Visualizing research prototypes for a service dashboard and machine panel in radiographic workflow

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Preface

This thesis report covers my master's degree project in Interaction Design (MIXD) developed at the Norwegian University of Science and Technology (NTNU). The research was conducted in the fall 2019 and spring 2020 semesters as the final part of my study at the Institutt for design in Gjøvik.

My original research plan was completed in 2019 and was significantly affected and modified in response to the coronavirus COVID-19 crisis and campus closure in March, just days after my research plan was approved by Norsk Senter for Forskningsdata (NSD). My approved research included plans to shadow and interview students on their practical training in the 3-year Radiography program in Gjøvik and Trondheim. The travel restrictions, practical-training scheduling changes, and social distancing measures postponed that practical arrangement. I was nonetheless able to include interviews and insights from students and faculty on both campuses.

The project has taken a deeper aspect as a background and scoping study on design methods, cognitive psychology, and radiographic imaging. I have taken the opportunity to read more about HCI, and James Gibson's work on ecological perception.

The realization of the prototypes presented the opportunity to learn more about prototyping tools, CD tools and simulation.

I also completed two online courses on contact tracing and incorporated scenarios based on triage for COVID-19 in radiography practice.

And I continue my study in Norwegian language at Gjøviklæringssenter with a great group.

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Abstract

This exploratory interaction design research presents a scoping study focusing attention on routines and workflow in clinical radiography. Background theory supports the specification of perceptual tasks for a set of research prototype concepts. A *machine panel* and an *Imaging optimization dashboard* presents an adaptive and responsive service environment for the completion of task sequences to support radiographic imaging referrals and report fulfillment. The qualitative research design develops insights from interviews with clinicians working in the specialization by way of service design methods and task analysis that chart interactions and processes. The specification of tools reinforces cognitive mental models and seeks to reconcile perception with attention and a more comprehensive view of human-centered design.

1.0 Introduction (Background, Theme and Problem)

Visualizing a patient treatment plan and dashboard to assist radiographic practice and patient care considers the direct perceptions, tasks, and responsibilities of clinical technicians, physicians, nurses, and other system users. While the patient is the end-user or the service recipient, the here mentioned specialists are equally important as primary users of the clinical service systems. This interaction design research engages professional radiographers, clinicians and students on their practical training. The aim is to iteratively develop a set of research prototypes, to design a more effective workflow, and to develop better interfaces and tools.

The research is drawing from cognitive science and psychology, interaction design, user-centered design (UCD) and human-computer interaction (HCI) to explore routines and workflow in clinical radiography for the development of a set of research prototypes. *Interaction design* refers to the design of interactive products, environments, systems, and services in which a designer's focus goes beyond the item in development to include and iterate upon the way users interact with it (Cooper, 2007).[1] Language, syntax, and semiotics operate at the level of encoded interfaces, information architectures and navigation. Documented user contexts, perceptions, goals, attitudes, needs, and constraints are valued and scrutinized sources which inform and specify the system and interface criteria. In interaction design, consideration is given to the wider holistic context of user experience (UX) to design better interactions into the material design specifications, information architectures, navigation, and service routines.[2]

The tasks and workflow supporting radiographic services need to facilitate physician referrals and reporting, medical records, imaging system, calibration protocols and ergonomics

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[1] Cooper, Alan; Reimann, Kaye; Keezer, Leiben (2007). *About Face 3: The Essentials of Interaction Design*. Indianapolis, Indiana: Wiley. ISBN 978-0-470-08411-3. Retrieved 18 July 2011.
[2] User Experience (UX) is defined by ISO standards as "person's perceptions and responses that result from the use or anticipated use of a product, system or service".[1] (ISO 9241-210)

with each patient referral on the service schedule. There is also personnel rotation and the need for adaptive and controlled customization of screen configurations. Busy clinics will often process 40 or more CT and Xray referral patients a day (MRI team lead, May 28, 2020). In a demanding daily referral queue, clinicians need to work efficiently and be able to reach the information they need. There are perceptual, cognitive, and social factors that pose notable challenges to the clinical users of these systems and tools.

Training students with the background knowledge perform on their feet and in direct contact with patients. These specialists complete imaging referrals with the information they get from PACS, RIS, the patient records system, the clinic's intranet, medical and technical equipment, and a variety of other tools. Also, radiography students get core training in anatomy, pathology, radiation physics and patient care.[3] Health treatment plans include phases of consultation, examination, diagnosis, specific procedures, and operational treatments along with longitudinal care planning (LCP) which may include physical rehabilitation and after-care.

This design research has been approached as an exploratory scoping study with the goal of reaching sufficient working background in perception theory, cognitive science, radiography, and prototyping techniques.[4] The clinical and student interviews for this project were all conducted in Norwegian, and the information letter and release forms were prepared in both English and Norwegian. Indeed, a formidable challenge is with professional literacy, both technical and cultural. While the three-year bachelor's degree program in radiography at NTNU has a Norwegian language requirement,[5] the standard in the master's program for interaction

[3] https://www.ntnu.no/studier/mtrad/laringsutbytte
[4] **Scoping studies** or reviews may be defined as "exploratory projects that systematically map the literature available on a topic, identifying key concepts, theories, sources of evidence and gaps in the **research**"
[5] https://www.ntnu.edu/studies/brad

design is English. Not surprisingly, the professional standard in Norwegian clinical health service is Norwegian.

Design specifications for the development of a set of medium-fidelity prototypes are the result of synthesis and ideation informed by the background research, literature review, conceptual framework, clinical interviews, contextual inquiry, and ethnographic research. Many of the gathered insights are further explored and developed with service blueprints, stakeholder maps and user-scenarios which are further analyzed using HCI research methods and service design techniques.

Special emphasis in the theoretical section is on a deeper inquiry into ecological perception, affordance and perception-in-action, as articulated by James J. Gibson. His unique paradigm of ecological perception inspires a novel conceptual transformation that is used in the specification and simulation of tools for this project. Visualization of the machine panel builds on Gibson's notion of perception and invariance (Gibson, J. 1979). The visualization of the machine states and internal processes requires careful specification of detail, the accuracy of measures along with considered abstractions. The information architecture and system design are characterized by perceptual tasks and syntactically specific interactions. Encoding of visual and semantic representations carries through the information architecture and affects comprehension, recognition, and attention. The research places a priority on user-centered design and the insights of radiographers in the clinical environment through the iterative development and user testing of the prototypes.

The problems confronting radiography technicians including fatigue, lack of interest, high workload, and stress are considered in terms of attention, memory, cognitive engagement, and cognitive distancing. Innovations in machine learning present higher volume caseloads and productivity pressures. As the rapid developments in imaging technology and machine learning propel these technologies into service in radiography, clinical integrations and implementation in the local work routines will need to accommodate new procedures and evaluate their qualities, effectiveness, and usability.

Radiography students describe the often inconsistent and conflicting information architectures of clinics and hospitals and nonetheless persist in a seamful training situation or temporality. "There are naming conventions that are the same on different systems, and functions that have different names. The first weeks are like that on a new system, It's like, yes, I know *what* that is, but I don't know *where* it is.." (3rd year radiography student, Nov 22, 2019). Valuable insights are gained from impromptu problem-solving and wider goals.

As noted by Gransjøen (2018), there are also ethical guidelines to observe in the justification of imaging, and this has become even more relevant with such exciting potential for machine learning resources in the workflow.[6] Research has shown that for all modalities positioning errors are stated as the main reason for the need to retaking an image, and account for up to 50-77% of extemporaneous imaging and exposure (Hofmann, 2015). The emergence of machine learning heralds increased effectivity and faster diagnosis which, in turn, increases caseload capacity.

Patient privacy rights must also be maintained in the adoption of automated processes (Van der Lei, 1991).[7] The fact is that patient's right to explanation is not a substitute for

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{Gransjøen, 2018 #10}
Nasjonal faglig retningslinje for bildediagnostikk ved ikke-traumatiske muskel- og skjelettlidelser. (2014).

7 Proposal to Norwegian Parliament 2018, page 68. The European General Data Protection Regulation (GDPR) provides data subjects with the right not to be involved in a decision that is based exclusively on automated handling when this decision has a significant impact on the individual in question.

informed consent (GDPR, 2016).[8] Even as the research lobby advocates to extend patient access and control of their personal medical records,[9] the use of patient data within the health system is increasingly complex. There is legitimate use for anonymized data for research, but the ethical prerogatives that assume that right are uncontested (Van der Lei, 1991). The gradual incremental expansion of interventional research beyond its original scope is easily lost on consumers, and the data protection authorities routinely review active research.[10]

According to a survey commissioned by the Norwegian Ministry of Health and Care Services, the use of radiographic and radiological services in Norway has shown a steady growth at around 3-5% per year (Riksrevisjonen, 2016). Labor market projections from 2017 predicted a 32.7% growth in the specialization through 2035. The projections for education in radiography over the same period is even higher, with an expected growth of 45% by 2035 (Statistisk sentralbyrå, 2019).[11] There's clear growth both in the number of radiographic examinations and the number of images collected on each patent referral.

The U.S. Bureau of Labor Statistics (BLS) predicts 7-9% growth for radiology and radiography technologists in the next decade, ahead of the growth rates in other economic sectors.[12] That means more students, more procedures, more clinics and higher volume and detail in imaging that puts more demands on technicians and the technology. Therefore, maintaining consistent attention, engagement, accuracy, relevance, and quality of service is paramount.

There is a continued need for service environments that assist the radiographer with the

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[8] European Parliament and Council of European Union (2016) *Regulation (EU) 2016/679*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32016R0679&from=EN
[9] Teknologirådet
[10] When any person or organization domiciled in Norway processes digital data, they must take into consideration that such processing may trigger obligations and rights under to the Norwegian Personal Data Act. (Datatylsynet)
[11] Statistisk sentralbyrå, (2019), Arbeidsmarkedet for helsepersonell fram mot 2035: tabell 5.1 and tabell 5.2
[12] Bureau of Labor Statistics, U.S. Department of Labor, *Occupational Outlook Handbook*, Radiologic and MRI Technologists,at https://www.bls.gov/ooh/healthcare/radiologic-technologists.htm.

manipulation of digital images, markup, transcription, notation and for image optimization and measurement as well as machine status monitoring and gantry ergonomic settings.

This qualitative research design brings together interviews and analysis from clinical visits and contextual inquiry focused on a team of professional clinical radiographers. It also identifies a population of NTNU radiography students in practical training that is part of their three -year bachelor programs in Gjøvik through the Department of Health Sciences and in Trondheim at the Institute of Circulation and Imaging Diagnostics as a target survey and user-testing group.

The clinical visits provided many insights about the workflow, system and procedure protocols that inform the basic design specifications for the set of two-component service dashboard prototypes. Clinician insights gleaned from the interviews and academic literature are further developed using HCI research methods, task analysis and service design methods including user scenarios, and service blueprints.

A good part of the scoping research is also recognizing the theoretical contributions of classic and everyday notions of perspective, ergonomics and HCI. The interactions in the digital workflow and with the referral system consist of perceptual tasks, monitoring of patient and critical systems, and more cognitively detailed reporting. The survey of literature and industry developments from academic and trade sources also helps to bridge the conceptual framework to a selection of methods and creation of fact-based scenarios.

How might the features of a patient treatment sequence be visualized in research prototypes for interventional radiography and practical training? How might the dashboard and system be designed to sustain the attention and interest of users while they are subjectively engaged in their tasks? And finally,; how can the visualization of dashboard designs resolve cognitive distancing and the perceptions of specialists in a way that minimizes disruptions in structured parts of the reporting sequence and task fulfillment workflow? The effort seeks answers in the design of functional research prototypes that formulate tasks with a variety of information design and interaction strategies.

In many respects, the exploratory research supports and identifies conservative design constraints and operationalizes or specifies tools and details for working with visual perceptual task metrics in the workflow. In a cluttered field, a goal is to limit the distractions and pain-points in the workflow, providing engaging tasks while maintaining consistent standards and system status for adaptive and work routines. Task analysis divides specialist responsibilities between three types of specialist functional roles and seven stages of referral service fulfillment, from patient reception through the imaging acquisition and to reporting.

Interaction design and UX design is typically concerned with screen-based interfaces and navigation. HCI relates to computer science, and lays within the fields of cognitive science, and human factors engineering.

System service-design for radiography draws from several information systems, including PACS, RIS, inter-specialist communications, inter-departmental referrals, and scheduling. Interaction design and user-centered UX design methods, data visualization and information design strategies are employed to improve human-computer interaction (HCI) at specific progressions of the patient treatment.

What is found in the clinical setting is often an inconsistent and seamful implementation of tools and strategies. There is often too much screen space given to too many menus and polyheirarchies expressed in competing proprietary gadgetry, as well as too many bells and whistles. The diagnosis may be a case of “more is less”.[13] While it is great to present lots of powerful options, the tailoring of an effective system requires considered constraints, selection of tools and tailoring of preferences for a customized service suite.

An early research hypothesis is that alignment and reference to the anatomical planes has a direct bearing on the accuracy and consistency of perceptual tasks, and that results are best when consistent with classic perspective orientations. The sagittal, coronal and transverse anatomical planes correspond with invariant regularities of perception, recognition and semiotics in the interface and consequently raise important implications to the standardization of tools (Varga, Pattynama, & Freudenthal, 2012). There is support for the idea that designs and prototype solutions that observe and provide mental models reinforcing these conventions will produce more consistent productivity and accuracy, and these, in turn, will benefit overall patient care and wellness goals. The most important aspect of (image) interpretation is maintaining spatial orientation (Varga, Pattynama, & Freudenthal, 2012).

Iterating from those premises, the prototypes are designed to test a range of perceptual and semantically structured tasks in the completion of a referral protocol. This interaction-design research is focused on the front-end development of interactive research prototypes, presenting useful task simulations, and is informed by ongoing dialog with clinicians and students on practical training. Emphasis is on in the way that direct perception, design specification and human factors intersect in imaging and radiology workflow routines.

The role of the interactive designer is, of course, distinct and separate from the radiographer, and the approach as a designer is to be respectful of the practice and expertise,

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[13] Philip Johnson's *Mies van der Rohe*. While the aphorism “less is more” is attributed to minimalist architect Mies van Der Rohe, the concept is also adopted as a principle for engineering and technological by Buckminster Fuller; “doing more ith less”

knowledge, and cognitive skills that the radiographers possess. Also, proper care has been taken regarding research in the clinical setting, regard for patient confidentiality and not interfering with clinicians in the course of their work. The role of a radiographer is not implied here to be interchangeable with that of an interaction designer or UX designer.

This research emphasizes the better use of methods and tools. X-ray, CT and MRI are cornerstones of digital imaging technology and the prototypes pursue the compositional and perceptual, ideational and formative, generative and summative, interpersonal and system integrities.

User-centered research from the contextual inquiry, interviews, and surveys as well as written sources are the specifications for two interactive dashboard prototypes used for further user-testing in a generative and iterative design process. The two prototypes are descriptive of separate screen-based panels for managing and monitoring the radiographic technician´s work. The first dashboard is a machine view with dedicated controls for monitoring X-ray and CT or MRI system status, and the next panel is a dashboard environment for image optimization, reporting and referral workflow.

The service design interfaces bring together many sources of information and data. The functional workflow is a multichannel and multimodal collection of internal and external information systems and services. Some of the variety of service relationships are not immediately obvious. The clinical visits, interviews and focus group activities reveal service waypoints, behaviors, problem-solving and routines that are mapped in the service blueprint. The major information systems include RIS (patient medical records), PACS (imaging), patient journals, calendar, scheduling, machine-specific settings, ergonomic and radiation levels, protocol presets, monitoring systems for medication alerts, consultation, and transcription.

1.1 A Breif History of Radiographic Modalities

X-ray and axial CT tomography are the modalities that set the technical and conceptual foundations, so first we'll take a retrospective look for some of their legacy features. The cathode tube and *computerized transverse axial scanning* (tomography) of radiodensity information is fundamental to radiography (Seeram, 2009). The radiographic x-ray and tomographic processes trace their origins to Roentgen and Hounsfield. Their early prototypes are inspiring to the project and it is the axial tomographic model that sits at the center of the basic specification of a prototype concept. While the technology has come a long way and today the process is largely digital, with many impressive image processing features, the fundamentals of the x-ray tube, radiodensity, voltage and power system, and signal processing are present in today's digital CT and the principle of axial rotational beam sequencing is adapted in the MRI modality. Also important to the project is a good basic conceptual or mental model for visually encoding radiodensity and internal processes.

1.1.1 X-ray "Röntgenograms"

In 1895 Doctor Wilhelm Conrad Rontgen discovered what is known today as the X-ray while experimenting with the conductivity of high-voltage through a low-vacuum Lenard tube. He observed a fluoroscopic glow affecting a barium platinocyanide sample laying on a table across the laboratory. This was a very mysterious accident and Wilhelm surmised that escaping radiation was causing the illumination. He then investigated the effect of the escaping cathode rays experimentally using a modified Crookes-Hinton tube with an aluminum plate painted with barium platinocyanide as a radiation collection screen. A Rühmkorf induction coil supplied the high voltage current. Under current, the configuration of anode and cathode at a distance within the vacuum tube produced a by-product dubbed, *bremsstrahlung* or “breaking radiation”. He called the amazing ray an “x-ray” (Röntgen, 1896).

Rontgen tested the cold cathode x-ray on his wife Bertha. A 15-minute exposure produced a radio-graph image of her hand. She is reported to have exclaimed, “I have seen my own death” (Thompson, Hall, Hathaway & Dowd, 1994). The deflected radiation captured on a detection plate produced the first “Röntgenogram” x-ray image!

The imaging technique made radiographic densities of the body visible, or “invisible” as it may appear. The range of densities projected appears as a continuous gradient from black to white, or fully attenuated. The densities can more generally be divided into 5 basic radiodensities: Air, fat, fluid or soft tissue, bone, and metal. Bone and metal block nearly all of the radiation beam from exposing the plate and render a white, or clear region on in the resulting image.

Roentgen published his findings in 1895 in his paper *On a New Kind of Rays* presented to the Würzburg Physio-medical Society. In January 1896 it was published in Nature in English and in 1901 Rontgen was awarded the Nobel Prize in Physics (Röntgen, 1896) (Karlsson, 2000).

A unit of electromagnetic radiation exposure is the roentgen. Most x-rays have a wavelength ranging from 0.03 to 3 nanometers, corresponding to frequencies in the range 30 petahertz to 30 exahertz and energies in the range 100 eV to 200 keV. The wavelengths are beyond the spectrum of visible light and are shorter in wavelength than UV radiation, so we need a film or digital detection method to detect it.

In 1913 William Cooledge introduced the improved hot cathode x-ray tube via General Electric which used a wrought tungsten anode and cathode for increased performance, with sharper focus and lower vacuum pressure. (Robson, 1923) (Robinson & Moore)

A limitation of the traditional x-ray is that it depicts volumetric detail on a flat 2-dimensional film. This can obscure and conceal detail related to superimposition of structure (occlusion). In general, the practice in conventional radiography (CR) is to take x-ray images from two views: supine or laying down and orthogonal, or standing or upright.

The use of two views improves the detection of details that might be obscured and provides more reliable information of the precise positioning of the area of interest (Varga, Pattynama & Freudenthal, 2012). Imaging from posterio-anterior (PA); back to front and /or anterio-posterior (AP) front to back positions, will result in a difference in the sharpness of focus in features. Objects or organs that are closer to the detection plate will appear sharper, while objects closer to the cathode tube will appear less focused or blurry (Mathur, 2018).

1.1.2 Hounsfield and Computed Tomography

The invention of X-ray Computed Tomography, also known as the CT scan, is attributed to Godfrey Hounsfield and Allan Mcleod McCormac. They won the Nobel Prize in Physiology for Medicine in 1979 for their contribution to the field. Hounsfield was a RAF radar technician in Britain during the war. In the 50s he was the chief engineer to EMI Laboratories, producing England’s first business computer. EMI Ltd. is perhaps known as much for its recording venture with EMI records, The Beatles. The success of the Beatles made it possible to develop the CT scanner (Maizlin & Vos, 2012).

Axial radiography is based on 2D projections of radiation rotationally captured through a 3D object. The first prototypes were made with a simple adjustable rotating table surface. Hounsfield's next prototypes were built on a modified lathe.[14] The CT scanner can detect the distal radiographic density of an object by sending a signal through the material. Radiodensity is

[14] See Appendix Item I

measured in Hounsfield Units (HU) with the Hounsfield Scale- and is a measure of the mean attenuation of x-rays by different tissues. (Seeram, 2009)

In the first iterations of the scanner, a fixed pencil beam captured the measurements as it passed through a rotating object. The projections were in turn reassembled and differentially calculated to produce a 2D “slice map” of the object. The CT machine uses a cross-sectional pencil beam that rotates around the body. Slices or a continuous spiral motion produce an x-ray profile that can be viewed as 2D cross sections of a 3D model. The process today is digital.

Radiodensities can also be visualized in 3D voxel space. The mean attenuation of tissue or material is measured in a unit cube called a voxel. A voxel is something like a pixel. While radiodensity is not a naturally visible phenomena, objects detected in voxel space are constant according to physical laws that correspond to the objects we see in the physical world.

The value of a voxel may represent many densities. In CT scans, the values are Hounsfield units (HU) giving the opacity of material to X-ray projections.

The densities of different bodily tissues or materials such as glass, metal, or stone, all return characteristic radiodensity (HU) values. Indexing and mapping of the values on the Hounsfield scale produces a broad range and disbursement that requires some fitting to visually differentiate. As it so happens, the densities are not evenly distributed and so one puzzle of visualization is how to represent (and read) the scale of HU values measured by the scanner. Even if it were possible to make a clearly graduated visible scale of radiodensity, the identification of organs and features requires contextual knowledge or information about the physiology and anatomy to recognize the features in an image.

The mathematical basis of tomographic rendering can be traced even further back to German Scientist, Johan Radon’s 1917 technique of collecting multiple image samples. The measurement of line integrals is collected from many angles to produce a set of projection lines called a Radon transform or sinogram. A Radon-transform or sinogram is a depiction of the summation as a continuous multidirectional image capture.[15]

The calculation of complex and rich Radon transform information is the computational output of the CT machine. Today, the reconstituted mapping of the image is output in a digital onscreen visual format that can be read much like a traditional 2D film x-ray.

Improvements and additional detail for various purposes can be achieved with some of the variety of beam arrangements. A pencil beam, a column or row of beams, a fan array of beams or a cone shaped array of beams will produce some different effects. For example, it is possible to reconstruct a 3D image of the jaw, with a cone shaped beam (CBCT) on a mobile dental device used together with a detection plate makes it possible to reconstruct a 3D image of dental features. A part of the device is placed inside the mouth of the patient. The divergent configuration of the beam arrays allows for the calculation or projection of the features in 3 dimensions using epipolar geometry.[16]

Intensity-modulated radiation therapy (IMRT) uses non-uniform beam intensities from five to nine beam directions. Inverse planning is the calculation of intensities that will give the optimal customized dose distribution. Use of inverse treatment planning, as opposed to a projection method such as CT which finds densities, starts with the object profile and works back to calculate optimized beam intensity. In this kind of use the radiation is directed to intense precision radiation for the treatment of tumors. The apparatus is an iteration of the mechanical

[15] The radon transform is the integral transform which takes a function f defined on the plane to a function Rf defined on the (2D) space of lines in the plane, whose value at a particular line is equal to the line integral of the function over that line

[16] https://web.stanford.edu/class/cs231a/course_notes/03-epipolar-geometry.pdf

concept that originates from Hounsfield's CT scanner and is also based on a rotational gantry setup and directional radiation from beams.[17]

1.1.3 Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) uses strong magnetic fields to re-orient the polarity of water and fat molecules (or hydrogen atoms) in the body. Pulse radio frequency sequences and strong magnetic field gradients are used to produce detectable contrasts in the tissues. The organs of the body exhibit different characteristics during relaxation phases and excited states of the magnetization. The polarity of the hydrogen molecules line up in a certain way when they are excited. In some tissues it will take longer for the atomic nuclei to revert to a natural un-polarized state and this can also be measured.

The T1 and T2-weighted states describe the magnetization and direction induced. Spin-lattice (T1) orients the magnetization in the same direction as the magnetic field. Spin-spin (T2) is alignment transverse to the magnetic field. These weightings along with signal strength variation and pulse-sequencing can be optimized to induce a kind of “focus” on different tissue types. High signal T2 weighted magnetization is used for tissues with more water content (tumors, infarction and clotting) or Low signal T1 and T2 weighted magnetization is more optimal for bone. Non-ionizing radiation is especially good for imaging soft tissue and the nervous system. Contrast solutions can also make the detail of zonal and circulatory systems more receptive to the magnetization and in turn provide a better signal for imaging. The magnetization decay time can be different in the present solutions. These variable adjustments allow for the optimized viewing of various tissues.

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[17] Topics for further study: Fan beam vs cone beam: 1st pencil, 2nd row, 3rd Fan Detector, 4th Ring detector, “slice drawer”, measuring line integrals, Sinogram, image reconstruction and inverse treatment planning.

One of the benefits of MRI is that it does not use the ionizing radiation of x-rays and so the radiation risk to clinicians and patients is nearly irrelevant as a safety concern.

The MRI scanner consists of a electromagnetic and gradient coils. The machines also uses liquid helium as a cooling agent and so they need to be kept very cold (- 270 C - 4 kelvin). The machinery is cooled with coolant compressor using liquid helium.

Today, Xray, CT, MRI imagery is viewed in digital workspaces. This has changed many things in the way that images are processed, but many of the fundamental system and process models and user mental models of those mechanical and machine processes are still relevant. The way users perceive the internal operations of these machine processes is via a detailed specification and representation of machine states visualized on their interfaces. Attention turns to this relationship between machine and perceptual tasks and indirect perception in the next section.

1.2 Layout and Outline

Chapter two introduces the theoretical and conceptual framework that informs the research and how it will be dispensed. It is followed by subsections 2.1.1 - 2.1.6 on HCI and interaction design, direct-perception and naive realism, cognition and attention in HCI, and a somewhat more in depth look at James J. Gibson’s paradigm of ecological perception. It continues with semiotics and encoding for design, a typology of markedness for Roentgen, epipolar geometry and the Radon transform, a few words about machine learning and generative design and then a quick summary of the ideas that are taken forward in Section 2.2. Section 2.3 introduces relevant research and section 2.4 presents selections from the literature review, by theme. Section 2.4 offers some reflection some critical reflection on the idealism of user-centered and iterative design.

Chapter 3 starts with an introduction to the methods section, followed by an overview and justification for what was done, and a description of the mixed methods qualitative research design. Sections 3.3 and 3.4 recount the academic interviews and insights, the clinical interviews, the interview guide, and the information letter. Section 3.5 describes the survey, survey system, data collection methods and information privacy and informed consent notification forms. Section 3.6 presents descriptions of service design methods used; card sorting, task analysis, service blueprints, and user journeys are presented as subsections within service design. In section 3.8 a narrative user-journey scenario follows a student on their practical training, and 3.9 reflects on participation in a lab based simulation focus group.

Chapter 4 presents the resulting early prototypes, the use of the semiotic typology, sketching and wireframing, an introduction of the interactive prototypes, the machine panel and its specifications, the imaging dashboard and its specifications, the usability and concept test and an overview of design tools and software. Trigger action circuitry and generative design are presented with design heuristics as a forward-looking reflection.

Summing up, are concluding reflections about the project and a summary of accomplishments.

2.0 Theoretical and Conceptual Framework

The theoretical departure for this research is alternately and concurrently empirical, ecological and systems rational and is academically situated in the field of UX and interaction design. Constructs of attention, cognition and perceptual affordance establish the main features of a conceptual framework for human-centered service design for research in digital radiographic imaging. Together with the preliminary user-research and scoping study, the following theoretical and conceptual framework informs basic assumptions and criteria for the development of the research prototypes and tools. A problem central to the theoretical discussion concerns the reconciling of perceptual acuity, focus, and attention within scripted tasks, system competencies and guidelines. There is an investigation of encoding for perceptual tasks and semantic design and a look at perception from a perspective of naïve-realism and ontological objectivity. What are the regularities of perception? This chapter introduces academic discussions on the key theoretical themes and describes how these academic issues are relevant to the synthesis of basic specifications for responsive research prototyping tools and simulation, and later for the analysis of insights and user-data.

The topics of human computer interaction (HCI) in interaction design, direct-perception and naïve-realism, cognition and attention, James J. Gibson's paradigm of ecological perception, semiotics and encoding for design, epipolar geometry, and responsive and generative design and machine learning are introduced in that order as themes in the chapter subsections.

User- experience design (UX) and interaction design are usually concerned with empirical research, valuing the human-centered perspective regarding human goals and needs.[18] The theoretical discussion presented here aspires to defend the value and priority of direct human-centered perception and naïve realism, sustaining that through the research design. The assertion is that user-reported perception can be a reliable human-centered source for design specification. The theory shows how academics on the topic have come to terms with the issues of consciousness and perception.

Behaviorism has been largely supplanted by cognitive theories which incorporate ever more detailed schematic and systematic mappings of consciousness and attention (Neisser, 1967) (Szokolszky, 1997). Meanwhile, the articulation of unmediated and direct perceptual theory provides insight and justification for human-centered perceptions that inspire useful information

[18] Uxdesign.com, "UX Design Defined", 16/08/2010

visualizations. Perception theories also provide a broad context for studying subjective and unscripted strategies valuing ontologically objective modes of activity, especially “perception-in-action". How clinicians and students "think on their feet" and adapt to new routines is important.

Near the end of the chapter an effort is made to align of the features or constancies that hold true between ecological optics and classical perspective geometry. These constancies help to further align the conceptual schema as a set of assumptions used for the specification of tools and methods.

The pedagogical aim of the research is to improve communication, enable cooperation, initiate dialog, support education and training, and improve task effectiveness and professional engagement in the area of interaction design and UX. The professional and educational aims extend to the client relationship and the value of interaction design for the radiography specialization. The main point is that these theoretical underpinnings demarcate a conceptual framework that is aligned in terms of the user and human-centered perspectives in the resolution of perception and attention.

The academic syllabus for undergraduate and master studies in interaction design are inclined toward the cultivation of empirical, cognitive and practical methods for design. Cognitive psychologist and designer, Donald Norman is often put forward as a "godfather figure" to interaction design, human-centered usability engineering and UX. He defined an affordance as “the design aspect of an object which suggest how the object should be used; a visual clue to its function and use” (Norman, 1988).

However, the origins of the term affordance can be traced to a somewhat more challenging theoretical conceptualizations originating in the philosophical and psychological territory of naïve/realism, consciousness and the ecological perception of James J. Gibson (Gibson, 1966). There is a more in-depth account of Gibson's ideas in section 2.1.2.

Gibson is not exactly maligned. On the contrary, his work is revered in psychology and philosophy and predates the field of UX design. He is most notably renowned for his concept of affordance and his paradigm of ecological perception. While the human-factors engineering of Norman is oriented to empirical and cognitive design, Gibson's work seeks to specify regularities or constants by way of direct visual perception and from the observation point of realism and consciousness.[19] The novel aspect of his approach is that he finds specification of stable constancies in view within the domain of perception psychology. His insights challenged behavioral and cognitive science, and later greatly influenced UX designers, among others, to recognize user -perceptions, -autonomy and –competence from a perspective of subjective realism towards action scaled-affordances.

So, while UX and interaction design is largely concerned with empirical research, human computer interaction (HCI) and interface design, it is critical to specify user affordances in a human sense. This seems especially pertinent for the project of simulating instructional processes for human understanding.

The research on radiography imaging routines brings together the reported insights, perceptions and goals of students and clinician, and the research tools are designed and iterated in response to the way students and clinicians perceive and interact with them. The exploratory research design is intended to provide background and context to the field of radiography and

[19] "Empiricists, for their part, view the aim of science as the affording of truth, and want therefore to exclude from science any activity of a hypothetical nature. Realists, on the other hand, see the aim of science as concerning understanding as well as truth, and view informed speculation about the nature of the real world as a worthwhile attempt to obtain such understanding" (Dilworth, 2007)

seeks out these specialists in their practical training, in the context of their efforts toward professional development and amid their ongoing training and lives.

The prototypes are specifically designed for interdisciplinary research in the radiography specialization and will be of ongoing relevance and interest for practical training, client-relationship building and professional and academic use in both fields. The resulting specification is for a basic feature set of interactive research prototypes that function simultaneously as tools that focus research for ongoing iterative creative rounds. At this stage they are not overly syntactically specified. Most specifications are essential, and a central feature in each screen is the visualization of multi-view or rotational navigation and transformation for viewing the body and the machine orientation. These could be fairly described as early-stage research prototypes. Many aspects of the interface function to confirm, benchmark and tag design-capacities and metrics, gauge client interest and establish baseline conventions for undistorted simulation in a functioning research tool.

Presentation of the theoretical concepts are built up in the following chapter subsections introducing the main ideas and justifying their use and application, modification, or transformation. This part is then summarized with a reflection on the ideas that hold the most relevance to the synthesis of the research methods and approach to the specification of tools. The chapter's accompanying literature review includes select academic research supporting the theoretical framework and practical specification. These entries tend to be representative and specifically relevant studies rather than part of a comprehensive. The review is organized topically, thematically and by relevance and is presented as a considered, hybridized synopsis, taking cues from Bloom's taxonomy and put in a reporting and review format used in clinical medical practice. Bloom's cognitive taxonomy originally was represented by six different domain levels: (1) knowledge, (2) comprehension, (3) application, (4) analysis, (5) synthesis, and

(6) evaluation. All the Bloom domains focused on knowledge and the cognitive processes. (Bloom, 1956) The review entries introduce the research, main theoretical concepts and how they are applied in the methods along with description of the synthesis of their insights to the specifications.

2.1 Conceptual framework

The conceptual framework is built up from the theoretical ideas that are most relevant to specification and further research. This is not establishing a theory-driven design approach as much as it is background research that grounds the specification of prototypes in important precedents for an interdisciplinary interaction design project. The application and modification of theories to their use in specifications constitute a transformation which may differ considerably from their original context. This project includes some novel adaptations of the perceptual and cognitive ideals outlined in the theoretical frameork.

2.1.1 HCI in interaction design

At the core of human -computer-interaction (HCI), is the dynamic interrelationship of computer science, cognitive science and human factors engineering (Löwgren, J.,1993). While human-factors is often explained in terms of ergonomics, HCI and human-factors engineering are more broadly invested in language, programming, and semiotic and semantic use-affordances. Much of the research on cognitive engineering in HCI involves linguistic analysis, data analysis and AI (Doherty, K., & Doherty, G. (2019). Ergonomics, as it is conventionally and popularly understood, is corporeally localized or proximal in the tactile relations of persons and the things in their environment. Physiology is one of the three defining domains of ergonomics,[20] while

[20] According to the International Ergonomics Association, there are three broad domains of ergonomics: physical, cognitive, and organizational.

HCI is more specifically concerned with cognitive systems such as language and syntax. Linguistic agency, in contrast, functions at an agency extended and abstracted remove. The distinctions of semantic and surface structure are central concepts for interface design and persist all the way from the theoretical discussions through to material design specification and information architecture (Schneiderman, p. 222). HCI introduces a human cognitive relationship, which a described in the methodology section (Lazar, 2017 #21)

What is called theory, could also be considered scope or background. There are branches of interaction design which are a part of human-computer interaction (HCI) and user-centered design (UCD) while a big undercurrent deals with human-centered perception, attention, and psychology.

This study looks at clinicians and students of radiography in their daily routines, around the theatre based radiographic imaging consoles and machinery and beyond their systems interactions. The hope is that the research also can recognize “system users” as people with complex goals and aspirations. Their wider sense of their place in their work environment cannot be underestimated. While the ecological theory on perception and consciousness is primarily focused on human experience, the discussion on cognition and task planning is pre-scripted in a system view of cognitive science.

The concern of HCI is not merely about the ergonomics of surfaces or organizational ergonomics but also with interaction and perceptual affordances at a symbolic, semiotic, and semantic level.

Cognitive research and human-factors concerns were part of the shift from design-theory or system developer-centered design to user, or human- centered design. (Löwgren, J. (1993). In the following section supporting theories about perception, cognition, and interaction are aligned to a human-centered perspective.

2.1.2 Direct Perception and Naïve-realism

Direct-perception can be linked to conceptions of naïve-realism as a subjective state of perception that occurs without mental models, memory, cognitive processes, or assumptions. The proponents of direct perception often describe perception as though it is a "neutral instrument" with its fundamental or unmediated awareness or "ability". A perception of naive- realism harkens the method of observation practiced by painters. The painter specifies the surface of a canvass in a selective and subjective manner. Perceptions are inextricable from consciousness and often influenced by psychology.

Kurt Lewin's field theory considered people's behavior as a function of their psychological "life space" (Lewin, 1943).[21] Developmental psychologist Jean Piaget saw naïve realism in the "egocentric lens" that children experience the world through (Piaget, 1964). According to Professor Paul Treffner, the term naïve-realism is frequently used in an elitist or pejorative sense to describe an attitude of objective bias. (personal communication, December 29. 2020) Everyday perceptions are imbued with ontological meaning.

[21] Within the realm of facts existing at a given time one can distinguish three areas in which changes are or might be of interest to psychology:
1. The 'life space'; i.e., the person and the psychological environment as it exists for him. We usually have this field in mind if we refer to needs, motivation, mood, goals, anxiety, ideals.
2. A multitude of processes in the physical or social world, which do not affect the life space of the individual at that time.
3. A 'boundary zone' of the life space: certain parts of the physical or social world do affect the state of the life space at that time. The process of perception, for instance, is intimately linked with this boundary zone because what is perceived is partly determined by the physical 'stimuli'; i.e., that part of the physical world which affects the sensory organs at that time. Another process located in the boundary zone is the 'execution' of an action. [….]Lewin (1943), p. 306

John Searle offers a delineation of the fundamental modes of consciousness which include sentient awareness, subjectivity, a unified sensory field, and modes of intention (Searle, 2014). Searle holds that direct-perception is a temporally unified presentation of the senses rather than the "sense data" of classic cognitive science. He argues further that we don't need to discount ontological categories of appearance as useless for science. (Searle, 1997)

2.1.3 Cognitive Considerations in HCI / Cognition and Attention

Classic cognitive science assumes a systems-view which conceptualizes human information processing within a task logic scheme. Visual perception is presented as a staged progression through a sequence of information processing stages including:

a. input of stimulus via reflective light

b. a central processing reflection, presumably referencing stored knowledge, and

c. output in expressed as action, or motor output behavior

In contrast to naïve realism, the view tends to place motivations, affectations, attention and even awareness within our stored knowledge. This human information-processing paradigm (HIP) (Lindsay, Norman, 1972), is useful for systems planning but we may miss some of the human context by "reducing phenomena in the outside world to stimuli" (Benyon, 2010). The analogies that found cognitive theory often ascribe characteristics of computing onto human processes of memory, perception and language.

There are those who would argue that there are "two-cultures" or schools of thought about cognitive science; realists and empiricists. The utility of more complete or realistic cognitive theory is compelling; researchers can strive for more complete models of human cognitive psychology and in turn design from a more user-centered conception. Ulric Neisser advocated the need for a more dynamic view of cognitive psychology that could start from the vantage of motives. "Instead of asking how a man's actions and experiences result from what he saw, remembered, or believed, the dynamic psychologist asks how they follow from the subject's goals, needs, or instincts." (Neisser, 1967) (Szokolszky, 2014)[22] Jonas Löwgren articulates human-computer interaction (HCI) mostly in terms of practical methods for system development. *The goal* is the basic notion of what the user wants to accomplish. He sees the emergence of user-centered systems development as a break from theory-based design. (Löwgren, 1993) In many ways the naïve-realists would also favor everyday perceptions over cerebral theorizing as well, although Löwgren is an HCI engineer developer in the more pragmatic tradition of cognitive science.

There are many figures in the field of cognitive psychology and HCI engineering who have advanced a more complete or "realistic" view of human psychology and motivation for design. Computer-scientist and professor in the field of HCI, Ben Schneiderman, advanced the recognition of user-centered needs in systems engineering for information design with an influential set of heuristics that focus on user-centered design. The shift arose from insights about human psychology and human needs and goals, and reflect the "cognitive revolution" which originated in cognitive linguistics and coincides with a critique of behaviorism. The debate may be exemplified in a scathing critique of Skinner's statements dismissive statements about human-consciousness. (Chomsky, 1959)

Schneiderman's more recent collaborative research investigated the specification of visual data through the choice of encodings. *Semantic* or semiotic visual encodings of information are readily accessible or perceptible utilizing "bottom-up" processing, while longer

[22] Neisser worked alongside James and Elanor Gibsaon at Cornell university considered his influence to be a profound influence on his subsequent work in cognitive psychology.

term is “top-down” *syntactic* detail is case specific and usually involved with linguistic structure requiring more from attentional and mental or cognitive resources. Top-down internal semantics is a general plan, task model or internal representation progressing from a very general, to a more specific, detailed, and contingent planning. (Schneiderman, 2012)

Cognitive attention researchers note that we attend to the “big- picture”, top-down processes such as goals and needs with different strategies than bottom-up cognitive processes which may include perceptual tasks. (Kinchla and Wolfe, 1979) But it’s an oversimplification to say that perceptual attention is bottom-up, and planning is top-down; “Whether an object captures our attention depends on its bottom-up salience, that is, how different it is compared with its neighbors, and top-down control, that is, our current inner goals.” (Melloni et al., 2012) Rauss & Pourtois (2013), investigate the ways that the top-down, bottom-up processes can work as contingent and interactive processes rather than as a dichotomy.

Long term planning and goals are part and parcel of our sense of personal autonomy. The more dynamic approach of cognitive psychology carries through HCI design and finds expression in heuristics aimed at user-control and freedom; “Experienced operators strongly desire the sense that they are in charge of the system and that the system responds to their actions. Design the system to make users the initiators of actions rather than the responders.” (Schneiderman, 1978)

The way these issues of cognition and specification play out in system and interface design is where the rubber starts to hit the road in interaction design. A poorly organized information architecture with an ambiguous or conflicting set of navigation icons can make a system cognitively “hard”. Physical tasks are not as hard as mental tasks, or so the argument goes. Green’s cognitive dimensions of notation focus on aspects that make learning and doing *hard* for mental as opposed to physical or ergonomic reasons. (Green, 1998) For example, button size is a physical usability attribute while tasks that require translation and mental processing, abstraction and calculation before an action is taken are cognitive attributes.

The “gulf of execution" demarcates the deficit of affordance that separates the physical system from the user’s goals. (Norman, 1988) It is only partly related to ergonomics. This gulf can also be put in terms of the amount of effort exerted to interpret feedback. Norman calls the variant the “gulf of evaluation”. Now we are at the level of semiotic effectiveness and syntax. Hard tasks may require more cognitive resources, or simply miss the user goals altogether.

Human-centered design and interaction design owe a tremendous deal to the field of cognitive science. The unresolvable debates over consciousness, subjectivity and direct perception inevitably contend with temporal factors of attention, memory, and planning. Cognitive science provides fundamental insights to system and interaction design. The goals and motivations of students and clinicians on practical training and during routine workdays also inform the kinds of affordances and opportunities that are best for a design.

2.1.3.1 Measuring Cognitive Engagement

The basis for evaluating cognitive engagement is founded on a variety of temporal measures in HCI. Measurement of psychomotor function, speed, working memory, accuracy and form completion are designed in the prototype as background processes that can also include contingency skill levels or mandatory completion stages, scripted task interactions or navigation of the workflow.

Assessment of cognitive engagement and cognitive distancing can be set generally in terms of user perception, task completion, and performance. Observation, questionnaires, interviews, and other forms of self-reporting are designed for the collection of both subjective and objective data. Objectivity-oriented measures reduce metrics to task specific and actionable performance data or behaviors (Pignoni, 2019).

Subjectivity-oriented measures tend to target the perceptual and experiential nature of the concept. These categories can be further decomposed into categories of ontological and epistemological subjectivity as per John Searle's rubric and argument; "the ontological subjectivity of a domain does not preclude an epistemically objective science of that domain" (Searle, p.7, 2014) What this means is that can take a scientific approach to *at least some* categories of subjective experience.

Ernst Poppel's cognitive experimentations in HCI proceed from a positivist certainty that temporal neurobiological factors determine a reliable assumption for measuring even subjective perceptions of phenomena. Human consciousness and perception occur within a limited temporal sensory range, and therefore many performance criteria for psychomotor function and attention, learning and working memory, accuracy, and reaction timing, can be scaled for experimentation in terms of perceived simultaneity, successiveness, temporal order, duration, and continuity (Pöppel, 1997).

These cognitive research approaches inform the experimental design strategies that are used for a variety of perceptual and information-oriented task types in the imaging workflow. Another paradigm inspires the visualization of the axial tomographic machine process.

2.1.4 James J. Gibson's paradigm of ecological perception

Psychologist James J. Gibson set out to propose a "new" paradigm of ecological visual perception founded on naïve-realism and direct perception. His ecological perception describes the way people see by way of observing and moving around in the world (Gibson, 1979). Gibson's assertion is that human perception recognizes and specifies phenomena in the optic array directly and without the need for mediation by the sensory system. "The old idea that sensory inputs are converted into perceptions by operations of the mind is rejected" (Gibson, 1950). His ecological view is compatible with a more inclusive recognition of useful ontological relations or affordances than a strictly objective systems view. It has been described as an enactive approach to perception. (Noë, 2004) Gibson´s paradigm is presented in his *Ecological Approach to Visual Perception*, as a kind of "ecological physics" and as an attempt to resolve the way ambient optics of light interact with surfaces (Gibson, 1979). One lecturer describes it as "an account of the physics of the situation, in terms of the way the sources of energy interact with environmental surfaces" (Heft, 2010). Ambient detail is taken as independent from the field and ground distinction of objective and gestalt models of spatial representation. Ambience is still set in context but refers to "how things look from here in these conditions." (Noë, 2004). This is our naive-realism or direct perception.

Gibson's concern with specifying the detail of surfaces can also be read as leaving a range of assumptions about the nature of substances unspecified. What he maintains is a conception of the optic array in which phenomena can nonetheless be specified and analyzed in terms of reciprocity and variance. "What we need for the formulation of ecological optics are not the traditional notions of space and time, but the concepts of variance and invariance considered as reciprocal to one another." (Gibson, p.67, 1979)

Gibson´s ecological signs and signifiers seem a bit strange at first. The terms Gibson uses to describe the ecological array include specification, medium, substances and surfaces. He talks about ambient forces and "visual solid angles" [23] Gibson's notion of the specification of

[23] In geometry, a **solid angle** (symbol: Ω) is a measure of the amount of the field of view from some particular point that a given object covers. That is, it is a measure of how large the object appears to an observer looking from that point.

things in the visual optic array via visual solid angles is inspired by a "regression to the geometric optics of Ptolemy and Euclid" (Gibson, 1974). Perspective extends from the observer and encompasses the field of view. This is how artists observe the landscape. The geometric system was drawn in terms of angles to the viewer's point of view rather than in the optics of an information processing system. The optical tradition of naive-realism comes from a time prior to the discovery of the retinal image and the basic assumptions of "cognitive" sensory systems. Natural perspective had been based on direct observation and it was mostly the domain of artists and painters. When the geometric and mathematical optics of Euclid and Ptolemy later arrived on the scene, in the 4th and 3rd century BC, it was called "artificial perspective".

The reciprocity or complementarity of the environment and the observer are perceived and sensed according to "regularities" of temporal variance, according to Gibson (Gibson, 1979, p.99-101). He describes the visual phenomenon of occlusion and how movement around and between things simultaneously reveal and obscure features as you take another point of perception. Gibson was interested in aviation and perception, particularly the way pilots and people driving cars perceive movement and negotiating turns. (Gibson, 1938) In WWII he was a researcher in the Air Army corps and studied the effectiveness of training films and the visual identification of aircraft. The interplay of visible and "out-of-sight" edges is also engaged during the estimation of depth perception and exhibits "the principle of reversible occlusion" (Gibson, 1979, p.192). Occlusion is reversible. By tracing movements back, you can bring an occluded surface back into view. (Gibson, 1979) Gibson says the cues for depth perception include one cue called "movement parallax" and another called "super-position," both relate to the principle of reversible occlusion. (Gibson, 1979, p.77) Vital contextual information about distance, motion and scale are available via direct perception of textured detail in the optical "field of expansion" (Gibson, 1938)

Overt attention and ocular adjustments are a part of an active exploratory perceptual system which is not a mental process or "filtering " of attention, but instead... “the rules that make visual egoreception useful” (Gibson p.122) are at an immediate level of perception and afford the detection and specification of surfaces. This moving about in the world detecting invariance independently of the mental processes while subjectively immersed in (your) perception is direct perception in-action.

The radical suggestion here is that this reciprocity and invariant constancy extends into the "deep structure" of psychology and the ontological empirical experiencing of the world.

A contemporary and philosophical supporter can be found in John Searle who says that it is entirely possible to make a science of subjective consciousness. Specification can be both ontologically subjective and useful to science. (Searle, 1997)

A sensation-based theory of perception presents the all too human complications of intentions, memory, preferences, past recollections and expectations or planning. Our goals bias our perception. Searle in his many lectures on perception and intentionality says that goals supply background and “by-way-of relations” which can be perceived as affordances unto intentional actions. (Searle, 1983) There are human attitudes, habits, assumptions, hypotheses, expectations and goals, imaginings, contexts, and inferences which characterize the distinction between sensation and perception.

Gibson's wife Elenor also conducted notable research on the depth perception of babies with the “visual cliff” experiments. The study looked at how babies experience depth perception on ledges. (Gibson & Walk, 1960) There are obvious correspondences between the study of infants in early development, visual perceptual ability and the notion of a pre-cognitive perception. The depth perception and active navigation of an infant in its environment can certainly be understood in terms of naive realism and direct perception.[24]

2.1.5 Semiotics and encoding for design

The perceptual recognition of symbolic meaning and language is the next stage between unmediated experience and a pre-cognitive science. The phenomenon of reciprocity flows through social conventions of communication. Encoding of meaning involves a transformation of ontologically subjective experiences by way of perception and the encoding of empirical signs and signifiers.

The interest here is in semiotics as it relates to the design of useful tools and task sequences that support learning and attention.[25] As such, effective encoding of symbol and an understanding of the functioning of purposeful symbolic syntax and semantic labeling in the design of a navigable user interfaces is what the prototype is designed to test. How well the labeling can encode iconic and heuristic syntax into the tasks in a design system will have a direct impact on the accessibility and usability of its tools. Think action-scaled affordances and usability heuristics rather than all of the specified surfaces perceptible in the setting, or the wider "cultural array".

Ferdinand De Saussure, in his *Course in General Linguistics*, introduces the study of semiotic signs and the observation that; "Symbols can be recognized as holding no natural

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[24] The interest in a science of introspective perception and sensory experience has much earlier precedents in the work of the structuralists Tcheicner and Wundt (1879, Leipzig). Wundt differentiated between mediate and immediate experiences.

[25] Saussere and semiotic theory which has its origins in linguistic analysis and symbolic representation has undoubtedly had a profound after-effect on literary theory, critical and post-structural literary theory which spills out in the entire genre of academia engaged with deconstruction of contested concepts and cultural practices. While this is related to the insight that signified concepts are not intrinsically bound to their representations or signifiers....That's another discussion!

connection between the signifier and signified" (Saussure, 1916). The meaning of symbols is founded on constructs of social agreement through linguistic evolution. Charles Sanders Pierce differentiated between types of signifiers, drawing out the natural connections between the signifier and signified; Icons possess attributes of physical resemblance and indexes can trace to a direct relational link between signifier and signified (Pierce, 1903). The relationship of signifier and signified is at once arbitrary, categorizable and differential.[26] Said another way, meaning is agreed upon, can be sorted according to a semiotic typology, and is contextual. If there is no natural sign, language can provide an index for it.

Linguist Roman Jakobsen contributed to structural semiotics regarding phonology and the factors of linguistic function. A 1960 article of his expanded on the work of his predecessors and contemporaries to describe six functions of language. (Jakobsen, 1960) According to his model, in order to communicate there must be the relations of:

ADDRESSER REFERENT CODE CHANNEL MESSAGE and ADDRESSEE

SENDER CONTEXT CODE CHANNEL MESSAGE and RECEIVER

Jackobsen decomposes as the stages of the process of encoding of messages in terms of their signal. These stages are delineated as a cognitive process encoding "markedness" (Jakobson, p.353)

The bearing that semiotics and markedness has on radiography has distinct relevance for the design of an interface and suite for image analysis. Symbolic and iconic representation of

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[26] Pierce's semiotic is triadic (sign, object, interpretant) whereas the Saussurian semiotics is presented as a dyadic (sign/syntax, signal/semantics).

tools and functions is one level, then we can move on to the semantic and syntactic structures supported in the information architecture, and finally there is a collection of tools that are specifically designed for perceptual tasks for image optimization and screening.

2.1.6 Markedness for Roentgen

Jakobson's theory of markedness has been useful background in the development and specification of a classification system for local signs in Roentgen semiotics. Markedness is a concept that supports the system of symbolic encoding on the basis of visual separation effects. This is the basis for the radiographic semiotic typology. (Cantor, p.2)

Markedness in diagnostic imaging follows a hierarchy of distinctive features that are descriptive of radiographic boundaries. Local signs in radiographic images are perceptible in terms of spatial separation and contrast separation, line separation and edge separation on the diagnostic screen (Cantor, p.2). Technically, these boundaries are not detected via direct optical perception but rather are a visible product of the radiation signal captured on the detection plate. The screen information represents the radiodensity signal as a tomographic image. The intensity of the radiation beam signal is able to map the radiodensity of a substance. Projective geometry supports the reconstruction of a visual representation on the screen.

Perception of the variation and hierarchy of attenuation and line separation is an aptitude that radiographers become skilled at. Interpreting the data from the screen can be said to be drawing from both direct-perceptual acuity and cognitive training. There is the direct discernment of qualities of the image and then recognition of characteristic syntactic detail that links the local characteristics to a particular condition. Perceiving a difference in tone or visual acuity is one kind of direct attentiveness, but without syntactic detail it is somewhat limiting.

It is important to distinguish between tasks related to direct-perceptual interaction with the screen information, and the way that the indirect- encoding of the source signal is detects radio density in a body or substance. We talk about direct-perception in relation to the screen information and indirect-perception in regard to the largely invisible machine processes.

Interaction at these “levels” are dependent on factors such as device and screen calibration, which requires contingency in task planning and system design. Interaction with the perceptual tasks related to a typology of local signs is contingent on the machine calibration.

A set of reference tools are specified for the Imaging dashboard for assisting with pre-diagnosis windowing and ROI optimization.

2.1.7 Epipolar Geometry and the Radon Transform

Projective geometry from two points can provide the basis for reconstruction of a three-dimensional simulation of an image. Epipolar geometry is the basis for the projective calculation in axial terms. “The epipolar geometry is the intrinsic projective geometry between two views.” (Hartley, 2004). Projective geometry makes it possible to determine epipolar lines for any point in an image, however it has no notion of a “world coordinate”. In other words, an object’s full detail can be inferred from the object details available. The basis for the projection are the invariant properties of the object itself, rather than an arbitrary scenic vanishing point or a GCS. [27] The novel regularity in Gibson's ecological paradigm sets variance and invariance at the center of unspecified substances.

Tomographic reconstruction is a type of multidimensional inverse problem where calculation produces an estimate of a specific system from multiple or continuous projections.

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[27] **Geographic coordinate system (GCS)**

The Radon transform projects a two-dimensional intensity distribution into a two-dimensional parameter space. [28] The intensity of radiation beam signal is able to map the radiodensity of a substance. Projective geometry supports the reconstruction.

These two geometric projections illustrate the fundamental processes useful for axial tomography. The beam rotation around the body simulates the invariant rotation, or change of view. Instead of a two-point projection the CT machine is able to capture a continuous 180, 360 or spiral projection of the radio density distribution of a substance.

The beam directly receives or "senses" the radiodensity of substance in terms of a signal which is keyed to a 3D mapping of the unspecified interior of the substance. The alignment of a direct detection signal and receiver will be suitable when we want to describe a sensor as a perceptual device. Borrowing again from Gibson's terminology we can use the idea of "stimulus information" (as opposed to stimuli) when we talk about the information provided by a beam or signal. Searle calls this stimulus information "sense data".

2.1.8 Machine Learning

A Stanford University Research group presented their paper in 2017 that demonstrated a 121-layer convolutional neural network (CNN) algorithm that can detect pneumonia from chest x-rays to a level significantly exceeding that of practicing radiologists (Rajpurkar, et al., 2017). At the time, ChestXray-14 comprised a dataset of chest imaging numbering 112,120 images. In their study, a dataset is pre-curated, and batch normalized and then trained against an algorithm for detecting the disease; each image is annotated according to descriptive protocols from 14 diseases. Among the pathology labels are many of the classes of assessments that radiographers are trained to recognize for image reporting. Consolidation, effusion, infiltration, and pleural

[28] The Radon Transform https://www.youtube.com/watch?v=MA2y_2YySq0

thickening exhibit attributes that are recognized and evaluated on the basis of the perceptible radiologic signs when supported with a general knowledge of the disease (Rajpurkar, 2017).

The project is set up as a cognitive-perceptual task-set for the human evaluators and results are compared with the detection capability of the CheXNet machine algorithm designed to detect the same criteria. (Rajpurkar, 2017) In the study, neither the examiner-clinician nor the machine learning system has the opportunity to refer to previous data from the patient medical history. This control measure focuses the experiment to the specific task of identification of the pathology from the image. The experiment's resource subset of 420 images (trained on the radiographers) for pneumonia entrain for a metric considering a detection and recall scoring [29] (Rajpurkar, 2017).

The emerging technology and alogrithms of machine learning has great implications for the future of radiology workflow. The Stanford experiment describes the kind of standardization and metadata labeling that will be useful for the specification of resource sets in a permanent system.

The prototyping of the imaging dashboard in this project explores how resource images and sets are displayed on the screen and how the machine learning system functions in the contingent task sequence. The function of batch analysis or machine learning is a secondary resource in support of the current patient imaging on the deck. The presentation of comparable resource imagery alongside the patient imagery presents the need for unambiguous labeling and verification safeguards, so that images don’t get mixed up. Machine learning does not dispense with the need for trained radiologists, clinical care, and proper human factors design.

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[29] Interestingly the images are down sampled in resolution to 224 x 224 (?) which seems very low in resolution but may be pushing the limit of the processing capacity for large batch analysis. The result shows that a poor performing 0.435 (less than 50%) rate of consistency

In Norway, there is a push by the independent technology research lobby to make use of or gain access to individual patient data, such as medical imaging for the development of health research in machine learning. (Teknologiradet, 2020) The sharing of personal medical data with machine learning training sets is a sensitive issue that raises plenty of ethical issues.

2.2 The concepts that make a point

The salient concepts and themes that are taken forward from the theoretical section to inform the choice of methods and guide the specification of tools include affordance, naïve-realism, empiricism, ontology, direct- and indirect-perception, invariance, sense-data, perceptual tasks, cognitive activity and attention, short-term memory (STM) and long-term memory (LTM), semiotics, encoding, markedness, semantic and syntactic structure, epipolar geometry, the Radon transform, tomography, machine-learning, simulation and generative design.

The conceptual framework has been laid out to delineate the strong trends in the academic and professional tradition and as a basis for reconciling human-centered specification models. The visualization of task sequences, machine states and presentation of services requires some critical choices. There are necessary abstractions and simplifications, along with essential integrities and metrics. How machine states are visualized to illustrate and convey progress in a sequence of tasks is a matter of careful planning and creative rendering.

The visualization of an essentially invisible machine process is a functional abstraction that illustrates select and specific syntactic and surface details accurately to communicate critical system information.

It is quite commonplace today to participate in surveys that gather subjective user attitudes and opinions about an interface, service or interaction. Some kinds of subjective claims can be verified independently while others cannot. It is even possible to visualize and aggregate data about subjective claims that cannot be independently verified, which carries serious ethical connotations. John Searle's rubric differentiates between ontologically subjective and epistemically subjective claims. (Searle) According to this distinction, pains have a different status than epistemically subjective claims of preference and opinion. The way these distinctions are resolved in a project premised on user-centered design is a critical issue. Research on the subjective attitudes of system users while they are involved with a cognitively engaging task may prove difficult to independently verify. The way that interest and attention to perceptual tasks are maintained or disrupted presents a more complex challenge.

The contextualizing of perceptual tasks in radiographic workflow engages the technician in a variety of perception based and more technically or syntactically structured tasks. In the development of tools designed to research system engagement there is a need to keep view of the semantic interactions with cognitive and perception-based tasks alike. The typology of semiotic signs provides a gestalt structure for the performance of tasks related to image optimization, evaluation and categorization of imagery. The temporal arrangement and sequencing of tasks for in referral fulfillment is also of interest. The way that interactions and task sequences allow for disruptions and resuming mid-sequence and communicate status also relate to short (STM) and long term memory (LTM).

The information architecture of in the early iterations of the prototype dashboard take cues from this conceptual framework. There is the integration of a version of roentgen sign typology into the tool set, a descriptive framework following the best practices for radiographic reporting is presented as a form submission tool, and a process framework for task sequence fulfillment is customizable, showing status states and progress and alerts to name a few.

- A systems framework looks at the encoding of signal and the semiotic and iconic synthesis of trigger action gadgets for machine system monitoring.

- The concept of variance and invariance aligns well with the epipolar geometry model. Specifying the simulation of axial signal detection in a machine process is a synthesis of technical precision, illustration and visually encoded signal.
- Knowledge and historical context and an overview of the development of digital radiographic systems since the early 1990s provides background.
- Service design
- An associative framework for the alignment of image resource sets for machine learning requires metadata conventions and visual cues that ensure that images cannot be inadvertently misidentified on the reporting. This involves the design of context safeguards for the visual task reporting environment.

Key theoretical authorities

1. JJ Gibson on the side of perception in action and the specification of rendering for the machine state simulations. Visualizing axial radiodensity output as a precise abstraction, preserving Gibson's properties of invariance and affordance for a directly perceptible screen-interface simulation of an invisible machine process.

2. Ernst Poppel's insights about cognitive science and cognitive psychology inform temporal design and HCI relationships to optimize memory, attention and recall in the task design.

3. John Searle and Poppel both support views of consciousness that can be responsive to user centered perceptions. Poppel represents a top-down cognitive neurobiological view of behavioral science while Searle respects the operationalization of subjective ontological categories of user need.

Some of the goals that are important in the prototype design are:

- ready recognition of domain objects

- machine learning resources and making a platform for this technology fit in the task scheme as a supportive subordinate process to the patient referral workflow
- User acceptance of source and resource material; the reliability of resource imagery depends on standardization, quality control and ethical use of patient information

The master thesis in interaction design is a consolidation of design and academic research. An original working hypothesis anticipates optimal ergonomic or design positional orientations referring to the anatomical planes, and that their alignment with perceptual tasks will require simulations that are free of specific conceptual distortions. It is inappropriate to visualize imaging processes after theoretical models grounded in natural reflective light. The lighting effects have no justification. The prototype needs to provide an accurate abstraction.

In the radiographic modalities the detection of radio density is a signal rather than a directly visible phenomenon. The display and interface are visual and maintain a precision and accuracy while it is indirect representation.

Radiography is a specialization which relies on technical competence and perceptual acuity. Cognition and perception are interdependent. Both cognitive preparedness and perceptual skills are projected in the design of tools, routines and procedures that rely simultaneously on experience, observation and behavioral consistency. Cognition and perception take on complex and shifting emphasis over the course of a patient imaging diagnosis and when engaged with different tasks.

Navigating a resource directory, completing a radiographic report, loading a procedure protocol, loading and calibrating a beam pattern, taking a contrast sample of a region of interest on a (ROI) diagnostic image and comparing the local features to the Roentgen typology for identification, each engage perception and cognition in different ways. The goal is to explore the way these tasks can be articulated in tools that can collect temporal response with the ensuing device.

Awareness and consciousness are delegated between the clinicians, patient and machine processes. The design of a service environment with tools to monitor the machine states, track patient attitudes and clinician engagement among the streams of information from many channels present a challenging relationship of service design, system and human user objectives. The console itself is the bridge for perceptual tasks, imaging optimization and the management of knowledge and information resources.

2.3 Relevant Research

The current and relevant innovation in the field is inaugurating a very exciting potential for machine learning, generative design and UX design for human centered design.

2.3.1 About the Literature Review

The literature review includes academic sources organized by theme and is presented as a part of the theoretical context and background.

At the outset of this project the research question was more broadly articulated as a part of exploratory research in radiographic imaging and included a subtopic on the visualization of interventional treatment and patient treatment planning. In the project planning phase, a methodical literature search was conducted using key words and concepts. The industry standardization of PACS and digital imaging in radiography in the early 90s and the emergence of HCI set some historical boundaries for the search. Databases searched included Oria, Google Scholar, EBSCO, and a selection of academic sources. The library system hosts 26 databases indexed under radiography including *NEL –norsk elektronisk legehandbok* and the *International guideline library* and the *Visible body anatomy & physiology* database.

A search on Oria produced 410,105 results for the topic of radiography and over 15,878 titles for radiography and interaction design.

The effectiveness of a comprehensive systematic review was deemed to be impractical for the interdisciplinary exploratory research design. Instead, an inductive collection of relevant research matching the specialization, source quality, and that illuminate aspects of the research questions has been ongoing. Academic sources were identified on electronic databases, reference lists, hand-searching of key journals, relevant organizations, and conferences. Peer reviewed academic sources have taken priority. Most material is academic literature but there are also some mass-media articles and things from trade publications as well as technical guides on programming and research form.

The form of the synopsis or review entry takes cues from the form of medical research reporting used in medical practice in nursing. In time the selection of sources has become more organic, and I've found many sources in the bibliography or reference pages of the key articles. Many of the most valuable sources were recommended by colleagues and at several sources were identified during the writing of this report.

2.3.1 About the Literature Review

The literature review includes relevant academic material on radiographic imaging, interaction design and data visualization. The sources covering theory include academic texts on semiotics, cognitive science and psychology, perception and human consciousness.

The literature about the medical imaging specialization is part of background research for the scoping study and so representative textbooks covering the fundamental systems and processes is relevant. It may be impossible to be comprehensive, but the goal is to be relevant to the fundamental modalities and user population and to interaction design. As an

interdisciplinary topic the themes were developed in an inductive process of searching.
It is a vast field, and a properly comprehensive study would require training as a radiographer.

The reviewed items are categorized within several themes including data visualization, human-computer interaction, and radiology specific subjects and refer primarily to scholarly and peer-reviewed academic sources. I've especially focused on materials that document academic and field specific standards and practices regarding imaging technology and user-centered design research in the specialization. The literature review deserves a section with synopsis on all of the cited texts from the theoretical framework section.

2.3.2 Literature Review (selections)

RADIOGRAPHY / RADIOLOGY and MEDICAL SPECIALIZATION

DeBenedectis, C. and Rosen, M. (2019). Teaching Radiologists Who Perform Image-Guided Interventions Effective Communication Skills Through Simulation. *Current Problems in Diagnostic Radiology*, 48(5), pp.433-435.

Part of a communication training workshop based on radiologist patient interaction scenarios, the research includes a pre- and post-workshop survey with questions about perceived preparedness with informing patients about informed consent, changing or canceling an image-guided procedure, dealing with a combative patient, and disclosing and apologizing for a medical error.

Cantor, R. M. (2000). Foundations of Roentgen semiotics. Semiotica, 131(1-2), 1-18. doi:10.1515/semi.2000.131.1-2.1

This academic paper presents a general topology of diagnostic radiological signs derived from semiotic theory of local signs. The system visualizes states of spatial and contrast separation.

“Visual separation is the combined perceptual effect of both spatial separation and contrast separation” (p.2 Cantor). The variant types of signs illustrate attenuation, line-separation, edge separation, boundary gradients, inverse projection, sharpness, and density. The set of Roentgen signs is a reference for drawing inferences about conditions at an anatomic boundary by observation of its radiographic image. The signs can be depicted as a graphic typology.

The signs are general rather than specific regarding the recognition of physiology or iconic characteristics. The contextual and specific recognition of pathologies is another level of cognitive knowledge which can be supported by resource protocols. As such the local radiographic signs are keyed to perceptual tasks ahead of cognitive attributes and for data visualization, tools are readily specifiable as a set of technical criteria which are independent of specific pathognomonic features.

Relevance: Radiologists and clinicians bring the cognitive recognition-knowledge from their education and training in physiology and pathology. Pathology classes for chest disease protocols include: Atelectasis, Cardiomegaly, Consolidation, Edema, Effusion, Emphysema, Fibrosis, Hernia, Infiltration, Mass, Nodule, Pleural Thickening, Pneumonia, and Pneumothorax, feks.

Rajpurkar, P., Irvin, J., Zhu, K., Yang, B., Metha, H., Duan, T., Ding, D., Bagul, A., Ball, R., Langlotz, C., Shpanskaya, K., Lungren, M. and Ng, A. (2017). CheXNet: Radiologist-Level Pneumonia Detection on Chest X-Rays with Deep Learning. *arXiv Cornell University*, [online] 25 Dec 2017.

Precedent setting Stanford study from 2017 built on a 121-layer convolutional neural network (CNN) for analysis of x-rays. At the time of publication ChestXRay-14 was the largest publicly available dataset with over 100,000 radiologist annotated chest X-rays including 14 diseases.

Their algorithm CheXNet is uses density mapping, dense connections, and batch normalization in combination with heat mapping for F1 diagnostic performance. Limitations cited are that only a single frontal view of each image is analyzed. The researchers predict performance improvement of the incorporation of 2 perspective as frontal and lateral views are necessary for up to 15% of diagnoses.

Sajedi, P., Salamon, N., Hostetter, J., Karnezis, S. and Vijayasarathi, A. (2019). Reshaping Radiology Precall Preparation: Integrating a Cloud-Based PACS Viewer into a Flipped Classroom Model. *Current Problems in Diagnostic Radiology*, 48(5), pp.441-447.

The study features a survey of participant perceptions about secure and anonymized PACS interfaces to assist in practical training in the radiography specialization. A simulation of the PACS environment for a quiz and survey-based curriculum and anonymized diagnostic response introduces the web-based learning concept of "flipped classrooms". Tools and interface design utilizes cloud-based simulation. While this is in the style of an academic research paper the presentation is more a finalized product marketing presentation.

Morgan, M., Branstetter, B., Mates, J. and Chang, P. (2006). Flying Blind: Using a Digital Dashboard to Navigate a Complex PACS Environment. *Journal of Digital Imaging*, 19(1), pp.69-75.

Reduction in turnaround time on reports are attributed to an interface that assists reporting, workflow consolidation, workload distribution, and urgency evaluation. The primary diagnostic interface screen views are Worklist Mode and Image Viewing Mode, both needed for reporting and maintaining records. Traffic light metaphor, digital signature. PACS (Philips/Stentor, Brisbane, CA, USA. Individual, Division, and Enterprise screens. DHTML w/ Asynchronous Javascipt

and Extensible Mark-up Language (AJAX) scripting (Fig. 1) (2006). In dash app, ActiveX controls enable queries of server for User, Division, and System.

Morgan, M., Branstetter, B., Lionetti, D., Richardson, J. and Chang, P. (2007). The Radiology Digital Dashboard: Effects on Report Turnaround Time. *Journal of Digital Imaging*, 21(1), pp.50-58. *A PACS-based dashboard providing status alerts, coupled with a report signing application, resulted in a 24% reduction in turnaround time between transcription and report finalization.*

Sistrom, C. (2005). Conceptual Approach for the Design of Radiology Reporting Interfaces: The Talking Template. *Journal of Digital Imaging*, 18(3), pp.176-187.

The Talking Template concept integrates natural language processing (NLP) and spoken dictation into radiology reporting interface systems. The concept allows the (RI) to produce reporting while viewing imaging and without looking away. The model is designed to reduce cognitive workload fatigue, boredom and reinforce memory. Supporting research compares cognitive disassociation to dyslexia. The concept is also compared to routines in SRS (stereotactic radiosurgery) and point and click information templates used with DIPS. The author advocates a hybrid model incorporating templates, speech recognition and speech synthesis for "the talking template". Radiology reporting requires also high-fidelity communication between physicians and technicians with forced choice responses for definitive diagnoses.

Stokke, Randi. "Maybe we should talk about it anyway": a qualitative study of understanding expectations and use of an established technology innovation. Innlandets forskningskonferanse for Helse- og Sosialfag; 2018-09-27 - 2018-09-27

A study looking at patient safety devices and the response expectations of outpatient users and at home or care centers in after-care or home care. Findings show that scripted design, concepts and prototype designs do not consistently or reliably align with end-use behaviors. Patients find and use the gadgets they are given in ways that were not scripted or intended.

Hofmann, Bjørn; Stokke, Randi; Berntsen, Astrid; Waaler, Dag; Aabel, Ingunn; Andersen, Jacqueline Kirsti; Toft, Benthe; Nergård, Eva. (2010) Empiriske prosjekter i bacheloroppgaver - et unødvendig gode?. *Hold Pusten.* vol. 37 (5).

Use of interactive simulator mannequins "SimMan" and "Resusci Annie" train NTNU bachelor students in critical intervention preparedness and for monitoring physiological states of blood pressure, pulse and respiration. The 3-year bachelor program trains students from a human centered perspective. Students learn to master stress and are prepared to respond to anaphylaxis, hypovolemia (loss of fluids) or heart attack. Students also train in their own skeleton lab with diagnostic equipment.

Varga, E., Pattynama, P. and Freudenthal, A. (2012). Manipulation of mental models of anatomy in interventional radiology and its consequences for design of human–computer interaction. *Cognition, Technology & Work*, 15(4), pp.457-473.

Study on mental-model related processes that intervening radiologists (IR) use in referencing 2D image sources for navigating a 3D prototype on minimally invasive radiological surgical procedures. Refers to the main traditional anatomical orthogonal cross-sectional images used in diagnostics and in communication among doctors. The prototype has sectional orientations based on the traditional A. axial, B. sagittal and C. coronal perspectives, and non-traditional volumetric, oblique and needle line views. Findings are that preoperative 2D imagery does entrain spatial

structure for mental (conceptual) modeling. Rotational manipulation is an imaginative cognitive processing of the mental model(s) which can be built up from multimodal (and multiple) image sources. Oblique views or oblique cross-sections are difficult and not trusted as baseline orientations. Visualization techniques must conform effectively to human capacities and cognitive processes as well as to techniques and workflows of current medical practice for MRI, CT, tomography, fluoroscopy use.

Yoshino, S., Miki, K., Sakata, K., Nakayama, Y., Shibayama, K. and Mori, S. (2015). Digital reconstructed radiography with multiple color image overlay for image-guided radiotherapy. *Journal of Radiation Research*, 56(3), pp.588-593.

Study proposes a new visualization methodology based on reference positioning of the beam to the distal target position and registration of patient anatomical structures. The beam can then be rotationally adjusted to precise oblique angles. Imaging is enhanced with color overlays.

Yudin, A. (2014). Metaphorical Signs in Computed Tomography of Chest and Abdomen (1st ed. 2014. ed.).

Representations of pathology types of a range of conditions and severity refer to radiological signs derived from metaphors. The descriptive set of pathognomonic patterns observed primarily on CT supports memorization and long-term (LTM) memory.

HUMAN COMPUTER INTERACTION (HCI)

Löwgren, J. (1993). Human-computer interaction: what every system developer should know. Lund: Studentlitteratur.

Usability and specification, user testable design methods, and prototyping and their practical implementation within HCI. A concise and readable designer's guide from 1994 which anticipated or specified many of the prototyping practices and functionalities in use today in programs like Figma.

PROTOTYPING

Anderson, F., Grossman, T., & Fitzmaurice, G. (2017). *Trigger-Action-Circuits: Leveraging Generative Design to Enable Novices to Design and Build Circuitry*. Paper presented at the Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology, Québec City, QC, Canada. https://doi.org/10.1145/3126594.3126637

The paper presents Trigger Action Circuitry (TAC), an interactive system leveraging generative design in the production of circuitry specification for gadgetry based on behavioral descriptions. Alternative iterative design variants are generated by the system based on given specification constraints. The case examples are in component circuitry and IoT. The example has relevance to material design and customization.

RELEVANCE: Relating the concept of (TAC) to a highly specified customized task fulfillment environment; a service dashboard, the user-interactive customization of workflow micro-interactions and gadgetry as a frontstage customization for these specialized users.

Saffer, D. (2013). Microinteractions. Sebastopol: O'Reilly.

An atomic design level look at interactive triggers, haptics, switches, alerts, rules, feedback, modes, and loops via practical design examples for use in mobile apps, web widgets, and appliances. From the popular design and programing guide series with a forward by Don Norman.

COGNITION AND ATTENTION

Thyvalikakath, T., Dziabiak, M., Johnson, R., Torres-Urquidy, M., Acharya, A., Yabes, J. and Schleyer, T. (2019). Advancing Cognitive Engineering Methods to Support User Interface Design for Electronic Health Records. *Elsevier International Journal of Medical Informatics*, 292-302(83).

Task Analysis is used to identify knowledge, thought processes and goal structures. This study looks at electronic health records. A limitation is that console and interface interaction may not capture clinician knowledge states and strategies when they are not proximately engaged with the system. Methods: Cognitive Task Analysis traces patterns of navigation sequences through the patient's and health network's information needs during typical clinician–patient encounters. Preflight preview of patient records, preparing procedure protocols, greeting and checking patient status and attitudes, imaging procedures including machine and ergonomic setup, review and concurrent reference comparison, notes and administrative reporting.

VISUAL PERCEPTION

Gibson, J. J. (1979). The ecological approach to visual perception. Boston, Mass: Houghton Mifflin.

James Gibson's classic on visual perception presenting a novel paradigm of direct natural perception. The bottom-up concept proceeds from the assumption of a non-cognitive POV. Direct perception of environmental stimuli can be perceived without the necessity of additional cognitive reference. Cues and information about the visual field are sensed in terms of variance and invariance within the optic flow. The meaning of interactions with the physical world are *involved with perception and action-affordances. Perception is interactive with the environment and its affordances. "A fixated form of an object only specifies certain invariants of the object and not its solid form" (Gibson p.227) Gibson has been called a radical empiricist.*

Gibson's paradigm of direct visual perception informs a novel reflection informing the simulation of objects within an indirect perceptual system concept for radiography.
The invariant / variant specification and ecological POV are preserved, while the detection of density rather than reflected light replaces the optics of reflective light. The beam can be described as directly perceiving objects.

Pöppel, Ernst, the Institut für Raumexperimente (Institute for Spatial Experiments). (2013). Lecture: Visual Dominance (neurobiology and perception) [Image]. Retrieved from https://vimeo.com/77787642

Pöppel is herein presented as representative of insights from a more specifically cognitive and neurobiological view. His paper on eye movement and spatial attention reveals anticipatory repositioning of visual focus which follows temporal predictability. He refers to four domains of consciousness: perception, memories, emotions and volitions. As such, Pöppel's view is relatable to a user-centered (rather than behavioristic) view of consciousness. His research suggests that temporal perceptual recognition is nonetheless physiologically bound to neurobiological or involuntary behavioral constraints, (which support a somewhat positivist cognitive behavioral science). Meanwhile, percepts and concepts can be demonstrated as separate or congruent systems or states of consciousness. The synchronization of concepts and percepts can be scientifically studied in terms of temporal and spatial alignment or calibration.

The relevance of his perspective for this research is to ground the specification of perceptual tasks to attention in a cognitively specific workflow. Much of this is relevant to temporal and graphical aspects of the interface design, short term memory and design optimization for the fields of central perifoveal and peripheral vision. His research on attention and detection of scripted visual cues has implications for perceptual task performance within the specialized interface and workflow.

Searle, J. (2004). *Intentionality*. Cambridge [u.a.]: Cambridge Univ. Press.

Intentionality and perception in action. Clarifies intention in action. Two versions of the Subjective-Objective distinction and Consciousness. John Searle may be also classed as a radical empiricist. Ontological subjectivity.

WRITING ON RESEARCH REPORTING AND LITERATURE REVIEW

Grenness, Tor (2020). *Slik løser du metodeproblemene I bachelor – og masteroppgaven*. Cappelem Damm Akademisk.

Solving methodology problems in the bachelor and master projects. Writing and research form.

Bettany-Saltikov, J. and McSherry, R. (2016). *How to do a systematic literature review in nursing*. Open Univ. Press.

Introduces frameworks for systematic literature review: PICO and PEO frameworks. PICO: Population and their Problem, Intervention or exposure, Comparative Intervention, Outcomes or themes. PEO: Population and their problem, Exposure, Outcomes. Writing a Protocol.

2.4 Critical Reflection

The interrelationship of attention, perception and cognition is fundamental to the concept of *use-*

affordances. Interaction design operates at semantic and syntactic levels of visual communication and information architecture. It is tempting to turn over the responsibility for design to an existential idealism. User-centered design does not escape this conundrum by saying that use-affordances are subjective.

Iterative, user-centered design research ought not to overly abstract our community or encode tentativeness and unaccountability either. "We are in a very abstract (disembodied) community when we talk of data populations of "preferences, reactions or abilities", (Halpern, Mitchell, Geoghegan, 2017) Where is this community exactly?

Critical theoretical commentary on user-centered design and the promise of "smartness" cautions against an "uncertain future through a constant deferral of future results; for perpetual and unending evaluation through a continuous mode of self-referential data collection".(Halpern, Mitchell, Geoghegan, 2017) In the idea of self-sustaining, adaptive iteration there is an assumption that self-organizing systems will maintain and forward their own development by simply specifying relationships among technology, human sense perception and cognition. "The temporal operation is thereby linked to an ideal of self-organization… and linked to the operation of optimization". (Halpern, Mitchell, Geoghegan, 2017) Design has not escaped critique by transferring the responsibility of learning, content, teaching and training to the affective domains of students or users in general. Work that is engaging needs to be programmatic and progressive.

If the ethnographic context helps to detail the human picture, away from the console, the prospect is misunderstood when it is aimed at establishing services at every waypoint in the user experience or user journey. That's not really the goal. Service mapping and user journeys can illuminate much more than waypoints for existing or new services. We gain something from a narrative perspective. On discovering seamful, competing and complex service mappings too many “developers” jump-to-the-conclusion that everything should be consolidated under one service umbrella. Or, there is a rush to develop a service structure to smooth every disruption. This misses the critical insight that pastiche may be the result of complex social behaviors, perceptions and strategies. Observational and contextual research is meant to uncover the deeper values and motivations of the human actors in our scene. If there is a reciprocation for every eventuality e may also need spaces to rest, to be inspired or to imagine.

3.0 Methods

The following chapter presents the qualitative research design which includes early open format and exploratory interviews, and the research plan approved by the *Norsk senter for forskningsdat*a - (NSD), which consists of a semi-structured interview and web-based survey, prepared in versions for Norwegian and English versions for students, faculty and clinical professionals working in the radiography specialization. The focus of the questions is centered on the clinical setting, routines and workflow in the modalities of x-ray, CT and MRI.

The aim of the interviews is to find out more about work routines, and to get a view of the workflow and systems in use on a on a daily referral schedule. The clinical visit also provides a descriptive sense of the technician’s personal relation to their work. As a part of a background study the inquiry is about human-factors, work routines, how the specialists stay engaged with their work and the screen based environments of the X-ray, CT and MRI modalities.

Open format and semi-structured interviews and surveys were prepared and tailored for the principal population subgroups identified for the study.

Service design methods are employed in the subsequent analysis and take account of the survey responses and interview data, contextual inquiry, observational studies to develop stakeholder maps, user journeys, and user stories to map the clinical service context. This part involves informed and specified creative development.

Methods for further processing of insights for HCI research include a hierarchical task analysis, an online card sort and affinity mapping test which is reflected in the results and specifications presented in the prototyping section in Chapter 4.

Clinical interviews were conducted at Aleris Roentgen in Gjøvik in the spring of 2020. The interviews were arranged in advance with the CT responsible clinical leader who was provided with the NSD approved pre-survey and information letter along with an informed consent and patient confidentiality statement and release. Each participant signed the consent and release form allowing the use of their anonymized interviews in the research. The interviews were 20 -30 minutes each and conducted in Norwegian, following 11 open structured questions. An initial observational study and contextual inquiry site visit preceded the interview session. The interviews took place on a second visit in May, consisting of four recorded interviews with clinical radiographic technicians who work as a team on daily referral schedules for x-ray, CT and MRI.

Hospital visits included shadowing an interventional surgery procedure at Innlandet Sykehus which is recounted in narrative form, (Appendix Item F). Notes were taken on a CT head scan sequence. Additionally, there was a visit to the medical imaging section at the main hospital in Gjøvik and an observational study on a sonogram procedure at a clinic in Moelv.

The study program of Radiography at NTNU is organized under the Faculty of Medicine and belongs to two different departments on NTNU. Department of Health Sciences in Gjøvik and The Department of Circulation and Medical Imaging in Trondheim. Three-year bachelor programs are offered on both campuses. The population of students identified in the radiography specialization at NTNU between both campuses affords 85 active students in Gjøvik and 115 in Trondheim (2019-2020). The number of employees connected to this study programme is 14 in Trondheim and 7 in Gjøvik (2019-2020). Several open format interviews with a group of nurses in practical training and students in the bachelor program were recorded in a written journal notebook format.

Early attempts to engage the Radiography programs of NTNU included pre- research scoping and contact with 10-15 faculty and administration sources in Trondheim and Gjøvik and semi structured interviews about routines and practices in room scheduling among the study programs in Radiography at NTNU, on both Trondheim and Gjøvik campuses.

The research population identified in the pre-project is the target research group for both the prototype concept test and the online survey, both specifically composed for the thesis project. Their focus is on radiographic consoles, workplace systems, order fulfillment and clinical routines.

3.1 What was done and how

Pilot versions of the online surveys were prepared initially on NTNU's SelectSurvey system and then updated in a responsive format for the student group and the clinical research group on Nettskjema. NTNU IT has decided as of May 2020, that SelectSurvey will be discontinued at NTNU in favour of 'Nettskjema' from the University of Oslo (UiO). The University maintains a data security agreement with the system. Versions are prepared in English and Norwegian language, and the clinical survey is presented in a responsive questionnaire format, presenting questions according to the participant categories.

3.2 A Qualitative approach

The research design is approached as exploratory and qualitative research, structured around the interviews, participation in relevant webinars and online coursework related to the background scoping study and the development of case scenarios and a service profile.

The research question has also, over the course of the year, become more specifically focused on how to design in a way that lessens the disparity or “gap” between attention to scripted tasks, domain objects and user perceptions. The early formulations of the research question sought to investigate how one might design and visualize a better patient treatment intervention system for radiographers. The need for a sufficient understanding of the background, wider service context, workplace routines and social milieu broadened the research scope. Even with the eventual design focus on specific prototyping solutions and ideation, consideration of pre-care, operational, after-care and long care planning all converge in the tools and domain objects. The suite of services and functions are realized as a collection of task and workflow tools set in the wider scope of workflow and job routines.

The conceptual framework has bounded the research in a paradigm accommodating to perceptual affordances and perceptual tasks and in the semiotic and semantic aspects of visualizing and encoding domain objects in a dashboard and machine panel. This has generated new, more specific questions. What symbols and icons are recognized and recalled and how does recall and recognition affect the performance of tasks? Elaborating beyond that, how does the task sequencing and scripting carry syntactic structure in a way that is meaningful and engaging to the user? For what actions or functions of the system interaction sequence is “ease of use” desirable? and how should domain objects and information architecture be best designed to hold interest and attention? Is it always done by conserving cognitive resources? What is the best way to introduce training into the task flow? and, how well can the system sustain attention and temporal engagement?

The choice of a mixed methods qualitative research design is guided by the conceptual and theoretical framework and takes an exploratory approach to investigating the primary relationships, existing specifications, perception-in action and interpretation of service affordances in the first stage. Getting a view of the routines and attitudes of the identified population groups gives us a contextual picture and human voice.

The recognition uses and application of a semantic system of buttons, alerts and cues expressed in the form that the information architecture takes is critical. With these things in mind, the accounts of users further inform our specification of two screens. There are at least two stages. The first stage relates to specification for scenario building and the basic criteria for the low-fidelity prototyping. The second is specification and customization for concept testing and usability in the prototype. What follows is a description of the methods and procedures used in developing and processing the user-insights.

3.3 The Interviews and insights

Interviews were done in several stages of the research. The earliest interviews included a visit to the Radiography department at St. Olav's hospital in Trondheim in 2019. The research population was identified in an earlier project focusing on room scheduling and booking systems, and I prepared some additional exploratory interview questions with the future research on radiographic systems and patient treatment planning in mind. The exploratory on these topics survey was submitted to NSD at this early stage. In Trondheim we had conducted a focus group on the scheduling systems and given a tour of the IT department in the radiography section. The department in Trondheim as very helpful and interested in our research.

I conducted an open format interview in March with Eva Nergård on the radiography section in Gjøvik also. She is a guidance counselor for the program, basis group and practical training contact for bachelor students in the program and serves a similar role in the study program for microbiology and other parallel study programs. Eva is also a teacher and lecturer. She works with reference groups, as a lecturer and as a guidance counselor for bachelor students in radiography. I included the exploratory and long form interview guide for that interview and asked some of the questions related to patient treatment planning, PACS and how the practical training works. She recommended to contact Sykehustet-Innlandet for a work-praxis disclosure agreement which would be necessary to follow or "shadow" students on practical training in the patient / hospital system. Evå was generous with her answers and descriptions. I conducted the interview in Norwegian and reconstructed my notes from memory shortly after the meeting.

In the fall semester I began work on the research plan and arranged several meetings with faculty in the Department of Health Sciences in Gjøvik. I found that in general the faculty in Gjøvik were less responsive. As a general observation of policy, the radiography training also makes a point to model the appropriate conduct of clinicians regarding patient confidentiality and so the training rooms are also usually not “open” for students outside of the program. I was able to attend several first-year radiography lectures, including one on radiation protection and one about the monitoring of patients for medication effects and allergic reactions. This can be especially critical when there are synergistic medication effects that the care specialists need to be aware of. Some procedures make use of contrast solutions or medications to enhance imaging, and the radiographers need to be aware of the individual patient issues that could pose complication. In most cases this is simply a matter of previewing the patient medical journal information and following the correct patient check-in procedures. In the case of complications due to an allergic reaction, the radiographer has training on the appropriate interventions. I interviewed several students that were attending these lectures and was invited to visit with a group of nurses in training.

3.4 The clinical interviews

The clinical interviews are conducted in a semi structured format around questions pre-prepared in the interview guide. The interview guide was made available to the clinical team manager for advance review, and I think the others I interviewed heard the questions for the first time when the interview was conducted. An information letter describes the scope and purpose of the research and informs participants how the collected information will be handled.

The 11 main questions inquire about workplace routines, background and training, patient care, teamwork, how clinicians stay focused on their work, and their perspectives and attitudes about machine-learning processes. At times, the interview questions were probing and offered some of their personal reflection on the emerging trends in machine learning, while an effort was made so that the speculative comments were obtuse or at least non-committal. The radiographers tended to respond with their own longer and descriptive elaborations. Getting a sense of their voice and about their sense of responsibility in their job as an important aim of the study. Also, what they were inspired and motivated by, what their typical day is like, challenges and pain points and a bit about their workspace and tools. Finally, we talked about machine learning and how they keep abreast of new innovations in the field.

The participants were all very generous with their answers and patient with my still improving Norwegian. I appreciated the detail and thoughtfulness behind each response even more when I transcribed and translated them over the following weeks. I was actually very lucky to arrange the interviews during a time when the local coronavirus restrictions were eased in the end of May. Their daily referral schedule had been reduced and so they had time to meet with me without interruption for up to a half an hour each. I was also taken up to the clinic to see the control booth and exam theatres for both CT The transcribing and translating of notes was arduous, but naturally provided another round of processing to an inductive extraction of the key user-insights. The transcriptions also provided new insights; into the sequence of reporting, for example. I had assumed most of the reporting was done directly after an imaging service, but the technicians described morning pre-flight routines accounting for most eventualities to be the norm. One radiographer described previewing the day's schedule of referrals and the procedure protocols each day in the first half hour before patients arrive. The CT and MR specialists both described the opportunities they were afforded for customization of procedure protocols and the opportunities for ongoing training they received. The protocols must be approved, but the effort is welcomed. There is sometimes a contention of aspiration in the roles of technicians who want very much to get validation for their skills of recognition and diagnosis. That is the radiologist's responsibility. The design of suitably engaging training and technical assignments for the radiographers provide the basis for activity that holds interest and attention, and cognitive engagement. I made written notes about the details directly after the visit.

I've included three of four of the clinical interviews in the appendix.

3.4.1 The Interview Guide and Information Letter (APPENDIX ITEM F)

The Interview Guide and Information Letter introduces the project and the scope of the research and explains to participants how the interviews contribute to the development of the research prototypes and the wider project. It includes the informed consent release that explains the *Norsk Senter for Forskningsdata* -NSD approval [30], and the planned use of collected data. Going through this formal step also establishes a secure data repository using the Nettskjæma system of Universitetet i Oslo - (UiO). which maintains a recognized data security agreement with NTNU.

The concern over patient confidentiality and patient data is a sensitive issue on all medical wards, and the letter clarifies that the research interest is HCI, workflow routines, and

[30] NSD – Norsk senter for forskningsdata AS | NSD – Norwegian Centre for Research Data
Harald Hårfagres gate 29, NO-5007 Bergen Referanse: 196948

the design of tools and interfaces. Proper care and non-disclosure regarding patients or patient information is observed. The letter explains also that collected personal data is handled separately from the results of the survey data, and that their participation will remain anonymized unless they are contacted separately for an expert or personal interview. The participants are given a choice to provide their e-mail for follow-up focus-groups or more interviews. The NSD approval allows for the collection of recorded interviews and e-mail contact information into 2021.

3.4.2 Insights from the Interviews

What is distinctive from the clinical visits is the enthusiasm the radiographers have for their jobs. They feel very lucky. What they report is descriptive and responses are often measured. I think they have been instilled with a sensitivity to patient privacy issues, and some clinicians, particularly at the hospitals are guarded. The clinicians I talked to were comfortable enough in talking. A salient expression is the recognition that their job makes a real impact patient care.

"My job is very exciting. I think my job is very important. X-ray is a big part of the health service when it comes to eradication and detection of different sicknesses and assistance. The job we do here is as a private clinic, it saves the hospital a lot of money. And we save the local community from many inpatient admissions. It´s very important in that way. "

They also feel excited about the way that their work is on the leading edge of innovations, and that training and progressive responsibility is a part of their long-term security and supports their professional goals: They love that the clinic sends them on training seminars and that there are opportunities for interaction with the protocol customization.

The radiographers interviewed hold a clear understanding of their role as technicians. They also get a sense of meaning from the recognition of their perceptive contributions to diagnosis and patient care. It is notable that the radiographers that I interviewed did not talk much about activities outside of work.

When asked about things that they did to prepare for work, they responded mostly in terms of the day's referral schedule. They reported a typical referral schedule of 25 or more imaging services in rapid succession each day. Roles were implicitly and formally agreed upon, with some flexibility and rotation. Login and console responsibility was according to shift scheduling on each modality and assigned to a technician/manager assigned to that modality. Then, there is usually a flexible or rotating arrangement around patient assistance. Nurses and radiographers help the patients through an intake process, the patient completes a pre-care release and checklist.

It is the dynamics of these kinds of responsibilities, in the workflow of the department that reveal the extended needs of the console and referral fulfillment system. The radiographers are responsible for many contingencies and need to monitor things that may come up like, allergic reactions or assisting patients with special settings on the gantry adjustments. These are alternately fixed and flexible waypoints in the completion of a service which is accompanied by the imaging order and radiographer report delivered to the radiologist or referring physician.

There is a clear division of tasks and monitoring which are part of a comprehensive service platform, but that function as separate component systems on the console within the theatre. These are the tasks related to presetting of ergonomics and machine settings and Imaging optimization and reporting on post-production. The machines typically come with their own proprietary systems, protocols, and training, which more or less work coordinated with the RIS, PACS, referral scheduling system and clinic reception and scheduling system. Several of the informants reported the inconsistency of standardization between the system manufacturers.

There is even inconsistency in naming conventions for functions on the different proprietary systems. One student described names for processes on two systems that were the same, but nonetheless indicated unmatching functionalities.

3.4.3 The Interview Guide

3.4.4 Information privacy and informed consent

Information privacy and the regulations related to the collection of personal data from participant informants is taken seriously for this project. Over the course of the research, the formality of properly notifying participants about the handling of their data and what their rights are has been followed with diligence and care. This regard is extended in the collection of interviews, surveys and participatory design sessions as well as personal communications. There is a critical relationship between privacy protection and ethical research.

The main interviews and surveys are expressly described to participants as anonymized in the results. Considerable care and planning is taken to ensure that the information about attitudes and actions that are volunteered of informants in the surveys are saved and presented in a way that protect participant anonymity. Further, the participants interview responses are not saved together with personally identifying information. This protects participants and the internal or unconscious bias of the research analysis as well.

The NSD approval process requires extra documentation and written informed consent forms to be provided to participants to sign, along with the information letter which describes the purpose of the project.

3.4.5 Choice and total number of informants

Interviews were arranged as in person meetings with faculty on the campus in Gjøvik (5) and

Trondheim (3), Students (5), nurses (4) and clinical radiographers on the site visits (5). Additional dialog is cited from web communications associated with lectures and webinars (3).

3.5 The Survey

The survey has been prepared in variant iterations for the students in radiography and for clinicians on Nettskjæma[31]. There are demographic questions, rating based and likert scale questions, matrix questions and short-answer type questions. The adaptive questionnaire is designed with contingency branching and automated question selection which allows for a tailored presentation according to respondent status and alternate versions in Norwegian or English. The use of contingency branching is also a strategy for focusing subjective judgements on issues of related relevance. The basic survey consists of 20 questions. There are 8 demographic questions, 4 questions about study and practical training status, 4 Likert and matrix questions about the radiographic modalities, and another matrix question about the personal prioritization of responsibilities on the radiographic detail.

The clinical version of the survey is prepared with alternate questions from the approved interview guide.

3.6 Developing the insights with service design methods

3.6.1 Card sorting

An online card sorting test was made in the early stages of the research collection phase to help prioritize and group concepts of interest and help structure functions, themes and categories for furter conceptual development. The focus group for this test included other students of interaction design. The cards were curated concurrently ith several weeks of post-it note ideation.

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[31] Information Visualization and Interface Design for Patient Treatment Planning in Radiography: https://nettskjema.no/a/140033

The set of 30 cards were derived from a brainstorming exercise. The top 30 words or concepts from all the modes of approach were presented as a random set. Participants are asked to categorize and label the words into labeled and hierarchical groups.

Typical results included categorization by work-process, ethical issues, the radiographic modalities, technical equipment, personnel issues, information architecture and visual perception.

3.6.2 Task Analysis

Hierarchical task analysis is part of the set of structured analysis methods used in development, engineering and HCI that are used to develop and detail the qualitative data and insights from the scoping interviews, clinical visits, and survey information. Task analysis models can be drawn as generative or ideational plans or document the current system dynamics.

Task analysis illustrates a model for the fulfillment of a sequence of stages in the referral for diagnostic imaging and reporting fulfillment. The mapping of the task stages shows three concurrent and aligned service sequences which can be configured in an adaptive way to 3 or 4 radiography care specialists. The primary roles are Team lead, modality lead (who is usually the reporting radiographer), radiologic-care specialist and radiology technician.

These are color coded and correspond to:

1. the machine panel and technical ergonomic settings for the modality
2. the referral management and image reporting,
3. the patient care-support following the check- in routines and physical assistance

The task flow is structured as a 7-stage progressive hierarchy and analyzes various essential task contingency procedures along a modal departmental workflow. The fulfillment stages appear also on the imaging dashboard and machine panel and represent progress as a visual system state. The stages defined for the task model in this iteration span the activities of the team. Preflight login, Patient reception, Procedure preflight, Pre-procedure evaluation (PCE), Image acquisition, Image markup and consultation, and Reporting finalization and certification. Task level-sequences detail subtask sequences for the two screens, and the patient interactions, and map variant contingency groupings. There are optional completion items, optional completion sequences, fixed or variable completion sequences, pause system states, cyclical sequences, and concurrent operations.

The prototypes in this case are semantically concerned with the fundamentals of the workflow and so specifications are tentative. Still, the task analysis can help to describe the functional roles and there are examples of perceptual tasks, semantic system status alerts and cognitively detailed or syntactically involved parts of the procedure and image reporting fulfillment.

Structured analysis also includes the service design methods; use case scenarios, service blueprints, actor maps and narrative user journeys. (Annett & Duncan, 1967)

3.7 Service Design methods (1:00)

Service design methodologies consist of research tools and techniques for analyzing the context of service interactions. Service design (typically) considers the actors, locations, objects, and interactions involved in the service delivery in proximity to business at “the line of interaction”. A relational understanding of service-design recognizes the formal designer /client context, which implies relationships in co-design. In its broader scope the service design perspective considers all the organizations, stakeholders, services, and points of interest along the service journey. A user-centered perspective would consider the various actors and participants in light of their personal and professional goals and motivations.

The user- goals and motivations relevant to service design don't always fit neatly into customer and service schemes, nor do they necessarily imply or designate the need for a service relationship or waypoint. Actor maps and user-journey mapping charts the behavior and activity of actors and stakeholders beyond the service blueprint into the domain of user-experience design and ethnographic study. This wider framing in an exploratory study has a descriptive or aim. As academic research, it is aspiring to an unbiased or journalistic integrity in the collection of data. Maps can take this documentary view, presenting or reporting relationships as they are, and it can concurrently develop a planning-view where service-relationships are specified for development or improvement. The goals and motivations of human actors are often illuminated or expressed in temporal expressions of perception and experience. Ontological yearnings and personal inspirations motivate people to raise families and go on vacation, enjoy a sunset or take up some new interest.

Service design is used in the pre-research in documentary and descriptive ways as a method for collecting data and processing facts, specific details and insights. The aim is to describe radiographer clinicians and students on practical training in real scenarios. Narrative techniques are used to contextualize specific, documented relations and conditions.

Service design techniques are also utilized in the planning phase as specifications are developed. Material specifications are charted by way of a temporal transformation between the way things can be accounted for, and then how iteration of specifications can lead to improvement.

The service design perspective promoted by Nielsen and Norman is set in a more definite client and service centered relationship.[32] As this is academic and exploratory research, the clinicians are considered in their personal, civic, and ethnographic context. The human picture of goals and motivations are captured by way of an independent or journalistic approach to service and stakeholder mapping.

The service design methods used include:

Service Blueprint

User Journey

3.8 The COVID-19 Scenarios (1:00)

The initial research for this project was framed broadly on how we might better visualize a patient treatment planning within radiographic practice on practical training. As the unprecedented COVID-19 pandemic and public health crisis began unfolding in February and March 2020, the practical use and place for radiography in a response to the infectious disease pandemic was still developing. While CT can provide a detailed confirmation of the staging and presence of the disease, it is not used as a primary or first-line diagnostic tool due to inefficient triage and sterilization requirements and is not typically used for crisis processing of infected or screening of unconfirmed cases. The presence of the disease could be and is discovered in the diagnosis for another condition. Also, the symptoms and characteristics are like other early-stage lung pneumonia. The presence of pneumonia and the distinct radiographic signs that characterize COVID-19 are indeed routinely discovered prior to RT -reverse transcriptase [33] and as case

[32] Service design is the activity of planning and organizing a business's resources (people, props, and processes) in order to (1) directly improve the employee's experience, and (2) indirectly, the customer's experience. (Nielsen Norman Group)

[33] The COVID-19 RT-PCR test is a real-time reverse transcription polymerase chain reaction (rRT-PCR) test for the qualitative detection of nucleic acid from SARS-CoV-2 in upper and lower respiratory specimens (such as

studies, the images can be a very useful instructional and research reference. The use of CT and X-ray are especially useful in illustrating of the staging of COVID-CoV-II induced pneumonia. The imaging helps clinicians in developing a mental model for the disease and progression of deterioration. The visualizations are also useful in how tells us about the kinds of situations and considerations that come in to play.

Reverse Transcriptase RT-PCR testing is the gold standard, or the preferred method for testing for the presence of COVID-19. The test turnaround time is 6-72 hours. (Stanford Medicine).

The use of CT is controversial because the procedure depends on radiologist or radiographer availability and the theater needs to undergo de-contamination. The impact on radiographic workflow is significant and so the value of radiographic imaging is more for training. A recent Stanford study found that the imaging training does support increased accuracy in clinical diagnoses in general.

Fantastic 3D medical visualization / simulations have been modeled from CT and MRI such as the Surgical Theatre COVID 19 VR video.[34] The LA based company used CT source imagery to "VR-alize" scans of patient lungs and produce a dramatic immersive fly through visualization. The radiographic imaging shows cytokine storm, ground glass opacities and other radiological signs. In general radiographers would be prepared to recognize the presence of the general features of pulmonary opacity and its characteristic boundary "markedness". These are any area in the chest radiograph that is whiter than it should be. The mucous in the upper

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nasopharyngeal or oropharyngeal swabs, sputum, lower respiratory tract aspirates, bronchoalveolar lavage, and nasopharyngeal wash/aspirate) collected from individuals suspected of COVID-19.

[34] https://www.youtube.com/watch?v=AWxyy8LkMVo

respiratory tract makes it difficult to breathe. The visualizations in the Surgical Theatre video colorizes the boundary features of organs (blue) and the pneumonia (yellow).

Intervention scenarios from a cognitively distanced remove

A collection of use-case scenarios including several journey maps shadowing doctors and specialists in radiography includes crisis intervention scenarios based on COVID-19. User journey mapping explores the intervention and triage in the clinical setting and with a student on practical training. Scenarios are based on interviews, survey data, written accounts, real procedures and courses of action recommended by local and national health authorities.
The case-example user-journeys are developed through narrative service mapping modeled on insights gathered from citizens, students, volunteers, health care workers and crisis interventional workers.

My approved research plan involved shadowing and contextual observation of bachelor level radiography students on practical training. When the COVID-II crisis and restrictions cancelled many of the in hospital and on campus activities, there was some weeks of uncertainty and cancellation of many of their scheduled activities. I made some scenarios involving a student on "praxis" reporting to a radiography and include case examples following interventions in response to the COVID-19 crisis.

3.8.1 The User Journey Scenarios

1. a patient is referred by a general physician to a medical imaging specialist at a private clinic
2. a radiology student on practical training with a local hospital
3. a patient admitted for testing and diagnosis of corona induced pneumonia
4. a COVID CoV-II patient gets CT scan to trace presence of pneumonia

Andrea Scenario

This user journey follows a student on practical training beginning in early March 2020.

Andrea is starting on her practical training in Radiography at NTNU in Gjøvik when COVID-19 pandemic begins to emerge. She is following her regular studies and attending on-campus lectures in her first year that include General Pathology and Digital Imaging. She gets regular updates about her lab and study section via the course pages on Blackboard.

On Tuesday she bikes from her dorm at Sørbyen to attend two lectures on campus and a lab on radiation physics. On the way, she gets an SMS from her advisor and practical training coordinator reminding her to come by the Radiography department at the Institutt for Health Sciences to get her practical training schedules. She will meet her practical training coordinator to confirm her clinical assignments for the next week and preview a patient information questionnaire. The practical training coordinator arranges the student´s "praxis" schedule with a radiography clinic in Gjøvik. On Monday, Wednesday and Friday the next week Andrea will report to RT, Harald Asmundersson at "Oppland Roentgen".

The schedule is set, confirmed and matched with the clinic through the RIS system[35] and a confirmation is sent to the coordinator at NTNU. Then a confirmation and schedule reminder are sent to Andrea the week before and then again on Sunday night before her scheduled start date.

Andrea checks her plan and finds that the clinic is within walking distance from the campus. She looks at MazeMap to be sure she knows where to go.

The clinic is quite modern and has relatively new equipment and the facilities are all designed and operated in accordance with ISO clinical safety and workplace standards.

[35] A radiological information system (RIS) is the core system for digital management of imaging departments. The major functions of the RIS can include patient scheduling, resource management, examination performance tracking, reporting, results distribution, and procedure billing.

On Monday, Andrea shadows Radiography Technician, Harald Asmundersson in the CT section on the afternoon rotation for about four hours. There are two radiographers and a nurse working on that section as a team, and Andrea gets a view of how they work together on the PACS system[36] *to take in a patient who is experiencing symptoms of pneumonia. The radiographers have already received referral information from the patient's general practice doctor, and so they will perform a sequence of scans on a Siemens CT scanner. Andrea watches the procedure from the control booth with Dr. Asmundersson.*

The patient arrives and is checked in at reception, then a nurse dressed in a mask and gown brings the patient in and fills out a patient information checklist, like the one Andrea has seen in class. The form asks about pre-existing conditions and if the patient has any metal implants, or problems that may interfere with the CT machine. The patient is brought to the dressing room and then the 2nd radiographer assists to position the patient in the gantry table of the CT machine for the diagnostic imaging procedure. The imaging sequence is started from behind a glass window from the control booth. The procedure goes very quickly, the machine makes some noises, and some lights blink, and the patient imaging procedure is done in about ten minutes.

Dr. Asmundersson looks at the images that are produced on the screen showing the lungs of the patient. He looks very concerned. The radiographer calls a radiologist physician to view and verify the output images. Soon they are both concerned. The RT explains that it is a special case and that they must follow a special safety protocol. The RT thanks Andrea and says he will explain what has happened on her next practical training day, on Wednesday. Andrea is dismissed early for the day.

The radiographer knows that the attenuation patterns he sees in the images matches the protocol for COVID-19 induced pneumonia and the radiologist agrees, and so a RT (reverse

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[36] (**PACS**) is a medical imaging technology which provides storage and access to images from multiple modalities (source machine types). Images and reports are transmitted digitally via PACS. The universal format for PACS image storage and transfer is DICOM (Digital Imaging and Communications in Medicine)

transcriptase)- nose swab -test is ordered right away. The patient is triaged to a location on Øverby where there is a tent set up for coronavirus testing.

There is more in the news about the spread of COVID-19. Andrea is advised via SMS from the FHI (Folkehelseinstitutt) about social distancing and to stay at least 2m from people. A contact tracer working at the clinic calls Andrea in the afternoon and advises her to self-quarantine until her test results show that she is not infected.

She wonders how this will affect her studies. She receives a notification via a pilot app, Smittestopp that her RT test is negative, and she is free to continue her praxis for the time being.

On Wednesday, Andrea is at the clinic in the morning again and with the radiographer reviews the report notes that have already been sent for diagnosis by the attending radiologist at the hospital. The lung scans from the patient exhibit signs of "ground glass opacities" and "crazy paving" in the lungs. These are visible in the images as distinct attenuation patterns that appear as cloudy streaks on the diagnostic image. On Friday, the COVID-19 test is confirmed positive and the hospital arranges for an ambulance to transport the patient to the (ICU) intensive care unit.

The order and the notes from the CT scan are all put on the (RIS) and Kjernejournal, mobile patient record system. The information on the RIS is confidential and is sent via a secure channel just between the clinic and the hospital.

The Kjernejournal, FHI or PasientSky apps allow the patient to get some alerts about appointments, prescriptions and status for public health announcements.

Andrea spends her praxis time on Friday on the telephone, talking directly with the patient and contacting the family and close contacts to find out who may also be at risk.

On March 12 NTNU cancels Andrea's practical training for the spring semester. Andrea and all the radiographers that were in direct contact with the patient are also placed on an at-home quarantine order for 10 days as a precautionary measure and asked to get a nose swab test.

After 2 weeks in the (ICU), the patient's pneumonia stabilizes, and the patient is ordered to continue recovery on a 14-day home isolation.

On March 26 Andrea learns that the patient has also recovered, and they are both off quarantine. It is like an early vacation. No school and nothing to do.

Andrea decides to attend a special training session on contact tracing in Trondheim and arranges to take a train ride to visit the cathedral there and visit the MRI facility at St. Olav's Hospital, in Trondheim.

The status of the pandemic situation in a crisis or emergency response has a different workflow than the day-today practice or scheduled outpatient services routines. The current crisis may indeed have far reaching implications for how radiology and virology on ICU wards are integrated or set apart from other specialized sections (mammography, ultrasound, nuclear medicine). As it is common for hospitals to have both an emergency and ICU ward, we may also see permanent viral ICU containment type wards, complete with dedicated radiologic equipment. It is more feasible for clinics in large municipalities to maintain dedicated wards with quarantine protocols, robotics and isolated control booths designed to minimize nosocomial spread of infectious disease. In smaller communities and as a practical feasibility for high caseloads, this is less realistic, not to mention that there is often a very limited number of CT machines in smaller communities.

Crisis interventions are in all practicality a form of "trial by fire" usability testing. The tools and medical equipment rushed into use in response to COVID-19 were, in many instances, improperly suited for longer term implementations, or designed well. [37]

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[37] Purchasing done under the pressure of a crisis may be ill suited for the long term. With the shortage of ventilators at the outset of the crisis there was a great number of ventilator prototypes presented online. After some weeks, the use of ventilators was adapted more effectively. It was found that intubation (placing a tube in their airway) of

The scenarios and service maps include consideration of interventional factors, tools and logistics that affect workflow. These items were considered, and many are integrated into the prototyping scenarios for radiography workflow (as they are in practice):

- Sanitation methods using UV light to disinfect coronavirus
- Air purification systems, HEPA
- Ventilators
- Insulated control booths
- Robotics including tele-factoring devices operated by technicians
- Florescence imaging[38]
- BIM image resources for machine diagnosis verification or referral
- haptic systems for alerts
- Viral diagnosis testing kits (RT nasal swab tests)
- Personal protection equipment (PPE):
- Powered Air Purifying Respirator (PAPR)
- N95 masks, goggles, gowns
- Robotic or physician administered bronchoscopy, delivery of medicine, triage, surgery and in the specific case of coronavirus robotic surgery devices utilizing live or continuous MRI imaging for navigation of procedures.

If this seems like the stuff of science fiction, it is. Science fiction writer Frank Herbert wrote about "crechepods" - fully automated trauma "pods" - in his 1972 science-fiction novel

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patients could be counterproductive in less serious cases. (find) Meanwhile, the improvisational pressure of the crisis has produced practices of triage that are better adapted to the situation.

[38] The rRT-PCR fluorescence generating process utilizing a bound fluorescence and quencher pair of molecules as the probe for specific types of cDNA

The Godmakers: Will we need wards run radiographic interventions from completely by remote booths and all handlings done with robotic arms? Is this even desirable?

3.9 Simulation Lab visit

In the spring and autumn of 2020, I participated in research focus-group studies the NTNU Geomatikklab at the Institutt for vareproduksjon og byggteknikk (IVB) in Gjøvik. The research involved testing navigation and controls within a simulation VR environment of a newly built campus building to solve several tasks in two handcrafted scenarios. The system simulates the accurate architectural layout of the building's infrastructure. The immersion allows the user to navigate everywhere within the 3D space and to preform maintenance and inspection reporting tasks within all parts of the building. Navigation is done using two handheld controllers. As a part of the testing and focus group I took the opportunity to use and familiarize myself with the simulation equipment. Visual orientation and spatial demarcation were areas that we speculated and talked a lot about.

The use of simulation and 3D modeled environments has corresponding development in the medical industry. Surgical Theatre has been demoing a VR navigation environment for VR navigation of internal physiology.[39] The immersive simulations are another example of merging of accurate specification and abstracted use of imaging data to create a navigable and immersive environment for aiding in medical procedures. These are used for demonstration, training, or actual procedural assistance. Colorization and visualization for immersive fly throughs and scaled perspective viewing is awesome convergence of scientific accuracy from imaging and

[39] Surgical Theatre https://www.youtube.com/watch?v=2le-3urv75s

creative specification abstractions that illustrate and emphasize key features in the simulation view.

4.0 Results

What is found in the research has been multifaceted- rather than one or several insights, what is discovered something like a scale of linguistic and visual affordance that is practical for an environment of tasks. These operate simultaneously and at different ranges. They are realized in the prototyping tools as concurrent instruments for monitoring and interacting with and completing tasks in the workflow. The tools are stratified each at their own gestalt and their Information architecture presents the tasks at their respective gestalt. Gestalt may be the wrong concept to introduce, because it does not explain the full texture and ambience of ontological perception. Gestalt describes rather something more about the range and modes that task strategies occupy.

The tools within the prototype include passive and dormant states, progress alerts and perceptual tasks that call on the system user to use their sense and recognition at different levels of engagement. Visual acuity and recognition of the typologies engage perceptions in a distinct “direction-of-fit" (Searle) between the system and the world.

There are corresponding tasks, which cognitively engage the technician at a level of linguistic detail, writing the radiography report or calculating the beam configuration that optimizes against excess radiation exposure. Some problem-solving sequences may involve syntactic interaction at a more specific level, while providing ready access to the resources needed to complete the micro interaction that moves the task flow along. The completion of the technical sections of the radiographic report requires the operator to verbally describe the ROI characteristics of the present study and correlate the reporting from the patient’s prior imaging history. The support resources, references and automated processes are designed to support these reporting, while the technician contributes their competence in the specifics of the case. Procedures of a higher technical skill level may require more calculation, problem solving, or direct consultation with the physician. The radiographer consolidates the vital information sampled from a set of gestalts, and ultimately the radiologist or physician interprets the findings for diagnosis.   The research prototypes demonstrate the local system information in alignment with the patient care situation occurring in the examination room. .

4.1 Semiotic Signs in specification (1:00)

A number of routine perceptual tasks are part of the imaging workflow and are completed in the Image optimization and reporting mode. Perceptual tasks involve the radiographer making direct visual assessments of the qualities of radiographic images. The technician is directly interacting with the screen data and reporting qualities of acuity or contrast, or other general features that they recognize. The tools support identification and measurement or sampling of scaled values to the ROI. A set of support tools can help to code or match ROI characteristics to the set of local semiotic signs for roentgen.

Encoding: Identification and resource (set) verification for Roentgen signs.

These interactions with markup tools are intended to explore the perceptual / cognitive identification of anatomic boundary attributes. The set of contrast separation types exhibit unique attenuation characteristics for a variety of boundary types found in radiographic examinations. The descriptors for the roentgen signs are basic technical terminology for diagnostic radiographers.

Visual contrast is a perceived difference in optical density between adjacent regions of an image. Optical density refers to a level on a gray scale. Internal and external characteristics, edge and boundary characteristics can be described and optimized for image quality optimization, and so a radiographer needs to be proficient with the technical terms.

In a formal technical sense these are in fact general rather than specific attributes comprising a "set" of radiographic descriptors at a gestalt. This is also a kind of design positional orientation.

4.2 Sketching and wireframing

The sketching included ideation exploring the look of the material aspects of the devices and how they might operate. The mental model informing a lot of the sketching is inspired by the early prototypes of Hounsfield and the axial rotational principle of computed tomography.

These were also approached with a certain naïve approach to specification. The indispensable conceptual specifications were rotational or variant /invariant beam capture, a settings display, an image display, the x-ray tube, portability and handheld controls, dynamic representation of voxel space and use of the anatomical image planes. The x-ray tube was adopted directly from general or texbook specifications that have been largely comparable for decades. I rendered 3D models of the tube from a 2D schematic drawing using fusion360 and imagined a circular beam track configuration with a radius of 700cm.

In some of the more fantastical sketching of the material form of the device concept, there is ideation around portable devices that combine the radiation beam device and the control screen in one portable apparatus to directly image the patient.

4.2 A cognitive framework for pathology

In the clinical setting it would be normal that radiographers draw from more than technical criteria. Monitoring of risk-factors, awareness of medication effects, allergic reactions, longitudinal patient history and patient interactions are important care responsibilities. Radiographers are trained in general pathology, physiology, patientcare, radiation safety, medication effects, allergic reactions.

The radiographer already refers to the definitions of medical conditions in preset imaging procedure protocols. These are valuable resource definitions that are a part of the data available through a PACS system and loadable to the imaging device deck of the device manufacturer. These protocol templates contain information about the configuration and settings for specific image procedures. For example, a profile for a chest x-ray for a teenager would include settings optimized for the anatomy of the patient, their weight and body fat and ergonomic positioning.

Radiologists refer to a set of criteria that are essential for the diagnosis of pathology from radiographic imaging. A complete radiology report covers all these categories and provides essential documentation for a differential diagnosis.

- Condition
- Definition
- Epidemiology
- etiology
- Pathogenesis
- Risk Factors
- Classification Staging
- Grading
- Gross Appearance and Key Histological Features
- Complications and Associations
- Clinical Presentation and Natural History
- Treatment and Prognosis

Of the criteria there are many which are technical criteria that are provided by the radiographer. While the radiographer does not interpret imagery or make a diagnosis, they do preform visual assessments and provide detailed typological notation on regions of interest (ROI) for descriptive purpose and to consult with the radiologist about the optimization of the image quality. In some cases, they will provide a preclinical evaluation (PCE), prognosis and recommend actions including triage. Recognition and identification of the characteristics of common disease conditions is an expected competence, but diagnosis is not their proper role. The tasks of radiographic services are structured around those parts or fields of the framework that can be directly measured or sampled technical terms, and those reporting tasks which are verifiable. Categorization and notation of local typological features, measurement ad contrast image optimization specifies the functions of of the imaging dashboard, while the technical categories from the framework for pathology define the detail fields for the provided radiographic report.

4.3 Medium fidelity prototypes

4.3.1 The Machine Panel

The Machine Panel is specified as a research prototype. It is a dashboard for the dedicated monitoring and calibration settings for the machines of the modality. It monitors one workstation or a collection of machines within that clinical modality or ward. Typically, it is for one lab, booth, and theatre. The service dashboard provides a clinic or hospital wide service interface customizable to any of the main radiographic modalities x-ray, CT, MRI, and sonogram.

The current prototype version explores CT axial tomography and axial rotational beam configurations for monitoring, calibration, machine maintenance, service scheduling, and system status. The panel works in combination with the imaging dashboard and gets current information from the clinical system about the current procedure protocol on deck in the referral cue. The protocol holds the definitions for a particular procedure. The machine panel is used to monitor the modality machine operation status and temperature, radiation load, serves as an interface for modifying the local protocol presets, confirmation and setting for ergonomic and machine settings and for setting the beam intensity and strength prior to each new imaging set on the cue.

It also generally monitors safety-critical machine states including temperature, load status and calibration. The procedure protocol (CPT)[40] is the standardized reference profile for most of the clinic's medical radiologic imaging. The prototype features these functions:

Beam Selection: **S**election and calibration of fan, column, and cone beam variants and beam power and intensity settings. The interface is a visualization that displays accurate rotational position, gantry level and angle adjustments, and temperature.

UV sanitization mode: a system alert reminds the lead about regular or scheduled cycles for a UV sanitation. During the sanitation cycle the power settings and gantry position are locked, and the corresponding toolbar functions are disabled. On the screen the disabled tools appear darkened while a status sequence shows the progress of the maintenance cycle.

The protocol "snipe" is a graphic label that indicates the current procedure protocol (CPT) on deck. The full protocol definition contains information about the voltage and intensity settings, beam configuration and ergonomic settings for the current patient procedure. The snipe indicates the loaded protocol set that the machine system is currently accessing for the machine voltage and ergonomic settings and appears as a passive metadata reference. Certain metadata labeling is unextractable from the protocol, and the protocol profile information and procedure coding is encoded into all of the patient images. This kind of metadata is also in resource and reference imagery.

The detector plate indicator displays a graphic indicator of the current digital detector plate installed in the CT gantry. It displays information such as the battery charge state and detector type. There are corresponding loading and recharge instruction sequences.

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[40] A **CPT code** is a five-digit numeric **code** with no decimal marks, although some have four numbers and one letter. **Codes** are uniquely assigned to different actions.

A temperature alert is part of general monitoring of safety critical machine states and operation. On a critical sensor reading, the system displays an alert status and produces a haptic alert. The machine panel notifies the Imaging dashboard of its status and the job referral cue can be redirected to another section or ward.

Voice recognition (VR) and intercom system: A voice recognition and intercom system is an audio reporting and alert link to assist communication between the machine and the service database. Prompts can dictate service support.

Responsive design: The machine panel is specified as a dedicated semi-portable tablet to be used in close proximity to the control booth and theatre console. The research prototype is configured for adaptable sizing on iPads and tablets. The beam and simulation protocol models support a consistent accurate scaling between the different interfaces.

4.3.2 The Imaging Dashboard

The Imaging Dashboard is specified as a functioning research prototype.

Machine-learning window: how are the machine-learning resources kept subordinate to the patient imaging?

Contrast optimizer: task sequence involves identification and selection of tools, rotating an object and optimizing the radiodensity reading with an optimization loop. A pilot test on Maze samples data on recognition and recall of named and unnamed tool icons, functionality, and task completion.

Reporting and referral screens: task sequence demonstrates micro interaction states activating minimized screen features and tools on a response form. The task progression is indicated.

Reporting radiographers work within imaging teams[41]; Common roles within those teams include, for example, writing pre-clinical exam reports for musculoskeletal and chest region imaging[42].The technical sections are typically provided as a part the clinical services, while the interpretations and differential diagnosis are handled by a radiologist. The referral provided by the referring physician contains the specific services and procedure protocols and (CPT)[43] codes. Radiology and radiographic reporting contain important coding and legal information and so the authorization and sign-off on actions and radiologist diagnoses is a critical part of the authorization and fulfillment on both ends of the interaction between the physician and the radiographer. Therefore, recommendations for action are out of place. Also, there are ethical considerations around recommending imaging when it is not needed or has already been done.

There is a formal structure and style to the report, and the proper standard is succinct, accurate, clear, and unambiguous. A high-quality communication appeals to the attention, conveys its message, and elicits a response. “Judgy” terms are out of place, as is non-committal language (Lewis, 2017) (Hartung, 2020). The referral and reporting function is an important part of the Imaging Dashboard. Input form fields for reporting on the system include categories that are either open or hidden dependencies. While the radiographer will in most cases be responsible for completing detail for the technical and human factors of the patient imaging service, there may be cases here the radiographer communicates a pre-clinical diagnosis or critical findings that

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[41] The Royal College of Radiologists and The Society and College of Radiographers (2012) Team working in clinical imaging. London: The Royal College of Radiologists.

[42] NHS Improvement and NHS England (2018) Allied Health Professions Supporting Patient Flow: A Quick Guide. London: NHS Improvement.

[43] Level I **CPT codes** are the numerical **codes** used primarily to identify medical services and procedures furnished by qualified healthcare professionals (QHPs). **CPT** does not include **codes** regularly billed by medical suppliers other than QHPs to report medical items or services.

require special action. The basic set of criteria in the radiology report will be familiar to all radiographers and include:

Study Type: This is the Study Title or CPT code set which may correspond to a clinical billing code but is more accurately a procedure protocol which is also standardized to the machine presets. For example, “CT Abdomen and Pelvis with Contrast” or “CT Chest with Contrast”

Date : this is a variant field and would include order date, imaging date and report fulfillment dates

Indication: The indications include signs, symptoms and history and are best expressed referring to the billable clinical indications.
The radiography imaging panel prototype concept includes tools based on the roentgen typology of signs, which gives the radiographer opportunity to preform perceptual identification and reading of local line separation signs. The local signs are helpful to the physician, while the multitude of metaphorical signs descriptive signs are not always standardized.

Technique: number of views, area imaged, post-processing, contrast (CPT code set). Much of this forms the order fulfilment requirements for the radiography report. On CT and MRI modalities there is specific information about the body part, contrast solutions used (i/v or oral), in what sequence it is done, post processing services and additional imaging, colorization, simulation and 3D reformats.

Comparison: It is important in the reporting to be consistent with comparative metrics. Do not mix metrics for millimeters and centimeters, for example.

Findings: The findings are usually done by the referring physician or a clinical radiologist. There may be more than one finding or procedure in one report.

Interpretation / impression: Again, this is usually the purview of the radiologist or referring physician.

Notifications: This would include information about equipment settings, preparations, the approach, the samples taken, medications and complications as well as follow up.

CRITICAL RESULTS and CRITICAL TESTS get a special urgency rating. Unexpected findings also get a special urgency rating. Examples may be things like intracranial bleeding, aortic aneurysm, abdominal hemorrhage, pulmonary embolism, ectopic pregnancy, etc.

Style: Style considerations would recommend the use of present tense for interpreting studies (PCE) and past- tense for procedures that have been preformed

4.5 The Usability and Concept test : Appendix Item

An online test of the *Usability and Concept test* is prepared as a (pilot) study with another online service, Maze. Maze enables a survey format. Simple tasks are prepared that collect responses on symbol recognition and recall. These are set up as task completion challenges. The user is asked to navigate the interactive elements on the screen.

Interviews are recorded on:

ZOOM: H1n Handy Recorder microSD 32GB to MP3 format

4.6 Design tools

Atomic design

Atomic design is a methodology for creating and maintaining UI design systems in prototype and graphic programs such as Illustrator, Sketch and Figma. It consists of a set of practices, thoughtful hierarchies, pattern libraries, and techniques for managing assets in the design and development workflow.

Figma and Maze

Figma is a digital design and prototyping tool used in front-end development to develop presentable and functional screen to screen interactions. The visual programming lets the designer work with prototype paths and interactivity between screen scripts. It is also possible to use and modify instances of components across screens and throughout a design system.

button states, adaptive screen sizing, drop-down and screen-based interactions, delays and animations.

The prototyping system generates CSS code which can be helpful in the communication of specifications between developers and other designers.

As a prototyping tool, rather than a full development or programming language, there are some presentation limitations. The most obvious is limited interactivity within components.

The design environment in Figma is suitable for “atomic design”

Used in combination with Maze it is possible to present questionnaire-style prototype surveys.

4.7 Reflections on Generative Design and Trigger-Action Circuitry

“We are not passive receivers of social cues, influencing our decisions in some stimulus-response cycle following a cognitivist stance. We are actively giving form and sense to ourselves, the practices, objects and tools in our environment. we actively perceive and choose what to perceive" (Merleau-Ponty 1962)

Generative design could be regarded as a distinctly *ideational stage* in developing a strong concept. This contrasts with an *evaluative stage*. There are some conceptions of the idiom that approach generative design from a more human-centered practice of evaluation. There are also some articulations setting generative design at the interactive node or decision-boundary of machine systems and HCI. (Höök & Löwgren, p.23:5) This is a continuum which could invite creativity to a service interaction. In their various expression, the production of "designs" are the result of an iterative interactive sequences of improvement and assessment. The client, designer and your chosen methods are functioning together, or not, in an interactive system.

As a print graphic designer, it is customary practice to set up a sequence of "creative rounds" in the client approval process. Also, your client also may be a creative input and sensibility. Design guidelines and strong concepts are the collaborative tools. It is helpful to tolerate both synthesis and divergence within, and so to discriminate in successive iterative improvements. "It should be made clear that the notion of generative and evaluative modes is an analytical distinction... spanning a field and naming two aspects of the discipline" (Höök & Löwgren 23:3)

Within machine learning there is also the parlance of the term generative design to indicate a process in which a designer defines technical constraints for production through a computer and then an algorithm produces designs that fit all the designer's specifications. This may imply programming, coding and even IoT circuitry. Trigger-action circuits (TAC) represent a novel concept that leverages generative design by way of tools that can encode ideational semiotic signs as a trigger mechanism for building circuitry. (Andersen, 2017) While machine learning is analytical, generative design is in a process of creative production and optimization. Instead of specifying details of a solution, the problem is specified and the computer itself synthesizes solutions. (Andersen, 2017) The idea of "solving the problem in the best way" carries the implication that there may be multiple or even unlimited solutions, and that the best solution is optimal in relation to the designated constraints (be it time, material or economic).

In the case of the functionalities in radiographic workflow, the trend is towards more use of machine learning in the analysis of reference imagery. In the prototypes the image analysis workspace features dedicated tools for the reference channel. Batch comparisons and analysis is not to be (interchangeable) with the on-site patient workflow. How a reference and machine learning channel/function is situated within the clinical patient workflow is a critical constant. There are security fail safes and safety critical considerations. Generative simulation tools and editing features are limited in the workplace consoles and so exploration of generative design finds its expression most often in an early stage of the design process. The idea of iterative user centered design is a commitment that many manufacturers are adopting as "4th generation" (self-optimization, self-configuration, self-diagnosis, and cognition)

The semiotic layer of encoding in the prototyping concerns the design of interactive buttons.

Customization is "unlimited within limits", so to speak. The presentation of encoded modular and actionable controls for preset behaviors in the production of new componentry is novel but not seamless.

This is two different things. Adaptive settings and customizing menus and toolsets, for example, can be configured for specific tasks as well as users. Meanwhile, the geometry of workspace windows can be manipulated or constrained, while forces like snapping in guides implement behavioral settings in the workspace preferences.

Finally, trigger-action circuitry (TAC) establishes preferences in the encoding of these attributes and behaviors at the level of a user-programmer or designer-user building a system.

Iterative prototyping could be considered a form of slow-trigger circuitry. The fidelity of prototyping is not accurately only low, medium and high functionality, but instead “low and medium-fidelity” prototyping can measure high-level user interactions between signs and encodings of very different perceptual and cognitive (apprehension).

We can describe the system parameters mapping to behaviors which can be conceived as goal directed behaviors represented as symbolic encodings, rather than functional system centered integrities.

Specifications can test cognitive response, perceptual response, memory, recognition at a charted grouping of semiotic sign-types.

CSS

4.8 Designing to meet heuristics

Focus groups and a usability walkthrough gauges perceived usability, aesthetics, focused attention, involvement, novelty, and endurability.

Additional perceived challenge, feedback and control, motivation, and affect

The cognitive dimensions set forward by Green focus on usability aspects that make learning and doing “hard” for mental as opposed to physical reasons. (Green & Blackwell, 1998) For example, button size is a physical usability attribute while tasks and functions that require translation, mental abstraction and calculation before an action can be taken are cognitive usability issues.

The issues of cognitive engagement and cognitive distance is set to information design notation criteria and applied to the radiographic system prototyping based on Green & Blackwell's cognitive dimensions. "The notation comprises the perceived marks or symbols that are combined to build an information structure. The environment contains the operations or tools for manipulating these marks. The notation is imposed upon a medium, which may be persistent, like paper, or evanescent, like sound" (Green & Blackwell, 1998)

Many of the information architectural structures are fixed as contexts or resources, while other artifacts are modeled in terms of notation tools, image and machine monitoring gadgets and their use. We distinguish between non-interactive and interactive artifacts in the design of a dashboard. Constraints limit the interactivity of the interface contexts.

The environment for radiographic and radiologist notation is layered. In Green's terms viscosity is a measure of how the user's intention is expressed in a sequence of actions, and the ease of recovering from a deviation from the execution of those actions. Hard mental operations put a high demand on cognitive resources and attention. Attention is the cognitive process of selectively concentrating on one aspect of the external or internal environment while ignoring other aspects.

Some examples of a less psychological subset of cognitive dimensions in the notation system include;

Abstraction: Discontinuous or fragmented viewing requires more cognitive effort. Continuous or seamless action reinforces bottom-up perceptual processing more in keeping with Gibson's ecological paradigm. Motion pulls our attention toward it. The rotational visualization and scrollable or zoomable interaction with machine states minimizes the cognitive disruption of a fragmented view presented in multiple perspectives.

The notation system for radiographer and clinical markup and cueing is color coded with contrasting markedness to prevent change blindness between patient images and resource images as well as clear indication of oblique and sequential progressions in image sets. Change blindness is an attentional effect impairing the detection of change states. It is especially critical in a workflow (Rensink, 1994)

Hidden dependencies: Not all dependencies need to be visible. The dashboard serves the purpose of presenting controls and system status for multiple interdependent systems and information streams. Many backstage processes, IT services, routing and system functions are irrelevant or at least a distraction to the task fulfillment workflow. The PACS, RIS and scheduling an appointments system all occupy screen space in a tailored presentation.

Premature commitment: sets constraints on the order of doing things. Insight from interview. The notes before and after the patient consult.

Also, within the radiographer notation fields are some incremental or tagged reporting detail tasks. This is a balance between over constraining the fields and space for notes. Color coding can provide some status categorization to notes and field scripting.

Secondary notation: voice activated reporting reinforces short term memory and is minimally disruptive to cognitive resources because it is utilizing a complementary mode. Research on short term memory (STM) shows that visual spatial tasks and recall tasks can be done simultaneously in parallel with low impact on task cognitive engagement. “a concurrent visual task does not impair performance of a verbal task” (Braddeley, 1986)

- Visibility is linked to incremental task provisionality:
- Positionality and accountability are built into system log in requirements.

- Provisionality is built into the incremental task completion sequence, and order fulfillment:

The dashboard manages information streams and task functions for separate sub-devices or "gadgets". The collection of devices each have their own notation, environment and medium.

Microinteractions:

Four distinct types of user activity (corresponding to Green's framework) are managed within the service dashboard environment:

Incrementation: images, notation, patient information

Modification: (many proposals here for the screens and specifications of the information architecture

5.0 Conclusion

The current disposition and achievement of the research tools is a broader working background knowledge about radiography, a survey of James J. Gibson's ecological perception and cognitive attention theory, semiotic theory, and the development of a conceptual framework from that supports the specification and visualization of a set of research prototypes. The view of tools to assist radiography treatment and planning are now focused on a much broader variety of design strategies to meet both direct perceptual and more syntactically detailed tasks. Perceptual tasks that engage technicians in visual assessment of radiographs are contextualized with consistent positioning and with reference to a set of tools that allow them to grade local signs according to the semiotic typology. System status and progress cues and completion reminders are designed at a semantically accessible level, and more interesting and engaging tasks are designed to involve users at a syntactic level that meets their specialized knowledge. In end the prototype presentation is something of a suite of interaction design methods, aimed at several kinds of cognitive engagement or action scaled affordances.

5.1 Future work

Future work is realistically assessed in terms of opportunity. The collection of design methods and techniques are counted as skills in the designers toolbag. The continuing campus access limitations in response to the coronavirus render the future of this project tentative.

There is more coding and task scripting that could be done to improve the prototypes.

The prototypes are iterative and interactive tools, and it seems that scenarios around the use of the prototypes themselves would need to be client or sponsor driven. I think the prototype tools would make a great classroom project. The development of the prototypes could be built around specific curriculum as learning modules specific to the specialization, for example.

I think there is a balance that we strike over sustainability. The original research plans identified students on practical training as a research group. I think also that the material design specifications of the devices themselves could be more robust. Working with trainees and specialists to develop task scenarios with a realistic and testable interactions is important.

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Zhengyou Zhang: “Determining the Epipolar Geometry and its Uncertainty: A Review”

Lectures

RAD1031 – General pathology (basis course, 1st year) Patient observation

RAD1031 – Allergic reactions and medication monitoring, Jacqueline Andersen

RAD1031 – Autoimmune sickness, Jacqueline Andersen

Video Lectures

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Szameitat, A. (2017). Cognitive Psychology Lectures 1-7 PY2025. Lecture, Brunel University

Webinars

Lecture: Psychology for radiography (May 19)

Lecture: Digitalsamling (May19)

"Veien til Covid-19-kuren" Forskningsrådet Webinar

John-Arne Røttingen, NTVA - Norges Tekniske Vitenskapsakademi (8.april 2020)

Training

Fusion 360, Figma, Maze, CSS, Inkscape and Illustrator

APPENDIX

Appendix Item A - Machine Panel and Imaging Specifications

Appendix Items B-D : Reserved for Prototype pages

Appendix E Interviews

E.1 Interview Guide and Information Letter

Interviews

Student interview

E-1-1 clinical interview 1

E-1-2 clinical interview 2

E-1-4 clinical interview 4

APPENDIX ITEM F: Contextual Inquiry: A hospital ward site visit

APPENDIX ITEMS G: Interview Guide (English and Norwegian), NSD approved survey: Information Visualization and Interface Design for Patient Treatment Planning in Radiography

APPENDIX ITEM H: MACHINE PANEL PROTOTYPE (light grey panel) v4 10.12.2020

APPENDIX ITEM I: SERVICE DESIGN BLUEPRINT COVID-CoV II INTERVENTION