigh the initial investment in resources. The robustness and standardisation of DICOM SR ensures that our generated reports will be compatible with various medical imaging systems and widely accepted in healthcare.

In conclusion, the adoption of DICOM SR as the chosen format for Structured Reports is in line with our commitment to provide accurate, standardised, and interoperable diagnostic reports to improve patient care and advance medical research as part of our project.

4. Medical image viewers

4.1. Introduction

A medical image viewer is a software application or tool that enables the visualisation and interpretation of medical images (Mousa, 2023). It allows healthcare professionals, such as radiologists, to view and analyse various types of medical images. The viewer provides functionalities for manipulating, zooming, panning, and adjusting the visual characteristics of the images to help in diagnosis of a medical case. Additionally, some viewers offer advanced features such as 3D rendering, image segmentation, measurement tools, and annotation capabilities to improve the analysis and understanding of medical images. In this section, we will analyse existing viewers and compare them.

4.2. Comparison criteria

When evaluating and comparing different viewers, several aspects come into play. In our context, we will describe existing viewers based on specific criteria that are crucial for our use case:

- **Web-based:** A key requirement for this project is to have an online viewer that grants access to different albums, studies, series, and images. This enables sharing features among team members and ensures accessibility from various machines. Moreover, the viewer needs to be web-based to integrate with the existing Kheops platform. Further details regarding this integration will be discussed in the implementation section.
- **DICOM SR support:** Since one of the project's objectives is to generate a Structured Report, it is essential for the selected viewer to be capable of reading or, at the very least, saving DICOM SR files. The level of DICOM SR support may vary across different viewers in terms of implementation and version, but the critical requirement is that the viewer supports this format.
- **User interface:** An intuitive and user-friendly interface is crucial for efficient usage of the viewer. The viewer should propose a well-designed interface that allows users to navigate through images and perform necessary tasks with ease.
- **Integration capabilities:** Possible integration with other systems or platforms is a valuable aspect to consider. The viewer should have integration capabilities that enable interoperability with existing healthcare information systems, such as the PACS. This ensures the exchange of data between different components of the healthcare infrastructure.

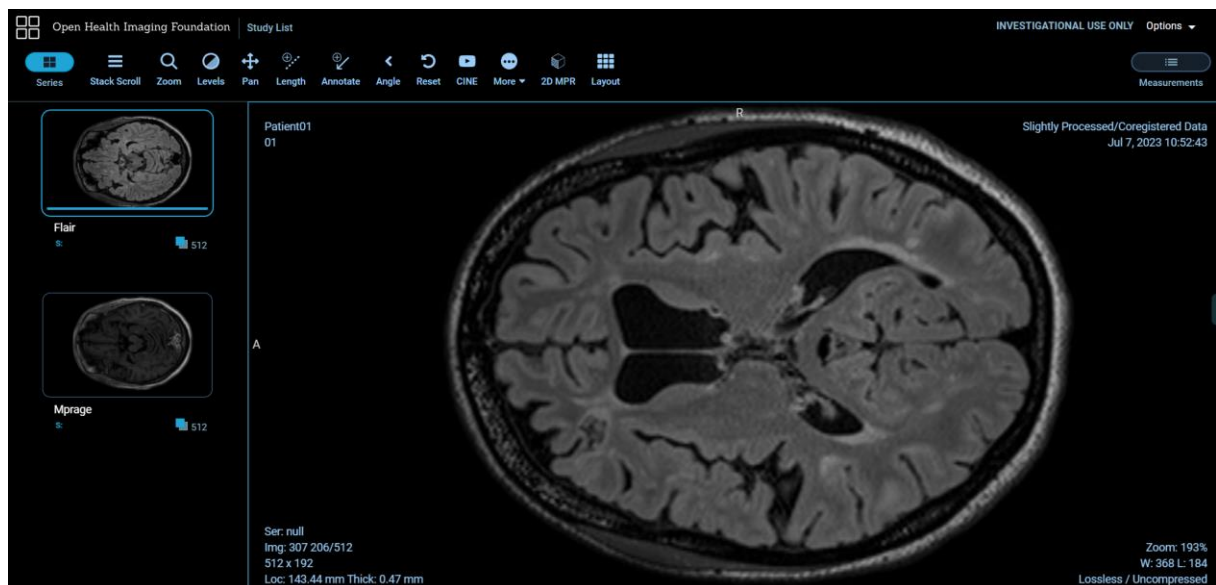
4.3. Analysis of existing viewers

In the following sections, we will analyse six distinct viewers, providing a concise overview of their key features and evaluating their compatibility with the criteria mentioned above. By exploring these viewers in detail, we aim to gain a comprehensive understanding of their capabilities and determine their suitability based on our specific requirements.

4.3.1. OHIF

Open Health Imaging Foundation (OHIF)⁹ is an open-source web-based viewer for medical images. It provides two main features which are visualisation and annotation. It supports various formats, including DICOM, can handle medical images very well, and therefore ensures compatibility with a wide range of imaging systems. Its flexibility allows healthcare professionals to view and interact with medical images from different devices easily (Open Health Imaging Foundation, n.d.).

Figure 7: OHIF image visualisation



Author's source

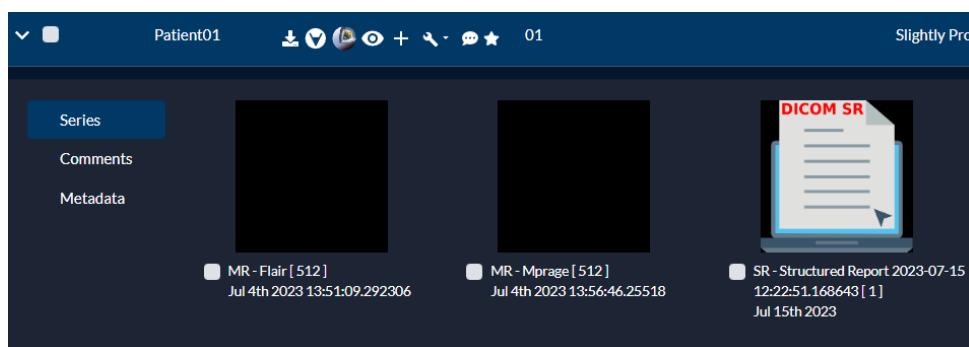
The interface of OHIF viewer typically consists of multiple components. On the left pane, there is a workspace that displays a hierarchical structure of folders and files, allowing users to easily navigate through different studies and series. This enables efficient organization and retrieval of medical images for analysis.

⁹ <https://ohif.org/>

In the central area of the screen, the medical images are displayed in a dedicated viewer panel. OHIF offers various interactive tools and functionalities to manipulate and analyse the images. Users can zoom in or out, pan across the image, adjust windowing and levelling, and apply various image processing techniques to enhance the visualisation.

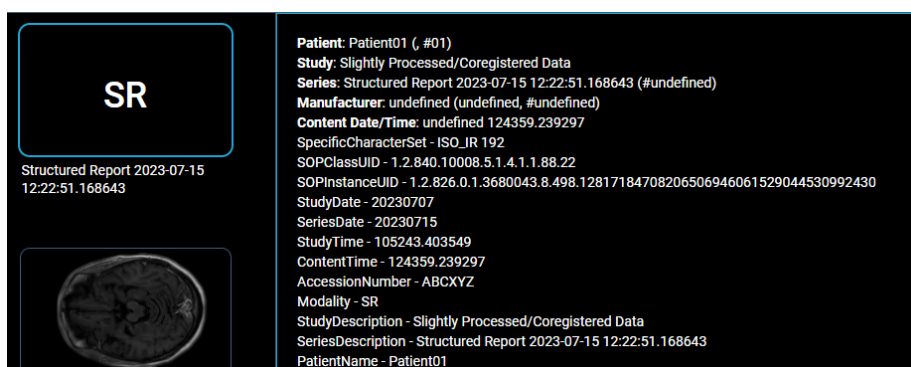
OHIF is capable of storing, reading, and displaying DICOM SR files.

Figure 8: OHIF DICOM SR storing support



Author's source

Figure 9: OHIF DICOM SR reading



Author's source

OHIF also provides annotation capabilities, allowing users to draw regions of interest, place markers, and add textual annotations directly on the images. These annotations can be used for documentation, measurement tracking, and collaboration among healthcare professionals. These annotations can be exported as DICOM SR. Furthermore, OHIF allows the rehydration of measurements by utilizing previously exported DICOM SR enabling precise measurement tracking and analysis within the viewer itself (Measurement Tracking | OHIF, 2022).

Additionally, OHIF Viewer is capable of invoking DICOM web REST APIs, it might be worth noting this information, for development purposes (Arvindpdmn (A.), 2023).

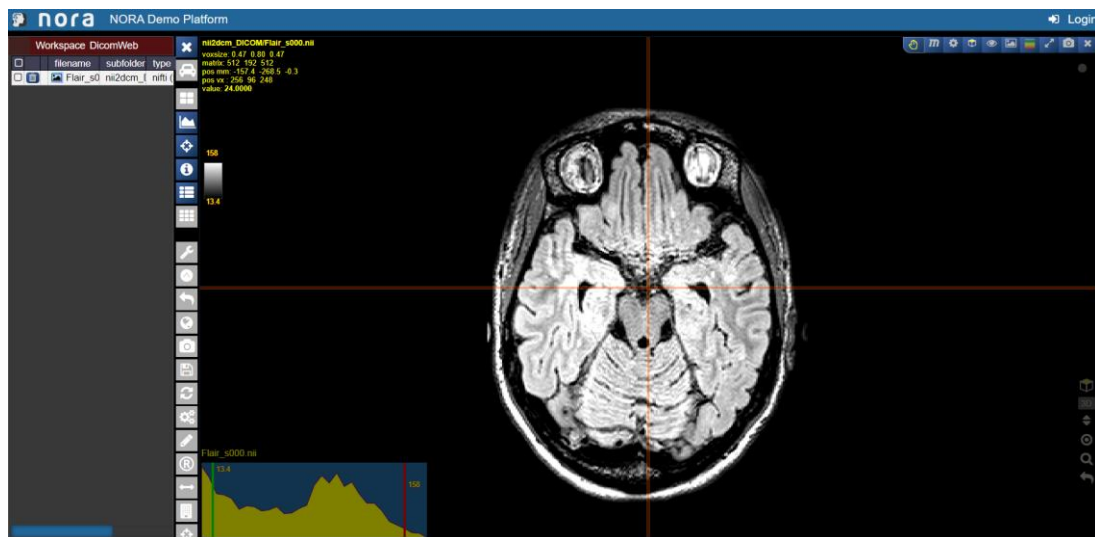
4.3.2. Nora

Neuroradiology Online Reporting and Analysis (Nora)¹⁰ is a web-based platform specifically designed for generating neuroradiology reports. It supports various image formats, including DICOM, and provides specific tools for generating Structured Reports (Elias (E.) Kellner, n.d.).

Nora itself does not provide native capabilities to store or read DICOM SR files. Instead, it focuses on extracting information from radiology reports and transforming it into structured data that can be further utilized or integrated into existing systems.

Its interface consists of a workspace located on the left pane, which contains folders and files, and the central area of the screen where the medical image is displayed. This intuitive layout allows users to navigate and interact with the viewer efficiently, facilitating the analysis and interpretation of medical images.

Figure 10: Nora Image visualisation



Author's source

The viewer can be tested in two ways: through web access or by using the desktop application. By offering both web access and a dedicated application, Nora helps users for their diverse needs, allowing them to choose the most convenient way to access the viewer and analyse medical images effectively.

¹⁰ <https://www.nora-imaging.com/>

4.3.3. ITK-SNAP

ITK-SNAP¹¹ is a powerful open-source software application designed for segmenting anatomical structures in 3D medical images. Its primary focus is on image segmentation and analysis, making it a valuable tool for researchers and healthcare professionals. ITK-SNAP supports various image formats, including DICOM, which ensures compatibility with a wide range of medical imaging systems.

One notable aspect of ITK-SNAP is its clean and focused design. Unrelated features or functionalities that might distract from the core objective of image segmentation are kept to a minimum. This approach ensures that users can efficiently perform segmentation tasks without unnecessary complexity.

It does not have built-in support for DICOM SR.

Figure 11: ITK-SNAP image visualisation



Author's source

ITK-SNAP's integration capabilities lie in its ability to work with various image formats, and the ability to apply segmentation filters directly in the viewer.

¹¹ <http://www.itksnap.org/pmwiki/pmwiki.php>

4.3.4. OsiriX

OsiriX¹² is a popular medical image viewer and workstation software primarily designed for macOS. It supports the DICOM format and provides advanced visualisation and analysis tools for medical images (OsiriX DICOM Viewer | The world famous medical imaging viewer, n.d.).

OsiriX also supports DICOM SR, allowing users to view and import reports associated with the medical images. While it excels in the visualisation and analysis of medical images, its primary focus is on image interpretation rather than report generation.

In terms of user interface, the viewer offers an intuitive and user-friendly design. Its interface is designed to facilitate efficient image navigation, manipulation, and analysis. The software provides various tools and functionalities that allow users to adjust image parameters, perform measurements, apply annotations, and create 3D reconstructions.

OsiriX also offers integration capabilities with other medical imaging systems and workflows. It supports integration with PACS and allows users to connect to external servers for image storage and retrieval.

Since it is not available on Windows or Linux, no image visualisation will be tested in this section. Here is an image that looks like our implementation for this project.

Figure 12: OsiriX image visualisation



Source: <https://www.researchgate.net/publication/328845013/figure/fig4/AS:697263806509056@1543252054070/Screenshot-of-the-OsiriX-interface-showing-a-toolbar-composed-of-the-default.ppm>

¹² <https://www.osirix-viewer.com/>

4.3.5. 3D Slicer

3D Slicer¹³ is a free, open-source software for medical image, processing, and visualisation. It supports the DICOM format and some other common medical imaging formats (3D Slicer Image Computing Platform, n.d.).

3D Slicer does not have built-in support for DICOM SR, but it offers an extensible framework that can be adapted to accommodate additional formats and data types. For example, a module for DICOM is available, allowing importing, exporting and transfer of DICOM data (3D Slicer, n.d.).

The viewer proposes a user-friendly interface that combines powerful features with ease of use. Its interface is designed to facilitate efficient navigation, visualisation, and interaction with medical images. Users can explore volumetric data, perform advanced segmentation, register images, and create sophisticated 3D visualisations.

Figure 13: 3D Slicer image visualisation



Author's source

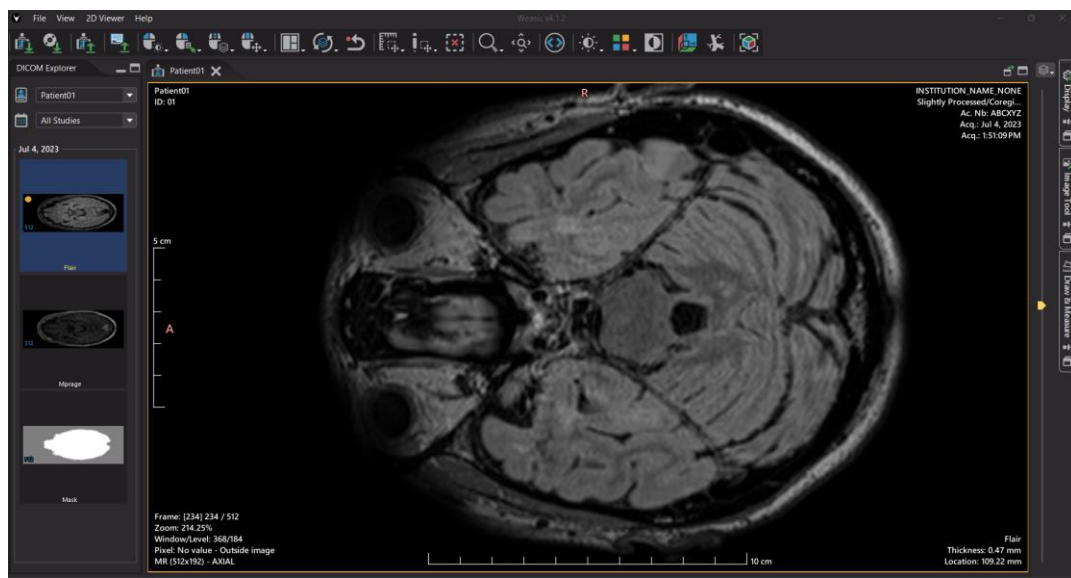
¹³ <https://www.slicer.org/>

4.3.6. Weasis

Weasis¹⁴ is a desktop application that supports various image formats, including DICOM. It is primarily focused on image visualisation and does not offer extensive features for generating Structured Reports (Roduit, n.d.).

It has a simple and user-friendly interface that makes it easier to view and analyse images. The design is well-made and has tools and features that are easy to use for image manipulation, measurements, and annotations (Roduit, n.d.).

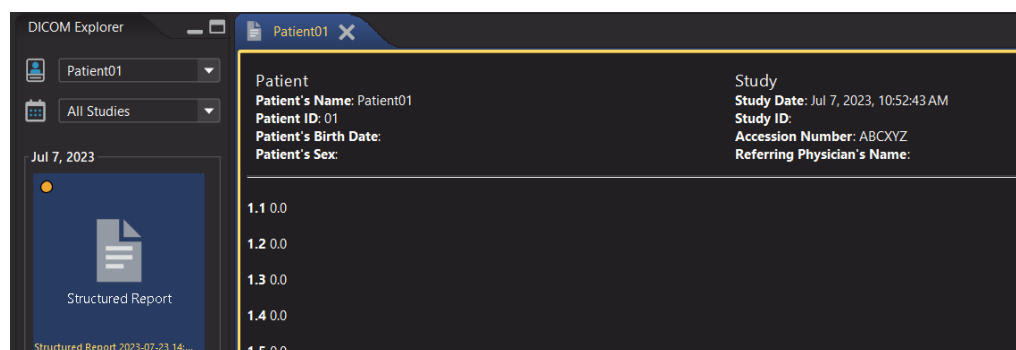
Figure 14: Weasis image visualisation



Author's source

It still does support DICOM SR by reading the files.

Figure 15: Weasis DICOM SR Support



Author's source

¹⁴ <https://weasis.org/en/index.html>

4.4. Comparison table

Based on the viewers previously mentioned, here is a comparison matrix between them. The idea here is to have a summary of all the viewers presented with the different criteria represented in columns. Each criterion is represented using the symbols "-", "+", "++", and "+++" as follows:

- “-”: represents a minimal level of the specified feature.
- “+”: represents a good level of the specified feature.
- “++”: represents a high level of the specified feature.
- “+++”: represents an excellent level of the specified feature.

Table 3: Comparison Table of existing medical imaging viewers

Viewer	Web-based	DICOM SR support	User interface	Integration capabilities
OHIF	Yes	Yes	+++	+++
OsiriX	No	Yes	++	-
Nora	Yes	No	+++	++
ITK-SNAP	No	No	+	++
3D Slicer	No	No	++	+
Weasis	No	Yes	+++	++

Author's source

Note: The information regarding DICOM SR support for OsiriX is imprecise due to its availability exclusively on a Mac machine. Unfortunately, we were unable to test it within our project, and thus, our evaluation is based on the data available online.

In conclusion, after an evaluation of various medical imaging viewers, OHIF emerged as the most suitable choice for our project, aligning with our specific requirements and objectives. Its web-based nature offers flexibility and accessibility, by allowing users to access and view medical images from any device. Its support of DICOM SR is invaluable for our needs. The possibility to both read and store DICOM SR information offers the integration of SR into our pipeline. Moreover, during our evaluation, we found OHIF's user interface to be intuitive and user-friendly. This facilitates easy navigation and interactions, making it an ideal choice for medical professionals. Considering all these factors, OHIF stands out as the optimal medical viewer for our project, and we think that it will meet our expectations.

5. Definition of uses cases

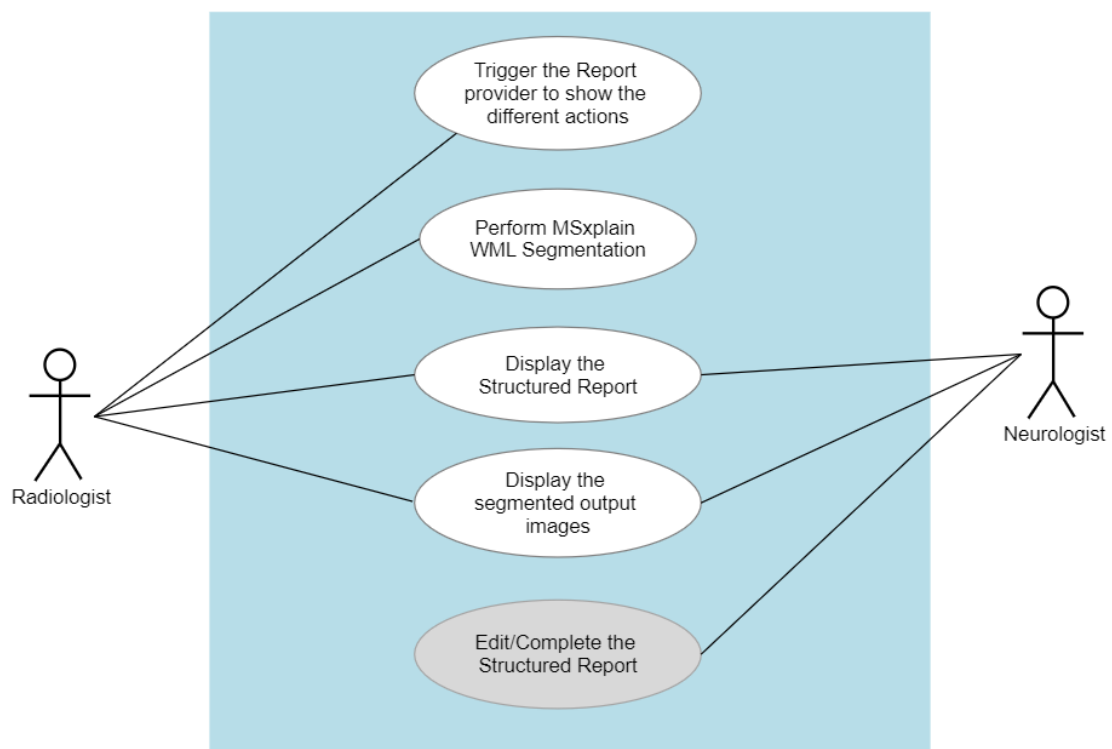
5.1. Context and diagram

The Structured Report that we want to generate is designed to facilitate the work of both the radiologist and the neurologist. Here we want to specify the roles of each actor in the process.

To better understand the roles and interactions of each actor in the process, we can use Unified Modeling Language (UML)¹⁵ use-case diagrams. These diagrams will illustrate the main functions and purposes of our system, showing how it interacts with the individuals involved (IBM documentation, n.d.).

The following use case diagram will serve as a visual representation of this integration.

Figure 16: Use Case Diagram



Author's source

¹⁵ Standardized modeling language

5.2. Radiologist

The radiologist has an important role in the interpretation and reporting of medical images. In the context of our use case, here is how the radiologist is involved:

- **Report pre-filling:** The algorithm will automatically pre-fill the report with relevant/important information extracted from the medical images. This includes details such as the patient's information and the number of lesions, the lesion volumes, and other quantitative features. This helps the radiologist save time and gives him a first draft of the report that can be reviewed.
- **Assistance in interpretation:** The algorithm can help identify important areas, spot anomalies, and give useful measurements. The final decision and overall interpretation remain the responsibility of the radiologist, who brings their expertise.
- **Report finalization:** After the report is generated, the radiologist can go back and access the medical images to review relevant sections, if necessary. This could help to interpret the results in the context of the patient.

5.3. Neurologist

The neurologist plays a crucial role in the overall patient care and utilization of the report generated by the algorithm. Here is how the neurologist is involved:

- **Review of the finalized report:** Once the report has been finalized by the radiologist, the neurologist can examine it to get a detailed evaluation of the imaging results and the outputs. The report provides key information about detected lesions to make the final diagnosis and treatment decisions.
- **Modification of the SR (Potential future improvement):** A possible future improvement could allow the neurologist or maybe even the radiologist, to modify the generated SR and storing the modifications in DICOM SR format. The integrity and interoperability of the report would therefore be maintained. Being able to change the SR would give the neurologist the freedom to add more clinical observations, notes, or personal interpretations based on their knowledge and specific needs of the patient. This will give him more power to customize the report and change it to better fit the patient's changing diagnosis and treatment.

6. Selection of development technologies

This section is dedicated to the selection of the development technologies. It includes both the backend and frontend aspects. The objective of this section is to find and identify the most suitable technologies that match with our needs and requirements for our project.

6.1. Back-end

For the backend development, two popular programming languages, Python and Java, are worth considering. Both languages offer robust ecosystems and have been widely adopted in the software development community. Note that the current backend of the system has already been written in Python and utilizes various libraries, such as PyDICOM¹⁶, which are crucial for our project's functionality.

- Python¹⁷, known for its simplicity and readability, aligns with the existing backend usage. Its large number of libraries and frameworks, including PyDICOM for handling DICOM data, provide the necessary tools to work with medical imaging data effectively. Python is a great option for improving the current backend and adding more features for the report generation and the implementation of the algorithm to calculate the number of lesions.
- Java¹⁸ is a very strong and commonly used language that has been around for a long time and has a lot of support and resources available. Java has powerful tools for the backend implementation and has an alternative of PyDICOM which is named dcm4che¹⁹. It offers many useful tools for parsing, manipulating, and extracting data from DICOM files. It helps with different types of medical image storage. The library is kept up to date and there are many people who use it, which makes it a good option for DICOM-related tasks in Java.

To make sure everything works well together, is easy to maintain, and take advantage of what is already there, it is suggested to keep using Python for the backend development. This decision can help us take advantage of the language's strengths and the already existing solution and smoothly combine with additional libraries such as the PyDICOM Structured Reporting²⁰ to generate a SR.

¹⁶ <https://pydicom.github.io/>

¹⁷ <https://www.python.org/>

¹⁸ <https://www.java.com/fr/>

¹⁹ <https://www.dcm4che.org/>

²⁰ https://pydicom.github.io/pydicom/stable/tutorials/sr_basics.html

6.2. Front-end

When considering the selection of a front-end technology for the project, several factors should be taken into account. React.js has already been implemented in the project for the front-end which is linked to Kheops (detailed later). This existing implementation provides a foundation that can be extended.

Although React.js offers many advantages, it is still crucial not to assume it as the perfect choice for this project, but to evaluate it to make sure it aligns with our specific objectives. It is also worth exploring other front-end technologies such as Angular or Vue.js.

- React.js²¹ is widely adopted, and this popularity brings several advantages, including a vast number of available resources, excellent performance, extensive community support, and numerous JavaScript libraries that enhance the project's capabilities. However, the frequent updates may require updating the code regularly (Mendes, 2023).
- Angular²² is a TypeScript-based open-source framework for complex enterprise-level applications, excelling in performance and high scalability. However, it can be heavyweight to implement and may lack flexibility (Mendes, 2023).
- Vue.js²³ is a lightweight, user-friendly JavaScript library for building interfaces, with easy integration into existing applications, simple syntax, and a large number of third-party libraries. However, it may have limited scalability, lack official documentation, and a smaller community compared to React and Angular (Mendes, 2023).

Considering these points, Angular may be relatively heavy to implement for this project, making React.js and Vue.js more favourable options. As we already had experience with React.js, and some elements were already implemented, we believe that using it remains the best choice for the front-end. This familiarity with React.js can contribute to time savings, the production of high-quality code, and the achievement of the project objectives.

²¹ <https://react.dev/>

²² <https://angular.io/>

²³ <https://vuejs.org/>

7. Implementation

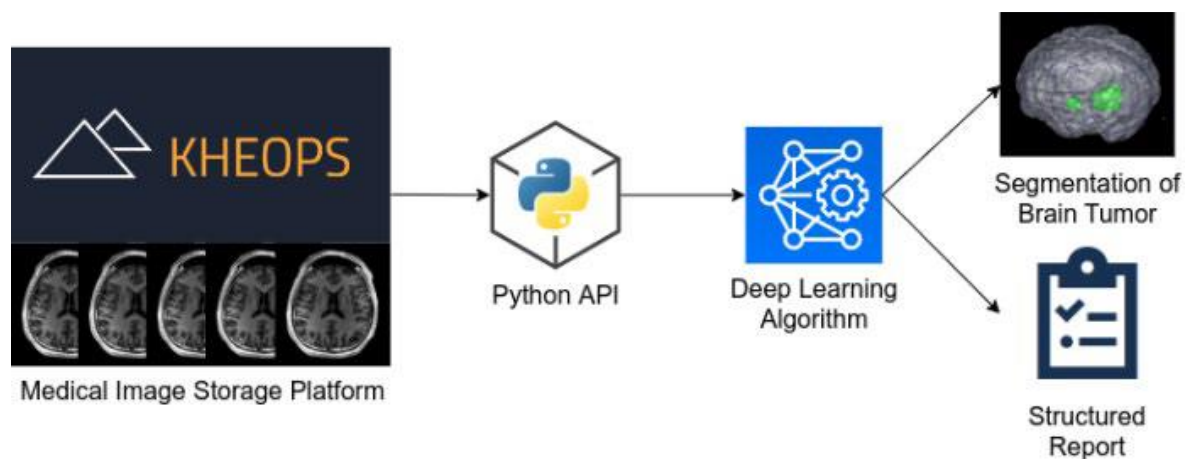
Now that we know how medical images are stored and shared, and the importance of Structured Reporting, we can start working on the implementation part. The primary objective is to integrate a report generation mechanism into an end-to-end pipeline. That would be very useful for future integration of the work done into the existing platform.

To begin, we will conduct an analysis of the entire pipeline, to see where exactly this project fits in. Subsequently, we will focus on critical components to see the main functionalities and interactions using a detailed activity diagram.

7.1. Description and schema of the pipeline

The following figure provides an overview of the global process of the MSxplain project. It uses a DL Algorithm to initiate the image segmentation process and generate a SR. While the initial phase of the project, involving the segmentation of brain lesions, has already been implemented, our focus here is on the subsequent stage.

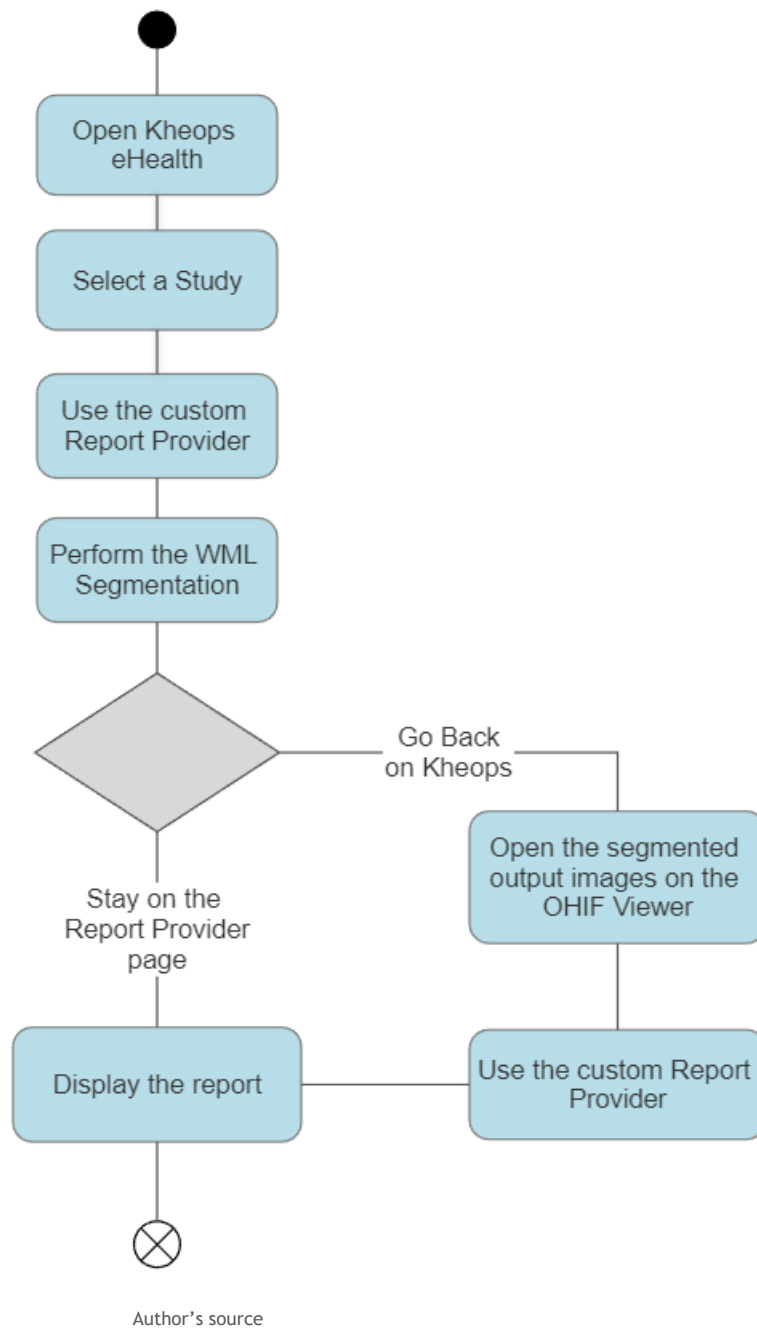
Figure 17: Schema of the pipeline



Source: Created by Adrien Depeursinge for MSxplain project

The following diagram illustrates the desired process for this project:

Figure 18: Activity Diagram for MSxplain project



First, let's look at the key parts and tools that are part of this pipeline.

- **Image dataset:** We used a publicly available dataset of medical images. This dataset serves as the foundation for our project and allows us to showcase the capabilities of the pipeline.
- **Kheops configuration:** Within the Kheops medical platform, we need to configure certain parameters that are essential to the process. These configurations will then allow to select a particular study to be used for the demonstration.
- **Algorithm execution:** We will use an algorithm to process the images from the Study selected. It performs analysis and extracts valuable information related such as the number and size of lesions, along with other relevant data.
- **Structured Report generation:** Once the algorithm completes its analysis, we will collect the results. The next thing to do is to change these outputs into a Structured Report that is well structured and follows the DICOM SR standard. The SR will contain the algorithm outputs and the metadata of the original image, including information about the patient. By keeping this information, we make sure that the Structured Report is accurate and can be traced back and linked to the correct image.
- **Structured Report display:** The last part consists of displaying the Structured Report that has been generated. By presenting the Structured Report in a clear and user-friendly format, we aim to help medical professionals with essential information about the patient's condition. The radiologist can efficiently interpret the imaging findings, while the neurologist can benefit from the comprehensive insights provided in the report.

7.2. Image dataset

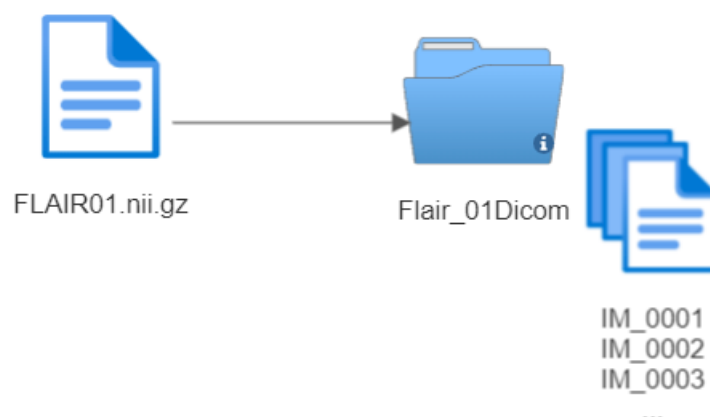
To build an end-to-end pipeline, we required a dataset that contains MRI images in the field of MS. Given the sensitive nature of such images, we needed a public dataset. We discovered an ideal dataset from the Laboratory of Imaging Technologies. The data is described in: Lesjak, Žiga, et al. “A novel public MR image dataset of Multiple Sclerosis patients with lesion segmentations based on multi-rater consensus.” *Neuroinformatics* (2017): 1-13. (Laboratory of Imaging Technologies, n.d.)

The main challenge here is that the images are stored in NIfTI format, whereas our pipeline required images in the DICOM format for compatibility with Kheops, and more specifically, the OHIF viewer. Converting NIfTI images to DICOM format was therefore necessary. As previously mentioned, NIfTI files are three-dimensional, whereas DICOM images are typically stored as two-dimensional slices. Consequently, it means a single NIfTI file can be converted into multiple DICOM files.

For this conversion, we used a python tool named “nii2dcm”²⁴. Specially designed for this purpose, it takes a single “.nii” or “.nii.gz” file as an input and generates a single-frame DICOM dataset. (Tomaroberts (T.), n.d.). Here is an example of use:

```
nii2dcm nifti-file.nii.gz dicom-output-directory
```

Figure 19: NiftI to DICOM explanation



Author's source

²⁴ <https://github.com/tomaroberts/nii2dcm>

Even after that, some tags that are necessary for OHIF or after the algorithm, are missing. We used again the tool named DICOM Browser to modify the files and add the following tags:

Table 4: Edition of DICOM Tags

Name	DICOM Tag	Value
Series description	0008 103E	Flair / Mprage
Modality	0008 0060	MR
SOAP Class UID for MR	0008 0016	1.2.840.10008.5.1.4.1.1.4
Photometric interpolation	0028 0004	MONOCHROME2
Pixel representation	0028 0103	1
Bits stored	0028 0101	16
Sample per pixel	0028 0002	1

Author's source

We also need to change the "studyUID" to the same identifier for both series. If it is different, they will not be stored in the same study.

Table 5: Edition of DICOM Tags - studyUID

Name	DICOM Tag	Value (Example)
Study Instance UID	0020 000D	2.25.57813621447072481234774682666597782873

Author's source

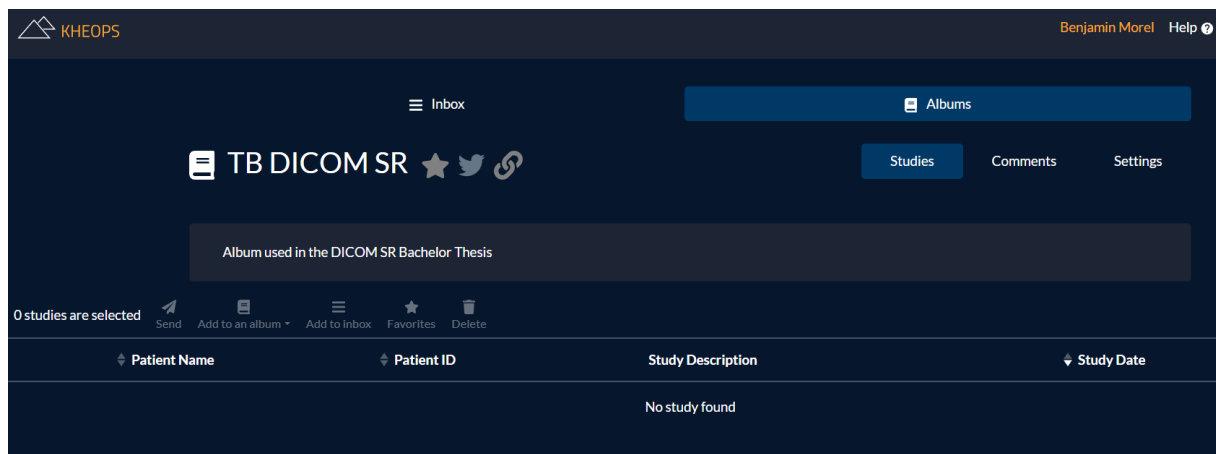
By making these changes, we made sure that the DICOM files were properly annotated and contained the necessary information to work well for the next steps of the process. These steps were very important in getting the dataset ready to use within the pipeline.

7.3. Kheops configuration

7.3.1. Album creation

Albums are collections of studies and series that can be shared with other users. Creating a new album is a straightforward process, we just have to provide a name and optionally a description (Albums, 2023).

Figure 20: Kheops album creation

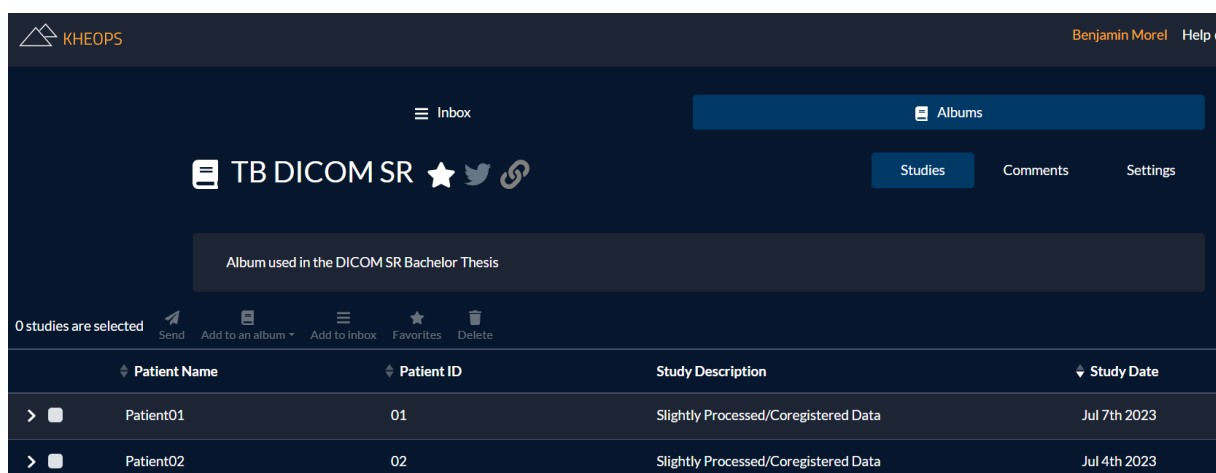


Author's source

7.3.2. Dataset import

We can then import the dataset that we converted in DICOM format earlier, by just drag-&-dropping the files in Kheops. Here is the result:

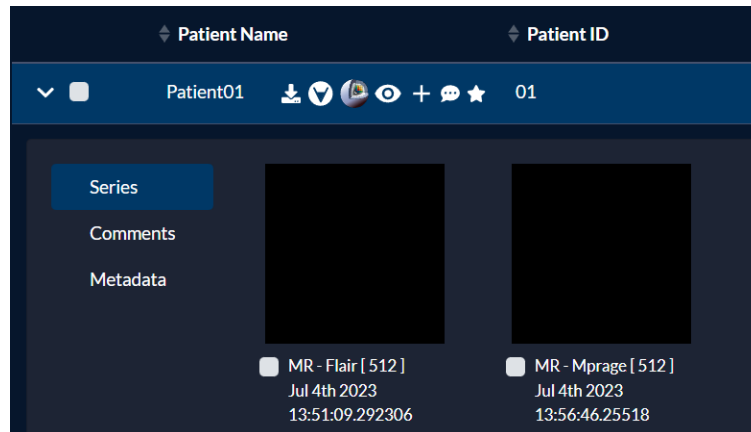
Figure 21: Dataset import Kheops



Author's source

We can see that the images are correctly imported.

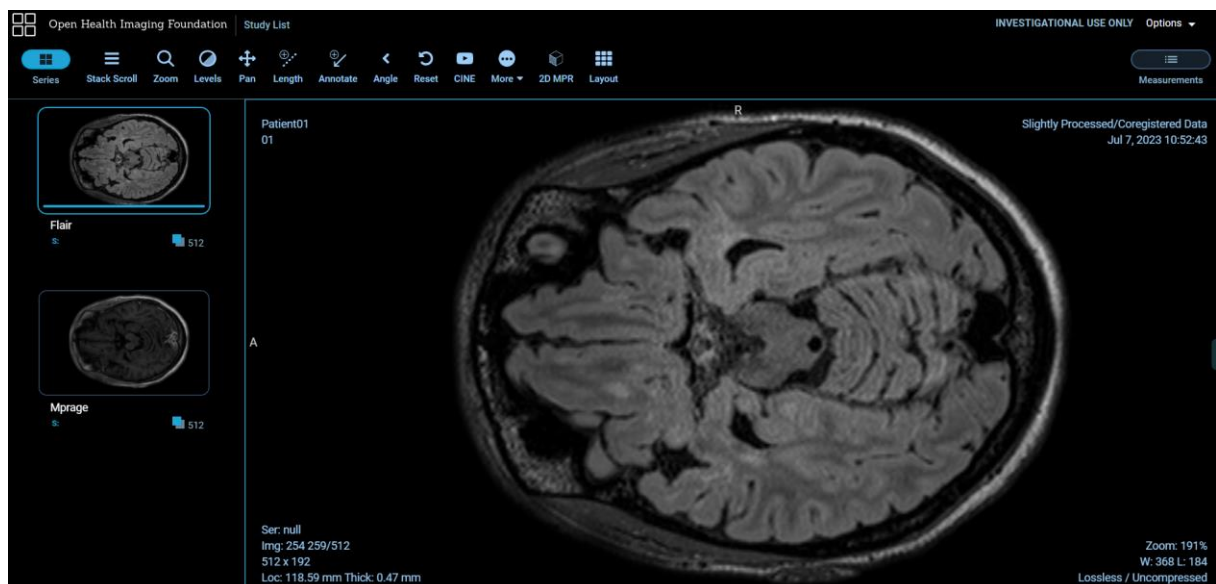
Figure 22: Successful dataset import Kheops



Author's source

And by clicking on one, we see these images directly in the imaging viewer. On the left pane, the two series are displayed in one column, and we can switch from one to another with a single click. In the central section of the viewer, the selected image is displayed, providing a clear and focused view.

Figure 23: Display image from the dataset



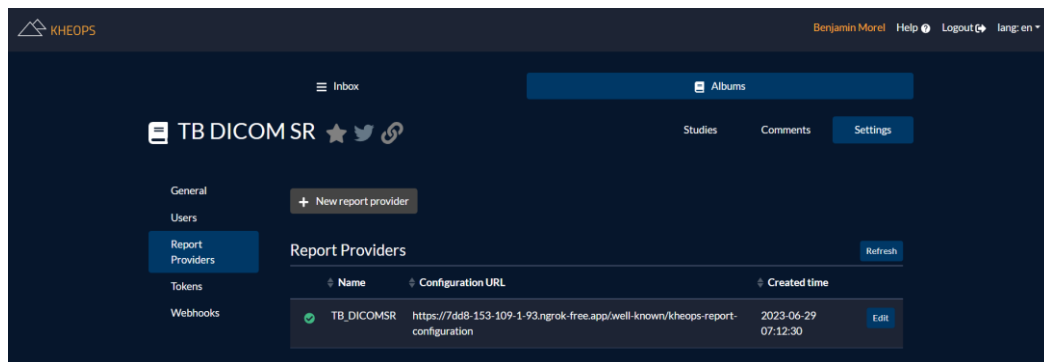
Author's source

7.3.3. Report Provider

Report Providers²⁵ are third parties that offer services for visualisation and analysis of medical information. Report providers have the ability to upload the data they obtain back to KHEOPS (Kheops, 2023). We used the existing report provider which was created especially for the MSxplain project.

For the configuration, we had to change some parameters, since the server is run locally. The modifications are made in the settings of the album “TB DICOM SR” that we created.

Figure 24: Custom Report Provider



Author's source

This figure shows the possible configuration for report provider. A tab on Kheops is dedicated to it, where we can put the configuration URL linked to the report provider that we created. To create this publicly available URL, we used a tool named Ngrok ²⁶.

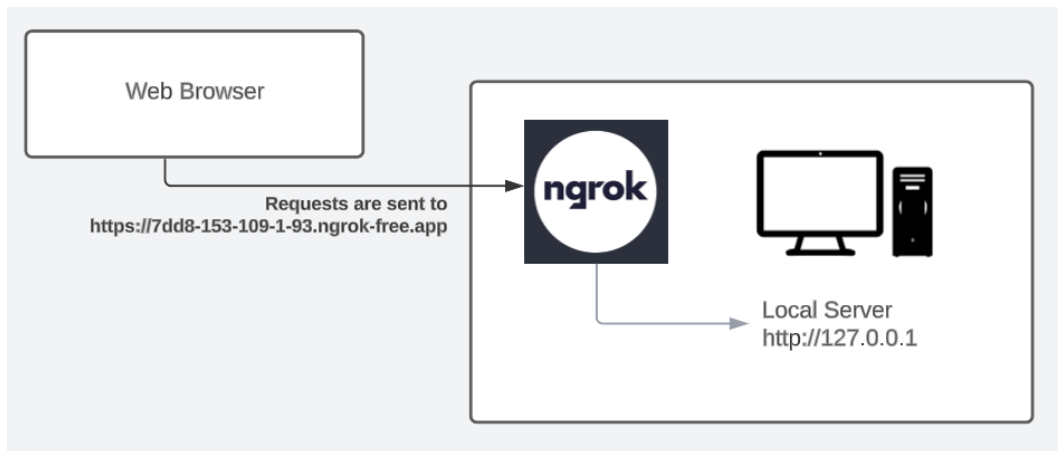
To connect a local address to the report provider we want to configure, we used Ngrok. It is a powerful tool that creates a secure tunnel between a public URL and a locally hosted server. It allows us to expose our locally running server to the internet, enabling remote systems or services to interact with it (Ngrok, 2023).

1. When we run our report provider locally, it listens on a specific port on our machine. By default, this port is not accessible from the outside network.
2. Ngrok comes into play by providing a secure tunnel that forwards incoming requests from a public URL to our local server's port.
3. We run Ngrok on our local machine and specify the port on which our report provider is listening. It then generates a unique public URL that is accessible from anywhere.
4. When external systems or services make requests to the public URL, Ngrok forwards those requests to our local server.

²⁵ https://docs.kheops.online/docs/report_providers

²⁶ <https://ngrok.com/>

Figure 25: Ngrok Architecture Schema



Author's source

In our pipeline, Ngrok is like a bridge between the report provider backend, which is running on a local machine. By setting up Ngrok, we can make a local address, like a certain port or endpoint, visible to the public and get a URL that anyone can access. The following command simply enables to do so on the port 5000:

```
ngrok http 5000
```

Figure 26: Ngrok configuration

```

♦ Announcing ngrok's Kubernetes Ingress Controller: https://ngrok.com/s/k8s-ingress

Session Status      online
Account             Benjamin Morel (Plan: Free)
Version             3.3.1
Region              Europe (eu)
Latency             13ms
Web Interface       http://127.0.0.1:4040
Forwarding           https://7dd8-153-109-1-93.ngrok-free.app -> http://localhost:5000

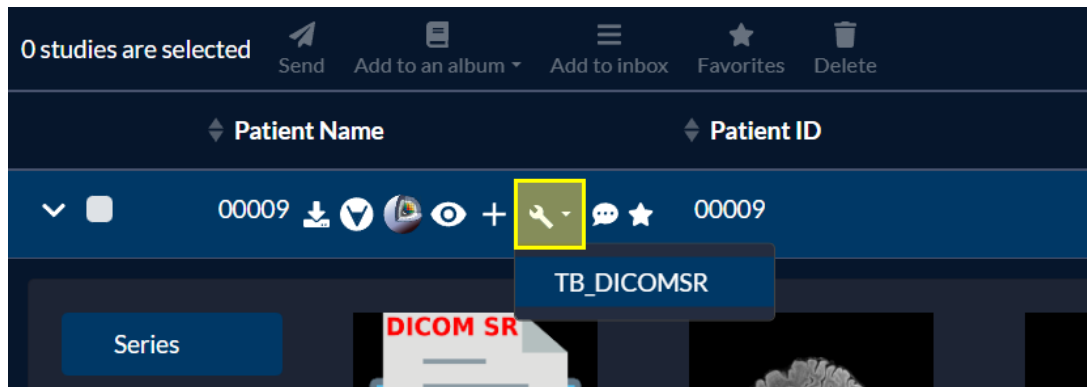
Connections         ttl    opn    rt1    rt5    p50    p90
                   9      0      0.01   0.00   65.08   65.27
  
```

Author's source

To complete the above figure, in this example the local address “127.0.0.1” on the port “5000” is redirected and publicly accessible to <https://7dd8-153-109-1-93.ngrok-free.app>.

Once the report provider is set up and Ngrok is running, we can then select an album and use the report provider by clicking on the “report provider action”, and a pop-up will appear. Then, choose the one that we created named “TB_DICOMSR”.

Figure 27: Using a Report Provider



Author's source

This page is now displayed.

Figure 28: Display Report provider

MSxplain Report Provider

Trigger a DeepLearning model with the current study now!

Get Study UID

Get Series Descriptions

Perform MSxplain WML Segmentation

Show Report

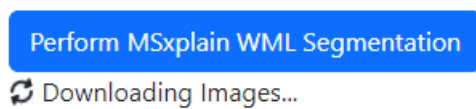
Back to Kheops

Copyright 2023 HES-SO Valais

Author's source

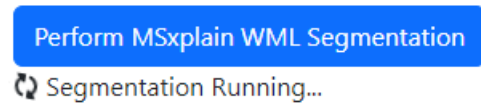
To proceed to the next phase, click on the “Perform MSxplain WML Segmentation”. In the first phase, the images will be downloaded, then the segmentation will be launched.

Figure 29: WML segmentation step1



Author's source

Figure 30: WML segmentation step2

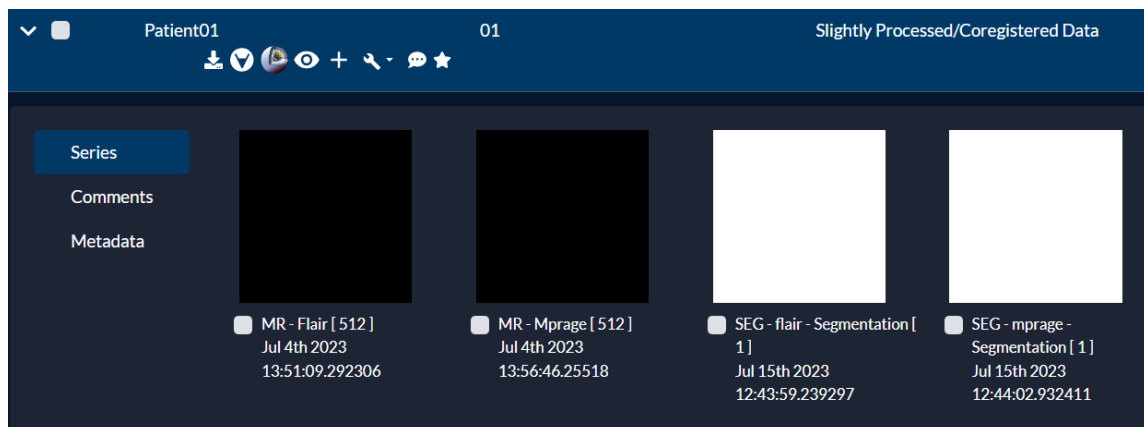


Authors' source

7.4. WML Segmentation

In this process, the selected images will be used to generate corresponding masks. Two new files have appeared on Kheops in addition to the basic Flair and Mprage files. They are named “Flair-segmentation” and “Mprage-segmentation”. These are the masks that will be used as input to the algorithm to the identification of brain lesions.

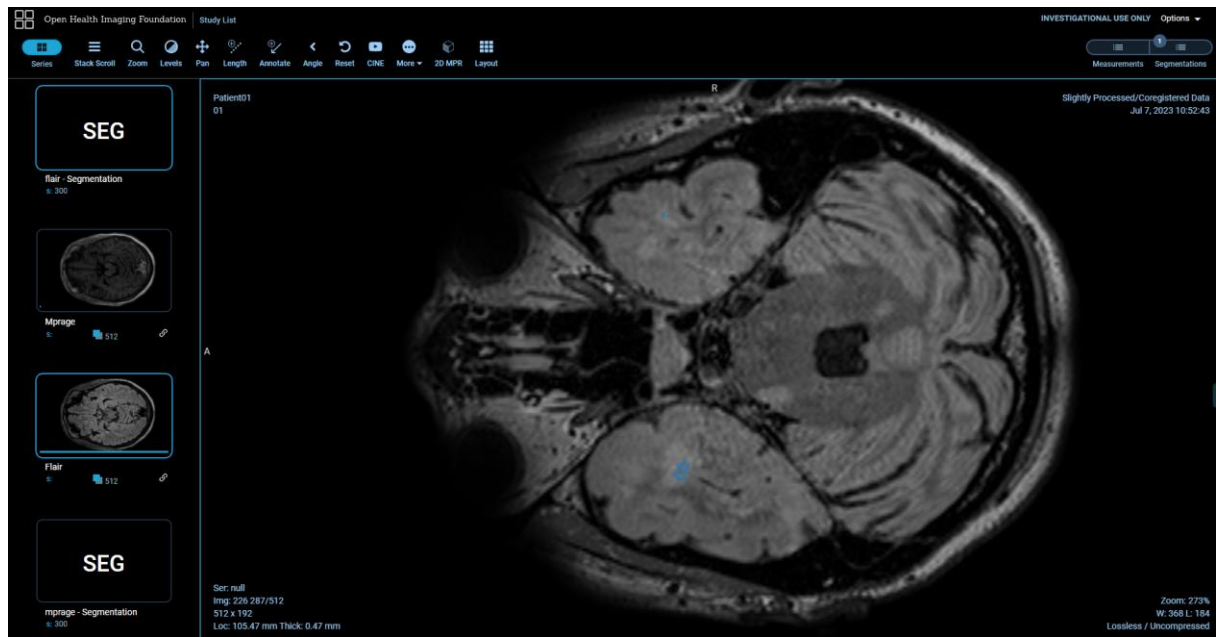
Figure 31: Adding segmented images on Kheops



Author's source

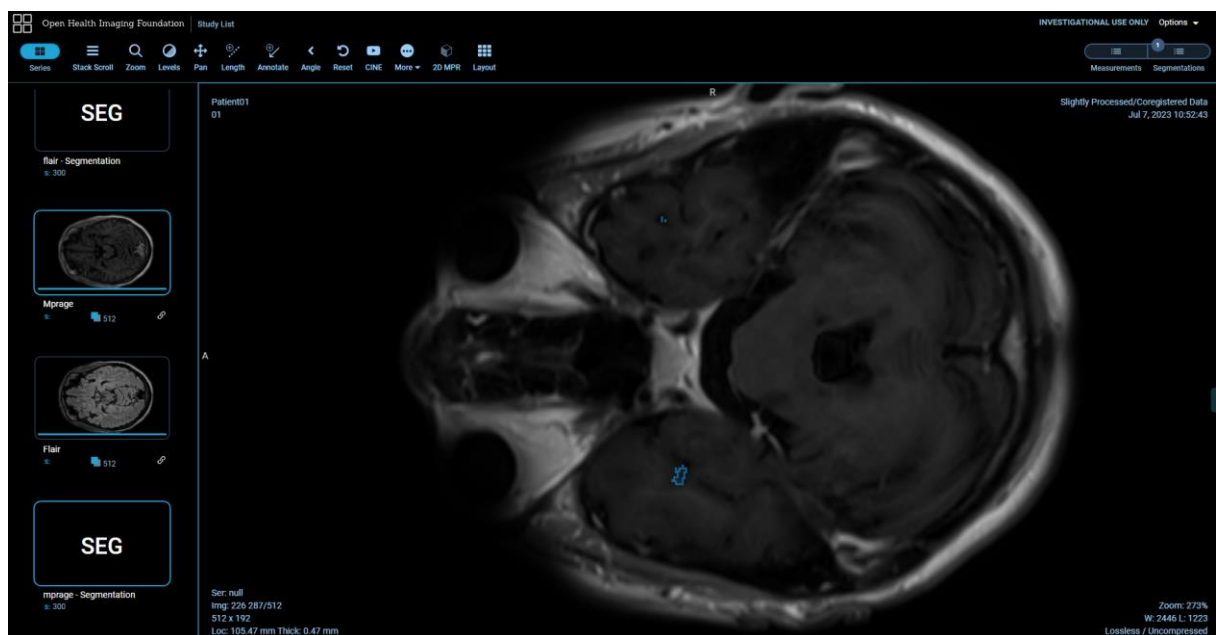
We can open these images and see the result. In the blue area, we can clearly see a lesion detected by WML segmentation. Here, we first have the Flair segmented image, then the Mprage segmented image. In both pictures, we selected slice number “287” from the 512 slices in this series.

Figure 32: Result of segmented image in Khoeps - FLAIR



Author's source

Figure 33: Result of segmented image in Khoeps - Mprage



Author's source

7.5. Algorithm execution

The algorithm responsible for analysing NIfTI images and determining the number of lesions was implemented in Python. This code was first provided by Federico Spagnolo, and it has been further modified and enhanced by Benjamin Morel.

Here is a clarification of a potential usage, using Python:

```
python lesion_information.py <name for the output file> <Subject1's ID>  
<Path to subject1's image> <Path to subject1's label mask>
```

Example:

```
python lesion_information.py patient01 01 flair_.nii.gz lesion_mask_.nii.gz
```

The algorithm will use the input image with the corresponding mask to find and calculate the lesion characteristics. It will output data corresponding to the following columns:

```
['ID', 'Lesion Count', 'Lesion Index', 'Lesion Voxels', 'Lesion Volume',  
'Note']
```

What really interests us for the SR, is the lesion volume. First, we want to filter them and only keep the ones that have a voxel number above a certain threshold. For our implementation we used the value “10”, which is defined in the “MIN_VOLUME” constant variable. This value simply eliminates lesions too small to be interpreted.

```
if num_voxel > MIN_VOLUME:  
  
    volume = num_voxel * unit_volume  
  
    lesion_volumes.append(volume)
```

We will then append the values to an array and return it to our main program. These values will then be used for the report generation in the next part. The output is the following:

```
[2.1150001287460327, 8.107500493526459, 7.050000429153442,  
2.996250182390213, 3.172500193119049, 12.337500751018524]
```

With this we have an array containing the lesions volumes with the measured values in float number, corresponding to the volume in cubic millimeters (mm³).

7.6. Structured Report generation

The final step of the pipeline involves generating a Structured Report in DICOM SR format. This report combines the metadata extracted from the DICOM images with the algorithm's outputs, providing a comprehensive and standardized representation of the findings. To accomplish this, we use again the PyDICOM library in Python.

7.6.1. Generic information

To retrieve the metadata from the original image, we select a “base” image that will serve as the input. We use the “dcmread” function from the library to read the DICOM file and then create a dataset:

```
ref_dataset = dcmread(dicom_seg_file)

sr_dataset = pydicom.Dataset()
```

A DICOM dataset is organized as a collection of data elements, each identified by a unique tag. Once we have the dataset, we can add various attributes by assigning values to the corresponding tags or create new values. For example:

```
sr_dataset.StudyInstanceUID = ref_dataset.StudyInstanceUID

sr_dataset.SOPClassUID = '1.2.840.10008.5.1.4.1.1.88.22'
```

This ensures that the Structured Report adheres to the relevant DICOM standards.

7.6.2. Lesion information

To include information about the lesions, we need to understand the outputs generated by the algorithm, which typically include:

- Number of lesions
- Lesion voxels
- Lesion volumes

When storing information about volumes in DICOM, it is crucial to use the appropriate DICOM tag to ensure compliance with the DICOM SR standard. According to the “dcm4che.org” website, the “Volume” measurement can be represented using the tag “(G-D705, SRT, “Volume”)” (VolumeMeasurements_7472 (Unnamed - DCM4CHE:DCM4CHE:POM:2.0.24 2.0.24 API), 2010)

Using PyDICOM, we can create “sequences”, which refer to a hierarchical structure used to organize and represent information within the report. A sequence is a collection of items, and each item can contain attributes or nested sequences. This hierarchical arrangement allows for the representation of complex structured data in a standardized manner.

```
sequence_a043 = pydicom.Sequence()

sub_a043 = pydicom.Dataset()

sub_a043.add_new((0x0008, 0x0100), "SH", "G-D705")

sub_a043.add_new((0x0008, 0x0102), "SH", "SRT")

sub_a043.add_new((0x0008, 0x0104), "LO", "Volume")

sequence_a043.append(sub_a043)
```

In the example above, we create new attributes with the “add_new” function, and we specify the wanted tag, the first one is “0x0008, 0x0100” and the CodeValue “G-D705”.

```
sub_a30a = pydicom.Dataset()

sub_a30a.add_new((0x0040, 0xa30a), "DS", lesion_volumes[i])

sequence_a300.append(sub_a30a)
```

Using a loop, we will parse the “lesion_volumes” array containing the output of the algorithm and add them to the dataset. We used the tag “0x0040, 0xa30a” to do so. The “DS” value representation is Decimal string (DICOM Standards Committee, 2023).

Using “ipython”²⁷ in a terminal prompt we can analyse the result by first importing the PyDICOM library, specifying the path of the SR file that has been generated, and using this file, again with the “dcmread” function.

Figure 34: Display SR using ipython

```
PS C:\workspace\dicom> ipython
Python 3.9.0 (tags/v3.9.0:9cf6752, Oct 5 2020, 15:34:40) [MSC v.1927 64 bit (AMD64)]
Type 'copyright', 'credits' or 'license' for more information
IPython 8.3.0 -- An enhanced Interactive Python. Type '?' for help.

In [1]: import pydicom

In [2]: path = "C:\\Users\\benja\\Downloads\\SRPATIENT01\\DICOM\\00000001"

In [3]: ds = pydicom.dcmread(path)

In [4]: ds
```

Author's source

The following figure shows the tree architecture of the sequences we just created. We can see the “Measured Value Sequence” we created using PyDICOM Library.

Figure 35: Result SR with ipython

```
-----
(0040, a010) Relationship Type                CS: 'CONTAINS'
(0040, a040) Value Type                      CS: 'NUM'
(0040, a300) Measured Value Sequence 2 item(s) ----
  (0040, a043) Concept Name Code Sequence 1 item(s) ----
    (0008, 0100) Code Value                  SH: 'G-D705'
    (0008, 0102) Coding Scheme Designator    SH: 'SRT'
    (0008, 0104) Code Meaning                LO: 'Volume'
  -----
  (0040, a300) Measured Value Sequence 1 item(s) ----
    (0008, 0100) Code Value                  SH: 'mm3'
    (0008, 0102) Coding Scheme Designator    SH: 'UCUM'
    (0008, 0103) Coding Scheme Version       SH: '1.4'
    (0008, 0104) Code Meaning                LO: 'Cubic millimeter'
  -----
(0040, a30a) Numeric Value                  DS: '59.748753637075424'
-----
```

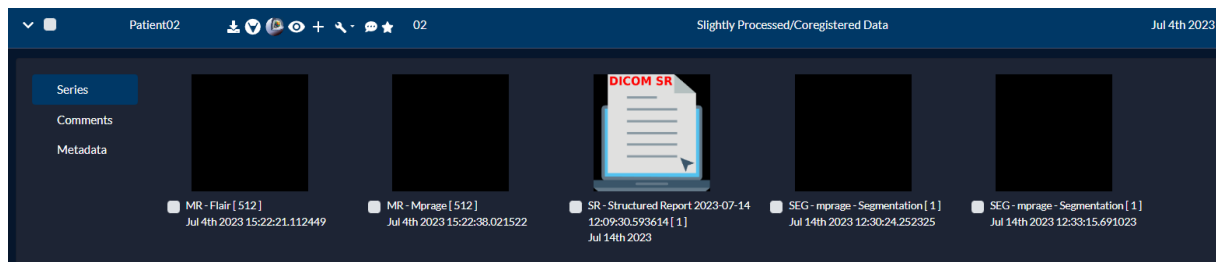
Author's source

²⁷ <https://ipython.org/>

7.6.3. Result

Once the generation of the report is finished, the files will be uploaded on Kheops. We have a new file named “Structured Report”, in addition to the existing ones.

Figure 36: DICOM SR Generation Kheops



Author's source

Once we open it, we can see various information, such as the patient's name, the modality, various dates, descriptions and also references to Study and Serie.

Figure 37: DICOM SR Generation result

```

Patient: Patient01 (, #01)
Study: Slightly Processed/Coregistered Data
Series: Structured Report 2023-07-15 12:22:51.168643 (#undefined)
Manufacturer: undefined (undefined, #undefined)
Content Date/Time: undefined 124359.239297
SpecificCharacterSet - ISO_IR 192
SOPClassUID - 1.2.840.10008.5.1.4.1.1.88.22
SOPInstanceUID - 1.2.826.0.1.3680043.8.498.12817184708206506946061529044530992430
StudyDate - 20230707
SeriesDate - 20230715
StudyTime - 105243.403549
ContentTime - 124359.239297
AccessionNumber - ABCXYZ
Modality - SR
StudyDescription - Slightly Processed/Coregistered Data
SeriesDescription - Structured Report 2023-07-15 12:22:51.168643
PatientName - Patient01
PatientID - 01
PatientBirthDate -
PatientSex -
PatientAge -
PatientWeight -
StudyInstanceUID - 2.25.151751080848009187232427976488312510716
SeriesInstanceUID - 1.2.826.0.1.3680043.8.498.11036447171360188114723798255300309721
RelationshipType - CONTAINS
ValueType - NUM
    
```

Author's source

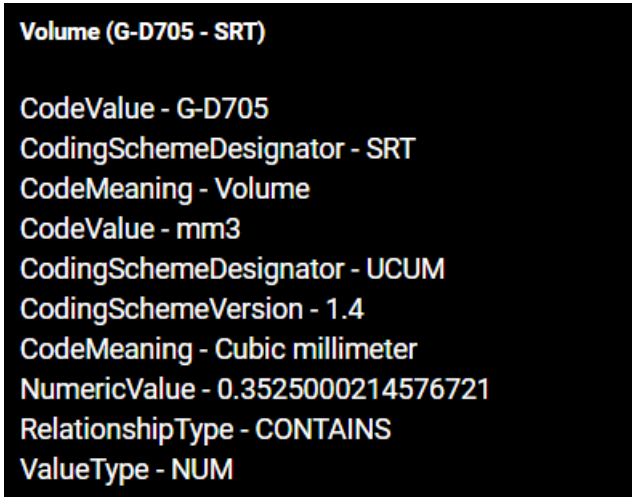
Some fields are empty here, such as the patient sex, or patient age. It means that the original image had no such information and could therefore not be transferred in the SR. In another study, that kind of information might be filled in, it will depend on the base image.

This report also contains structured content of the volume section just presented. The important information for the radiologist is:

- “CodeMeaning - Volume”
- “CodeValue - mm³”
- “CodeMeaning - Cubic millimeter”
- “NumericValue”

Other values are representing standards formats, or relationships between the sequences. It is not useful for the radiologist himself, rather the content of the SR.

Figure 38: DICOM SR Lesions result



```
Volume (G-D705 - SRT)
CodeValue - G-D705
CodingSchemeDesignator - SRT
CodeMeaning - Volume
CodeValue - mm3
CodingSchemeDesignator - UCUM
CodingSchemeVersion - 1.4
CodeMeaning - Cubic millimeter
NumericValue - 0.3525000214576721
RelationshipType - CONTAINS
ValueType - NUM
```

Author's source

A complete screenshot of the report is in [Appendix IV](#).

7.7. Structured Report display

7.7.1. Implementation

To access and display the SR, we follow a two-step process. Initially, we retrieve the SR from Kheops. Next, we extract the necessary data from the retrieved SR for presentation purposes. To facilitate this procedure, we used the Kheops API²⁸, which enables us to make specific requests and interact with the data stored in the system.

We can query the SR simply by creating requests and passing some parameters. Here we pass the “seriesUID” and “studyUID” to retrieve the specific data that we want.

```
`https://kheops.ehealth.hevs.ch/api/wado?requestType=WADO&contentType=application/dicom&seriesUID=${seriesUID}&studyUID=${studyUID}`;
```

To query an image, it is almost the same request, we can just specify the content type to be an image, in this case JPEG format.

```
`https://kheops.ehealth.hevs.ch/api/wado?studyUID=${studyUID}&seriesUID=${seriesUID_Flair}&requestType=WADO&rows=250&columns=250&contentType=image%2Fjpeg`;
```

We then added these queries to our React code to extract this information and images.

²⁸ <https://docs.kheops.online/docs/tokens/curl#get-a-list-of-series-in-a-study>

7.7.2. Procedure

To display the report, we simply have to go back to the Report Provider page and click on the “Show Report” button.

Figure 39: Report provider page

MSxplain Report Provider

Trigger a DeepLearning model with the current study now!

Get Study UID

Get Series Descriptions

Perform MSxplain WML Segmentation

Show Report

Back to Kheops

Copyright 2023 HES-SO Valais

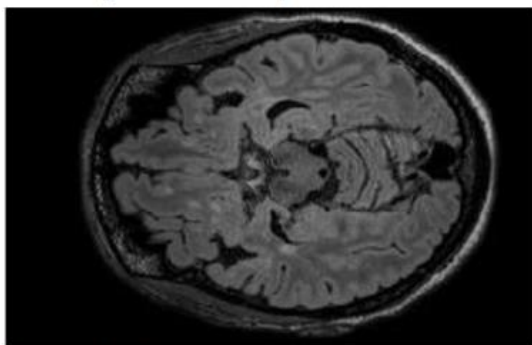
Author's source

7.7.3. Results

The Structured Report is designed to provide a simplified and organized presentation of key information. The report layout comprises an image of the series at the top, helping in the diagnostic process. In the bottom-left section, essential patient, and study details, including the date, time, and modality, are displayed. On the right-hand side, the report presents a comprehensive list of lesions, specifying their respective numbers and volumes measured in cubic millimetres.

Figure 40: SR Display

MSxplain Report Provider



Patient information

Patient ID: 01

Patient Name: Patient01

Study information

Study Date: 07.07.2023

Study Time: 10:52:43

Modality: SR

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Lesions findings

Measured Values:

Lesion 1 - 2.1150001287460327 Cubic millimeter (mm3)

Lesion 2 - 8.107500493526459 Cubic millimeter (mm3)

Lesion 3 - 7.050000429153442 Cubic millimeter (mm3)

Lesion 4 - 2.996250182390213 Cubic millimeter (mm3)

Lesion 5 - 3.172500193119049 Cubic millimeter (mm3)

Lesion 6 - 12.337500751018524 Cubic millimeter (mm3)

Author's source

It is essential to note that this current version serves more as a prototype, and no advanced analysis has been conducted to optimize the placement of each section. As we continue refining the SR, we aim to determine the ideal arrangement of components to enhance readability and usability further. The goal is to create an efficient and user-friendly format that facilitates medical professionals' interpretation and decision-making processes.

8. Testing

8.1.1. Manual tests

During the testing phase, we conducted manual tests on the complete pipeline using a diverse range of patients' medical images. Our objective was to verify the system's functionality and performance across various scenarios. We also verified the consistency of the pipeline's outputs by comparing generated reports for similar inputs.

During user interface testing for the report provider, we focused on evaluating the system's user-friendliness, clarity of information presentation, and overall user experience. This step allowed us to identify areas for improvement, ensuring an intuitive and efficient user interface.

8.1.2. Error handling tests

Errors have been handled at several levels, whether when retrieving information from the API, executing the algorithm, or displaying the SR. Using the try/catch mechanism, it allowed us to take care of errors properly, and if needed display an error message. In this example, we manage the error when we want to display a SR, but it does not exist in the current study in Kheops.

```
try {  
  
    // Code to execute  
  
} catch (error) {  
  
    setErrorMessage("No Structured Report has been found!")  
  
}
```

And the message is displayed on the screen.

Figure 41: Error management

MSxplain Report Provider
No Structured Report has been found!

Author's source

8.2. Futures tests

During this project, we were not able to perform usability tests with radiologists, neurologists, or any other medical professional. This could be done as part of the next stage of this project by creating a questionnaire, or by presenting what we have achieved to a whole team. It would be highly interesting and beneficial to collaborate with medical professionals to conduct this kind of tests, in order to get their feedback about possible interactions, interface design, or just on the overall user experience.

9. Project management

9.1. Team communication

To facilitate the communication between the team and to exchange information, a dedicated channel was established using the “Teams” platform. This channel was used for team discussions, document sharing, and updates. Messages were regularly posted to communicate important information, such as progress updates, documentation links, or any other relevant issues. This approach ensured that all team members were well-informed and provided a transparent and accessible platform for storing and accessing project-related documents and resources.

9.2. Scrum methodology

The agile methodology was applied for this project, more precisely the Scrum “framework” which serves as a foundation for effective project management. Scrum provides a structured approach to manage complex projects, allowing for flexibility and collaboration through the development process (Scrum.org, 2023).

In this project, a Product Backlog was established during the planning phase to define the main objectives and requirements to be achieved. The Product Backlog serves as a dynamic and prioritized list of features and tasks that drive the project forward. Plus, it allows for transparent communication between stakeholders, ensuring a clear understanding of the project goals and priorities.

To ensure regular progress and feedback, one-week iterations, known as Sprints with Scrum, have been defined. These timeboxed iterations provide a predictable and manageable timeframe for delivering incremental value. At the end of each Sprint, the team reviews the completed work, receives feedback, and sets goals for the next iteration.

In addition, a logbook has been created to trace the history of tasks and follow the evolution of working hours. This document provides a valuable record of the project’s progress, facilitating transparency and accountability.

By implementing Scrum in this project, several benefits can be achieved. It promotes effective collaboration and communication among team members, encouraging a shared understanding of project objectives and expectations. Scrum's iterative nature also enables the team to respond to changing requirements, and deliver value incrementally, ensuring early and frequent feedback.

9.2.1. Product backlog

The product backlog was divided into main themes to provide a clear and organized roadmap for the project. Each theme served as a focused area of development, helping to prioritize tasks based on their importance and relevance. A complete version of the product backlog is in the [Appendix V](#).

In summary, the following main themes have been identified for the project:

- **Familiarization with the existing tools & software components:**
 - Gain a comprehensive understanding of the tools and software components currently available for medical imaging and report generation.
 - Explore existing solutions and technologies used in the domain.
 - Learn about the Kheops Tool.
- **Learn about DICOM and DICOM SR:**
 - Acquire knowledge about the DICOM standard.
 - Understand the key concepts and data structures of DICOM.
 - Learn about DICOM SR.
 - Compare DICOM SR with Alternative Formats.
 - Evaluate alternative report formats and standards used in the field of neuroimaging and Multiple Sclerosis.
 - Analyse the advantages, disadvantages, and suitability of these formats in the context of the project requirements.
- **Find examples of existing reports in the field of neuroimaging:**
 - Research and gather examples of existing reports in the field of neuroimaging, particularly focusing on reports related to Multiple Sclerosis.
 - Analyse the structure, content, and relevant information present in these reports to identify common patterns and best practices.
- **Choose the most adapted format & technology for report generation:**
 - Choose the most adapted medical image viewer.
 - Based on the research and analysis conducted, select the most suitable format and technology for generating Structured Reports.
 - Provide a comprehensive justification for the chosen report format and technology.

- **Implement a report generation mechanism:**
 - Develop a mechanism for generating Structured Reports based on the chosen format and technology.
 - Design and implement the necessary components to transform raw data into standardized reports.

- **Test the report generation:**
 - Conduct testing of the report generation mechanism to ensure its accuracy, reliability, and adherence to the chosen format and standards.
 - Perform various test scenarios, including different input data, and error handling, to validate the functionality of the generated reports.

9.2.2. Weekly meetings

Regular meetings were conducted every week with the project team to discuss the progress, address any challenges, and ensure alignment with project goals. These meetings provided a platform for effective communication, collaboration, and feedback exchange. Detailed notes were taken, capturing the discussions and action points for future reference.

Each meeting had a specific agenda, focusing on the project's advancement, tasks accomplished, and planning for the upcoming week. Three main sections were discussed and written down in each meeting session, such as the points discussed previously during the last session, the points to be presented, and the points to be worked on for the next meeting.

The weekly meeting notes served as a valuable resource for tracking the project's evolution and served as a historical record of decisions made, and recommendations provided. They provided a great overview of the project's status at different stages.

9.3. Planification

The project began on 1 May and ended on 28 July 2023. The estimated time required for this project, which includes the production of this report and the implementation of the SR generation pipeline, is 360 hours. Actual hours worked were slightly higher with approximately 380. The repartition of the hours of work is represented in [Appendix VI](#).

For a better planification, we also produced a Gantt chart. It is useful for showing activities during time. On the left there is a list of the tasks and along the top is a suitable time scale. Each activity is represented by a bar. The position and length of the bar reflects the duration of the activity (Gantt.com, n.d.). The planification diagram is in [Appendix VII](#).

9.4. Use of AI

Another aspect we wish to address is the use of artificial intelligence in this project. We think transparency is a key principle and that it is essential to clearly define the areas where AI was used.

We want to specify that this document has been solely created by the student, without any direct involvement of AI. In certain cases, however, it was worth asking for help in order to obtain different results, or to ask it a more specific query.

The exchanges took place with ChatGPT²⁹ and mainly helped to resolve problems in the implementation part. Here are some examples of prompt exchanged:

The DICOM format uses specific formats such as "Decimal String", the PyDICOM library uses other formats, and the array of lesions returned by the algorithm subprocess needed to be in float. We had to find a way of converting these values to float so that they could be used in the SR. Here was the solution from ChatGPT using regular expression and by converting the array with float values:

Figure 42: Amelioration of code proposed by AI - 1

```
import re

# Clean the self.lesion_volumes_array and extract numeric values
cleaned_array = re.findall(r'\d+\.\d+', self.lesion_volumes_array)

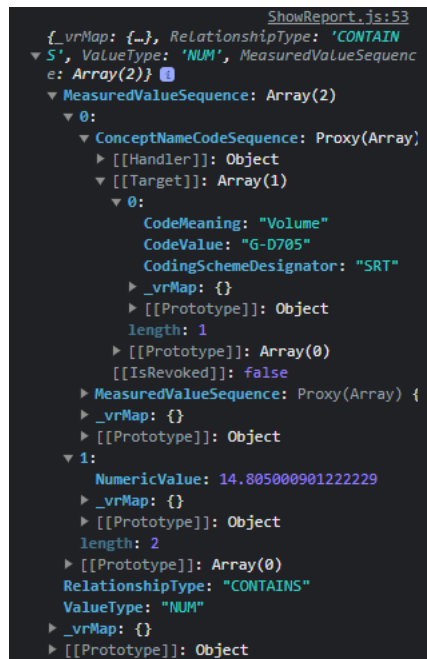
# Convert the cleaned array to a list of floats
self.lesion_volumes = [float(value) for value in cleaned_array]
```

Author's source

²⁹ <https://chat.openai.com/>

Additionally, another aspect of the project involved extracting the content of sequences to display the SR values. The Kheops API was used to request the SR values, and the challenge was to map these sequence values into a list. Due to the complexity of the tree structure, accomplishing this task was not straightforward.

Figure 43: Map returned by the API



Author's source

The AI improved our code assisting us in this mapping process.

Figure 44: Amelioration of code proposed by AI - 2

```
return contentSequence.map((item) => {
  // Get the sequence
  const measuredValueSequence = item.MeasuredValueSequence?.[0]?.MeasuredValueSequence;

  // Get and filter the measured values in the sequence
  const measuredValues = item.MeasuredValueSequence?.map((value) => value.NumericValue).filter((value) => value !== undefined);

  // Get the code value
  const measuredValueCodeValue = measuredValueSequence?.[0]?.CodeValue;

  // Get the code meaning
  const measuredValueCodeMeaning = measuredValueSequence?.[0]?.CodeMeaning;

  return { measuredValues, measuredValueCodeValue, measuredValueCodeMeaning };
});
```

Author's source

It is important to highlight that only authorized code, which was approved, was incorporated into the ChatGPT prompts. Any code supplied by other parts of the project was not used in this context.

10. Conclusion

10.1. Results obtained

In this section, we will present and critique the results obtained in our project. We will proceed by analysing each part separately and then provide an overall assessment of the pipeline.

Firstly, let's address the efficiency of the algorithm. Through our modifications, we successfully achieved the desired results, obtaining the number and volume of lesions accurately. The Python libraries used in the code made it straightforward and well-commented, leaving little room for further improvement. The algorithm's performance was well-suited to our project's needs and effectively addressed our problem.

Secondly, let's discuss the generated report. Our primary objective was to explore the DICOM SR standard and determine its suitability for the MSxplain project. After studying various ways of generating Structured Reports and examining existing report templates in neuroradiology, particularly for MS cases, we found DICOM SR to be highly relevant. Integrating it into the Kheops platform, which was already implemented, was a successful achievement, fulfilling our intended goal.

Regarding the quality of the report, we ensured that all essential information, including metadata related to the patient and critical details about the lesions, was present. This solidified the link with the basic DICOM image, contributing to an effective diagnostic process.

However, it is important to note that our current report display is in prototype form, rather than a fully deployable version. The prototype exhibits essential information, such as an image from the same series, patient and study details, and information about the detected lesions. Nonetheless, we have yet to implement a direct link to segmented images. To further improve usability for radiologists and neurologists, future work should focus on enabling direct access to images with lesions. This will make it quicker for them to make a diagnosis without having to go back to the original source of the images.

Overall, we find the solution presented in our project to be promising, demonstrating potential for valuable insights. Nevertheless, we recognize that further refinement and development are required to optimize its practicality and usefulness for healthcare professionals. With continued effort and improvements, we believe our project can significantly contribute to enhancing the diagnostic process in neuroradiology.

10.2. Future improvements

DICOM SR has given us a clear understanding of its purpose and functionality. However, one very important aspect that still needs to be addressed is how to show the results in a good way. Right now, available viewers, such as OHIF, offers limited capabilities, allowing only basic information to be displayed and do not give many choices for working with the data.

To address this issue, a potential solution involves creating a web application that extracts information from DICOM SR and presents it in an intuitive and user-friendly manner. This would enable users to not only visualize the data but also utilize it, such as linking specific areas or lesions mentioned in the report to related medical images for better understanding.

Moreover, most reports are currently in HTML or plain text format, but there is room for significant improvement by incorporating rich formatting and visualization options. Several ideas can be explored:

- **Image integration:** Combining DICOM SR data with related medical images to give a complete view of the results. This means connecting particular areas or lesions talked about in the report to related pictures to help see and understand them more easily. To further improve comprehensiveness of the report, the incorporation of a brain atlas could be instrumental. This addition would allow the inclusion of brain region information, giving a more complete and detailed perspective on the findings. The use of a brain atlas can enrich the content of the report and provide a better understanding of the results.
- **Annotations and markings:** Allowing to add notes to the report. In this way, the radiologist or neurologist can point out important parts or give more information, by adding them to the SR. The current focus is on using our algorithm to pre-fill the report. Initially, the radiologist or neurologist could complete the report with his personal notes. But an ultimate goal could be to generate a complete SR using only AI tools, without any manual intervention on the part of the radiologist. Achieving this level of automation would streamline the reporting process, improve efficiency, and generate accurate reports to improve patient care and clinical decision-making. As AI technology advances, this vision could become a reality, marking a milestone in neuroradiology reporting.

To achieve these goals, we can work on creating/developing a better viewer that can handle and display information from DICOM SR more efficiently and cover all our needs. This viewer should have an easy-to-use interface to move through the structured data, allow users to interact with it, and provide advanced tools to help understand and visualize the reports.

10.3. Difficulties encountered

One of the major challenges during the implementation phase was sourcing a suitable public dataset. As described in the implementation section, due to the sensitivity of medical images, we required access to publicly available datasets. In our case, we specifically needed MRI images in the domain of MS, which posed an even more specific requirement. After some research, we managed to find a dataset that met our criteria.

However, the dataset was provided in NIfTI format, which required additional steps for transformation and integration into our workflow. This introduced a significant level of complexity and required a substantial amount of time to comprehend and effectively incorporate into our system. The process of converting the NIfTI-format images to the required DICOM format added an additional layer of intricacy. We had to make an accurate and reliable data transformation. This involved understanding the complexity of the NIfTI format and validating the transformed images to ensure their fidelity and compatibility with our system. In the end, we managed to overcome these complicated situations and successfully added the transformed images into our system.

Another significant challenge we encountered was really getting acquainted with the complexity of the PyDICOM library. DICOM tags can be highly specific, requiring a deep understanding of their meaning and proper usage to accurately incorporate the desired information. Since our objective was to create a SR with well-organized content, it was crucial to adhere to these principles meticulously. Generating a SR using PyDICOM required an investment of time and rigorous attention to detail.

To overcome these challenges, we had to navigate through the library's documentation, comprehend the concepts of DICOM standards, and identify the relevant tags for capturing the necessary information. Each step demanded careful consideration to ensure the accuracy and integrity of the generated SR.

In addition to the challenges encountered during implementation, another notable difficulty resulted from the limited information and resources available on DICOM SR. As we researched for scientific reports on the subject, it became clear that the availability of comprehensive literature and guides relating to DICOM SR was limited. This rarity also extended to online sources, leaving us with relatively little material at our disposal during the selection process. As a result, we relied heavily on the expertise and insights of a leading figure in the field, David Clunie, who proved to be a leading source of information on DICOM standardisation, including DICOM SR.

Overcoming this knowledge challenge required increased perseverance and determination to fill in the gaps and fully understand the complexities of the DICOM SR standard. This challenge has been met using the invaluable contributions of David Clunie and a meticulous review of official DICOM documentation.

10.4. Personal experience

On a personal level, this work has been an incredibly rewarding experience. Conducting research of this nature requires a significant investment of time and effort, and it has truly allowed me to apply and consolidate the knowledge I have gained throughout my three years of training. It has also given me the opportunity to discover the world of scientific writing and contribute to the production of a scientific article.

I consider myself extremely lucky, to have had the privilege of working with passionate individuals who possess expertise in their respective fields. Collaborating with them on this research project at the Institute has been an absolute pleasure. Their dedication and profound knowledge were invaluable assets that have greatly enriched the project's outcomes.

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Appendix I: Report Template of Swiss Society of Radiology



IRM sclérose en plaques premier bilan [natif / avec contraste] du [date] :

Comparatifs : [Pas à disposition / Date]

Description :

T2/FLAIR lésions hyperintenses :

périventriculaire	(nombre)
cortical	(nombre)
juxtacortical	(nombre)
infratentorielle	(nombre)
souscortical (non spéc.)	(nombre)
spinal	(nombre)

Lésions avec prise de contraste :

périventriculaire	(nombre)
cortical	(nombre)
juxtacortical	(nombre)
infratentorielle	(nombre)
souscortical (non spéc.)	(nombre)
spinal (si inclus)	(nombre)

Nerfs optiques : sans particularité

Parenchyme : sans particularité et sans signes d'atrophie

Ventricules et espaces sousarachnoïdiens : normal pour l'âge

Vaisseaux intracrâniens : sans particularité

Orbites : sans particularité

Cavités nasosinusiennes et mastoïdes : sans particularité

Structures osseuses : sans particularité

Jonction craniocervicale : sans particularité si inclus

Autres constatations :

Conclusion :

Appendix II: Report template of Radiology Society of North America

MRI BRAIN WITHOUT CONTRAST, MS SCREENING

HISTORY: Patient Age

old Patient Gender

, possible demyelinating disea

TECHNIQUE:

MR images of the brain were acquired without intravenous contrast.

COMPARISON: None available.

FINDINGS:

BRAIN PARENCHYMA

T2 hyperintense white matter lesions:

*Periventricular: No lesions contacting the ependymal surface.

*Juxtacortical/Cortical: None.

*Infratentorial: None.

*Optic Nerve: None.

*Cervicomedullary Junction: None.

Reduced Diffusion: None.

Overall Disease Burden: None.

Parenchymal Atrophy: None.

Callosal Atrophy: None.

OTHER: None.

IMPRESSION:

Normal MRI brain.

2016 MAGNIMS MRI criteria to establish disease dissemination in space in multiple sclerosis (Lancet Neurol. 2016 Mar;15(3):292-303)

Involvement of at least two of five areas of the CNS as follows:

- * Three or more periventricular lesions
- * One or more infratentorial lesion
- * One or more spinal cord lesion
- * One or more optic nerve lesion
- * One or more cortical or juxtacortical lesio

Appendix III: Report template of University Hospital of Basel

Diagnosis

Befund

Es liegen keine Voruntersuchungen zum Vergleich vor.

<i>Bildqualität:</i>	Gut.
<i>T2 Läsionen supratentoriell:</i>	Keine.
<i>T2 Läsionen periventrikulär:</i>	Keine.
<i>T2 Läsionen juxtacortikal:</i>	Keine.
<i>T2 Läsionen:</i>	Keine.
<i>Hirnstamm/infratentoriell:</i>	
<i>T1 Gd+ Läsionen (mit KM-Aufnahme):</i>	Keine.
<i>McDonald Kriterien</i>	
<i>Örtliche Dissemination:</i>	Erfüllt.
<i>Zeitliche Dissemination:</i>	Erfüllt
<i>Atrophie:</i>	Visuell altersentsprechend.
<i>Sonstige Auffälligkeiten:</i>	Keine.

Beurteilung

- Anzahl und Verteilungsmuster der Läsionen sind vereinbar mit einer entzündlichen ZNS-Erkrankung.
- Örtliche Dissemination nach der McDonald-Kriterien von 2017 erfüllt.
- Zeitliche Dissemination nach McDonald 2017 erfüllt.

Follow-up

Technik

Siemens Avanto FIT 1.5T.

T1 MPRAGE sag morpho, 3D FLAIR sag, 3D T2* sag, DTI, T2 cor fs, T1 cor fs

Befund

Es liegen keine Voruntersuchungen zum Vergleich vor.

<i>Bildqualität:</i>	Gut.
<i><u>T2 Läsionen > 3 mm:</u></i>	
<i>supratentoriell:</i>	Keine.
<i>- periventrikulär</i>	Ja.
<i>- cortical</i>	Nicht sichtbar.
<i>- juxtacortical</i>	Ja.
<i>Infratentoriell</i>	Ja.
<i>neu:</i>	Keine.
<i>größenprogredient:</i>	Nein.
<i>T1 Gd+ Läsionen (mit KM-Aufnahme):</i>	Keine.
<i>Therapiekomplicationen (z.B. PML, IRIS):</i>	Kein Verdacht.
<i>Atrophie:</i>	Visuell altersentsprechend.
<i>Sonstige Auffälligkeiten:</i>	Keine.

Beurteilung

- Bekannte MS mit geringer Läsionslast.
 - Stabiler Verlauf verglichen zur letzten Voraufnahme ohne neue T2 Läsionen.
- Keine KM-aufnehmenden Läsionen.

Appendix IV: Structured Report generated

```
Patient: Patient01 (, #01)
Study: Slightly Processed/Coregistered Data
Series: Structured Report 2023-07-18 09:06:13.107295 (#undefined)
Manufacturer: undefined (undefined, #undefined)
Content Date/Time: undefined 093518.855592
SpecificCharacterSet - ISO_IR 192
SOPClassUID - 1.2.840.10008.5.1.4.1.1.88.22
SOPInstanceUID - 1.2.826.0.1.3680043.8.498.13216006928196490793329680922839498311
StudyDate - 20230707
SeriesDate - 20230718
StudyTime - 105243.403549
ContentTime - 093518.855592
AccessionNumber - ABCXYZ
Modality - SR
StudyDescription - Slightly Processed/Coregistered Data
SeriesDescription - Structured Report 2023-07-18 09:06:13.107295
PatientName - Patient01
PatientID - 01
PatientBirthDate -
PatientSex -
PatientAge -
PatientWeight -
StudyInstanceUID - 2.25.151751080848009187232427976488312510716
SeriesInstanceUID - 1.2.826.0.1.3680043.8.498.13407009793503278394386365099367464756
RelationshipType - CONTAINS
ValueType - NUM

Volume (G-D705 - SRT)

CodeValue - G-D705
CodingSchemeDesignator - SRT
CodeMeaning - Volume
CodeValue - mm3
CodingSchemeDesignator - UCUM
CodingSchemeVersion - 1.4
CodeMeaning - Cubic millimeter
NumericValue - 2.1150001287460327
RelationshipType - CONTAINS
ValueType - NUM

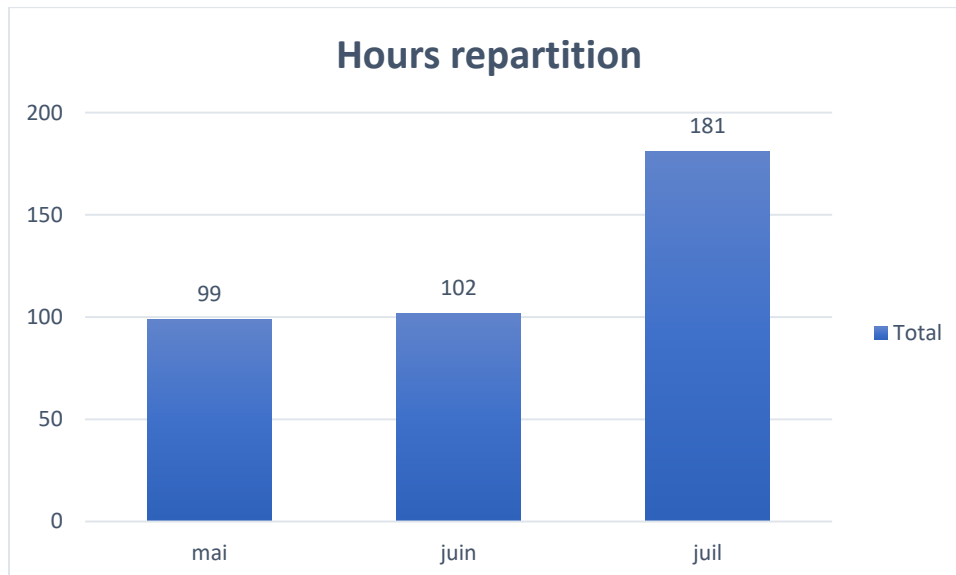
Volume (G-D705 - SRT)

CodeValue - G-D705
CodingSchemeDesignator - SRT
CodeMeaning - Volume
CodeValue - mm3
CodingSchemeDesignator - UCUM
CodingSchemeVersion - 1.4
CodeMeaning - Cubic millimeter
NumericValue - 8.107500493526459
RelationshipType - CONTAINS
ValueType - NUM
```

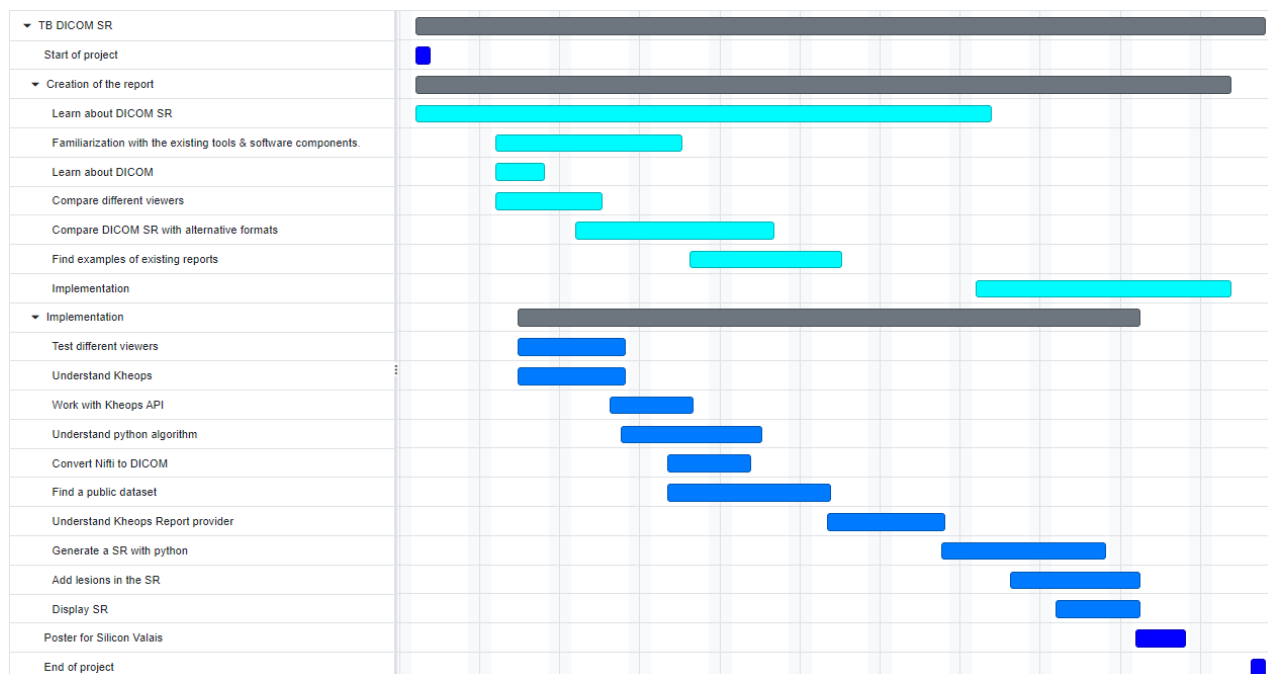
Appendix V: Complete Product backlog

US Nr.	Theme	As an/a ...	I want to ...	so that ...	Acceptance Criteria	Priority	Status	SP	MoSCoW
1	State of the art	Student	Familiarization with the existing tools & software components.	I can have a better understanding of the thesis	Explanation of the subject to someone else	1000	Done	1	Must Have
2	State of the art	Student	Learn about DICOM	I understand this standard	Format specificities, generation, visualization, etc.)	950	Done	2	Must Have
3	State of the art	Student	Learn about DICOM SR	I understand SR documents	Format specificities, generation, visualization, etc.)	900	Done	3	Must Have
4	State of the art	Student	Compare DICOM SR with alternative formats	I can compare it with other formats and see if DICOM is really relevant for this project	Research and gather information on DICOM SR format and alternative formats	850	Done	3	Must Have
5	State of the art	Student	Find examples of existing reports in the field of neuro-imaging	I understand what fields/parts are important in neuroradiology	Research and collect existing reports in the field of neuro-imaging	800	Done	3	Must Have
6	State of the art	Student	Compare existing medical image viewers	I understand the functionalities of each viewer, the advantages and disadvantages	Research information on each viewer	750	Done	2	Must Have
7	State of the art	Student	Choose most adapted medical image viewer	I can make a decision on which viewer is the most adapted	Comparison table with relevant criterias	700	Done	1	Must Have
8	State of the art	Student	Find examples of existing reports in the field of multiple sclerosis	I understand what fields/parts are important in neuroradiology, specially in the field of multiple sclerosis	Gather existing reports related to multiple sclerosis in neuro-imaging	650	Done	3	Must Have
9	Decision	Student	Choose most adapted format & technology for report generation	I can make a decision on which format is the best one for the thesis	Evaluate different formats and technologies available for report generation	600	Done	1	Must Have
10	Decision	Student	Justify my choice of adapted format	I am sure that the chosen format is the best one for the thesis	Provide clear and logical reasoning for selecting the specific format and technology for report generation	550	Done	2	Must Have
11	Implementation	Student	Learn about the Kheops tool	I can see what has already been implemented and understand how I can improve it	Study the features and functionalities of the Kheops tool used in the project	500	Done	1	Must Have
12	Implementation	Student	Have a look at the deep learning algorithms	I can have a better understanding of how the reports will be generated	Familiarize with the deep learning algorithms used in the project for report generation	450	Done	3	Must Have
13	Implementation	Student	Implement a report generation mechanism	I can display a report and see the result	Develop a mechanism that takes input data and generates a report following the chosen format and technology	400	Done	11	Must Have
14	Testing	Student	Test the report generation	I can confirm that the report generation mechanism work	Design and execute test cases to verify the accuracy and completeness of the report generation mechanism	350	Done	2	Must Have
15	Testing	Student	Handle errors of the report generation	I can avoid crashes and bugs	Identify potential errors and edge cases in the report generation mechanism	300	Done	2	Must Have
16	Documentation	Student	Write a scientific report	I can write down my findings and share this information with the team	Clear documentation, clearly separated	250	Done	11	Must Have

Appendix VI: Distribution of work hours



Appendix VII: Planification Gantt Diagram



Declaration of author

I hereby declare that I have carried out the attached Bachelor's thesis alone, without any assistance other than that duly indicated in the references, and that I have used only the sources expressly mentioned. I will not give any copy of this report to a third party without the joint authorization of the FR and the professor responsible for monitoring the Bachelor's thesis, including the applied research partner with whom I collaborated, except for the persons who provided me with the main information necessary for writing this thesis and whom I quote below:

- Mr. Adrien Depeursinge
- Mr. Roger Schaer
- Mr. Federico Spagnolo

Sierre, 28.07.2023

Benjamin Morel

