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Scuola di dottorato di ricerca in Ingegneria dell'Informazione – XXVI ciclo
Indirizzo: Scienza e Tecnologia dell'Informazione

A workflow for melanocytic lesion evaluation

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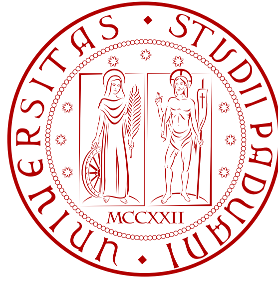

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SOMMARIO

Allo stato dell'arte, rilevare la presenza di melanomi quando questi si trovano nelle fasi iniziali di sviluppo rappresenta un compito impegnativo per i dermatologi. Nel periodo di sviluppo iniziale, il melanoma è pressoché identico ad una lesione melanocitica benigna (ovvero ad un comune neo), fatto che richiede una notevole capacità di individuare cambiamenti minimi nella forma o nelle dimensioni della lesione. La dermatoscopia, una disciplina che prevede l'analisi di pattern sospetti all'interno di immagini ad alto ingrandimento, aiuta i dermatologista a monitorare questi cambiamenti. Questo approccio ha però dei difetti. Tipicamente, il processo di identificazione del melanoma non è condiviso fra i dottori, e spesso non è neppure seguito pedissequamente da uno stesso dottore nell'arco della sua carriera. Ciò dà luogo a due problemi: (1) in molti casi, i dati prodotti dai dermatologi non sono confrontabili fra loro, come ad esempio nel caso in cui un dottore fotografi una parte del corpo, e un altro decida altrimenti, e (2) i dati prodotti sono spesso non coerenti all'interno dello storico di un paziente, come accade nel caso in cui un dottore decida di non fotografare una lesione, limitandosi a prendere delle note. Nel secondo caso, ci si può trovare di fronte a lacune nell'archivio fotografico delle lesioni, causando difficoltà nel controllarne l'evoluzione. Inoltre, il metodo di lavoro seguito dai dermatologi è molto dispendioso in termini di tempo, e potrebbe essere ottimizzato delegando alcune fasi, come lo scatto delle fotografie delle lesioni di un paziente, a personale non strettamente medico.

In questo trattato presentiamo MoleMapper, un'applicazione per sistemi Android che risolve i problemi suesposti introducendo un flusso di lavoro stabile. L'intuizione chiave del nostro lavoro è che, grazie ad un processo standard e ripetibile, possiamo creare un supporto applicativo che porti coerenza nei dati prodotti dai dermatologi, e automatizzi alcune fasi precedentemente laboriose.

MoleMapper realizza questi punti grazie a: (1) l'introduzione di un flusso di lavoro strutturato che guida l'utente nello scatto delle fotografie a quadri generali che verranno analizzate dal dottore, (2) una suddivisione del corpo umano che carpisce i dettagli di ogni zona che possa contenere nei, e (3) un'associazione biunivoca fra le immagini create dal dermatoscopio e le suddivisioni proposte nel flusso di lavoro. Contrariamente a quanto avviene per gli strumenti attualmente in commercio, i quali richiedono un continuo passaggio fra il PC e la macchina fotografica, MoleMapper utilizza un singolo strumento per l'intero processo.

Abbiamo valutato l'efficacia di MoleMapper tramite un esperimento di laboratorio semi strutturato, e tramite un successivo studio sul campo. Nel primo studio, abbiamo raccolto dati dai dermatologi durante visite simulate. Nel secondo studio, abbiamo intervistato e raccolto le opinioni dei dermatologi che hanno utilizzato MoleMapper con i loro pazienti. I risultati indicano che i dermatologi hanno trovato MoleMapper utile nel loro lavoro. Tuttavia, i dermatologi preferiscono scegliere quali parti del corpo debbano essere fotografate, limitando l'efficacia del processo di lavoro proposto. Hanno trovato l'interfaccia intuitiva, e ritengono l'utilizzo di un solo strumento un miglioramento significativo rispetto al loro precedente continuo passaggio fra PC e fotocamera.

In futuro, miriamo ad integrare MoleMapper con il suo progetto padre Cutis in Silico. MoleMapper fa parte di una famiglia di strumenti che ambiscono ad automatizzare lo scatto delle foto a quadri generali, e ad assistere i dottori nel rilevamento di melanomi. Uno degli obiettivi principali sarà quello di sincronizzare agevolmente in MoleMapper i dati ottenuti da PersonalScreener, uno strumento che permette ai pazienti di monitorare le loro stesse lesioni utilizzando i propri smartphone come dermatoscopi.

Abbiamo individuato 5 contributi di questo lavoro: (1) un riassunto dei vari processi di lavoro seguiti dai dermatologi ottenuto tramite interviste che hanno coinvolto 7 dermatologi. (2) Una suddivisione standard del corpo umano che può essere utilizzata per la fotografia a quadri generali. (3) Un flusso di lavoro

proposto per i dermatologi che introduce maggior coerenza e precisione nella loro pratica quotidiana. (4) Un'applicazione Android per seguire il flusso di lavoro proposto. (5) Una valutazione dell'applicazione e del flusso di lavoro proposto nella forma di un caso di studio che ha coinvolto dei dermatologi nel loro lavoro.

ABSTRACT

In today's current practices, detecting melanoma in its early stages is a challenging task for dermatologists. Early stage melanoma is nearly identical to benign melanocytic lesions, requiring doctors to detect subtle changes in shape or size of lesions that are easily missed, but are indicators of development of the disease. Dermatoscopy, a discipline that involves analyzing suspicious patterns in magnified pictures of skin lesions, helps dermatologists keep track of these changes. However, this approach has its shortcomings. Typically, the process of identifying melanoma is not consistent between doctors, or even within each doctor. This results in two problems: (1) it creates data that is not comparable between doctors, such as when one doctor captures photos while another does not, and (2) it produces data that is not consistent within a doctor's own records of a patient from visit to visit, such as when they switch between capturing photos of a mole or simply taking notes. In the second case, doctors may have gaps in photos available, causing difficulties in tracking the progress of moles. Further, their existing methods are time intensive, putting pressure on them to complete their evaluation quickly, and require them to perform actions that could be done by someone without a medical degree, such as taking pictures of a person's moles.

In our work, we introduce MoleMapper, an Android-based application that addresses the issues above by enforcing a consistent workflow. The key insight in our work is that, by having a standardized, repeatable workflow, we can create tooled support that both introduces consistency, and also automates parts of the process that were previously tedious. MoleMapper does this by: (1) introducing a structured workflow which guides the user in taking full body pictures for the doctor to review, (2) making use of a subdivision of the body that thoroughly captures all potential areas that may contain moles, and

(3) automatically creating a mapping between the pictures taken by a dermatoscope and the subdivisions introduced in the workflow. As opposed to existing tools that require dermatologists to context switch between a PC and camera, MoleMapper consolidates the entire process into a single device.

We evaluated MoleMapper by performing both a semi-structured laboratory experiment, as well as an in-the-field study. In the first study, we collected feedback from dermatologists during mock evaluations. In the second study, we interviewed and collected feedback from dermatologists that used MoleMapper with their own patients. Results indicate that dermatologists do indeed find MoleMapper useful in their existing process. However, dermatologists prefer to selectively choose which subdivisions need photographs, limiting the effectiveness of the streamlined workflow. They find the interface intuitive, and they see the single device approach as a significant improvement over their existing practice of frequently switching between PC and camera.

In future work, we aim to further integrate MoleMapper with its parent project Cutis in Silico. MoleMapper is part of a family of tools that aim to fully automate the capture of full-body pictures, and provide doctors assistance in detecting Melanoma. One of our main goals will be to provide seamless data synchronization between MoleMapper and PersonalScreener, a tool that lets patients monitor their own suspect lesions by taking dermatoscopic pictures with their smartphones.

The contributions of this dissertation are five-fold: (1) a summary of the different workflows practiced by dermatologists that was revealed in interviews with 7 dermatologists. (2) A standard subdivision of the human body that can be used when taking full-scale pictures of a patient. (3) A consolidated proposed workflow for dermatologists that would bring thoroughness and consistency to their practice. (4) An Android application to perform the proposed workflow. (5) An evaluation in the form of a case study for the application and workflow being used by dermatologists in-the-field.

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1 INTRODUCTION

1.1 MELANOMA

Malignant melanoma is the deadliest type of skin cancer [SMZ+14]. Despite being rare among the different forms of cancer, an increasingly large number of cases are diagnosed every year. The World Health Organization reports 232,000 new cases occurring globally every year (2% of all cancer cases); projections indicate 76,100 new cases in the United States for 2014, with 9,710 estimated deaths [SMZ+14]. According to Skin Cancer Foundation Statistics [Rob05], one in every five Americans will develop skin cancer in their lifetime. In Europe, malignant melanoma is the ninth most common type of cancer, with more than 100,000 new cases diagnosed in 2012 (3% of the total) [FSFLT+13].

Melanoma has one of the most rapidly rising incidence rates among all types of cancer. Figure 1 shows how both incidence and mortality rates for melanoma have been rising during the last decade (circled in black), despite a generally decreasing trend (circled in gray).

Typically, melanoma initially grows superficially, within the epidermis (melanoma in situ), and penetrates into the dermis (invasive melanoma) at a successive stage. Studies [CEG+89; BSG+01] have shown that prognosis in melanoma is best correlated with the vertical depth of the lesion, making early detection crucial for saving lives. Early-stage melanoma that only affected the epidermis, and is located near where it started (stage I) has a five-year survival rate of 92-97%, decreasing to 53-81% in case it affected the dermis (stage II), to 40-78% in case it spread to the nearby lymph nodes (stage III) and to 15-20% if it reached other parts of the body (stage IV) [BGS+09].

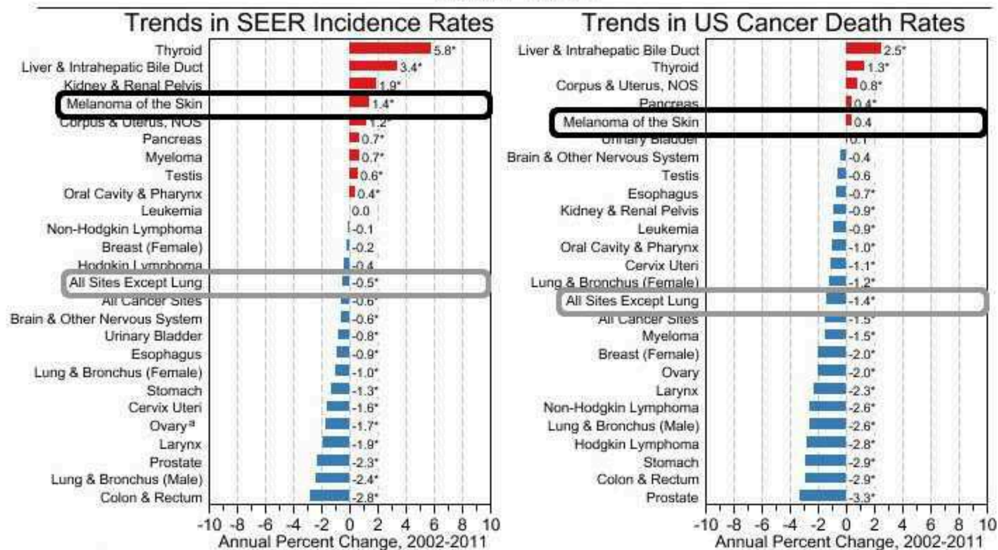

Figure 1: Although incidence and mortality rates yearly decreased on average by 0.5% and 1.4%, respectively, new melanoma cases increased by 1.4% and deaths increased by 0.4% year-over-year[HKG+14]. Lung cancer was excluded from the averages because it accounts for 14% of all new cases and 28% of all deaths alone.

Suspect lesions are evaluated through biopsy followed by histopathological examination: once identified, melanoma is surgically excised. This procedure is both good in terms of survival rates and very cost-effective. A late 1990s study [TRS98] estimated that 90% of the total annual direct cost of treating melanoma was attributable to patients with stage III and IV disease. Excision of earlier stage melanoma minimizes the risk of its evolution to a later stage, which would need to be treated using procedures that are more costly and more demanding on the patient, such as radiation therapy, immunotherapy, targeted therapy, or chemotherapy.

The primary tool that dermatologists use to identify melanoma is Total Body Skin Examination, a procedure in which the doctor "naked-eye" inspects the whole body surface of the patient for suspect skin lesions. It is difficult to distinguish early stage melanoma from a benign melanocytic lesion (i.e., from a

common mole), which has led to several proposals for a standardized set of discriminating lesion features. Among them, the most notable are the *ABCD* rule (and its extension, the *ABCDE* rule), and the Glasgow seven-point checklist.

The *ABCD* criteria, the first to be introduced in 1985 [FRK85], were intended for both doctors and laypersons, and included Asymmetry, Border irregularity, Color variegation, and Diameter greater than 6 mm. The fifth criterion, "E" for "Evolving", was later added [RFK+05] to account for changes that may occur to lesions, as changing nevi and new nevi are more likely to be melanoma: a 2005 study involving 309 high-risk patients reported that in patients of more than 50 years of age as much as 30% of all new lesions were melanoma [BKE+05].

The Glasgow seven-point checklist [Mac90] is an alternative set of features to be checked that was introduced in 1990, and comprises three major signs (change in size, shape, and color) and four minor signs (inflammation, crusting or bleeding, sensory change, and diameter of 7 mm or greater). Because of its higher complexity, the checklist saw less widespread adoption than the ABCD rule [RRF10].

1.2 DIGITAL DERMATOSCOPY

During the late 1980s, dermatoscopy (also known as *in vivo epiluminescence microscopy*, or ELM) emerged as a new approach. Dermatoscopy is a non-invasive, *in vivo* examination of the surface and subsurface of the skin through the use of a magnifying lens and incident light. This technology made it possible to include the dermoepidermal junction into the analysis of lesions, paving the way for novel techniques such as pattern analysis.

Pattern analysis, presented in 1987 [PSW87], is a technique based on the evaluation of some specific patterns, colors, and intensity of pigmentation of melanocytic skin lesions. These features are not visible to the naked eye, but are easily detected when dermatoscopy is used. Table 1 shows how sensitivity,

specificity and diagnostic accuracy of pattern analysis were all reported to be superior to those obtained using either the ABCD rule or the Glasgow 7-point checklist.

Regardless of the criteria used to evaluate lesions, dermatoscopy was proven to lead to more accurate diagnoses than naked-eye inspection whenever examiners are experienced, or have received specific training [KPW+02].

Rule set	Sensitivity	Specificity	Diagnostic Accuracy
pattern analysis	85.4%	79.4%	70.8%
ABCD rule	84.4%	74.5%	67.8%
Glasgow 7-point checklist	78.1%	64.7%	57.7%

Table 1: Comparison of three sets of rules for identifying malignant melanocytic lesions as published in [ABS+07]. Sensitivity is defined as $\frac{TP}{TP+FN}$, specificity is defined as $\frac{TN}{TN+FP}$, diagnostic accuracy is defined as $\frac{TN+TP}{TN+TP+FN+FP}$, where T means True, F False, P Positive, and N Negative.

Starting from the 1990s, Total Cutaneous Photography has been increasingly used to detect melanoma, as it was proven helpful in improving specificity and accuracy [FDM04]. Doctors take pictures of the whole body of the patient to identify changing or newly formed lesions that are more likely to be associated with melanoma.

With the increasing adoption of personal computers in medical practice, and with the advent of digital photography, the mid 1990s saw the natural evolution of dermatoscopy and Total Cutaneous Photography into digital dermatoscopy. Specialized hardware devices called digital dermatoscopes were designed to let dermatologists take both full-scale and dermatoscopic pictures of the patient's skin, and store them to an attached standard personal computer using dedicated software.

As dermatoscopic pictures became more common, thanks to the increasing adoption of digital dermatoscopy, new sets of criteria were proposed to improve on the established pattern analysis technique. Another 7-point checklist called the ELM 7-point checklist was introduced in 1998 [AFC+98]; as the name implies, its intended application was for diagnoses of clinically doubtful

melanocytic skin lesions in the context of epiluminescence microscopy (ELM). Its purpose was to provide a simplified version of the standard pattern analysis criteria that could easily be learned and applied, relying on a smaller set of features to be identified, and making use of a more straightforward scoring system.

Table 2 shows how the application of the ELM 7-point checklist achieves results that are comparable with the more complex pattern analysis criteria, and strictly superior to those obtained by the ABCD rule.

Rule set	Sensitivity	Specificity	Diagnostic Accuracy
pattern analysis	91%	90%	76%
ABCD rule	85%	66%	51%
ELM 7-point checklist	95%	75%	64%

Table 2: Comparison of three sets of rules for identifying malignant melanocytic lesions as published in [AFC+98].

1.3 RESEARCH QUESTION

The research question that this dissertation attempts to address is

Can dermatologists be more effective in detecting early-stage melanoma?

The key insight in this dissertation is that dermatologists do not follow a standard workflow. Each dermatologist, or group of dermatologists, develops their own style for diagnosing patients. The variability between the methodologies leads to previous visit data being hardly shareable between doctors, which translates to a loss of information about skin lesions evolution.

By proposing a standard workflow, and creating software for hand-held devices to support doctors in that workflow, we provide a common ground for

dermatologists to share their diagnoses and to keep track of historical data about a patient's skin lesions.

Further, the streamlined approach provided by the software helps doctors focus on diagnosing lesions, by reducing the cognitive overhead in deciding the best next step in the process.

1.4 CUTIS IN SILICO

Cutis in Silico (from now on, *CiS*) is a project that started in January 2012 in collaboration with the Dermatology Unit at the University of Padova that aims at improving the State of the Art in melanoma (and other diseases of the skin) detection.

The project consists of three main subprojects that are being developed mostly in parallel at the Department of Information Engineering, with the final goal of merging them together into an integrated solution. The three subprojects were named after their purpose: *MoleMapper*, *FullBodyScanner*, and *PersonalScreener*.

MoleMapper is a tool to help dermatologists organize their work. It was developed as an Android application for tablets to achieve better ergonomics than those used by state-of-the-art software applications. Because of its importance within CiS, MoleMapper was the first project to be developed. Aside from giving doctors a tool that they can use in their everyday routine, it was also useful to collect data on how they work, and feedback on how they wish they worked.

FullBodyScanner is a project that aims at automating the process of taking baseline pictures of the patient's body and highlighting skin lesions that may have appeared, or changed in size/shape/color. Interviews showed that this part of the process is perceived as a burden by the dermatologist: it is largely a repetitive task that doesn't require any medical knowledge on the actor.

One of the main challenges in developing MoleMapper was to envision a workflow that would make this part of the work as streamlined as possible, so that this step in a visit could take as little time and cognitive effort as possible, and possibly be delegated to somebody else. Although the goal was reached to some degree, having that part of the visit be taken care of by a machine within seconds would drastically reduce visit times, and could improve confidence in detecting changes in the patient's skin as soon as they take place. MoleMapper was designed so that it will be simple to replace the baseline picture taking. Doctors currently do this manually, but scans from FullBodyScanner will be used instead as soon as the system is ready.

Lastly, PersonalScreener is an application for Android tablets and smartphones that is meant to be used by patient themselves. One of the issues in detecting changes in skin lesions is that dermatologists are often overbooked, so complete skin mappings are seldom performed, at most once a year. For this reason, self-analysis was reported to be crucial in early detection of malignant melanoma [FRK85]. Having a personal software to keep track of a patient's own skin lesions and automatically update the dermatologist's database would allow for more informed decisions when the visit does take place, and could raise warning flags in case new lesions are detected, or found to be dangerously changed. The goal of PersonalScreener is not to evaluate moles, as that may incur unnecessary panic in patients if the app misdiagnoses some of their benign lesions as dangerous, or worse, it may give them a false sense of security when melanoma is not detected. Instead, it is intended to help the dermatologist make more informed decisions when the following visits take place.

This dissertation focuses on the development of MoleMapper and on all the interviews with dermatologists that led to its design and to its later changes.

1.5 RELATED WORK

We consider two categories of related work: (1) those pertaining with digital dermatoscopy tools, and (2) those with indications of how mole mapping should be performed.

1.5.1 Digital dermatoscopy tools

Several commercial systems designed to assist doctors in mole mapping visits have been developed throughout the last two decades. Among the most commercially successful, we can find the FotoFinder [Gmb15b] and the MoleMax [Ins15] families of products, and MelaFind [Sci15].

FotoFinder and MoleMax are two competing groups of tools characterized by similar design choices. Figure 2 shows the two main products for each of the two families. As can be seen from the picture, both solutions use custom trolleys to house a PC case, a keyboard, a display, and a gun-shaped dermatoscope. In the case of MoleMax, a secondary touch screen is used as navigation input, whereas FotoFinder uses a regular mouse. The dermatoscopic lens can be disengaged from the dermatoscopes, turning them into regular cameras that take full-scale pictures. Dermatoscopes are connected to the PC using thick cables that limit their range and maneuverability.

The main difference between these tools and MoleMapper lies in the ergonomic factors involved. MoleMapper aims at eliminating the constant switch between devices that these products require. Furthermore, our tool encourages dermatologists to follow a consistent workflow that guides their visits, whereas MoleMax and FotoFinder both rely on the user to determine their own workflow at every step. Similarly to MoleMapper, FotoFinder recently released an iPhone application called Handiscope whose purpose matches that of Person-

alScreener, providing patients with a way to monitor their own lesions and have their dermatologists examine pictures that they took.

Figure 2: MoleMax HD (left) and FotoFinder Vexia (right).

MelaFind is an optical imaging and data analysis system that uses multispectral imaging to provide microarchitectural information for concerning lesions. In a nutshell, multispectral imaging is a technique that employs the emission of radiation ranging from 400 nm to 1000 nm to highlight the vascular composition and pigment network of a lesion by showing 8 narrow-band spectrally filtered images to the user [EKR+01]. MelaFind automatically detects the border of lesions, and analyzes them to provide a recommendation to the user about the need to biopsy [FH12]. As Figure 3 shows, MelaFind's form factor does not significantly differ from that of MoleMax of FotoFinder. However, a touch screen is used for all user input, removing the need for the mouse and

keyboard pair. Although MoleMapper and MelaFind share the same goal of helping dermatologists detect early-stage melanoma, the approaches followed by the two applications are considerably different. MelaFind uses multispectral imaging to automatically detect melanoma, replacing or at least influencing the evaluation of the doctor. MoleMapper, on the other hand, uses traditional digital dermatoscopy to assist the dermatologist in taking more informed decisions.

Figure 3: The MelaFind system.

1.5.2 Workflows proposed in literature

A rich literature exists regarding ways to detect melanoma by analyzing dermatoscopic pictures [CKU+07; ASC+03; Jai12; BMJ13]. However, the topic of how mole mapping visits, i.e. workflows, should be performed in practice has virtually no coverage in literature. Guidelines on how to perform self-screening have been proposed [RC00], but their purpose was to help patients monitor their own lesions, as opposed to provide guidance for dermatologists in their practice. MoleMapper is novel in the sense that it is the first to digitally suggest a comprehensive workflow.

1.6 OUTLINE

The rest of this dissertation is organized as follows.

Chapter 2 describes the mole mapping practices followed by dermatologists as reported by them in preliminary interviews.

Chapter 3 is about the process that took us to the definition of a standard workflow and subdivision of a patient's body that is used by the application. A definition of the set of *personas* that we identified from analyzing interviews with doctors is included.

Chapter 4 illustrates the design principles that we followed when creating Mole Mapper, and discusses the choices that were made when designing it.

Chapter 5 is an in-depth analysis of the implementation details of the Android application that was built.

Chapter 6 reports the results of running a first experiment with dermatologists using the software to perform visits on the development team, together with results of an in-the-field deployment of the application.

Chapter 7 provides a summary of the contribution of the dissertation, and illustrates future paths that can be taken to improve Mole Mapper.

2 STUDY OF DERMATOLOGIST WORKFLOWS

Before building MoleMapper, we set out to understand the existing practice of dermatologists. We did this through a series of interviews involving 5 dermatologists of varying degrees of experience, using the methodology described in Section 2.1.

Data from interviews was analyzed through an open coding process that is typical of Grounded Theory [SC90]. The open coding categories that were identified are reported in Section 2.2, and examined in detail in Section 2.3.

The most interesting aspects that emerged from interviews are discussed in Section 2.4, which underlines the meaning of some of the statements made by dermatologists in the context of designing MoleMapper.

2.1 METHOD

2.1.1 Participants

Participants were chosen to cover the whole spectrum of dermatologist experience: interviewees ranged from graduate students to professionals with several years of working experience to a well affirmed professor with more than 10 years of research behind. 2 male and 3 female dermatologists composed this first sample set. All of the participants received specific dermatoscopy training, and they routinely used digital dermatoscopy systems for mole mapping

and diagnosis purposes. All dermatologists worked or had worked as private practitioners.

2.1.2 Interview protocol

Between April and June 2012, we conducted a set of informal, semi-structured interviews with 5 dermatologists associated with the University of Padova. Each interview lasted between 30 minutes and 1 hour, and involved one dermatologist at the time, plus 2 to 3 interviewers, with one interviewer writing down notes and the other(s) asking questions.

The goal of these first interviews was to get a detailed picture of how dermatologists work when performing mole mapping sessions. Questions spanned from how a visit takes place, how long it lasts on average, what tools do they use, to what doctors wished could be improved in their daily routine.

2.2 ANALYSIS

We used Grounded Theory [SC90] to analyze the data gathered from interviews. Using an open coding approach, we identified key insights and grouped them together based on a set of topics that were later discussed by the team; a shared understanding of the problems that needed to be solved was created.

Quotes from interviews were classified into 5 main categories:

- practical descriptions of what happens in a visit
- descriptions of methodologies used to evaluate lesions and pictures of lesions
- considerations on ergonomic factors

- personal views on dermatology as a discipline
- features a hypothetical mole mapping software should have

2.3 RESULTS

2.3.1 Practical descriptions of what happens in a visit

We collected a considerable amount of statements concerning how dermatologists perform mole mapping visits. Overall, the most interesting aspect that emerged from comparing descriptions from individual interviews was that *there is no standard procedure for mole mapping visits*. Every doctor described a series of steps that somehow differed from those reported by every other doctor, either in terms of ordering, or by the relative proportions of time dedicated to each step, or by how some steps are performed in practice.

The following is a list of the most relevant information that was retrieved from preliminary interviews concerning the routine of a typical mole mapping visit.

The number of people involved in a visit varies between 2 (doctor and patient) and 4 (doctor, patient, student/assistant/nurse). When children are involved, one or both parents are also in the room.

The most usual configuration for private visits includes only a doctor and their patient, whereas at the University Clinic a student assisting the senior dermatologist is in the room most of the times; the student or assistant typically operates the computer software while the senior dermatologist visits the patient. When a nurse is involved, they usually assist the patient and may occasionally take full body pictures for the doctor.

The main steps in a visit are:

- the patient undresses while their previous medical record is being reviewed
- (for first time visits only) anamnesis
- (for first time visits only) full body pictures are taken
- (if not a first time visit) full body pictures from previous visits are compared with the patient's skin using naked eye to detect potential new lesions
- suspect lesions are inspected with the aid of a dermatoscope
- (for follow-up lesions) previous dermatoscopic pictures are compared with either how they look through the dermatoscope, or with newly taken dermatoscopic pictures
- diagnosis
- a medical report is produced and given to the patient

No standardized subdivision of the body is used when taking full body pictures; most dermatologists use their own custom subdivision (or the one dictated by the clinic/organization for which they work), which is seen more as a general guideline over how pictures should be taken, rather than a ruleset to be rigorously followed.

Some special cases exist for which doctors operate on a case by case basis: these include moles in the inter-digital spaces or behind the ear (for which a custom adapter is attached to the dermatoscope "if needed"), in the scalp (for which dermatoscopic pictures are taken "only if truly relevant"), or in the genital area (which is photographed only in case it contains at least a high risk lesion and after explicit consent from the patient).

Visits can take between 15 minutes and 1 hour; first-time visits are usually shorter, because no comparisons between dermatoscopic pictures are needed. The average follow-up visit time is 30 minutes, which can be extended to up to 1 hour in relatively uncommon cases of patients with several hundreds of moles, or having many suspect lesions, or having a history of developing melanoma. Private clinics usually enjoy more relaxed timings (and patients): visits are usually in the 30 to 45 minutes range. Pediatric visits are usually kept shorter, rarely lasting more than 15 minutes, so as to avoid stressing children.

When a lesion needs to be surgically excised, it is highlighted on the patient's skin using a marker, and a picture of the general surrounding area is usually taken, printed and given to the patient. The patient will bring the picture to the surgeon on the day of the operation. In some cases, it's the patient that tells the surgeon which mole needs to be excised, with no picture involved. Dermatologists and surgeons don't usually communicate directly, unless of course they're the same person.

2.3.2 Descriptions of methodologies used to evaluate lesions and pictures of lesions

Evaluating skin lesions is at the core of a dermatologist's daily routine, and is perceived as an individual's craft that's continuously refined over the years.

Despite having all shared at least some part of their specialized training, each doctor that was interviewed provided their own personal contribution to the description of how skin lesions are evaluated. The following list includes the most interesting facts that emerged from interviews.

- Most dermatologists prefer to evaluate lesions by inspecting the patient's skin with naked eye first, and use a hand-held dermatoscope to analyze the most suspect ones in a following step
- Full body pictures are very seldom taken: some justified it by stating that it's a slow impractical process that would bring little benefit, others con-

sider older pictures more informative when compared against the current state of the patient's skin; new full body pictures generally replace older ones only in case the patient considerably changed (because of e.g., weight losses), or when a doctor wants to take a better quality picture (with "a better angle or under better light conditions")

- The ELM 7-point checklist [AFC+98] is the most used set of rules to evaluate lesions; however, the more experienced the dermatologist, the more likely they are to follow their own mix of criteria, including principles from both the ELM and the Glasgow [Mac90] 7-point checklist, and traditional pattern analysis [PSW87]

- The ABCDE rule [RFK+05] is only used by inexperienced dermatologists, as it is mostly regarded as a mnemonic list to be taught to patients, rather than something useful for a professional

- The Ugly Duckling [GB98] principle is used by all dermatologists: the more lesions a doctor has seen throughout their career, the more they will rely on said principle. A doctor reported to observe "all ugly duckling lesions, and then a few other regular naevi for comparison"

- Previous evaluations of a lesion are attributed different importance and meaning by different dermatologists: some examine them before proceeding with dermatoscopic analysis in order to make an a priori general idea of the state of risk for the patient. Some others review them after having inspected the lesion involved, to check if their new analysis matches the previous ones, and possibly use the historic information to give their new judgment. Finally, some doctors never look at previous data available for a lesion, because they don't want their own evaluation to be biased by previous considerations, whether they've been made by the doctor themselves or by another

- Since surgical excision of skin lesions has limited side effects on patients (most of the times they're left with barely noticeable scars), dermatologists prefer to have lesions removed when they suspect a melanoma is develop-

ing; histological exams are rarely performed on a dedicated biopsy, as it's considered poor practice to operate on a patient twice in case a lesion is found to be malignant

- Suspect lesions should be re-examined between 4 and 6 months after they've been detected; in practice, because of overbooked agendas, they are often examined up to 12 months later
- Two dermatologists reported that suspect lesions should be watched for at most 2 consecutive visits, after which they must be conceptually archived: melanoma usually takes less than 12 months to evolve, so a lesion that hasn't changed for more than 8 months is to be generally considered safe

2.3.3 Considerations on ergonomic factors

An important outcome of the interview process was a list of ergonomic factors involved in a typical mole mapping visit.

Since our interviewees included members of both genders and different ages, we were able to capture some interesting observations specific to only a fraction of the dermatologist population.

- Doctors are standing up from the moment the patient is undressed to when the report needs to be produced, at which point the patient is invited to dress up while the doctor sits at the desk behind the PC keyboard
- Patients lay or sit down on the doctor's couch while their lesions are inspected or photographed; there is no standard set of positions in which the patient must lie when full body or dermatoscopic pictures are taken
- When dealing with the elderly or the physically impaired, doctors do their best to minimize the number of times the patient needs to change position

- Some qualities of a skin lesion (e.g., the presence of nodules) are examined by touch
- Large (more than 5cm in diameter) lesions may not fit within a single dermatoscopic picture. When presented with one, dermatologists simply don't take the picture and only rely on on-the-spot inspections using a hand-held dermatoscope
- There is no concern over what a patient can see of what the doctor is doing on the computer; some dermatologists would actually like to have an external screen to show patients what they see through the digital dermatoscope
- FotoFinder's hardware is perceived as very clunky by all dermatologists because of the multitude of devices involved, and because of the bad ergonomics of the "pistol camera" that's used to take pictures; female doctors also find it heavy and feel physically fatigued after a few consecutive visits

2.3.4 Personal views on dermatology as a discipline

The informality of interviews let us capture some personal opinions that dermatologists emphatically shared with us about some aspects of their discipline.

Being personal, some of the points made in this section were completely opposite to what other dermatologists stated.

- The same atypia is evaluated in different ways by different dermatologists
- Keeping track of lesions that were historically monitored for a patient is controversial: for some, it would help making more informed decisions for future visits, whereas for others it can at best be used for statistical purposes that are only used in research, but don't help at all in practice

- Most doctors are strongly opinionated about which type of dermatoscope works best, but no definitive proof of the undisputed superiority of one method over the other was reported to exist
- According to one of the dermatologists, pictures taken with a polarized-lens dermatoscope can be evaluated without any specific training. This came as a big surprise, as dermatologists are given specific classes about the subject, and are generally strongly against one of the two types of dermatoscopy
- Some dermatologists reported that patients are never to be trusted, neither for monitoring their own lesions for changes or for detecting new lesions that may have appeared: photographic proof or the opinion of another doctor are the only evidence to be trusted
- Legal actions taken by patients were reported to have an influence over the easiness with which lesions are surgically excised: when in doubt, some doctors prefer to resort to surgery rather than risking to be involved in a trial

2.3.5 Features a hypothetical mole mapping software should have

Knowing what our final goal was when making interviews, dermatologists spontaneously talked about features they would like to see in a dermatoscopy computer application. A selection of the most interesting requested features is reported below.

- Private notes (shared among all users of the application) may be useful to remember how to deal with a patient in terms of verbal communication, or in case of therapies that patients are undergoing which are known to their relatives, but not by them directly

- Some dermatologists want to type quick free-text notes about the lesion they've just photographed using the dermatoscope. A quick way to associate a diagnosis to pictures would also be very welcome. In any case, responses from histological exams must be attached to dermatoscopic pictures of lesions that have been excised. In some cases, it would be helpful to save some annotations for many (if not all) pictures at the same time: for example, the patient may have been recently exposed to direct sunlight (and thus all pictures will tend to have a stronger red component), or some lesions may have been traumatized (and thus appear different from how they would otherwise look)
- Automated evaluation of some metrics for dermatoscopic pictures is a feature that proved to be very controversial: 2 dermatologists requested it, the other 3 stated that it's completely useless, if not misleading
- Doctors would like to be presented with the medical history of the patient as soon as they select them from the database. Data should also include pathologies of the patient that aren't strictly related to dermatology: a history of developing any form of cancer has a strong impact over the likelihood of developing melanoma
- An all-to-all comparison between dermatoscopic pictures is a feature that was requested by all dermatologists, as it would greatly facilitate the application of the ugly duckling principle
- All dermatologists unsolicitedly reported that dermatoscopy is a very image-centric activity, and therefore the bigger all pictures can be displayed, the better

2.4 DISCUSSION

Although in many cases the opinions of dermatologists collided one another, it is possible to identify many emergent behaviors that are shared by most (if not all). Some of the needs that were expressed by all dermatologists lead to design imperatives, such as:

- the new device must be easy to use and intuitive
- the new device must be wireless and lightweight
- the interface for the new device must be flexible enough to accommodate for the different styles of performing mole mappings

As stated, a key aspect in which processes often differ is the order between steps in a visit: some prefer to always scan through the whole body inspecting all interesting lesions (with naked eye, or with a hand-held dermatoscope) as the first step, no matter if it is a follow-up or first-time visit. Others instead focus on the lesions they marked for follow-up in the previous visit first, and then proceed with inspecting the rest of the body.

When taking dermatoscopic pictures, some doctors prefer to follow an order based on the position of the lesion within the body, while some others prefer to group lesions by similarity. The reason for this lack of a standard procedure may be related to digital dermatoscopy being a relatively young practice: every physician creates their own mental model of the activity, which is formed by performing actual visits, rather than by a shared set of principles.

When designing MoleMapper, it was crucial to let users easily navigate to the various parts of the application as freely as possible. Nevertheless, expert dermatologists pushed for a rigid set of steps to be followed when navigating the app, partly because they see computers as useful in a documentation phase that happens after they've visited the patient using a hand-held dermatoscope. In that setting, taking all pictures at once can be viewed as a single action that

complements the doctor's "true" activity. Since MoleMapper is meant to be at the very center of said activity though, a rigid structure could have made the app harder to use in daily practice.

Rigidity however was a necessary evil to solve one problem: sharing information about full body photographs. Supporting more than one standard way of subdividing bodies into whole body pictures would have lead to confusion in both data organization and finding lesions from the history of a patient.

History of images was another controversial topic. All interviewees reported that comparing two dermatoscopic pictures of the same lesion taken at different times is theoretically the best way to detect suspects. However, it is rarely done in practice. The reason for this mismatch between theory and practice may lie in the poor usability of current software solutions: images are either too small or low quality to be compared side by side, or the interface for comparing specific parts of the lesion is not easy to use.

A history of full-body pictures on the other hand was dismissed as mostly uninteresting: changes that can be detected at that level of zoom are very rare in a healthy patient, so most pictures will be virtually identical to the previous ones, bearing little to no information to the diagnosis. When a lesion is first thought to be dangerous, however, having the option to go back in time to find out when it appeared could be very helpful, especially since studies report that 70% of all melanomas are de novo [BSK+03; MF03].

Another topic for which strong opposite opinions were observed is the choice of dermatoscope type (polarized versus traditional). As previously stated, no clear winner emerged from the interviews, although an agreement over the impracticality of using traditional dermatoscopes seems to exist.

The need to apply immersion oil on the patient's skin was unanimously regarded as an annoyance, both in terms of time wasted applying the liquid and as a potential source of distraction for the user: both hands are needed, one to hold the pump bottle containing the oil and another to use a towel to dry the area that was previously photographed.

Since polarized dermatoscopy is unanimously reported to be more practical, and since one of the main goals of MoleMapper is to reduce distractions for the dermatologist, traditional dermatoscopes won't be considered in the design of the application. Dermatoscopes that can switch between traditional and polarized light mode are commercially available, although no portable versions exist at the time of writing.

3 MODELING A STANDARD WORKFLOW

Following the approach introduced by Cooper in [Coo95], after gathering and analyzing data from interviews with potential users, a set of *personas* and workflow models were defined. These abstractions were fundamental to capture the intentions behind the behaviors that emerged from interviews and to match them with organizational models that each class of users may find more suitable to their style of working. Personas are described in Section 3.1, whereas workflow models are analyzed in Section 3.2.

A standard set of subdivisions of a patient's body was needed to support the workflow models. Section 3.3 presents the standard that was proposed, along with the principles that guided its definition, including the iterations that lead to the final set.

3.1 PERSONAS

Building on the classification defined by Grounded Theory, and on observation of recurring behaviors among dermatologists, three personas were identified: one primary persona (Sofia), the main target for the design of MoleMapper, and two secondary personas (Flavio and Ilaria). Sofia is an expert user with a well established career at a public hospital. Flavio is a dynamic, affirmed independent professional working in a private clinic. Ilaria is a doctor who recently completed her graduate studies and started working at the Department of Dermatology.

After personas were created, all notes from interviews were analyzed again to check whether statements made by dermatologists could be reconducted to one (or more) of them. The personality of most quotes was successfully captured by at least one persona, and in some cases by two of them.

In the following definitions, some actual quotes from dermatologists were attributed to the persona for whom the statement seems to fit best.

3.1.1 Sofia

Sofia is a charismatic and strong-willed M.D. who's been working as a dermatologists in the city's public hospital for many years, and is confident of her preparation and experience. During her career she had several occasions to collaborate to international projects, and she makes sure she is always up-to-date on the latest findings and technologies. She has been working as a part time lecturer for Pediatric Dermatology in the University she graduated from for some years now, but she sometimes finds herself thinking of quitting, in order to be able to focus completely on her research.

Throughout the years, Sofia has perfected her system to quickly spot lesion "constellations, by identifying patterns on the patient's skin [...] by mentally connecting larger lesions to each other", so she can rapidly detect moles that may have appeared after a picture was taken. She uses polarized-lens digital dermatoscopes "most of the times", but she always "prefer[s] to look at the patient's skin with naked eye", as "a trained eye with a hand-held dermatoscope is the best [melanoma] detection system".

Her main goals are:

- to remain focused and in control throughout the visit, and all along the working day

- to feel knowledgeable, and to be recognized as such by her colleagues and the specialization students that help her out during the visits. She wants as well to let the patients know that they are in good hands, so to dissolve their fears; she would like to have a system of "push notifications about patients who haven't showed up for the scheduled follow-up visit", so she could remind them of "the importance of keeping [suspect] lesions monitored"
- to maintain her personal prestige inside the clinic and the scientific community
- not to be bothered with irrelevant requests for information from the devices. The digital dermatoscopy software she currently uses is too needy in terms of attention
- to keep the visit as short as possible; however, it is at least as important to her to still remain accurate and complete when inspecting the patient and filing the visit record, even when visits are "slow, taking up to half an hour"
- to collect data for scientifically relevant statistics, as it may be very interesting to know, e.g., "how many nevi having [suspect] globular patterns were excised between dates X and Y"

3.1.2 Flavio

Flavio is a brilliant professional exerting in a newly built private clinic. When he is working, he is sharply focused, and won't let anything else distract him. He feels the hours in a day are too few to be able to do all that he would like to.

Flavio is disillusioned on many theoretical precepts that he has been taught during his student life. He is convinced that common practices and guidelines

are intended to cover all generally possible eventualities, and forasmuch he is eager to skip passages when it is obvious they are not needed.

Flavio "go[es] crazy about gadgets", he absolutely "love[s] technology". He's strongly convinced that "the wow-factor is what matters most for private clinics: patients *demand* to see shiny things in a professional's office". He thinks a large, "at the very least 24 inches wide" display would be useful both for him "to identify patterns in the lesion", and for the patient to see what the doctor is doing.

Flavio owns both a polarized-lens dermatoscope and an older traditional one, a relic of his time as a student. He finds himself relying on the old dermatoscope more than he would like, because of its "vastly superior image quality", despite it being "so old school and impractical", because of the need to apply anti-reflective fluid before taking pictures. He finds it unbelievable that there is still "no decent software solution [...] that produces images of an acceptable quality" without making him wait "several seconds after a shot was taken". He would not think twice about "splurging money on a tool that lets [him] keep [his] pace when visiting", and that tool "*has to* be wireless".

Unsatisfied with the software solutions he tried, Flavio came up with a "DIY system to organize pictures of patient moles" in which lesions are "marked directly on the patient's skin". He would much prefer to use an "app that does that for [him]", but what he has now is the "most time-efficient" solution he's used so far, and it's "much better than what's used in public clinics, anyway [...] with those heavy, ugly cameras and dangling cables".

His main goals are:

- to demonstrate patients his level of professionalism
- to come to the correct diagnosis in as little time as possible
- to reinforce his reputation of a brilliant, rampant dermatologist

- to move quickly from one office to the other having instant access to his patient's data, as "very often dermatologists like portable devices better, so they can bring them from office to office"
- not to waste time on bureaucracy and formalities

3.1.3 Ilaria

Ilaria is a new acquisition at the Department of Dermatology. She is a trustworthy and precise person, and as such it didn't take much time for the people around her to appreciate her skills. More than a year has passed since she finished the specialization school, yet she rapidly started gaining experience and working her way up, performing up to twenty visits a day: she is the first doctor to show up at the institute, and the last to leave it in the evening.

Because of her reliability she was asked to collaborate with other departments within the city hospital as well. Working at different departments discouraged her at first, as she didn't expect the internal regulations and procedures to be so scattered and dis-homogeneous. She had to quickly build up her own system of values in order to keep sanity, while learning the internal codes and directions, and relying on her spirit of adaptation for uncovered cases.

Sofia knows she is the most frequent user of the digital dermatoscope in the laboratory, and she is always asked for help when in the harder days it is needed to speed up the visits. Nevertheless, she still prefers to use the traditional dermatoscope because "it's more practical to switch from naked-eye inspection [...] to the Delta 20", the model she uses. She thinks it "may be possible to use the digital [one], granted that the image quality is good enough".

She knows by heart what buttons to press and what is the best way to get things done fast with the digital dermatoscope at the clinic. Nowadays she feels she could almost be operating it without even looking, and "sometimes

[she] can still see the application's main screen even with [her] eyes closed", when days are very long. Still, there are many shortcomings in the digital dermatoscopy system at the clinic; she wishes she didn't have to work her way around them all the time, switching from device to device to complete her tasks. At the very least, Ilaria would like the camera she uses not to be "so heavy and clunky".

Notwithstanding the short time at her disposal though, she wants to make sure that she covers all possible cases regarding the patient's condition, and that she doesn't leave the patient exit the office with ad underrated or wrong diagnosis.

Her main goals are:

- not to feel belittled by stubborn technology
- not to have to switch from device to device, because she now has to "go back and forth from the patient to the PC screen"
- to revise what she has done during the visit, as "it would be useful to know what lesions have been inspected so far, at any time"
- to feel sure about her diagnoses
- to be considered a valued part of the team at the clinic
- to be able to precisely follow a definite routine for all visits

3.2 WORKFLOW MODELS

Although as previously discussed all dermatologists differed in the way they perform mole mappings, it is possible to split their work into individual steps that are common to all workflows. Every proposed sequence of steps can therefore be compared with those currently used in practice to determine which

workflow is the most likely to be followed by each persona, and whether their goals can be easily reached using the new procedures.

3.2.1 Steps definition

The set of sub-tasks that were identified is defined as follows.

ANAGRAPHICS - to handle the basic information about the patient, such as their date of birth or residence. Anagraphic information rarely changes over time. The underlying goal is that of correctly identifying the patient at the glimpse of an eye, and to make the patient feel comfortable showing to remember them personally

PATIENT REPORT - to handle additional information about the patient, regarding their health condition. Such information might comprehend anamnesis, familiarity with particular diseases, examination results, previous visit reports. Data in the patient report is slowly but constantly changing, and is updated with a frequency comparable to that of subsequent visits (months or years as a temporal quantum). The underlying goal is to recall critical information that could affect diagnosis, without having to rely on asking the patient with every new visit

PORTRAIT - to take full body photographs of segments of limb and torso, as with regular photography techniques. This is done in such a way that it eases comparison with future and previous versions of the same body part. The underlying goal is that of having a clear and easy to explore navigational tool

MARK - to individuate and label a lesion within the full body photograph as suspicious, so that it can be analyzed later. A lesion might be marked also for reference, even if it appears healthy. All diagnoses and characterizations should be referred to a marked lesion. This means that all lesions that have been taken into consideration during the current visit,

and those from previous visits whose status has not been considered normal, should be considered as marked. The underlying goal is that of being able to quickly locate lesions, as they are addressed mostly indicating their position on the body, instead of their visual characteristics

DERMATOSCOPIC - to take photographs of a single lesion with the aid of a digital dermatoscope. The underlying goal is that of analyzing the lesions in ways that would be impossible with the naked eye, and to apply the specialist knowledge. On one side this is a gratifying task, as it requires expert skills, and leads patients to feel the authority of the dermatologist; on the other hand, it is performed mechanically

ANNOTATION - to qualify a single lesion with additional characteristics. Distinguishment could be nominal and/or quantitative, and multiple ranges might be used. For example, the features employed on the 7-point checklist may be used, as well as free-form notes or predefined tags. The underlying goal is that of having a rapid overview of the features of a lesion, possibly assessed on known valid scales, to be more confident in performing the diagnosis

DIAGNOSIS - to determine the diagnosis for a single lesion, and to establish the corresponding prescription. Prescription should be corresponding to the status of the lesion, and be kept within the options: to excise, to keep in follow-up, OK, excised. The underlying goal is that of being sure to eliminate all threats to the health of the patients, and in second instance to minimize unneeded excisions. It is a stressful task, as it requires total focus, and it determines in the end the aftermath of the visit

VISIT REPORT - to enter information in the summary of the visit. The summary should be exportable into different formats, as deliverables might be given to the patient as well as the surgeon, as well as stored in the database internal to the health care structure. It should be identified with information taken from the anagraphics, and contain diagnoses and relevant annotations taken during the visit. The underlying goal is that of

producing a deliverable for the patient to carry with them, and of communicating what needs to be done to a surgeon if needs be

Some strong dependencies exist between sub-tasks: Diagnosis cannot happen before Annotation, which cannot happen before Mark, for example. There is a line of actions that includes Anagraphics, Mark, Annotation, Diagnosis, and Visit report that constitutes the main body of a mole mapping visit; these steps were included in all workflows described in interviews, and are always executed in regular visits.

Some exceptional cases exist though when it is desirable to skip phases altogether: when a patient comes back with the results from histological exams on a lesion that was recently excised, for example, the only needed action is Diagnosis, as no new lesions are inspected and no report is produced. In this specific case, Diagnosis still happens after Annotation and Mark, but they are not performed in the ongoing visit: they are part of the previous one. Some dermatologists reported that it is common practice in these cases to simply update data in the software application without associating it with a new visit. It would still be preferable to treat these check-ups as visits, as the information itself of meeting with the patient is worth being tracked, at least to help accomplish one of the goals of Anagraphics: showing patients that the doctor cares about them personally.

Some sub-tasks depend on others only in some workflows: for example, Diagnosis logically follows Dermatoscopic when the digital dermatoscope is used as a tool to evaluate lesions, which is not always the case. Expert dermatologists often come up with a diagnosis before even looking at the dermatoscope, and some doctors prefer to use a traditional hand-held dermatoscope before taking pictures. In these situations, Dermatoscopic becomes a documentation phase, which can be performed independently of Diagnosis.

Lastly, within the same workflow, some situations may arise that break inter-task dependencies. That is the case with Portrait and Dermatoscopic when the patient explicitly asks the doctor not to take pictures of sensible parts of the

body, such as their face or genitals. When that happens, the Portrait step is skipped for the specific area, but Dermatoscopic can still be performed.

3.2.2 Proposed workflows

Six possible workflows were left after excluding those that were obviously less practical variations of some other one. Consultations with users confirmed the validity of the proposed selection. Anagraphic and Patient report are always performed before any other step in all workflows, and were therefore omitted from Tables 3 and 4 below.

Workflows were grouped according to whether their practicality depends on having a system that allows to easily and rapidly switch between regular to dermatoscopic photography. The first three workflows all require mounting the digital dermatoscope only once, and can therefore be used even in case no solution to rapidly snap-in the polarized lens is available, or using a dedicated external camera to take dermatoscopic pictures is not possible.

1

```
for each Portrait
  Portrait
for each Portrait
  for each suspect Lesion
    Mark
for each Portrait
  for each Marked Lesion
    Dermatoscopic
for each Portrait
  for each Marked Lesion
    Annotation
    Diagnosis
```

2

```
for each Portrait
  Portrait
  for each suspect Lesion
    Mark
    Annotation
    Diagnosis
for each Portrait
  for each Marked Lesion
    Dermatoscopic
```

3

```
for each Portrait
  Portrait
  for each suspect Lesion
    Mark
for each Portrait
  for each Marked Lesion
    Dermatoscopic
for each Portrait
  for each Marked Lesion
    Annotation
    Diagnosis
```

Table 3: Workflow models that minimize switching between regular and dermatoscopic photography.

<table>
<tr><th>4</th><th>5</th><th>6</th></tr>
<tr>
<td>for each Portrait
  Portrait
for each Portrait
  for each suspect Lesion
    Mark
    Dermatoscopic
for each Portrait
  for each Marked Lesion
    Annotation
    Diagnosis</td>
<td>for each Portrait
  Portrait
  for each suspect Lesion
    Mark
    Dermatoscopic
    Annotation
    Diagnosis</td>
<td>for each Portrait
  Portrait
  for each suspect Lesion
    Mark
for each Portrait
  for each Marked Lesion
    Annotation
    Dermatoscopic
for each Portrait
  for each Marked Lesion
      Diagnosis</td>
</tr>
</table>

Table 4: Workflow models whose efficiency depends on the availability of a system to rapidly switch between regular and dermatoscopic photography.

As will be described in Section 5.1, the hardware slots that were designed to attach the dermatoscope to the tablet's camera didn't prove effective enough to allow for rapid photography mode switching. Hence, the second group of workflows was implicitly unfavored by the practical limitations of the device, and by the focus on realizing a single-device solution. When an assistant is available, though, using a secondary device can open up to parallelization of the task, and should therefore be considered a legitimate use case for the application.

Workflow 2 closely matches what is done in practice by many dermatologists. However, doctors need to rely on an external hand-held dermatoscope to inspect the patient's lesions, which is again contrary to one of the main goals of the project: minimizing context switches for the dermatologist. Therefore, supporting Workflow 2 was considered a secondary target, one that could be interesting for users that are strongly against modifying their habits when moving to MoleMapper.

3.3 A STANDARD SUBDIVISION OF A PATIENT'S BODY

One key issue on which, perhaps surprisingly, there is no consensus among dermatologists is how to take full scale pictures.

Some sets of standardized poses have been proposed in literature [SWJG92; HMB+03], together with guidelines on how to take pictures of the patient so that their whole body is photographed, but their adoption doesn't appear to be widespread.

Shared guidelines on how to perform Whole Body Photography would be helpful for several reasons. First, it would make it easier to pass data along to the next dermatologist, whenever a patient needs to be visited by some other doctor. Second, compared to the current practice of taking a picture of the general area that "seems relevant", following some fixed rules would lighten the cognitive load on the doctor, who would no longer need to think about what the best framing to identify a lesion could be.

Two additional benefits that can be gained by standardization are particularly important for MoleMapper: the possibility to run automated comparisons against previous versions of a Portrait, and a straightforward navigation model for the application's UI.

As reported in Section 2.4, dermatologists rarely take new pictures of a Portrait, as they prefer to maximize the difference between the stored image and the current situation. When examining patients that have many (i.e., hundreds of) lesions though, it is very hard to detect new ones at a glance, and doctors need to spend more time to perform accurate comparisons.

Since one of the known risk factors for melanoma is being affected by *Displastic nevus syndrome* [CRG+78; EGG+80], a condition that is usually characterized by high total body mole counts, the need to compare that many lesions for a single patient is not too uncommon.

Moreover, common sense suggests that people having many moles are more likely to be concerned about the possibility of contracting diseases of the skin, which is a fact that was confirmed by interviews.

Being able to examine two pictures of the same area taken at different times side-by-side would be a first step in speeding up the comparison phase. Automating the task would of course cut the time spent checking for new lesions even further. Obviously, using the exact same framing for both pictures would make automation easier, or even feasible.

All workflows that were presented in the section above iterate over all Portraits, which implies that full scale pictures need to be a core part of the navigation system for the application. Using a standard subdivision of the human body as a clickable map provides a very intuitive way to take the dermatologist to the corresponding picture, where all lesions appearing in it are logically grouped together.

3.3.1 Design principles

When designing the standard subdivision of the body that was to be used in MoleMapper, several factors had to be taken into consideration at the same time. As is often the case, most goals were in conflict with some other, so the final decision was the result of a trade-off process.

The following principles derived either from the interviews, or from technical/UI design considerations specific to the application. The order in which they are presented doesn't imply a hierarchy between them: indices are only used as a way to reference them in descriptions.

PRINCIPLE 1 – *Portraits should cover as much of the patient's body surface as possible*

While self-evident, this principle is interesting in that it doesn't state that the whole body surface must be captured. Rather, the percentage of the body that must be captured is a value that should indeed be maximized, but at the same time it is tolerable to exclude some areas that are particularly irksome to photograph, such as for example the inter-digital spaces or the genital area. As reported in Section 2.3.1, interviews revealed that in such special cases full scale pictures are never taken, and dermatologists rely exclusively on naked-eye inspection to evaluate lesions that may populate those areas. Hence, said parts of the body can be excluded from consideration.

PRINCIPLE 2 – *Given a part of the body, it should be straightforward to retrieve the corresponding picture in the application*

This is crucial for navigation. There should be as little doubt as possible for dermatologists when deciding which Portrait must be accessed to retrieve the previous history of a lesion. The first subdivision that was proposed, shown in Figure 4, relied on the strong medical background of dermatologists; regions were enclosed within borders that naturally followed prominent anatomical features, such as bones and joints. Although confirmatory interviews with 2 experts confirmed that the Portraits were indeed very easy to identify, the set wasn't complying with the requirements dictated by the two following principles, and was therefore rejected.

PRINCIPLE 3 – *Portrait total count should be minimized*

As mentioned in [HMB+03], and as confirmed by the interviews, any subdivision that's composed of more than 20 items won't be adopted in practice. A small set of Portraits is not only beneficial in terms of time saved when taking pictures (which could be overcome by a tool that automatically takes all pictures at once, such as FullBodyScanner), but it also improves the effectiveness of the navigation system. The more regions are defined, the larger the total

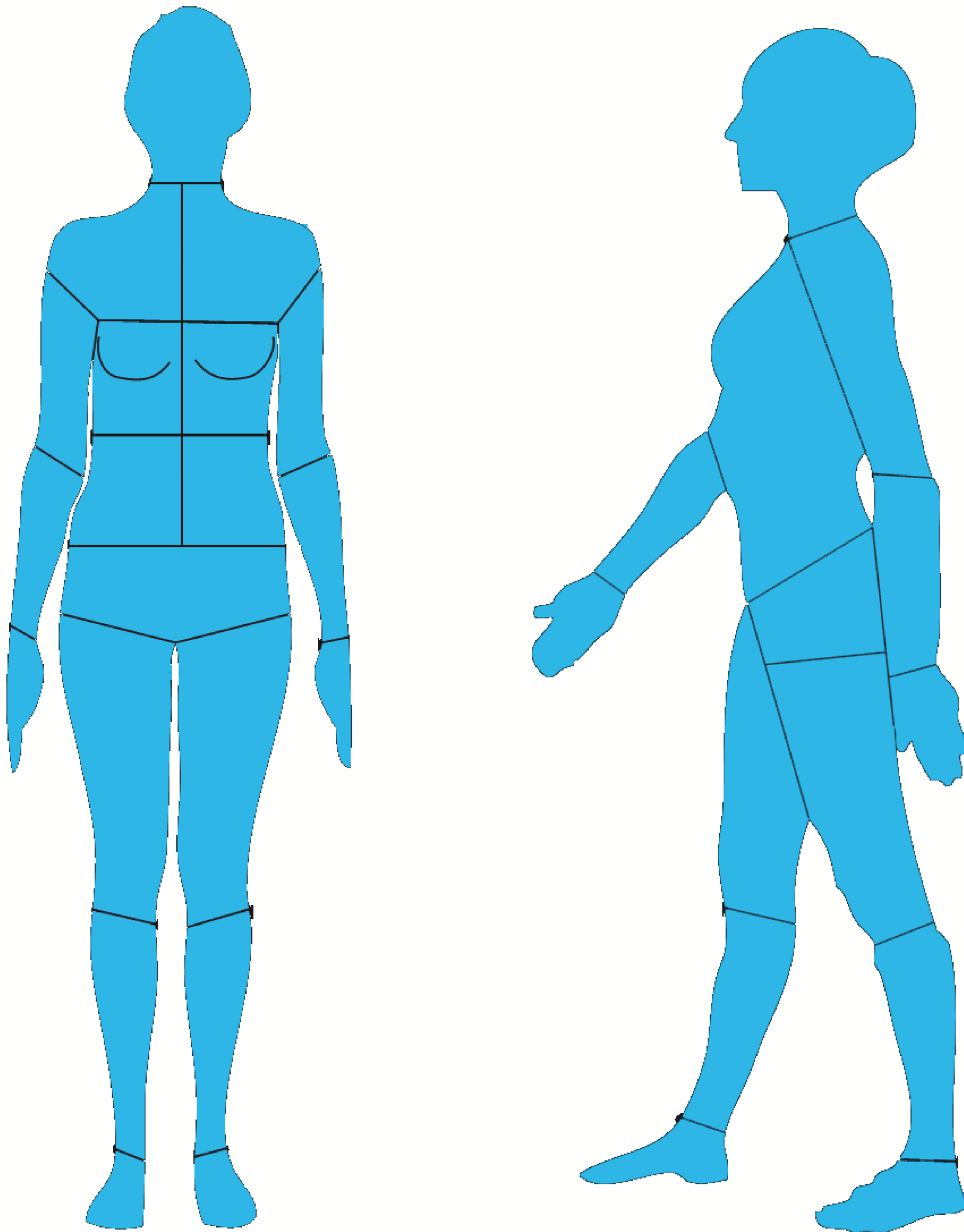

Figure 4: The first proposed set of portraits, frontal and left side (back and right side are equivalent). Major anatomical features such as knees, elbows, ankles, etc. are used to identify regions. The total portrait count is 68.

area occupied by border neighborhoods is. That is where this principle and the following affect each other.

PRINCIPLE 4 – *Portraits should overlap one another as little as possible*

The standards proposed in literature that were analyzed all overlooked this particular detail. While theoretically no two regions overlap at all, it's impossible to achieve such a perfect separation between photographs in practice. Overlaps are risky for two reasons: they increase the probability of marking the same lesion more than once, and they compete with Principle 2, in that it becomes harder to uniquely attribute a lesion to a Portrait when they partially overlap.

Since, as stated, overlaps cannot be completely avoided, a simple rule of thumb was suggested for situations in which the Portrait to which a lesion should be be assigned is not clear: lesions are always to be assigned to the top-most, left-most Portrait in the same pose. Whenever a lesion appears in more than one pose, its Portrait of reference is always the one where the lesion appears the most centered. This is admittedly a weak criterion to establish which Portrait should be used to map a lesion, and is therefore a very interesting subject on which user feedback needs to be gathered.

PRINCIPLE 5 – *The subdivision should account for the large variability in body shapes*

Proportions in human bodies vary significantly with gender, age, and general muscle tone. The subdivision should be easily applicable to all types of patients, regardless of their physical shape.

PRINCIPLE 6 – *No shadows should be cast from any part of the body onto another*

Dark shadows can completely hide information about the areas onto which they are cast, which is to be avoided regardless of whether these areas contain lesions or not. The information that a given area did not contain any lesion at

point x in time can be as valuable as that of a lesion being present, especially when Portrait pictures are rarely updated.

Positioning the patient's arms and legs in a way that minimizes this hiding effect strongly depends on the position of the light source as well as on its brightness. While largely irrelevant for dermatoscopy, lighting conditions in the room where mole mappings are performed have a significant effect over the outcome of Whole Body Photography. This aspect has been traditionally ignored because full scale pictures are never used in practice to check for changes in existing lesions, but only as a reference against which the current state of the patient's skin is compared. In that context, unless very dark shadows are involved, illumination is a largely secondary matter that's only useful to determine the average skin tone of the patient.

PRINCIPLE 7 – *All lesions larger than 2mm in diameter should be detectable from Portrait pictures*

Although the ABCDE rule suggests to only consider lesions having a diameter larger than 6mm [RFK+05], studies have shown that smaller melanocytic lesions can as often be associated with melanoma [SM92]. Lesions smaller than 2mm though are ignored in practice and often not considered nevi [Hap95].

The resolution of the camera is the main responsible for the distance at which pictures can be taken while fulfilling the requirement. Many modern tablets are equipped with 8MP-resolution cameras, whereas no commercial tablet could be found at the time MoleMapper was developed having a higher-resolution camera. Unfortunately, JPEG compression is often used at the OS level to save RAM when taking pictures, so the useful resolution for computer vision algorithms is usually lower. Nevertheless, standing at up to 1m in distance from the subject proved to produce pictures of a quality that makes it possible to reliably detect any lesion larger than 2mm in diameter. Principle 9 will impose a stricter constraint on this distance.

PRINCIPLE 8 – *Poses should be comfortable for the patient*

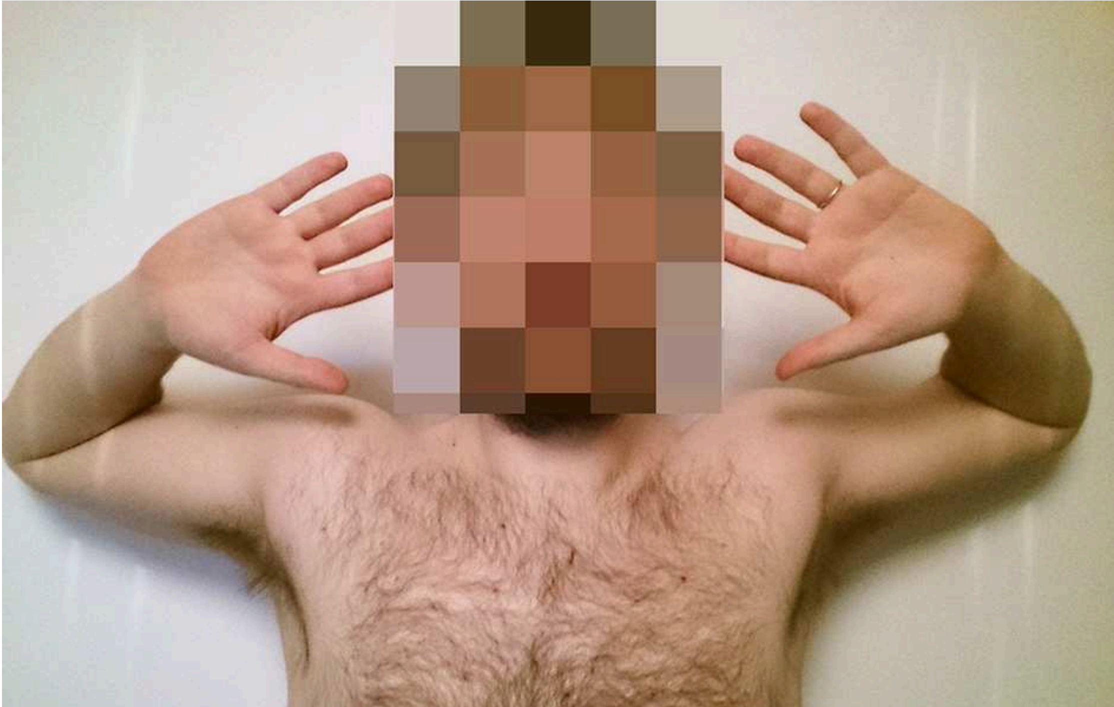

Figure 5: This pose had the advantage of making some otherwise hard to catch areas visible, namely the armpits and the internal part of the arms. The angle at which the patient needs to hold their arms could be uncomfortable for the elderly.

Some poses would greatly simplify covering some parts of the body that are usually not visible when assuming a normal posture. The comfort of the patient must nevertheless be taken into consideration, and when assessing it, Principle 5 imposes to think of older patients, or patients affected by minor disabilities. Some poses such as the one illustrated in Figure 5 were therefore discarded, as they were deemed too uncomfortable to be held while the doctor is taking the picture.

Other sources of discomfort include making the patient switch position several times, or having them stand while all full scale pictures are taken. The latter is easily addressed by using a doctor's couch, which is always part of a dermatologist office's furnishing.

PRINCIPLE 9 – *Taking full scale pictures of Portraits should be comfortable for the dermatologist*

As much as the comfort of the patient is important, that of the dermatologist cannot be neglected. Doctors need to be able to see the image displayed on the screen to verify that the camera is pointing at the correct area, and in order for the position to be comfortable they should be able to do it without stretching their arms too much, and without needing to stand on their toes.

Every set of Portraits was tested by having each development team member take pictures of every other, following the guidelines for the subdivision being tested. Tests took place in an office that's regularly used for mole mapping, using a standard examination table.

Because Principle 5 holds even for dermatologists, a minimum of 1.50m was considered for the doctor's height, which represents the bottom 3rd percentile in adult women globally [Org07], and a distance between the eyes and the top of the head of 10cm, representing the bottom 5th percentile in women [DHFETAG00]. Considering a minimum viewing angle of 20°, and a maximum horizontal distance of 25cm from the tablet to the doctor's head gives the maximum height in centimeters at which the device can be held:

$$150 - 10 - 25 \tan 20 \approx 131 \tag{1}$$

Standard examination tables range between 50 and 80 centimeters in height, so in the worst case the maximum vertical distance between the tablet and the patient is roughly 50cm. At that distance, the tablet that was used in tests was found to shot areas of size 50x38cm. Any Portrait containing an area larger than that can be uncomfortable to capture for some dermatologists. A footboard could be used for exceptional cases, such as with extraordinarily tall patients, but their usage shouldn't be considered part of the regular routine.

Due to Principle 9, the Portrait set that minimized the total Portrait count to 16, which would be the ideal with respect to Principle 3 compliance, was

excluded. The 4 posterior Portraits for the set are depicted in Figure 6, the other 3 sides were divided into 4 Portraits each in a similar manner. The set included the Portrait in Figure 5 which, aside from being in conflict with Principle 8 due to the uncomfortable angle at which the patient's arms must be held, is also including an area that easily exceeds 1m in width, which would be impossible to shoot without the help of a footboard, even for taller dermatologists.

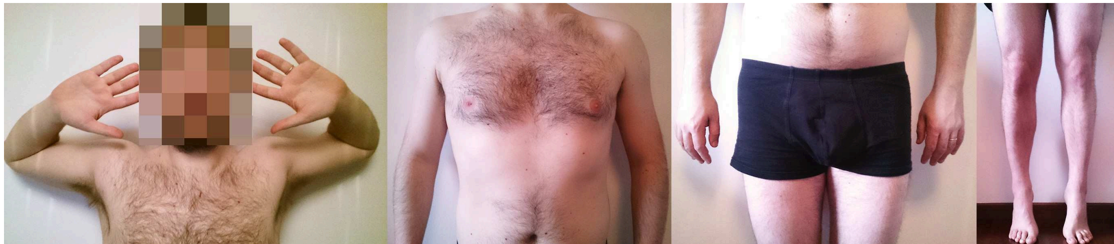

Figure 6: This subdivision included a total of 16 Portraits, the minimum that was achieved by any of the proposed sets (the other 3 poses all included 4 Portraits each). However, it was impractical for the dermatologist, as some of the Portraits required too long a distance between the tablet's camera and the subject when the latter was laying on an examination table.

3.3.2 The final Portrait set

The final set of Portraits to be photographed, and poses to be assumed by the patient is shown in Figure 7. A total of 24 Portraits divided into 4 different poses was identified. Patients lie down on an examination table while Whole Body Photography is performed.

Two models were generated using DAZ Studio Pro[stu12], one for each gender; the human figures were finely tuned to match a position that can be comfortably held by most patients regardless of age and physical status; Chapter 6 will show how this statement was confirmed by real life usage of the application.

It is worth analyzing how well the proposed Portrait set complies with the design principles from the previous section. As anticipated, not all requirements were fully met, so the trade-offs that were made will be described.

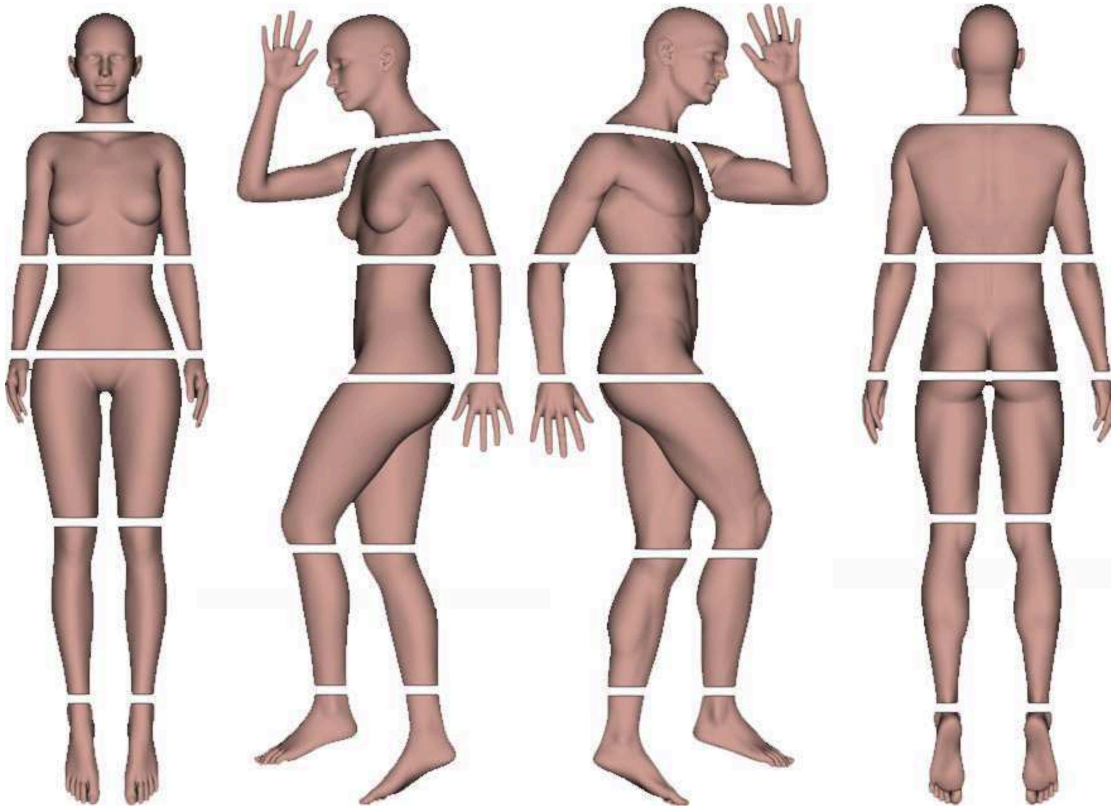

Figure 7: The set of portraits and 4 poses used by MoleMapper. The first two poses show the model that's used for female patients.

In accordance with Principle 1, as much of the patient's skin as possible is captured by the Portrait set. The only parts that were left out are the interdigital, genital, perianal and behind-the-ear spaces, which are not included in most visits.

All regions have been defined using some notable anatomic feature as reference, as is shown in Figure 8. When taking Portrait pictures, doctors are shown a message that explicitly states what part of the body is to be used as reference; in the case of Figure 8, two messages would appear aligned with the thick red lines: "Below the neck" on top, and "Above the elbow" on the bottom.

This solution was chosen to comply with Principles 2, 4, and 5. Minimizing the overlapping regions (Principle 2) and making Portraits easily retrievable given the position of a lesion inside of them by looking at the patient's skin

(Principle 4) are two goals that reinforce each other. The smaller the total area appearing in more than one Portrait is, the easier the choice of Portrait to be opened will be. All help messages were written in a way that specifically resolves conflicts that may arise when neighbor Portraits are captured.

Accounting for variance in body shapes (Principle 5) is also favored by using common anatomical features, such as bone lines: proportions between lengths of different bones may vary, but the proposed Portraits are anchored to some specific end, so they're easily adjusted to follow the patient's body.

As discussed when introducing Principle 9, the proposed set is not the smallest that was conceived, so compliance with Principle 3 (*Portrait total count should be minimized*) had to be relaxed to meet the more stringent requirements dictated by Principle 9. Because the goal of MoleMapper is that of supporting the daily practice of dermatologists, and because the minimal Portrait set would have required doctors to use footboards or replace their examination tables with smaller ones, practical aspects were prioritized over minimal intellectual effort for the user.

Further, the requirements of Principle 7 were easily met by the proposed subdivision. As stated when introducing Principle 9, a maximum distance of 50cm from the subject was imposed by ergonomic factors, giving a good margin before the device resolution limitations start being involved.

When reviewing how closely was Principle 6 followed, it is important to note that a considerable degree of variability in lighting conditions between doctor offices was reported to exist. When automation will be introduced to detect lesions that recently changed, having a mostly constant illumination will be crucial to minimize false positives, and will allow for better calibration of the algorithms that detect the shape of the lesions.

Since the purpose of the first version of MoleMapper is simply to help dermatologists organize their work in their current context, without introducing any new requirement for their office layouts, the most common lighting setting

was considered: offices with relatively weak fluorescent lamps illuminating the patient from above.

In that scenario, having the patient lie flat on the examination table resolves the problem of arms and legs casting shadows onto any other part of the body, and is obviously greatly beneficial in fulfilling Principle 8 (*Poses should be comfortable for the patient*).

However, care should be taken in considering how the person taking pictures, and the tablet itself, block light. Data from laboratory experiments and from a first field deployment of the application reported in Section 6.2 does not include any picture containing shadows cast from the dermatologist, but given the abundance of different office settings, it is impossible at this stage to fully exclude the possibility of lighting conditions becoming a problem for Whole Body Photography.

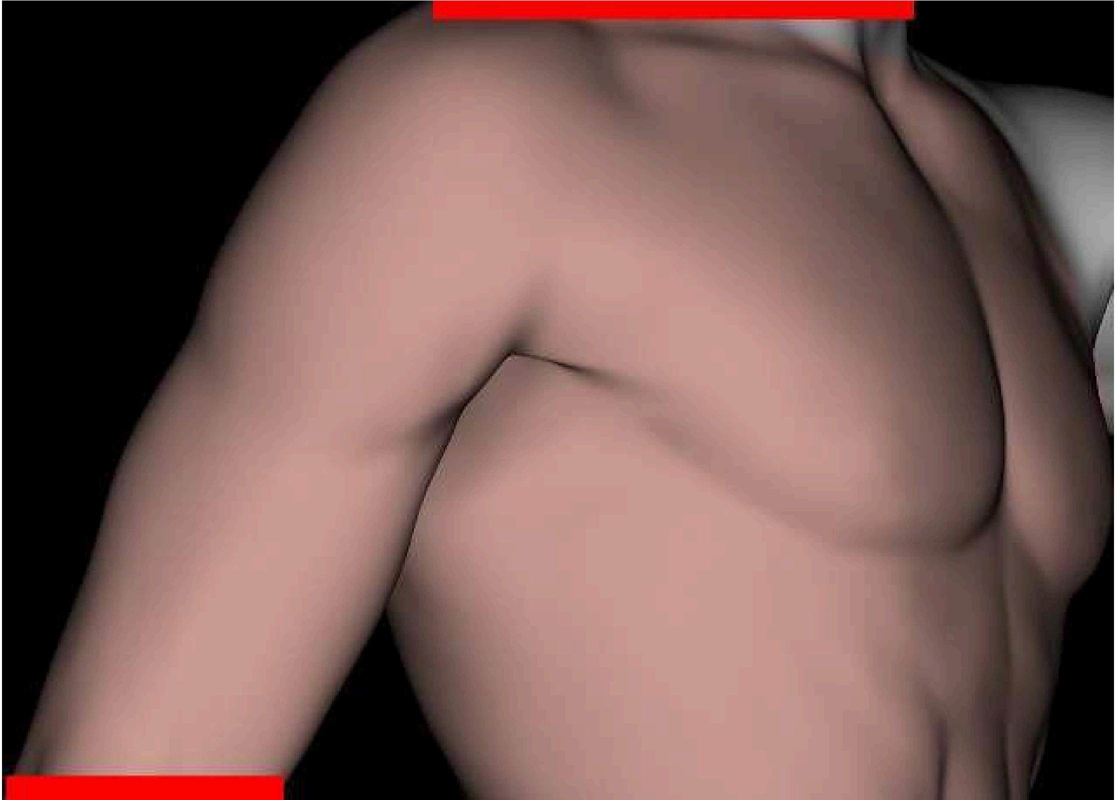

Figure 8: Portrait of the chest on the right pose for a male patient. Solid red lines instruct the user about which parts of the body should be used as guides to frame the picture.

4 DESIGNING MOLE MAPPER

The previous chapter presented data gathered from interviews, and described what we learned about the processes that doctors follow when performing mole mapping visits. In this chapter, we bring these lessons together and propose the design of MoleMapper.

MoleMapper was designed in three phases, which are presented in detail in this chapter. Briefly stated, these phases were: (1) identifying entities, (2) creating the action model, and (3) creating the visual framework.

In the first phase, we identified the entities at play, as well as their relationships with each other. These entities would become the entries in the application's data model described in Section 4.1.

In the second phase, we enumerated a list of actions that involved the items from the data model. These actions were determined based on the goals of the three personas encountered in Section 3.1. This translation from a set of goals to a compact set of functional procedures resulted in the action model defined in Section 4.2.

In the third phase of the design process, we created a visual framework for the application. We first used the action model to identify the individual views that would build the application's user interface. Then, we determined a set of design patterns and layout principles, and used those to organize the views to form the visual model outlined in Section 4.3.

Lastly, Section 4.4 includes high-fidelity mockups for every screen as originally designed, and describes the motivations behind the most interesting graphical choices.

4.1 DATA MODEL

The data model of the application was created by analyzing the descriptions of daily practices given by dermatologists. From These descriptions, we created an entity-relationship model [Che76] that would later be implemented using a relational database.

All identified entities, together with their roles in the application, are described as follows:

DOCTOR – doctors are the users of the application. In its first version, MoleMapper was designed as a multi-user application: many doctors currently share their digital dermatoscopy devices with other doctors from the same clinic. However, the shift to using tablets, which are perceived by doctors as cheap personal devices that can be carried from office to office, favors a single-user model. Despite these perceptions, the option of using another doctor's device is advantageous. For example, if their tablet is lost or broken, they could occasionally rely on a colleague's MoleMapper at hand. Hence, we continued using a multi-user model for the design.

Only the user credentials and basic personal details, such as their full name and possibly a profile picture, are needed by the application. Contact details are assumed to be stored in existing information systems, and explicit sharing of data between doctors is not considered at this stage.

PATIENT – as with doctors, personal details for patients need to be stored in the application's database. The set of attributes needed for patients is more extensive than those used for doctors. The application needs a patient's contact details and other information (such as the patient's SSN) for organizational purposes. Existing patient records from databases currently in use will need to be converted and imported to the application.

VISIT – visits are the most generic activities performed by doctors. A visit usually ends with the drafting of a report that is handed to the patient,

possibly containing instructions to be forwarded to a surgeon. In some cases, follow-up visits will only involve updating data about specific lesions that have either been excised or were subject of histological analysis. In these cases, no report is produced.

MEDICAL HISTORY – data about patients includes their personal medical history, which should only contain relevant information from previous reports. Two views are needed for medical history: (1) a compressed representation including short summaries of past reports, and (2) an expanded version containing all available data about previous medical records. These include artifacts such as dermatoscopic pictures predating the adoption of MoleMapper, and detailed results from histological exams.

In cases when health records are organized in a central system, such as Galileo [Sol15] (the one used by Padova's public hospitals), integration with remote databases introduces new requirements on how Medical History must be stored. MoleMapper must retrieve data from such systems on-demand, and upload its own artifacts (reports, dermatoscopic pictures) at the end of every visit or, equivalently, perform routine synchronizations at the beginning and end of every working day.

LESION – the lesion data entity is used to keep track of the evolution of a lesion, tying together all dermatoscopic pictures as time passes. If full-body pictures were consistently taken at consistent distance from a subject that perfectly keeps their position across visits, the (x, y) coordinates of a lesion within its portrait of reference may be stored. It would then become trivial to prevent the introduction of duplicate lesions: whenever doctors try to mark a new lesion in a portrait, the database could be queried to look for potential collisions, and reject the request in case a match is found. However, pictures are not yet automatically captured, making high precision alignment nearly impossible in practice. Since it is likely that patients have several lesions in close proximity, (x, y) information was excluded from the lesion entity, because it was too prone to measurement

noise. When integration with FullBodyScanner begins, this choice will need to be re-evaluated.

PORTRAIT – these are the artifacts produced by the portrait task defined in Section 3.2.1: a portrait is a full-scale picture of one of the standard regions of the patient's body listed in Section 3.3.2. New portrait pictures can be taken for every visit, so that newly appeared lesions can be easily detected by comparison of photographs saved at different times. Lesions of interest are marked by the dermatologist in portrait pictures, for easy retrieval.

DERMATOSCOPIC – a dermatoscopic image is a picture of a lesion taken through a magnifying lens attached to the camera. As with portraits, dermatoscopic pictures are updated with each visit in order to track dangerous changes that the lesion may undergo.

REPORT – a report contains an overview of all the lesions analyzed in a visit, including all the diagnoses made for each of them by the dermatologist.

Figure 9 depicts the relational diagram of the data model. The chosen cardinalities provide insights to particular interactions in the application. For example, the $m : n$ relation between doctor and patient implies that several doctors can visit the same patient, which justifies MoleMapper's focus on producing data that is easily shared between doctors. As another example, the $1 : k$ relationship between visit and portrait highlights the fact that at most a constant number of portrait pictures–24, matching the cardinality of the set of subdivisions of the body described in Section 3.3.2–can be taken in a visit, whereas the many-to-many relationship between lesion and portrait reveals that there is no such limit for the number of lesions that can be marked by the doctor for a given region.

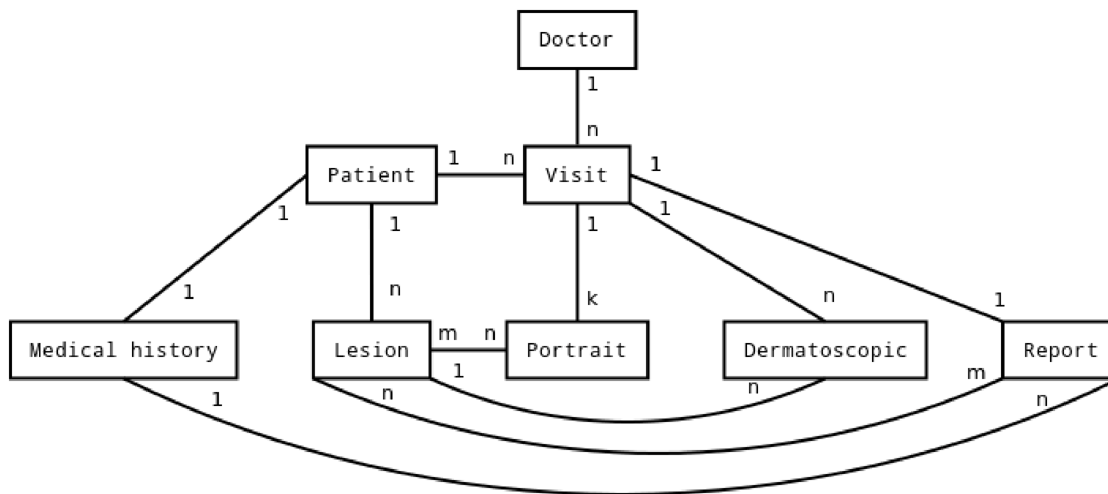

Figure 9: Relational diagram for entities in the data model.

4.2 ACTION MODEL

Using the data model as a guide, we identified the following set of functional requirements for the application through brainstorming sessions. These will be mapped to controls then implementing MoleMapper's user interface, whereas entries from the data model represent the content that will populate the application's data fields.

DOCTORS – doctors need to log in and out of the application; accounts must be password protected, and switching to a different user profile must be easy. User accounts can be added and removed from the system, and potentially synchronized across several devices.

PATIENTS – patients should be indexed by their unique SSN, and by non-unique attributes such as their name, date and place of birth, phone number, and email address. Patients can be added and removed from the system by any user of the application.

VISITS – visits can be scheduled, rescheduled, or canceled. Doctors must be able to track the progress of an ongoing visit at any time. All previous visits for a patient should be easily accessible from the patient's record in the database.

MEDICAL HISTORIES – medical histories must contain all available data about the health status of a patient. Entries in the medical history must be organized in a way that lets doctors quickly review critical facts about the patient. Nevertheless, doctors must be able to expand any specific record in the patient's medical history to gather all detailed information available. Updates to medical histories must happen automatically as they are retrieved from a central system, or from MoleMapper itself.

LESIONS – lesions must be marked in the portrait that contains them, and unmarked if no longer considered relevant. Lesions need to be diagnosed, and previous diagnoses should be easily accessible. In the event that a lesion is excised, its entry in the database must persist, and an entry in the patient's medical history must be added to highlight this important event.

PORTRAITS – portraits must be easily accessed from a body overview. For special cases not covered by the standard body subdivision (e.g., when suspicious nevi occupy the inter-digital spaces), doctors must have the option to add custom portraits where lesions are tracked. Since it is desirable that different pictures of the same portrait differ from one another as little as possible, dermatologists should be helped in aligning the camera to match the previous alignment as much as possible. An outline of the subject from the previous picture should be overlaid on top of the image feed from the camera to aid in aligning the picture. When taking the first picture of a portrait, this outline should be replaced by instructions on how to frame it, as illustrated in Figure 8 from the previous chapter. Dermatologists must be able to retake pictures of a portrait within a visit. Portraits must be compared side-by-side with their previous versions, and it should be easy to zoom-in and pan to check small lesions.

DERMATOSCOPICS – dermatoscopic pictures must be easily accessible from either the portrait that contains them, or from a list containing all marked lesions for a patient. It should be possible to use the tablet as a regular dermatoscope, inspecting the patient's lesions without taking pictures of them. Mirroring what is done for portraits, overlaid outlines should guide the dermatologist in taking pictures that maximize similarity with previous photographs of the same lesion. It must be possible to retake dermatoscopic pictures within a visit. Lesions must be compared side-by-side with their previous versions, and it should be easy to zoom-in and pan to inspect the lesion's patterns and structures. To facilitate the application of the ugly duckling principle [GB98], it must be possible to compare all dermatoscopic pictures of a patient's lesions taken in a visit.

REPORTS – reports must contain all relevant diagnoses for a patient's lesions: doctors should be able to configure what diagnoses are relevant (e.g., all lesions marked for follow-up, or all lesions for which a dermatoscopic picture was taken). Details about lesions must be easily accessible from visit reports, and diagnoses should be editable as long as the visit is not to be considered concluded. Visit reports need to be easily exported and printed. Reports should be easily retrievable from a patient's overview page.

4.3 VISUAL MODEL

The visual model describes how content from the data model and controls from the action model are organized in the application's user interface. This section will only discuss the layout of components, while considerations on elements of design, which dictate how the application will ultimately look, are left for a later stage, described in Section 4.4.1. Different styles can be applied to the same visual model without significantly affecting how doctors use the tool, so it is worth separating the two aspects when designing the interface.

A set of design principles were identified to guide the layout for the application, which we present in this section. These were motivated by a range of sources, from established design patterns such as the Wizard pattern or contextual navigation, to guidelines for the Android system [Inc15b], to our own intuitions built from our interviews. In its first implementation, MoleMapper was intended to be executed as a standalone application. We planned on developing a custom Android launcher that would prevent access to any other application installed on the device. Therefore, the traditional Android design guidelines were not applicable to our case. However, most of those ideas apply to any tablet environment, and many apply to any user interface in general, so they were included in our set.

4.3.1 Design patterns taken from visual design literature

This subsections presents three design patterns that we used for MoleMapper, the Wizard pattern [VWVDVE01], contextual navigation [Des15], and circular navigation [Sam12].

The Wizard pattern was used in the design of MoleMapper's navigation system. The pattern involves walking the user through a fixed series of steps. The user advances by repeatedly clicking on a button labeled "Next". The pattern minimizes the cognitive effort of performing repetitive tasks, by presenting the steps in a consistent manner, invoking the user's muscle memory. Hence, creating pictures becomes a rapid action, reducing the time needed by doctors for the photographic phase, which was universally regarded as tedious in interviews. A negative consequence of the Wizard pattern is that it leads to rigidity in navigation. Views can only be traversed forwards or backwards one at the time, making it not work well when many steps are involved. Contextual and circular navigation, the other navigational patterns used in MoleMapper, help mitigate these issues.

Contextual navigation is used to let users jump to specific views. This pattern is helpful in cases when dermatologists wish to capture some portrait pictures, but not all. In this case, a navigator widget with clickable areas will let them quickly jump to any portrait, removing the need to repeatedly click "Next", as a strict Wizard pattern would require. When evaluating all dermatoscopic pictures associated with a portrait, contextual navigation will let users load photographs in any order, making retrieving data about a specific lesion easier for dermatologists.

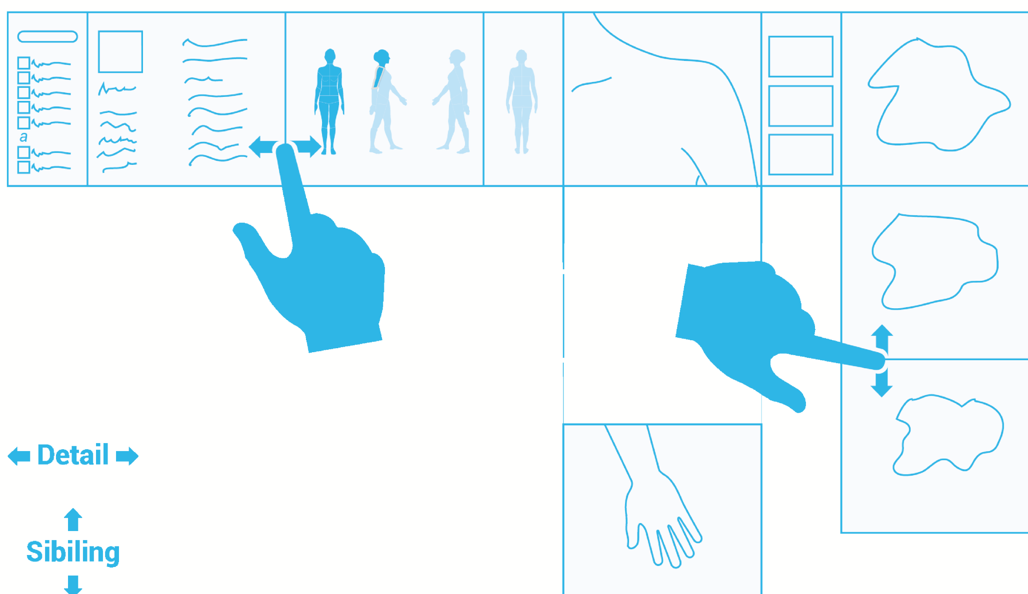

Figure 10: Schematics for the circular navigation pattern. Swiping horizontally navigates through different levels of detail, while swiping vertically navigates through items at the same hierarchical level.

Circular navigation is another navigational pattern present in MoleMapper. The pattern builds on a well-known two-dimensional model of the application's hierarchy. Illustrated in Figure 10, views are traversed horizontally from left to right (depicted by the finger swiping horizontally) when exploring an entity at increasing levels of detail. When stacked vertically (depicted by the finger swiping vertically), the user may browse items of the same hierarchical

level. Using the vertical axis to organize siblings, such as pictures of the same subject taken at different times, or pictures of a patient taken during the same visit, is consistent with the most common way of organizing list items in touch interfaces [Sch11]. Using horizontal space to stack views containing hierarchical data about an item is common in tablet applications, and is encouraged by the Android guidelines [Inc15c]. Figure 11 contains an example of how this model is shared by many tablet applications: vertical lists of items of the same type are organized in a horizontal layout. For example, "Starred", "Important", and "Sent" are at the same level, while one column over depicts the emails in each of those categories. The horizontal layout contains increasingly detailed views on the selected record.

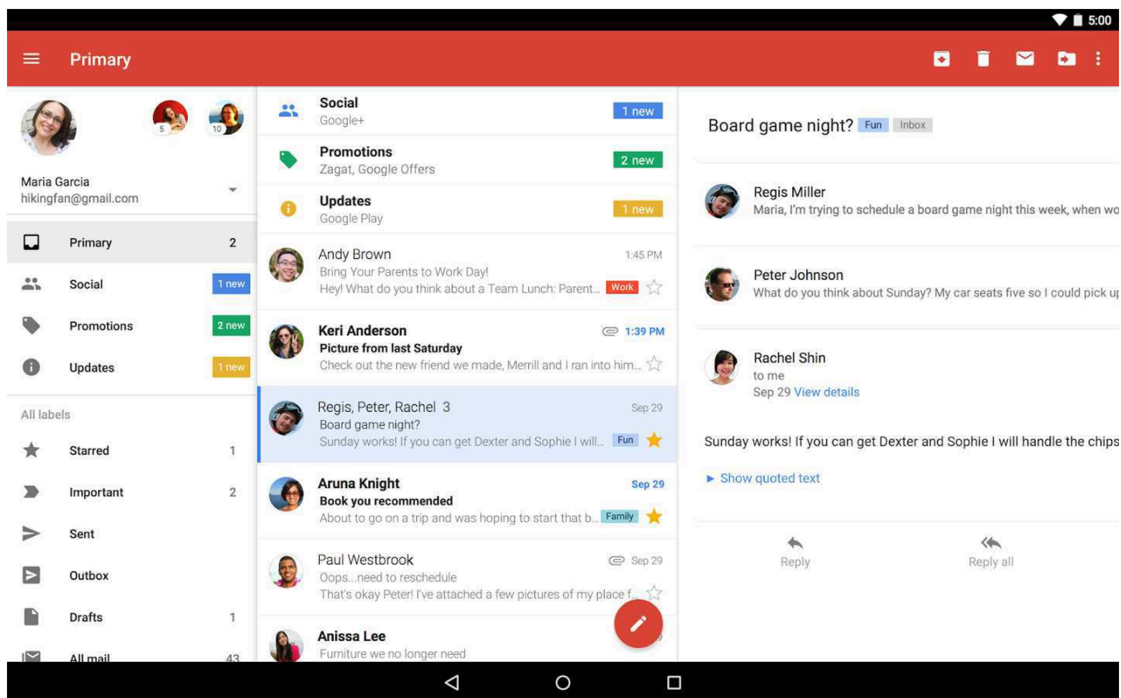

Figure 11: A screenshot of the Gmail application for Android tablets. The three vertical lists provide perspectives of emails from different levels of abstraction: from left to right, the hierarchy is composed of folders, conversation threads inside a folder, and messages in a conversation thread.

The peculiarity of the pattern that justifies its "circular" qualifier lies in the fact that the X axis folds in itself. The last view in the horizontal order is linked

to the first one, making it possible to complete all steps in the workflow and return to the home page by only navigating to the right. For example, if this pattern were to be applied to Figure 11, swiping right on the the emails in the rightmost column would take the user to the folders column again, hiding the others.

4.3.2 Design principles inherited from the Android framework

We reviewed the Android Design Principles [Inc15b] to only retain those that apply to MoleMapper's context. Some guidelines are focused on either platform integration, which is not relevant to the standalone app scenario in which we worked, or are specifically meant to capture the attention of casual Android users, who do not represent the target audience for MoleMapper. In the following list, design principles are rephrased to match the exact meaning that was attributed to them when developing MoleMapper. The original phrasing from Android design guidelines is reported between parentheses.

- **Keep screen complexity low** («*Only show what I need when I need it*»)

  Tasks should be broken into small steps, in order to avoid having too many components on the screen all at once. At the same time, navigation paths should be kept short, in order to minimize cognitive load. Long paths equate to complex context that is cognitively intensive for the user. Screens should contain as few elements as possible. Seven steps is heuristically the maximum path length, as anything greater exerts a mental burden on the user [Mil56].

- **Minimize input complexity** («*Real objects are more fun than buttons and menus*», «*Give me tricks that work everywhere*»)

  Touch gestures are the preferred method of input on tablet devices. Swipe, press-and-hold, pinch-to-zoom and two-finger rotate are common examples of actions in virtually all touch interfaces, regardless of the device's

form factor. They are common among all mobile platforms, and touch-enabled versions of the major desktop Operating Systems [Inc15f; Inc15a]. Most users will be familiar with these gestures from their existing devices, reducing the need for them to relearn the interface for each task.

- **Use good defaults, and make errors recoverable** («*Make important things fast*», «*Decide for me but let me have the final say*», «*It's not my fault*»)

  Confirmation dialogs should only be used in case of major, destructive events. Common experience suggests that users dislike being asked the same questions too often, so it is always preferable to decide on a sensible default choice, and rely on undo in case it happened to be wrong. Users should feel comfortable with performing any single action, knowing that it can never result in an unrecoverable failure. Undo should be available for all actions that edit or delete data, and those that cannot be undone should be preceded by warnings. It should be possible to rollback from transactions, as well as to restore recently discarded data. In case some types of errors can happen due to external causes (e.g., a network connectivity loss, or a failure in initializing the camera), clear recovery instructions should be provided to the user.

- **Make UI elements visually consistent** («*If it looks the same, it should act the same*»)

  When two graphical components look similar, their functionalities should match. Two similar-looking components with different functionalities will surprise the user.

- **Report progress** («*I should always know where I am*»)

  Providing feedback on the task in progress helps users consolidate their feeling of being in control of the process. After some practice, doctors should be able to estimate how much time is left in a visit at any step in the process.

- **Always provide visual feedback** (*«Sprinkle encouragement»*)

  Users should always receive feedback for their actions. Aside from the inherent satisfaction of getting their actions acknowledged by the UI, users can learn to detect subtle visual cues to gain confidence in knowing when their actions were understood by the application, or perform those actions again if they were not.

4.3.3 Design principles motivated by interviews

A set of design principles were introduced after revisiting statements made by the dermatologists during interviews. The design principles themselves were created during brainstorming sessions, and influenced by the experiences of the development team role-playing themselves as users.

- **Think of how the device will be held**

  Two considerations are especially important about MoleMapper. First, it could be used with multiple patients in a row, where the dermatologist must exert the effort of holding the tablet with each patient. Second, when taking pictures of skin lesions, a dermatoscope will be attached to the tablet's camera, adding to the device's weight. The combination of these two factors can lead to fatigue, since users will capture photos in two or more consecutive visits without a break. Care must be taken with the location of the most frequently used components. If possible, they should be easily accessible by the user's thumbs when they are holding the tablet with both hands.

- **Let users be inaccurate**

  When marking lesions on a portrait picture, dermatologists may need to bounce their attention back and forth between the patient's skin and the device in their hand. This can frequently happen whenever the suspicious

lesion is surrounded by others similar in size. In this case, doctors may operate on the screen while looking at the patient, decreasing their touch precision. The interface should accommodate for this and all other potential sources of inaccuracy by letting users fine-tune their choices at a later stage. The *make errors recoverable* guideline has a similar purpose, as it also aims at not "punishing" users for their errors or imprecisions. However, this principle takes a further step in the user's direction by letting them correct their mistakes.

- **Let the interface self-describe**

  Providing a straightforward interface should be the primary goal of any UI design. Intuitiveness will help users find their way long after they were taught how to use the application, and will let them understand how to use features they have never used before. It is an ambitious goal, but we attempted to enforce it by methodically reviewing design choices with untrained users and analyzing when more intuitive alternatives could be applied.

4.3.4 Views

Views are groups of controls and data fields that concur in defining how an action is performed. The subdivision of UI elements into views provides a semantic organization of a screen. Once users decide what task they wish to perform, they are guided by visual proximity in finding all relevant pieces of data that the application needs in order to accomplish their goal. Views do not necessarily coincide with screens, such as done with smartphones. Tablet applications are often composed of screens that contain several views in order to optimize the available space for better navigation.

When defining views for MoleMapper, several factors were taken into consideration such as:

- the amount of screen real estate needed by individual controls and widgets
- the logical sequence in which users perform actions
- the usage patterns involved (what elements are likely used together?)
- whether some elements are containers for other elements
- what is the best way to organize containers to optimize flow

With these factors taken into consideration, the final set of views is as follows:

LOGIN - where users sign in or out, and can search for their profile without typing their full account name.

SETTINGS - where the application settings can be changed (by users with administrative privileges).

PATIENTS - where all contacts and personal details for patients can be found. Entries can be added or removed from the existing database, as well as edited in case they're found to be outdated.

AGENDA - where all visits are scheduled. Visits can be searched by date, or by patient.

CALENDAR - where an overview of scheduled visits, as well as a log of those that have already been performed, can be consulted.

PATIENT - where all data about a patient's medical history, including past mole mapping visits, can be found.

PORTRAIT OVERVIEW - where a representation of the body subdivision can be used to navigate among portrait pictures taken for each region.

PORTRAIT - where a picture of one of the body subdivisions can be inspected. Users can look at lesions in a portrait in greater detail by zooming in. Lesions can be marked and unmarked, and their markers can be repositioned. Users can access side-by-side comparisons of lesions from the same portrait.

PORTRAIT CAMERA - where a shutter button lets users take full-scale photographs of the patient. Pictures can be taken multiple times, replacing the previous versions. In case a portrait picture from a previous visit is available, it is used to guide the user in aligning the new photograph with it. If no previous pictures are available, a model of the human body is shown with indications on what anatomical parts should be used to frame the portrait.

PORTRAIT COMPARISON - where pictures of the same portrait taken at different times can be compared side-by-side. Users can zoom in to compare pictures at a higher level of detail.

DERMATOSCOPIC OVERVIEW - where data about all of a patient's lesions can be found. Lesions are grouped according to the evaluation that was given to them by the dermatologist in the current visit. It is possible from this view to apply the Ugly Duckling principle, by comparing all dermatoscopic pictures at a glance.

DERMATOSCOPIC IMAGE - where a magnified picture of a lesion can be inspected. Users can zoom in to evaluate patterns in the lesion. An overview of the annotations taken during the visit for the lesion is shown. From the overview, it is possible to store a diagnosis for the lesion.

DERMATOSCOPIC CAMERA - where a shutter button lets users take magnified photographs of a patient's lesion. Pictures can be taken multiple times, replacing the previous versions. In case a dermatoscopic image from a previous visit is available, its outline is used to guide the user in aligning the new photograph.

DERMATOSCOPIC COMPARISON - where pictures of the same lesion taken at different times can be compared side-by-side. Users can zoom in to compare pictures at a higher level of detail. Users can also rotate the pictures independently, in case their alignments don't match.

VISIT REPORT - where a summary of a visit can be reviewed. Users can print or export the report.

4.3.5 Views layout

Views were organized into screens according to a semantic subdivision of the device's available display space that is presented in Figure 12. Consistent replication of the same high-level layout across screens helps users reinforce their mental model of the application, increasing confidence in using MoleMapper from the first uses. Further, the proposed 5-region subdivision closely resembles what is known in web design as the "Holy Grail Layout" [Wik15], a 3-column page organization that is used by a large number of popular websites.

In our proposed layout, two ever-present toolbars occupy the top and bottom of the screen. The bottom contains stepping controls, i.e. the "Next" and "Previous" buttons from the Wizard design pattern. These are placed close to the tablet's horizontal edges in order to be easily reachable by the user's thumbs when holding the device with two hands. The central part of the bottom bar contains system-related widgets, such as the indicators for wi-fi signal strength and battery charge, and the current time. The top horizontal region contains controls that affect the main central area, such as confirm/cancel, undo/redo, and fullscreen buttons. The left part of the top bar contains an indication of the current location in the workflow, as well as controls for switching containers in case more than one is available for the current screen, following the tabbed navigation pattern.

Location
View/Edit
Overview
Navigation
Content
Action
Description
Back
System
Next

Figure 12: Organization of screen space into semantical regions. The main areas are outlined in black, whereas secondary subdivisions have gray borders.

The two sides of the main area are the Navigation and Action panels which are placed at the edges of the table to be easily accessible. The same considerations about proximity to the tablet's edges that were discussed for stepping controls apply to these components. Users may rapidly switch views using one hand and act on them while using the other without needing to alter their grip on the device. It may seem counter-intuitive that the main content, which requires more frequent interaction than the side panels, does not benefit from being within thumbs reach. However, it is worth considering which of the views that occupy that area will be used the most. The overview and the comparison view panels are involved in the central activity of the dermatologist, which is finding newly appeared or otherwise suspicious lesions, and tracking their progress. The majority of the time spent by dermatologists in a visit will be in these two panels. These views all contain pictures and all but the

dermatoscopic overview are zoomable and rotatable, which are actions that involve using two fingers. Therefore, users will have to change the way they hold the device to a one-hand grip, making the view position in the screen largely irrelevant.

The "Overview" and the "Description" horizontal panels in Figure 12 contain contextual information about the Content area. Because the overview contains information that can be safely ignored, it is unobtrusively overlaid on top of the central panel using semi-transparent backgrounds. The Description, on the other hand, uses dedicated space when present since it provides more context to the central content.

4.4 MOCKUPS

The last step in designing the User Interface for MoleMapper consisted of producing high-fidelity mockups. These polished artifacts were essential in generating a realistic impression of the interface. Visual weights of elements, recognizability of controls, and overall consistency in how views are displayed are all aspects that can only be evaluated by looking at pixel-perfect mockups.

4.4.1 Visual style

As a preliminary step, a visual style needed to be chosen for the application.

By following the methodology presented in Cooper's About Face [Coo95], we applied the *building blocks of visual interface design*. These are visual properties for each element or group of elements in a layout that must be considered in order to to create useful and engaging user interfaces.

SHAPE - flat, abstract, and with no lighting effects. Three-dimensional elements may distract the observer from the bi-dimensional main content of MoleMapper.

SIZE - the size of elements depends on the specific combination of views on screen. Pictures occupy the majority of the screen real estate as they are the central content on which dermatologists operate.

VALUE - the interface is mainly composed of dark colors, highlighting the predominantly light colors of portrait and dermatoscopic pictures. Elements are mostly monochromatic and desaturated, to put less strain on the eye of the user when sessions are long.

HUE - shades of gray and desaturated cyan are used for most components. Occasionally, bright colors are used to highlight important parts of the UI. Color-coding is used extensively and consistently to match lesion evaluations; a traditional traffic light color scheme maps the different states of lesions: red for suspect melanoma, yellow for lesions that need to be monitored, and green for those that appear safe.

ORIENTATION - the application operates only in landscape mode. The proposed subdivision of the human body is based on pictures having a landscape aspect ratio, making it the orientation best suited for the device.

TEXTURE - compact textures are used to fill all containers in order to minimize the visual noise given by the interface.

POSITION - the position of elements depends on the specific combination of views on screen. Visual proximity is used to group views that are often used together.

4.4.2 Screens

The following section describes the mockups produced for MoleMapper, and contains observations on some of the most relevant design choices.

Login

Shown in Figure 13, the login screen contains a standard password field with automatic replacement of characters with asterisks as they are typed. The enter key submits the passwords. To add to the sense of ownership, and to make the interface look more engaging, users may set their profile pictures. The navigation area contains a list of all accounts that can access the device. At this stage, MoleMapper is targeted at small to medium-size organizations, which means that all users can simply be listed. As the list grows in size, doctors can search to quickly retrieve an account by typing a few characters. Alternatively, accounts can be retrieved from a list of those that recently accessed the application, sorted by most recent login time.

The login solution aims at saving keystrokes for users. However, there is another advantage: users do not need to remember their username. Using email addresses as unique identifiers is a common alternative solution to the same problem, but it is one that requires users to type even more characters, and it relies on users remembering which of their potentially multiple addresses they used for MoleMapper.

When resuming the tablet from standby, the most recently logged in account is automatically selected. Although the same device can be shared between a group of dermatologists working at the same clinic, interviews suggested that no more than 2 handovers of the tablet are likely to happen within a day. This lends credibility to the assumption that the user that last logged in will most likely be the next to log as well.

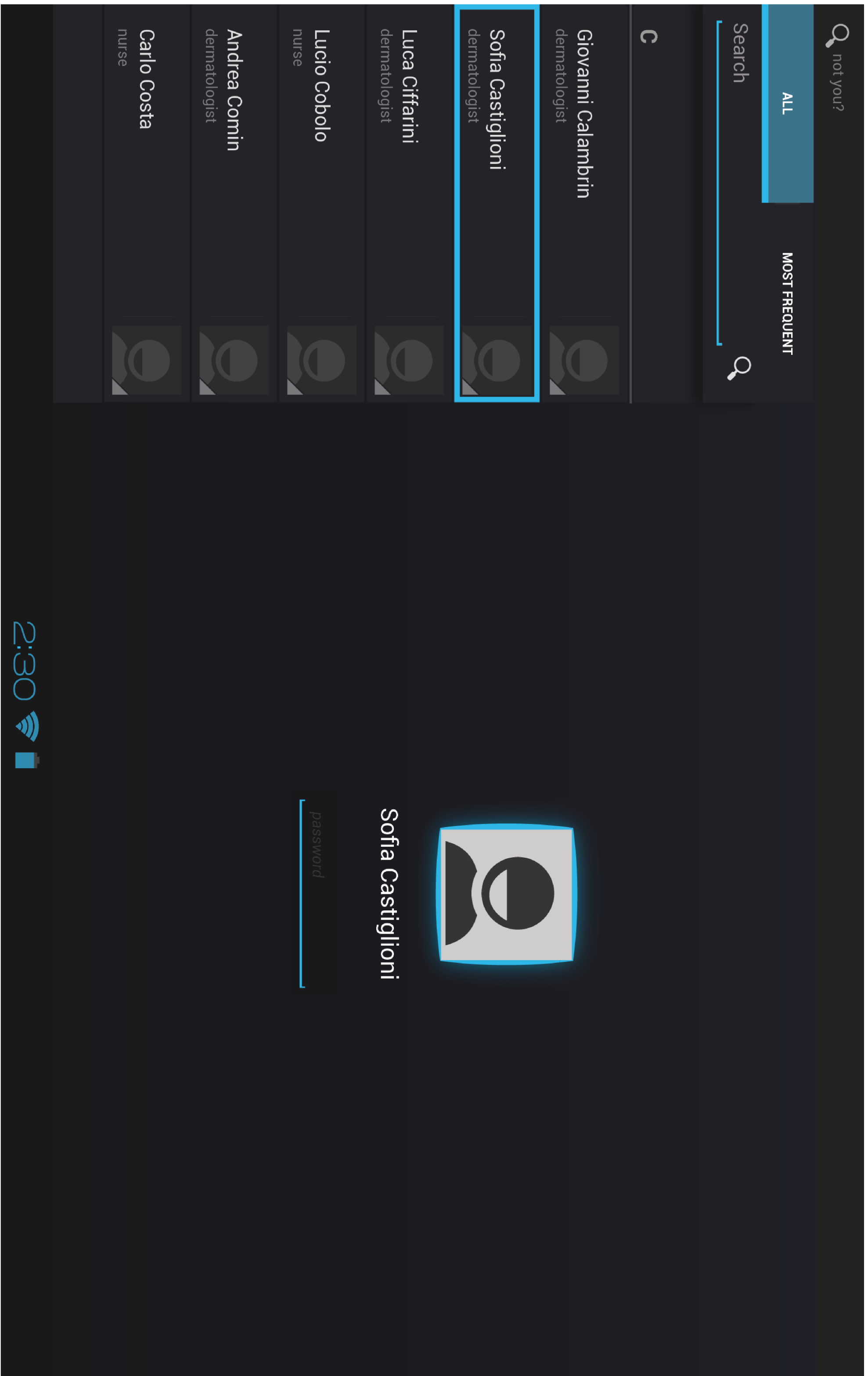

Figure 13: Mockup of the login view, search panel expanded.

Home

The home screen is depicted in Figure 14. The screen real estate is divided into two semantic regions. The current location is displayed at the top, and the system information and stepping controls at the bottom. In this case, "Back" is mapped to a shutdown icon, which can be used to either turn the device off, or logout from the current account. The "Next" button is mapped to Agenda, as that represents the first step in the most common scenario of dermatologists working their way through all visits scheduled for the day.

Users can skip directly to the patients screen in case quick access to the database is needed. This is useful in the already mentioned case of results coming back from histological exams or, more generally, whenever data needs to be consulted or updated without performing a visit. As an example, patients may call doctors on the phone, asking for more information on lesions they had examined, or requesting to reschedule an appointment.

The settings button leads to a traditional control panel, where preferences for the current user can be set, passwords can be reset, and system configuration can be changed.

Agenda

The agenda shows a list of all appointments scheduled for the current day, making all information needed to start a new visit quickly available. Shown in Figure 15, the representation of the agenda contains a navigation view on the left, and a detailed representation of relevant data about the selected entry on the right. Doctors can either scroll the list or use the date spinner to check all scheduled visits for a given day; the two controls are bound to each other: scrolling down to a different day updates the displayed value on the spinner, and setting a date on the spinner makes the list scroll to it.

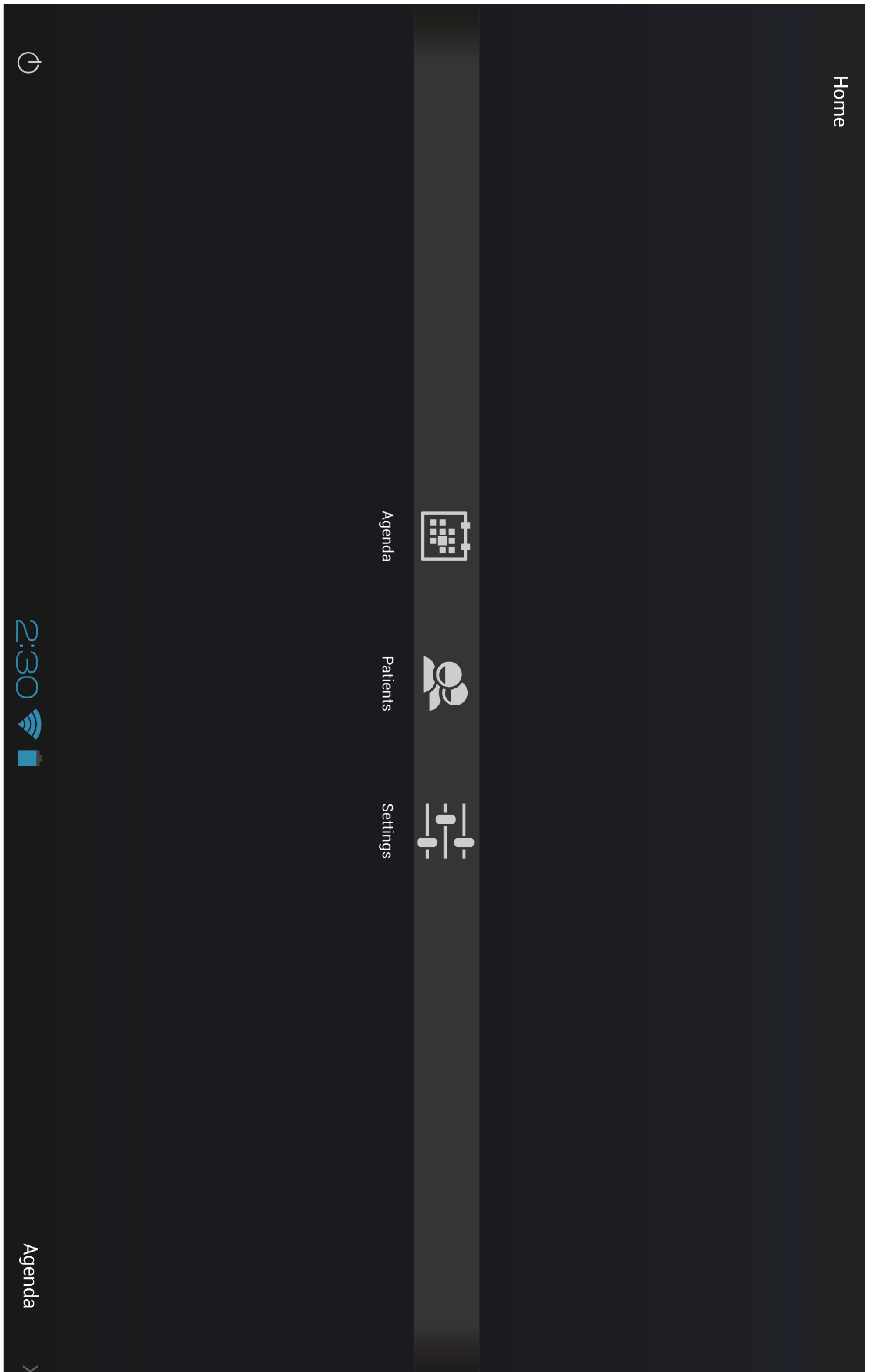

Figure 14: Mockup of the home screen.

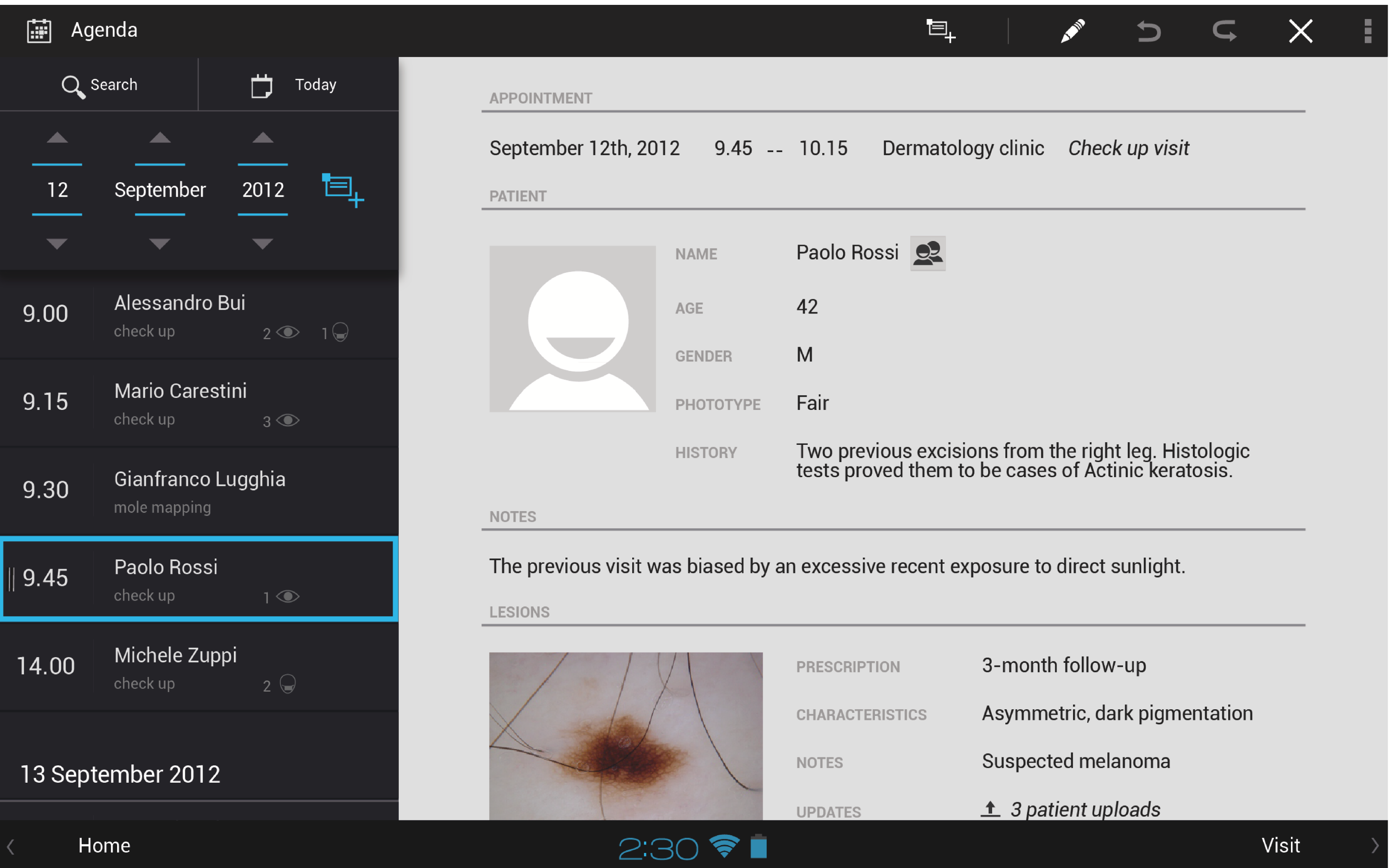

Figure 15: Mockup of the agenda screen.

Entries in the agenda contain the essential data about a visit: the time it is scheduled, the name of the patient involved, its type (either "Check up" or "Mole mapping"), and a brief summary of the outcome of the previous visit. This summary contains counts of lesions that were marked for follow-up, and of lesions that were marked for excision. By looking at these numbers, users can quickly estimate the amount of work required for a visit. With that knowledge, they may know in advance the intensity of the work day that awaits them, and can re-schedule appointments in case critical situations are detected within a day. When that happens, users may drag the selected entry by its displayed handle on the left, and drop it to the next time slot available. When appointments need to be rescheduled to a different day, doctors can use the calendar panel shown in Figure 16. The calendar can be accessed by clicking on the top-left "Agenda" toggle, which makes the new view enter the screen by pushing the currently displayed panels to the right, making the details panel exit the screen. In the calendar, days are color-coded according to the number of visits scheduled, and a vertical gauge is used to reinforce the concept. Press-and-hold is used to enable rescheduling of the selected visit, and drag-and-drop is used to change a visit's schedule. A pop-up dialog is used to reset the time of the visit for the newly selected date.

In the main view shown in Figure 15, details about a selected appointment include a minimal set of the patient's personal details (name, age, gender, and phototype), as well as data from the most recent visit available. A picture of the patient is shown in order to make doctors promptly detect cases of homonymy. The extended record for a patient can be retrieved by clicking on the button next to their name.

Patients

The patients database is accessed using the screen displayed in Figure 17. A lexicographically sorted list of all patients is shown on the left, matching the style, size, and position of the account list from the login screen. Typing on

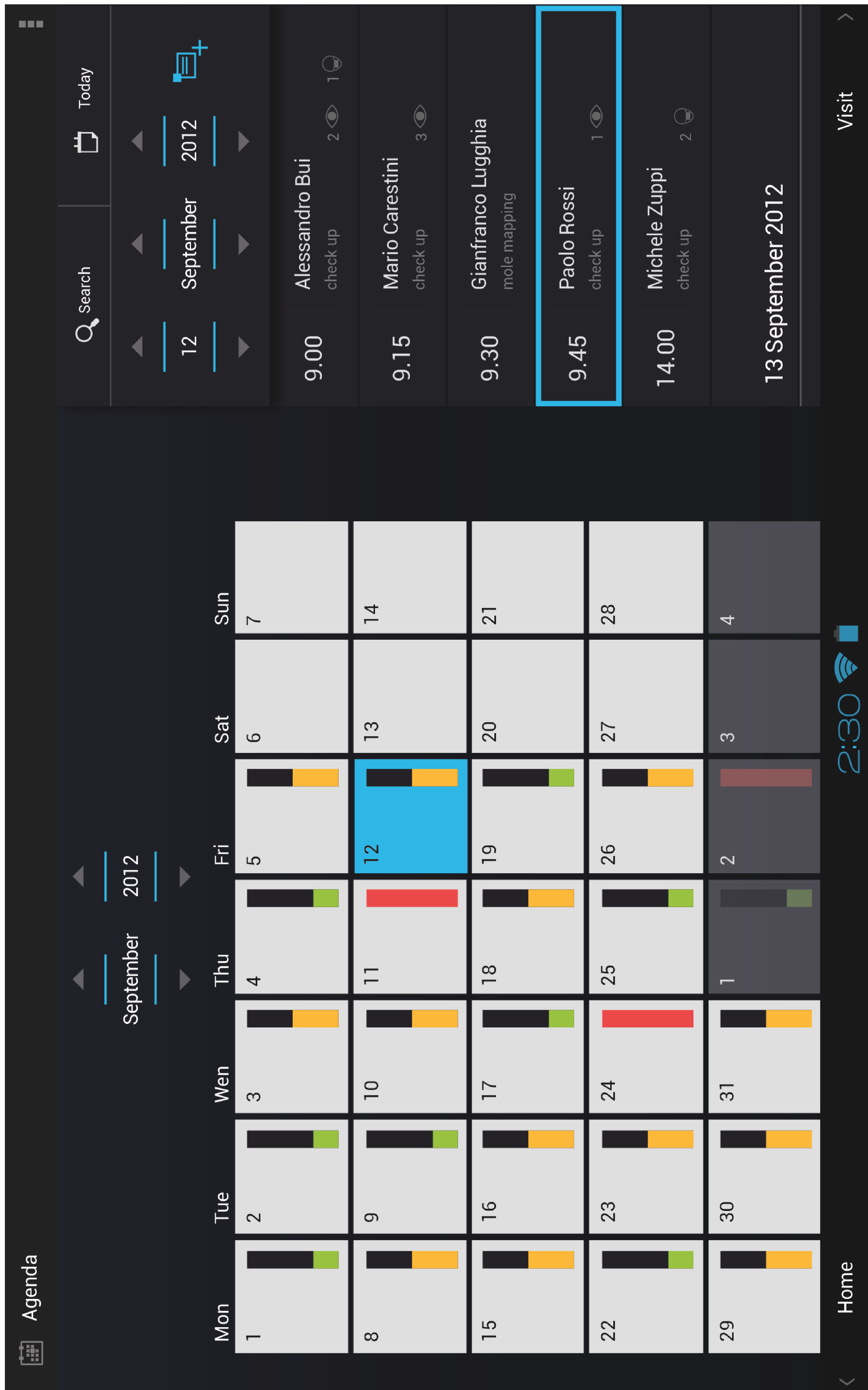

Figure 16: Mockup of the calendar screen, part of the Agenda.

the top-left search field dynamically filters records on the list below: patients whose first name or last name contain all characters in the query string appear on the list, while all others are hidden.

Increasing levels of detail about a selected patient are shown in the two vertical panels from center to right. The central panel contains information about the patient's next scheduled visit, as well as a list of artifacts that have been retrieved from the medical facility's central system, or from the patient's PersonalScreener when that becomes available. The right panel shows the complete set of attributes known about a patient, organized in collapsible groups according to the type of data they represent: anagraphics, contact details, medical history.

The right section of the top horizontal bar is occupied by editing controls. The pencil icon makes all attributes in the right panel editable. When editing details, undo and redo are enabled. Deleting a patient from the database requires a click on the "Delete" button on the top-right, as well as a confirmation on the pop-up dialog that is displayed afterwards.

Visit

Screens used by dermatologists while performing a visit all follow the same tabbed pattern. Three tabs can be switched using buttons on the top bar near the location label.

The organization of screens involved in a visit is illustrated in Figure 18. The visit screen contains three tabs that take, respectively, to an overview of the portrait pictures, to an overview of the dermatoscopic pictures, and to the report, which can be seen as an overview of the visit itself. The portrait and dermatoscopic overviews, in turn, contain three tabs each; on a high level, these can be semantically mapped to the actions of taking pictures, comparing them, and annotating them. Users can freely switch between tabs at any time,

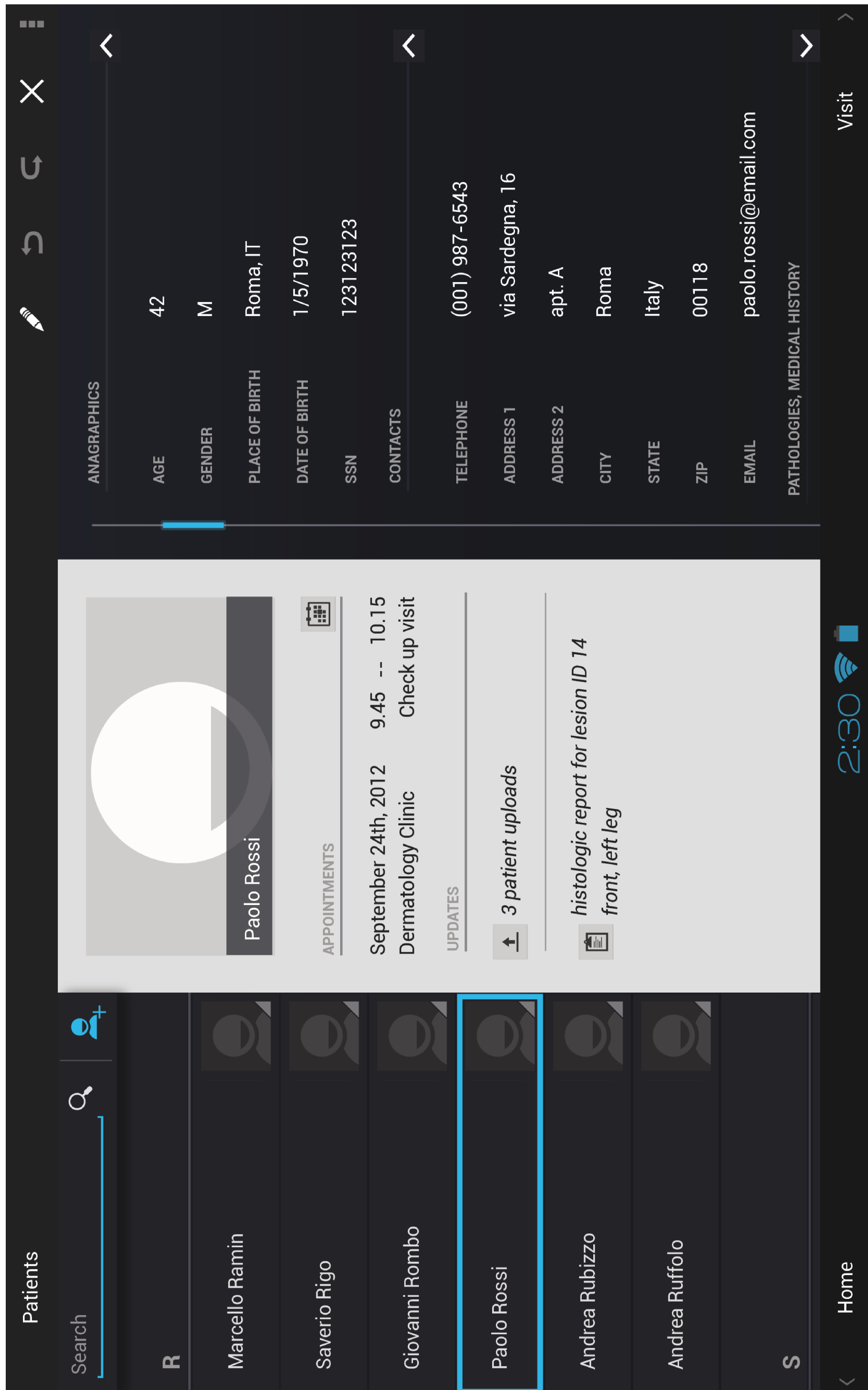

Figure 17: Mockup of the patients screen.

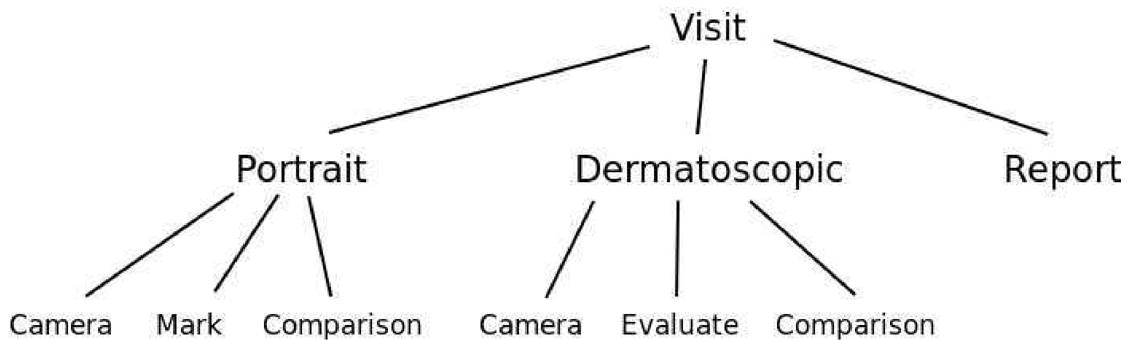

Figure 18: Hierarchy of visit screens. In this tree, all nodes but the root are tabs in the UI.

but whenever they push the stepping buttons on the bottom bar they are taken to the tab that corresponds to the next phase in the workflow of choice (among those presented in Section 3.2).

Visit - Portrait Overview

Figure 19 shows the portrait overview tab in the visit screen. Four models, one for each of the poses assumed by the patient when taking full-body photographs, are divided into the individual portraits, which are highlighted in case they have been photographed in the current visit. This way, it is possible to assess the current coverage of the patient's body at a glance. Clicking on any of the regions take the user to the corresponding portrait screen. Lesions appear in their belonging portrait, color-coded according to the evaluation given during the current visit, if available, or according to the last known one.

On the top right, two buttons can be used to add and remove custom portraits, in case the already discussed special case occurs of a patient having suspicious lesions in otherwise non-covered regions, such as the inter-digital spaces, or the genital area.

These mockups use the original poses and subdivisions of the body, which were devised before the review process that led to our final standard proposed in Section 3.3.2 took place. Since the new subdivisions were a result of running

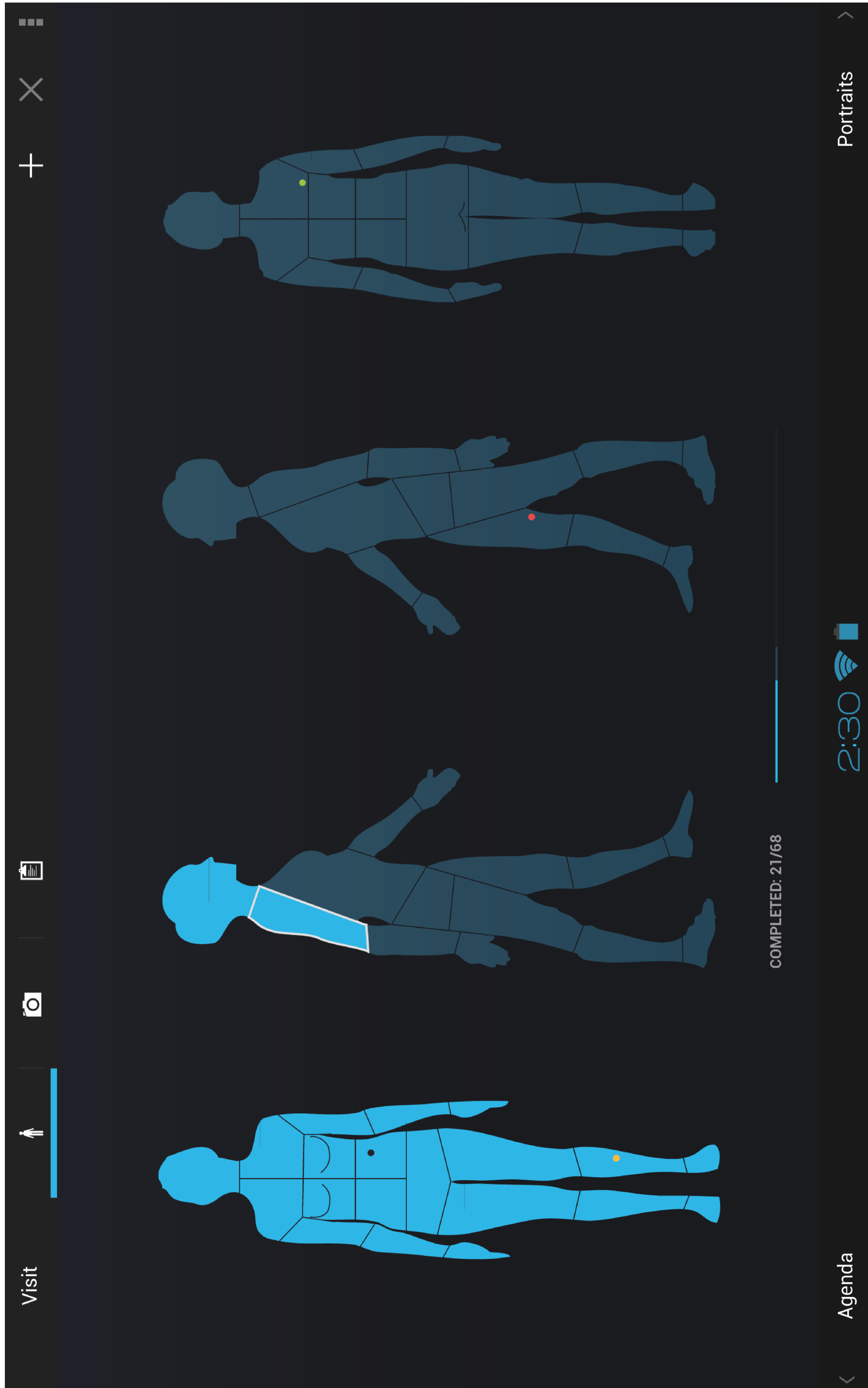

Figure 19: Mockup of the visit screen, portrait overview tab.

a pilot experiment using a preliminary version of the application, the original mockups were not redesigned, and the switch to the new models happened during a following refinement stage.

Visit - Dermatoscopic Overview

The dermatoscopic overview tab shows all dermatoscopic pictures taken so far in the current visit, along with those taken during the previous visit. Figure 20 shows how dermatoscopic pictures are organized in four vertical lists, one for each possible lesion state. The color-coding described above (red for excision, yellow for follow-up, green for healthy) is used to label the lists, with an additional dark gray label for lesions that have not yet received an evaluation during the current visit. Clicking on any picture takes the user to the corresponding dermatoscopic picture, whereas clicking on the "X" overlay button deletes the picture after requiring confirmation to the user through a pop-up dialog.

Lists are dynamically populated as lesions are evaluated. As with the portrait overview tab, it is possible to look at this screen to quickly estimate the current advancement in a visit.

In their current practice, dermatologists do not have a method to apply the Ugly Duckling principle that does not heavily rely on their mental model of the patient's lesions. At best, doctors can quickly skim through dermatoscopic pictures to find similarities in patterns, but they have no way of visually comparing them. The dermatoscopic overview screen can be used to overcome this limitation. If more pictures need to be displayed at the same time, users can click on the top-right grid button to access a gallery where all dermatoscopic pictures available for a patient are shown, with no controls or labels overlaid on top of them.

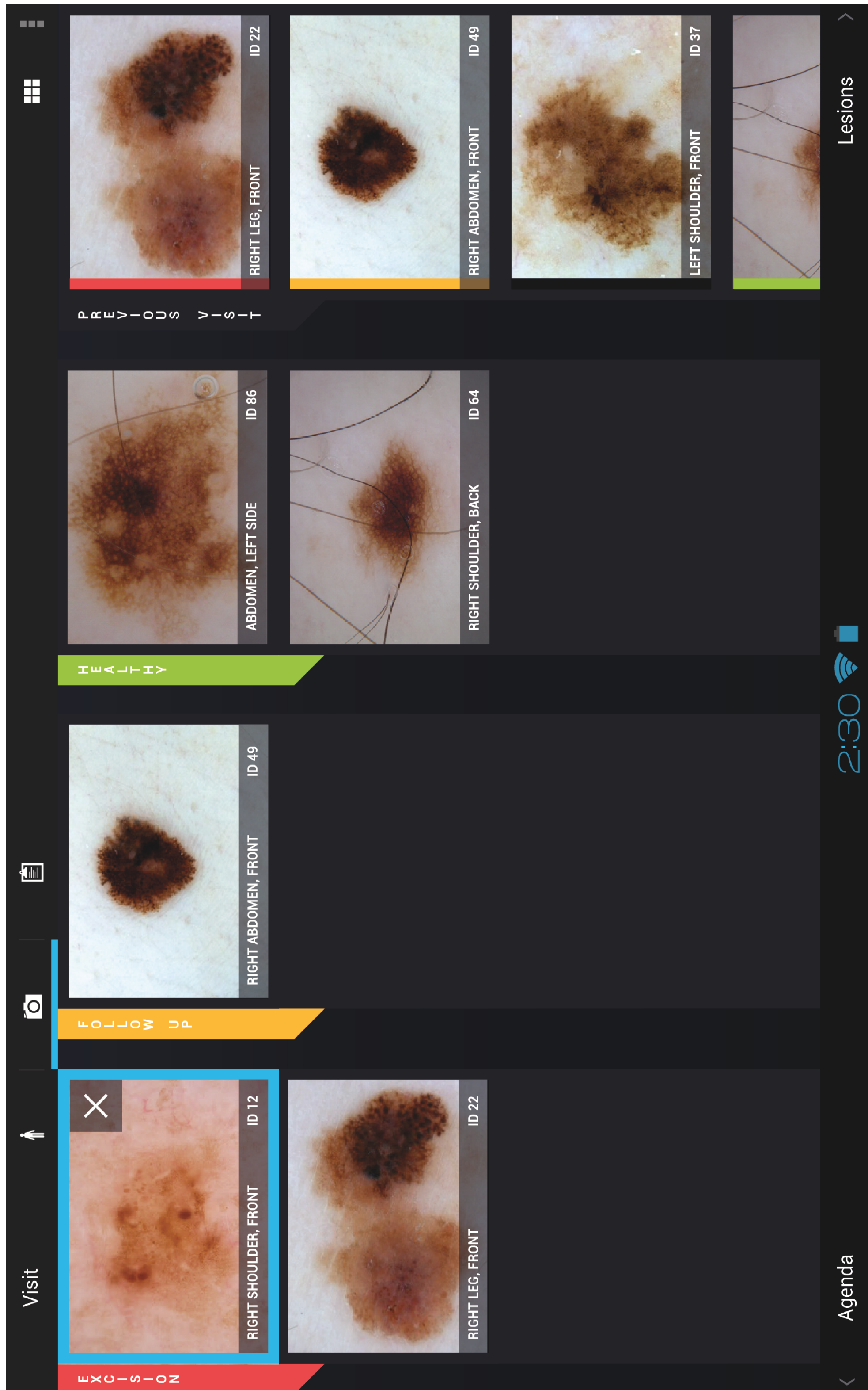

Figure 20: Mockup of the visit screen, dermatoscopic overview tab.

Visit - Report

The last tab in the visit screen contains a dynamically generated report that can be seen in Figure 21. All personal details about the patient that need to be part of any medical report are included at the top. It is possible to correct any error in the patient's data without leaving this screen, by clicking on the same buttons that are used for updating records in the patients view. Furthermore, a "Share" button is provided to let doctors print or send the report as an email attachment to the patient. The same button could be used to let doctors share reports with other specialists, or other departments. However, ownership of the patient's data was a controversial topic in interviews, and further legal investigations should be performed before enabling the feature.

As an improvement over the report format currently in use, dermatoscopic pictures of lesions that must be either monitored or surgically excised are included. To help localize the exact lesions involved, 3 levels of context are provided, namely: (1) the region involved, along with its position within the body, (2) the full-scale picture of the relevant region, and (3) the dermatoscopic picture of the lesion.

Portrait - Camera, and Dermatoscopic - Camera

The same layout is used for both the portrait and the dermatoscopic camera tabs. Figure 37 shows the layout in action for portrait photography. The main area is occupied by either the portrait picture, or by the live video feed from the tablet's camera. As soon as the screen is entered, the latest available picture for the portrait is displayed, in order to give users a reference for aligning the new photograph. The shutter button on the right, colored in bright cyan to highlight its importance, has two related yet slightly different functions. At first, it's labeled with a plus symbol to communicate its initial purpose of adding a new picture for the portrait. After it is pressed, its label is changed to

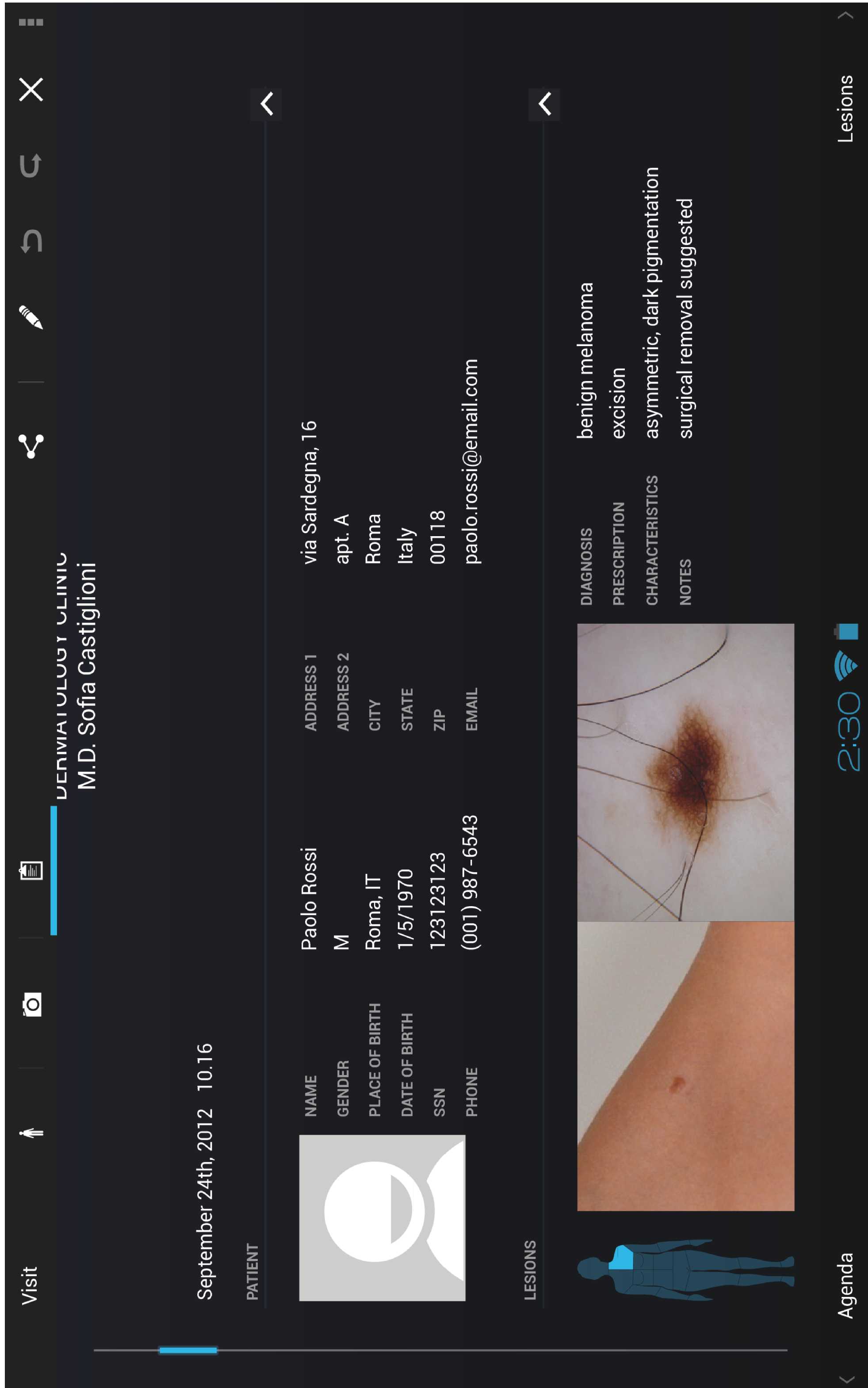

Figure 21: Mockup of the visit screen, report tab.

a camera diaphragm icon, to signify that pressing it again will result in taking a picture. At the same time, the content of the main area is changed to display the video input from the camera, with a thin but visible outline of the previous picture overlaid on top of it. Once the alignment with the previous image satisfies the user, the picture can be taken, and displayed in the main area, once again replacing the previous content. The label for the shutter button is reset to its initial state. Several shots can be taken for a portrait, using the undo and redo buttons that are dynamically enabled or disabled according to the state of the undo stack.

A reminder of the position of the portrait within the body is provided below the camera controls. As Figure 23 shows, this is the main difference between the portrait and the dermatoscopic versions of this tab. In the latter, the latest portrait picture corresponding to the area containing the lesion to be photographed replaces the human model that's used for portrait-camera.

The other minor difference between the two tabs is the icon on the top-left area of the screen. In both cases, clicking that button results in the contextual navigation panel sliding in from the left, hovering over the main content without making any other component change its size. The icon mirrors the aspect of the contextual navigation panel: in the case of portraits, one of the 4 human models shown in Figure 19 is used, whereas one of the 4 vertical lists shown in Figure 20 is used for dermatoscopic tabs. These two panels can be seen in the left portions of the screen in Figure 39 and in Figure 25, respectively. These panels can be horizontally swiped to navigate through the 4 different poses in the portrait case, or through the 4 different lesion states in the dermatoscopic case.

Portrait - Comparison, and Dermatoscopic - Comparison

Figure 24 shows the side-by-side comparison tabs for portrait pictures. The central area is split between the reference picture, on the left, and the latest

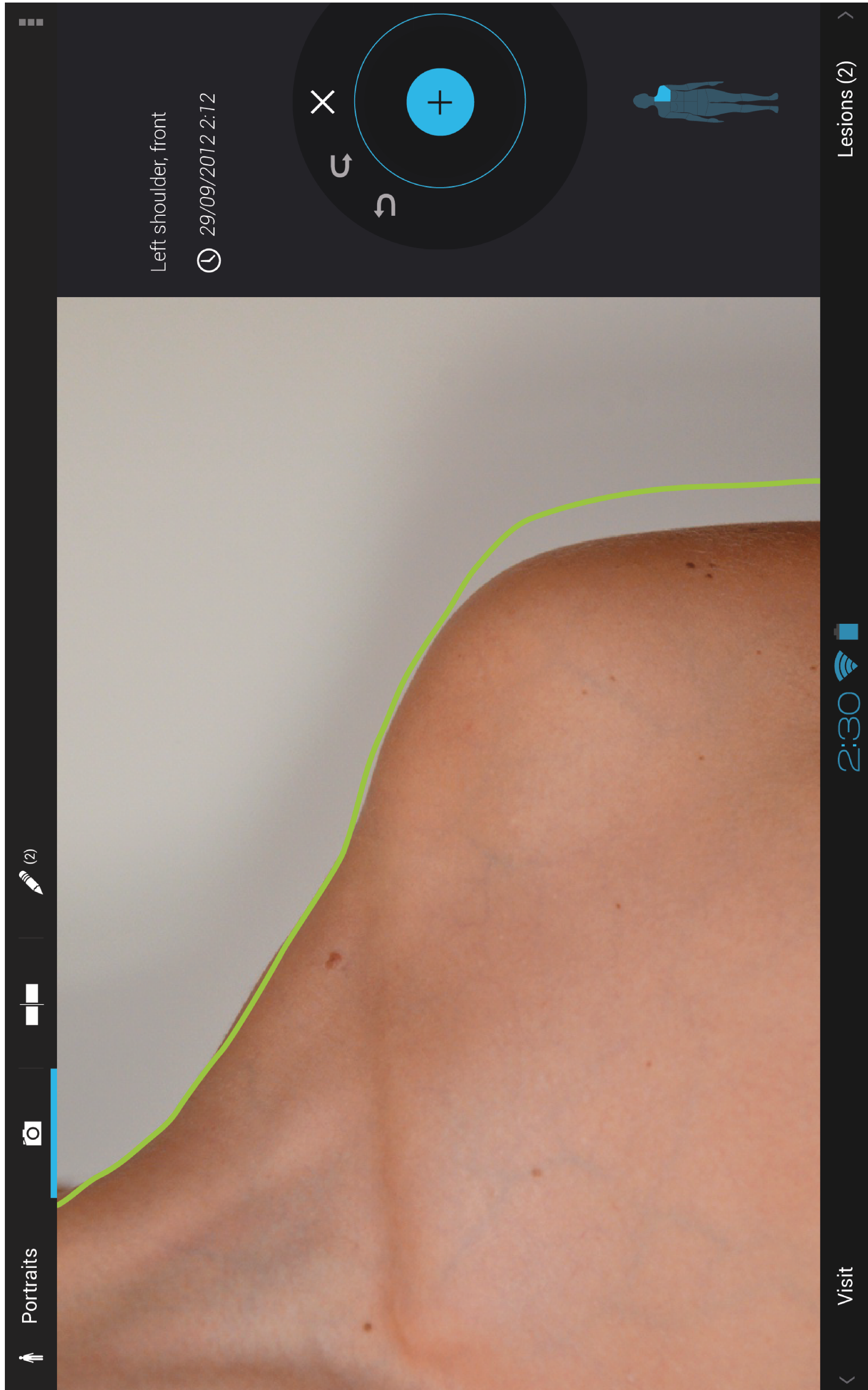

Figure 22: Mockup of the portrait camera screen.

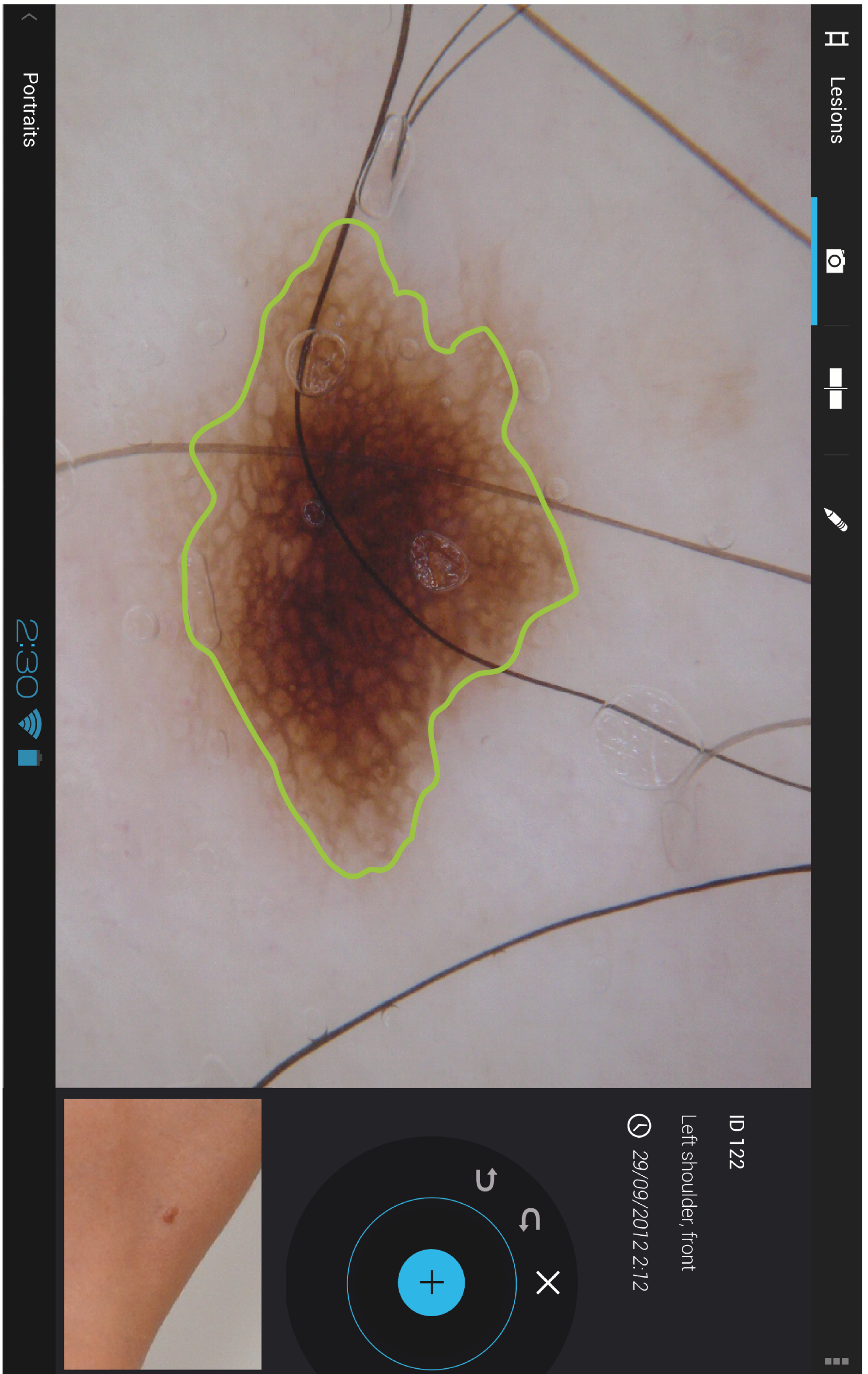

Figure 23: Mockup of the lesion camera screen.

picture, on the right. By selecting different entries on the leftmost vertical list, users can change the reference picture against which the current state of the patient's skin is compared. Lesions that were marked for follow-up appear circled on the reference pictures, with the usual color-coding. A numeric ID is attributed to lesions, so that users can remap them by fine-tuning the position of the relative marker on the right-hand side picture, in case perfect alignment was not achieved (which is likely the most common scenario, in practice). Single taps are used to select lesion markers, which can then be dragged for repositioning. Selected markers appear in cyan, and contain an "X" button that can be used to remove a lesion from the list of those to be examined during the current visit. Automatic lesion detection algorithms, if available, will set warning markers on the most recent portrait where new lesions are detected.

The "Overview" semantic region is used to display information about the position of the portrait, and the time at which pictures were taken. On the rightmost part of the overview for reference pictures, a lock icon is shown to indicate that markers saved for old pictures cannot be repositioned, or deleted. Three action buttons occupy the top-right section of the screen:

- the fullscreen button, which maximizes the area dedicated to the two pictures by removing all controls but the fullscreen button itself (which is used to return from fullscreen)
- the slideshow button, which provides a single-picture fullscreen view of past portrait pictures; users can swipe through older pictures to compare them with the patient's skin as seen with naked-eye
- the scroll-lock button, which toggles locking for navigating the two images: if enabled, panning or zooming on one of the two images automatically pans or zooms the other by the same quantity

Figure 25 shows the comparison tab for dermatoscopic images. The same general layout discussed for portrait comparison is used, with some notable differences. First of all, the leftmost part of the screen is occupied by the lesion contextual navigation panel. Interviews revealed that it is sometimes

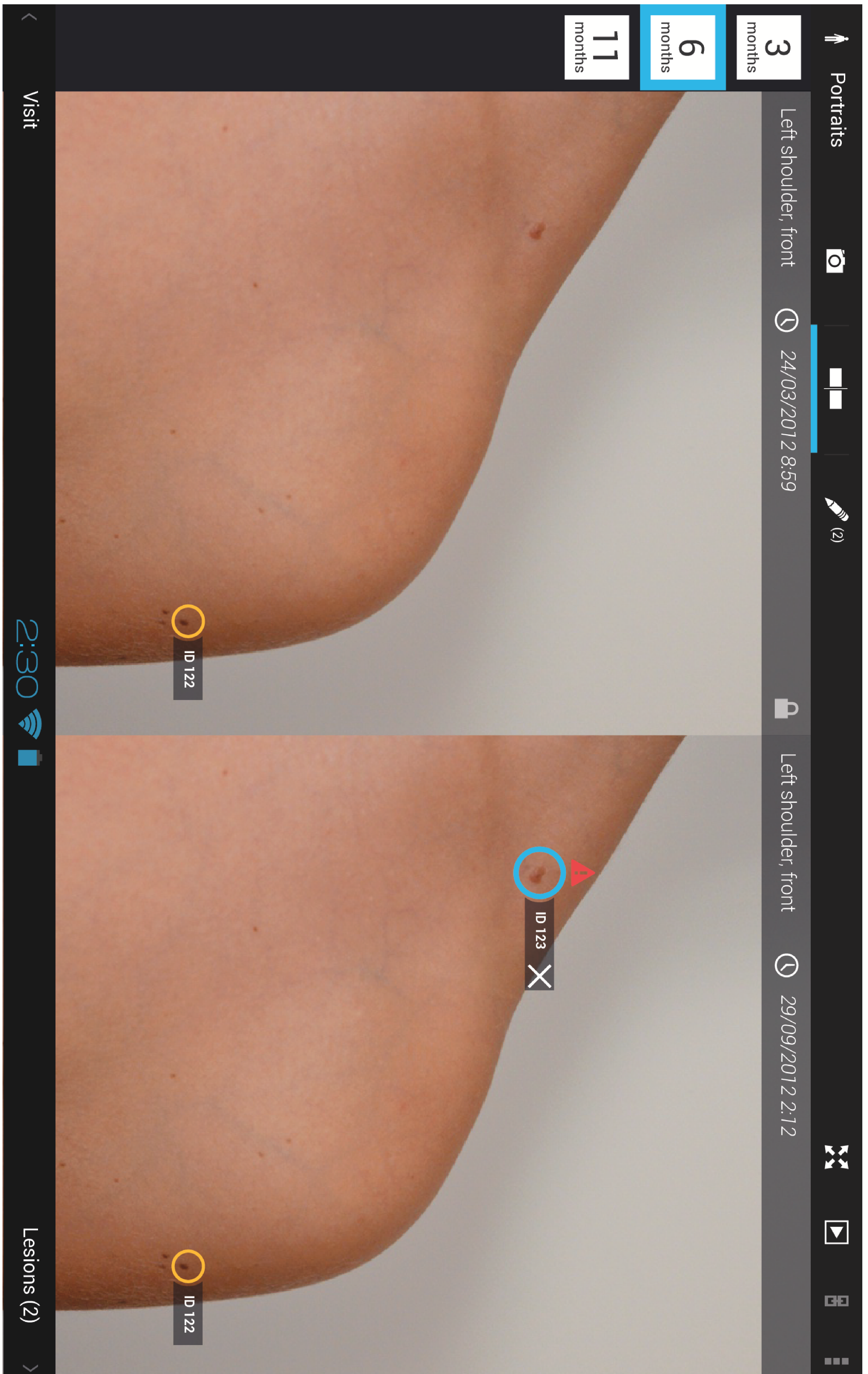

Figure 24: Mockup of the portrait comparison screen.

interesting to compare dermatoscopic pictures of different lesions, to evaluate whether some specific patterns are shared by many of the patient's moles (and are therefore not to be considered dangerous). Hence, the reference picture in the dermatoscopic case can be chosen not only among those for the same lesion taken at different times, but also from all lesions appearing in other portraits. Further, the "Description" semantic region is occupied by the context of the dermatoscopic picture: as was explained for the visit report, both the position within the patient's body and the full-scale portrait picture are provided. Lastly, previous evaluations about the lesion can be consulted by clicking the downward expansion icon on the left-hand side overview bar, and new evaluations can be given on the spot by using the overlay panel that is shown by clicking the one on the right. Controls on the overlay panels mirror those used for dermatoscopic Evaluation, and will therefore discussed when analyzing that tab.

Portrait - Mark

The portrait Mark tab, shown in Figure 26, contains a large picture of the recently photographed portrait, where lesions can be marked by simply tapping on the area of the image that contains them. As soon as a lesion is marked, an entry is added to the rightmost vertical view, using a crop of the selected area as thumbnail. Whenever it becomes available, the dermatoscopic picture taken for the lesion is used as a thumbnail instead, as it can be seen for lesion 122 in the mockup. When lesions are evaluated, their marker in the parent portrait picture is updated to match the usual color-coding scheme. Adjusting a marker's position, or discarding it altogether, happens following the same interaction scheme described in the portrait - comparison discussion.

The last entry in the list of lesions on the right is labeled "Explore". Doctors use it with the attached dermatoscope to freely inspect the patient's lesions without the need to have them previously marked. However, when in this mode, users are not allowed to take pictures as that requires marking.

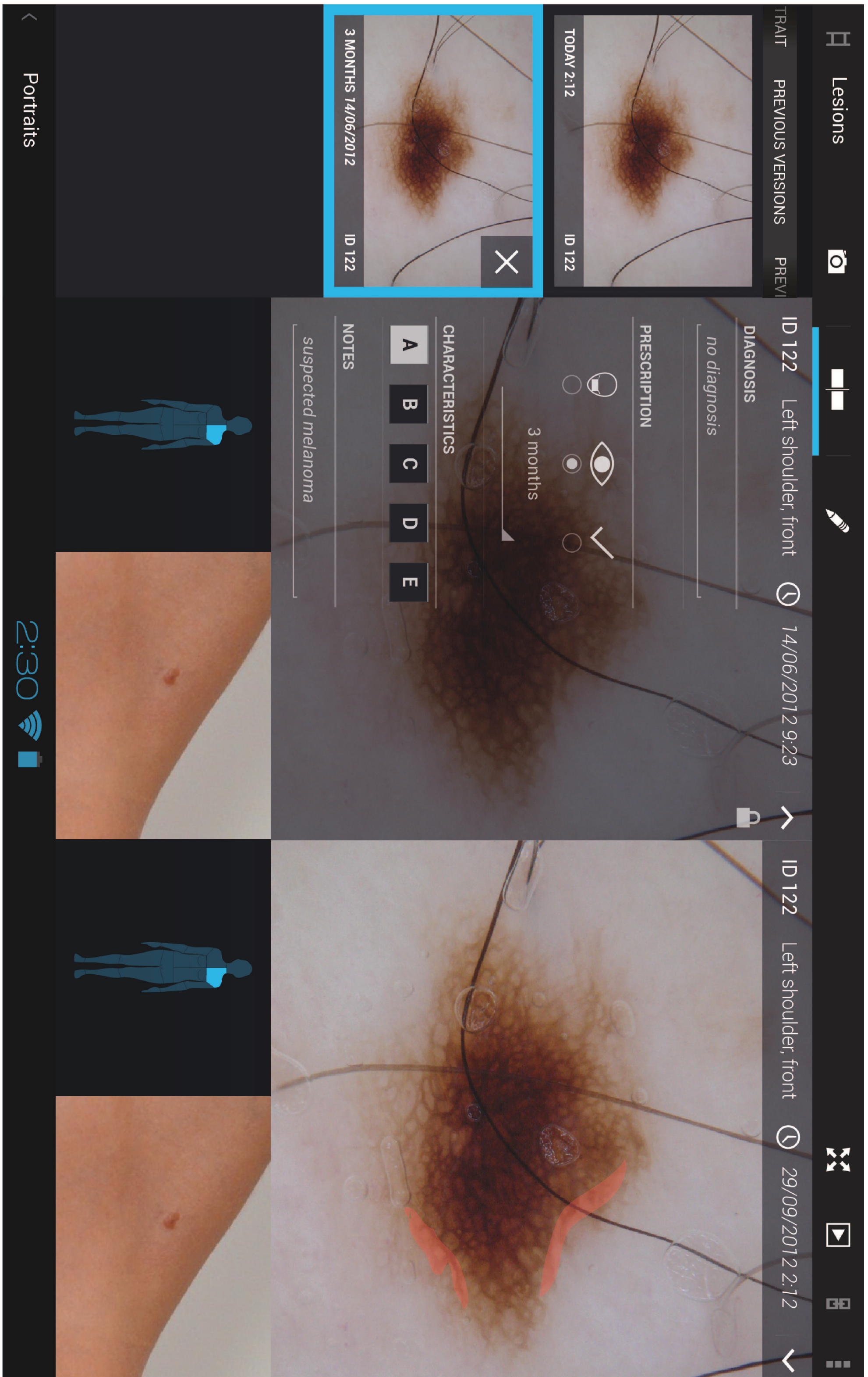

Figure 25: Mockup of the lesion comparison screen (lesion detail panel expanded).

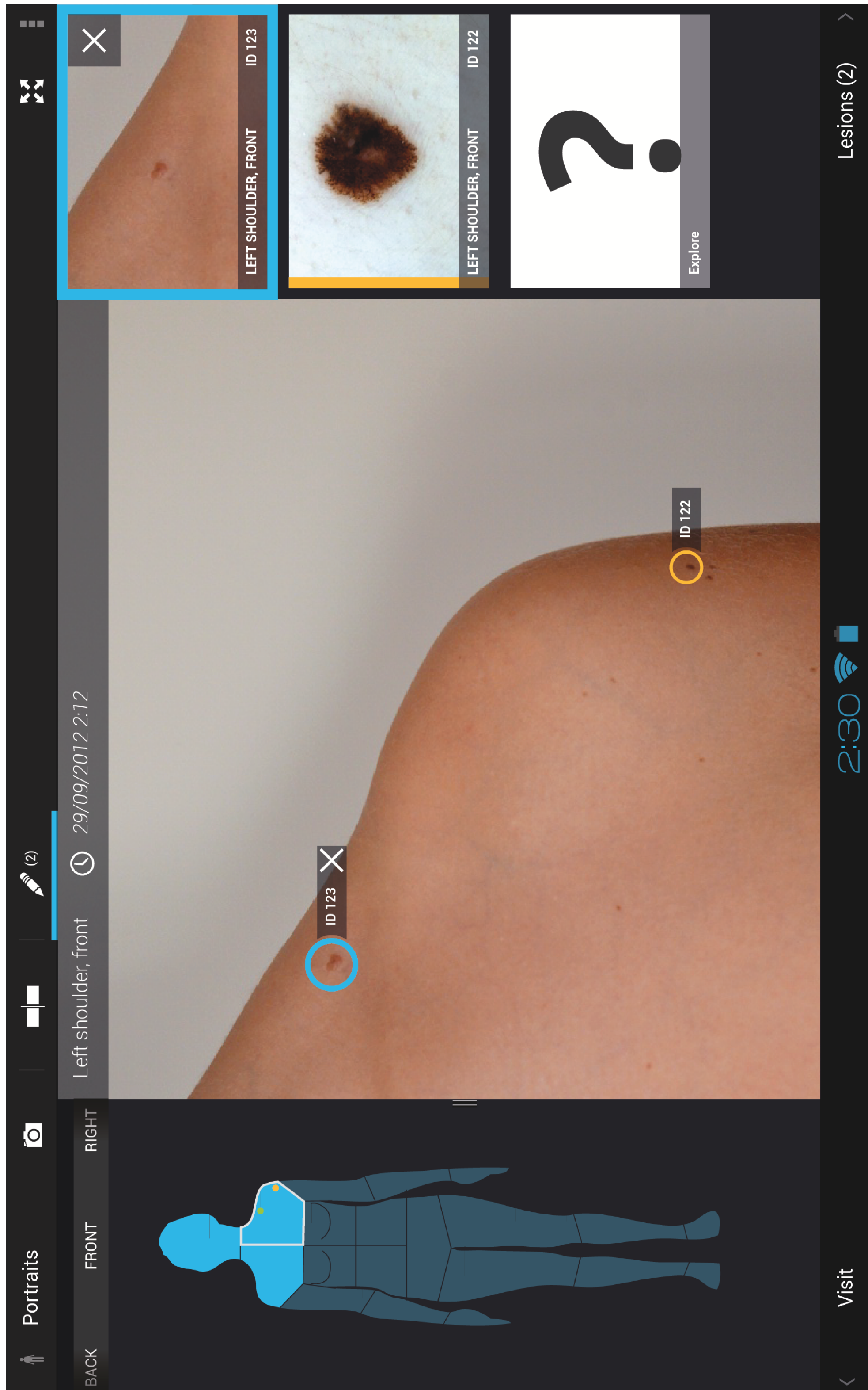

Figure 26: Mockup of the portrait mark screen, contextual navigation panel on the left.

Dermatoscopic – Evaluation

Figure 27 shows the lesion evaluation tab. Once again, the layout of the screen matches the one used for the equivalent portrait tab. The vertical list on the right is where the 2 tabs differ the most. In this case, it lets users provide evaluations on the specific features displayed by a lesion, together with a thumbnail-sized picture of the parent portrait for reference. Diagnosis and Notes are two free-text fields that can be used in case doctors want to provide detailed information about a lesion. The ABCDE buttons work as checkboxes, and are used to quickly summarize why a lesion was marked as worth tracking. The nearby update button can be used to change the characterization criteria to be evaluated. Any of the criteria presented in Section 1.1 that can be represented as a set of indicator flags can be used, and set as default characterization method in the settings screen.

Omitting to populate any of the aforementioned fields has no side effect on any other screen in the application. On the contrary, providing prescriptions for a lesion updates its status on all other screens where it appears, applying color-coding in all views that contain markers (or colored labels). The lesion is also moved to the appropriate list in the visit overview tab and Contextual Navigation Panels, according to its newly set status. Further, follow-up visits are automatically scheduled whenever one or more lesions are assigned the "Watch" state. The spinner element below the eye icon may be used to set one of the default follow-up times, ranging from 1 month to 1 year.

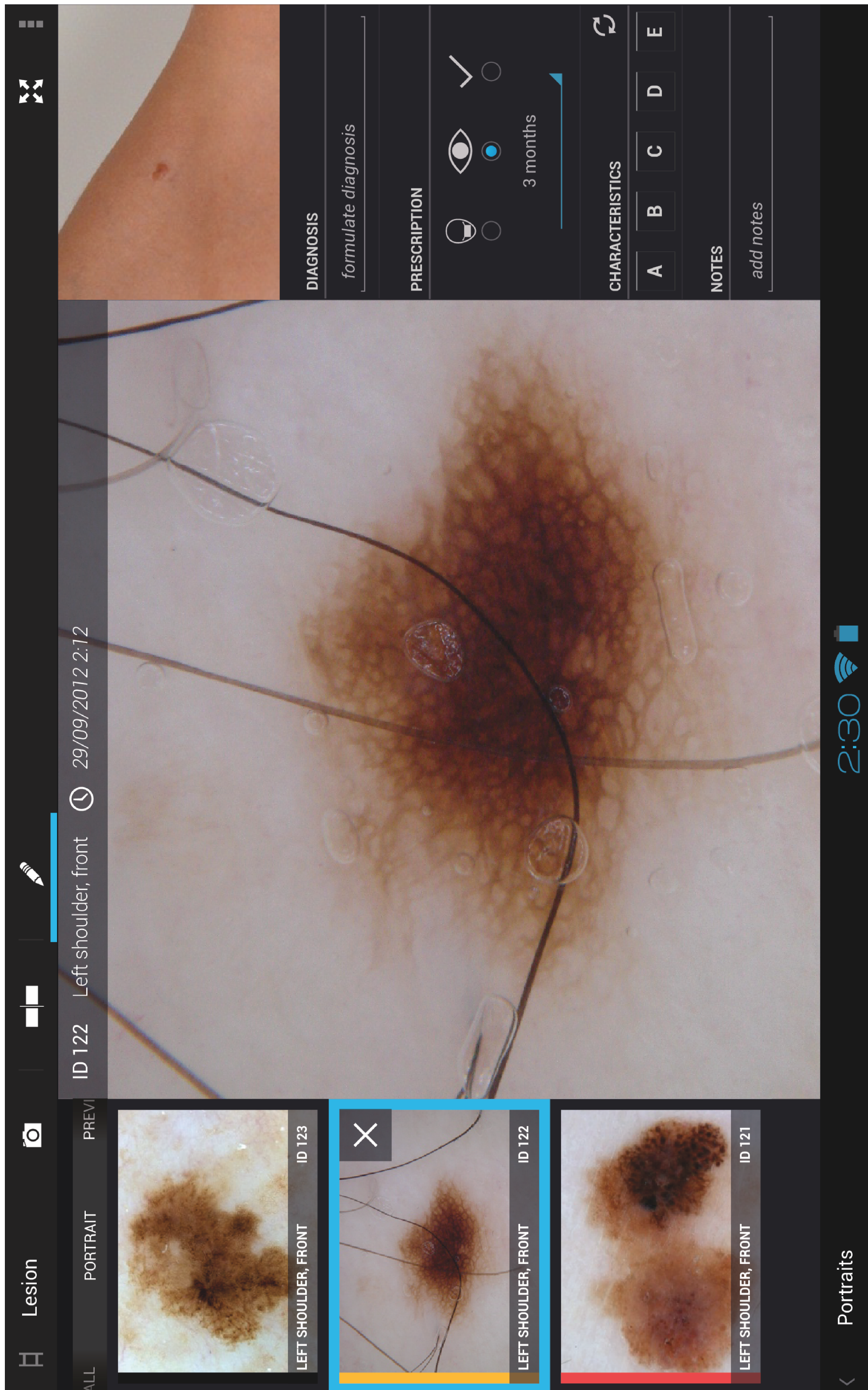

Figure 27: Mockup of the lesion evaluation screen.

5 BUILDING MOLE MAPPER

In the previous chapter, we presented the design of MoleMapper, as well as the high-fidelity mockups that would become the Android application. In this chapter, we describe how MoleMapper was built.

Before we could start developing code for the application, we needed to choose a device that would run it, and we needed to design a solution to make that device work with a detachable dermatoscope. Then, we converted the mockups into a working Android application that uses a local database to store its data. Dermatologists helped developing MoleMapper by providing feedback on the usefulness and usability of its features as they were presented to them using early prototypes.

The remainder of this chapter is organized as follows: Section 5.1 explains how we decided what tablet we would use, and describes the custom mount that we crafted for the dermatoscope. Section 5.2 describes how we implemented the data model from the previous chapter using a relational database, and shows how the application accesses it. Section 5.3 and Section 5.4 analyze MoleMapper's code in detail, providing a description of its organization into activities and fragments, and highlighting some of the most interesting implementation choices that we made.

5.1 HARDWARE

This section details the steps we took to assemble and setup the tablets that ran MoleMapper. The first subsection explains our choice of tablets during our prototype and deployment phases, and the requirements that affected our choices. The first tablet was a prototype model that guided us through development of the application, and was used for the first round of supervised tests. The second tablet was an upgraded, more professional-looking model that dermatologists would feel more comfortable using with actual patients, without giving them the impression of being part of an early-phase experiment.

The second and third subsections describe the lens and mounts used, and the challenges encountered in using them. At the time development began, no dermatoscopic lenses existed that could be attached to a tablet. We needed to design a custom mount to adapt an existing, off-the-shelf dermatoscope for use with our tablets.

5.1.1 Tablets and OS

Since dermatologists insisted on the importance of picture quality for their discipline, the leading requirement that guided our choice for a device was the resolution of its camera. Because of this, the Apple iPad, which was at its 4th generation at the time, was a poor choice for our study, despite it being the preferred device by the doctors we interviewed. The iPad's 5MP-camera made it a poor candidate in comparison to the available high-end Android devices equipped with 8MP-cameras. The inferior resolution of the Apple device's camera also diminished the benefit given by the sharpness of its screen. The high-resolution screen allows the doctors to notice lesions that occupy a small fraction of the containing portrait's surface, which they often do, but the camera quality must be sharp enough to allow doctors to zoom in. In this case,

the quality of the image matters more than the quality of the medium used to display it.

As Table 5 shows, the iPad also weighed, on average, approximately 10% more than the other tablets that were considered. Casual users may not notice a difference of 60 grams, but to a professional using the tool throughout their daily routine, the difference becomes pronounced.

Device name	CPU	Display	Camera	Weight
Apple iPad 4	1.4 GHz dual-core	2048×1536	5MP	650g
ASUS TF201	1.3 GHz quad-core	1280×800	8MP	586g
Samsung Galaxy Tab 10.1v	1 GHz dual-core	1280×800	8MP	589g
Sony Xperia Tablet S	1.3 GHz quad-core	1280×800	8MP	585g

Table 5: The final set of devices that were considered for the tablet choice for development and supervised tests.

The ASUS Transformer Prime (TF201) was the first tablet that we chose to support when developing MoleMapper. Aside from its 8MP-camera, the two main features that made this device particularly interesting were its detachable physical keyboard, and its elegant, subdued design. As can be seen in Figure 28, the TF201 can be attached to a companion keyboard that doubles as an additional battery, extending its declared operating time from 12 hours to 18 hours, making it usable for whole working days without the need to connect it to a charger. In addition to that, doctors could benefit from the better typing experience when producing reports at the end of a a visit.

The first round of supervised tests finished almost a year after development started. Hence, we checked what new devices could be used for a potential hardware upgrade. The tablets that were considered for this second choice are listed in Table 6. Having already developed MoleMapper as an Android application, we excluded the iPad from the set. The upgrades from Apple–the iPad Air and the iPad mini– featured 5MP-cameras that would have made them poor choices anyway. Interestingly, the TF201's successor–the ASUS Transformer Pad Infinity (TF700)– only brought a minor CPU improvement, while gaining 10 grams in weight. ASUS released another tablet, the TF701, which

Figure 28: The ASUS Transformer Prime, with docking station.

improved in terms of CPU clock and screen resolution, but equipped a 5MP-camera, a downgrade from the TF201.

As will be discussed in the next chapter, experiments with the dermatologists highlighted the importance of reducing the device weight to a minimum. For this reason, we chose the Sony Xperia Tablet Z, the lightest of the set. Samsung's late-2013 update to its Galaxy Note 10.1 tablet, code-named "2014 Edi-

Device name	CPU	Display	Camera	Weight
ASUS TF700	1.6 GHz quad-core	1280×800	8MP	598g
Samsung Galaxy Note 10.1-2014	2.3 GHz quad-core	2560×1600	8MP	535g
Sony Xperia Tablet Z	1.5 GHz quad-core	1920×1200	8.1MP	495g

Table 6: The final set of devices that were considered for the tablet choice for the in-the-field deployment.

tion", was an equally valid candidate, but it was ultimately discarded because of ts 40 gram increase over the Xperia's weight.

The Sony Xperia Tablet Z (shown in Figure 29) features a minimal design that gives it the appearance of a natural successor of the ASUS Transformer Prime. Although its declared battery life of 10 hours is shorter than that of the Prime, it remains enough to be useful for the entire working day before it needs to be recharged.

Figure 29: The Sony Xperia Tablet Z.

5.1.2 Dermatoscopic lens

When development began, only one dermatoscopic lens that could be attached to a regular camera existed, the DermLite FOTO. As can be seen in Figure 30, the FOTO is composed of a circular dermatoscopic lens attached to an external battery pack. A switch at the top of the lens activates the LED lights that illuminate the patient's skin. Unfortunately, lighting can not be controlled through an external USB port, and therefore, attaching the lens to the tablet requires two actions: (1) attach the lens to the tablet, and (2) activate the LEDs.

Figure 30: The DermLite FOTO attachable dermatoscopic lens.

A new, smaller attachable lens was available for the in-the-field deployment of MoleMapper, the DermLite DL3. Shown in Figure 31, the DL3 is a compact dermatoscopic lens that is specifically designed for use with portable devices. As for the FOTO, illumination is activated through a physical switch on top of the device. Although no specific connection kit was available for the Sony

Xperia Tablet Z, the DL3 proved to be easier to attach to the device than the FOTO, as will be discussed in the next subsection.

Figure 31: The DermLite DL3 attachable dermatoscopic lens, with its iPhone connection kit.

5.1.3 Dermatoscopic lens mount

Our goal when designing the mount for the dermatoscopic lens was to provide the easiest possible experience to the user, while keeping the total weight low. At the same time, the involved components should be resistant to wear and tear, as attaching and detaching the dermatoscope will be frequent operations. Furthermore, the design needed to rely on minimal customization over existing parts, as increased complexity would have required prototyping facilities that were not available at this stage.

With these considerations in mind, we designed the first prototype of the dermatoscopic lens slot, which is shown in Figure 32. A custom-designed aluminum bracket holds together the dermatoscopic lens and its battery pack. The bracket is attached to the tablet using a Manfrotto rectangular plate adapter, which is commonly used in photography to mount DSLR cameras on tripods. The base of the adapter is attached to the tablet through a silicone adhesive layer, whereas its detachable part is screwed to the bracket itself. To mount the dermatoscopic lens, users need to push it against the tablet until it snaps into place. To unmount the lens, the lateral lever can be used to release it from its base.

Figure 32: The DermLite FOTO mounted on the ASUS Transformer Prime using the prototype lens mount (left), and the part of the mount that is always attached to the tablet (right).

The availability of the DL3 allowed us to design a lighter, better-looking mount. As Figure 33 shows, the lens is attached to the DermLite iPhone connection kit, which is riveted to a semi-rigid plastic tablet case. To mount the dermatoscopic lens, users need to slide it diagonally towards the center of the tablet until it reaches the end-stop. To unmount the lens, users can slide it off the tablet by pushing it in the opposite direction.

Aside from being more aesthetically pleasing, the updated dermatoscopic lens mount helped in reducing the total weight of the tool. As Table 7 shows, the hardware upgrade led to a 297-gram decrease in weight when the dermatoscope is mounted, and to a 48-gram decrease when the tablet is used without

Figure 33: The DermLite DL3 mounted on the Sony Xperia Tablet Z using the updated prototype lens mount (left), and the part of the mount that is always attached to the tablet (right).

the lens. In the revised solution, the DL3 is directly attached to its slot, without requiring any additional custom mount. At 754 grams, the total weight of the tool approaches that of the first generation iPad, whose 3G-enabled configuration weighs 730 grams. Unfortunately, the off-center position of the Xperia's camera negatively affects the maneuverability of the device, making it feel heavier than an equally weighted, well-balanced tablet.

Component	Weight (grams)
DermLite FOTO with mount	431
ASUS TF201 with plate adapter	620
ASUS TF201 + DermLite FOTO + mount	**1051**
DermLite DL3	182
Sony Xperia Tablet Z with case and mount	572
Sony Xperia Tablet Z + DermLite DL3 + case + mount	**754**

Table 7: Weights of all components.

5.2 DATABASE

Data in MoleMapper is stored using SQLite [Res15b], a server-less, self-contained, transactional database that is part of the default Android framework. We chose to use a SQL-based database for two reasons. First, having a clean separation between code and data can be helpful when developing or debugging. SQL queries can be used to inspect the application's state at any time, and conditions under which issues occur can be more easily replicated. Second, the standard SQL layer on which the application is built allows for easy synchronization with remote servers. Ideally, most of the code that is used to access the local database can be used to access external ones, by simply modifying connection parameters.

5.2.1 Schema

The database schema is presented in Figure 34, in Crow's foot notation. Entities are represented as boxes, and relationships are represented as lines between the boxes. The notation uses different shapes at the ends of each line to represent cardinality, with maximum cardinality in a relationship shown closer to the respective entity, and minimum cardinality displayed on the inner labels. A summary of the possible cardinalities is shown on the top-right part of the image.

The two entities whose names start with the "Photo" prefix represent pictures. PhotoPortrait is the entity that represents a portrait picture that was taken in a specific visit, whereas PhotoLesion represents a dermatoscopic picture of a lesion, taken in a specific visit. Of particular note, the lesion entity is unrelated to visit, and it contains fields related to diagnosis. This is because we chose to anchor the representation of lesions in the database to their physical counterparts. Doctors evaluate lesions through pictures, they do not evaluate pictures themselves. In practice, this means that the most recent diagnosis a

dermatologist gives of a lesion is the only one that gets displayed. Interviews showed how doctors are not interested in the full history of past evaluations of lesions, but would rather prefer to only view the most recent diagnosis, if any.

As depicted in the schema, we chose to store images in files external to the database, and reference them using their file names. Benchmarks for SQLite showed that using external files to store binary content (such as images) larger than 100kb in size provides better read performance than storing that content in BLOB columns within the database [Res15a]. The file size of pictures taken with the tablet's camera ranges from 1MB to 2MB, and read performance for BLOB fields was shown to monotonically decrease with growing file size. This motivated our decision to use external storage without performing further measurements.

5.2.2 Access from the application

We decided to implement a Data Access Layer in the Android application to decouple data entities used in Java code from their representation in the SQL database. This way, whenever table definitions in SQLite need to change, the set of Java classes that need to be modified is limited to a specific package, which hides the lower-level details of storage from the rest of the application.

This intermediate layer, shown in the central portion of Figure 35, consists of classes from the `it.unipd.cis.db` package. A super interface called `IDataSource` declares methods to retrieve, update, and delete entries from a database table. Every entity in the data model is paired with an implementation of this interface, which provides the specific queries to be used when accessing data from SQLite. These accessor classes follow an `EntityName + "Source"` name format, so we have for example, a `LesionSource`, a `PhotoPortraitSource`, and a `PortraitSource`. Classes from the other subpackages of `it.unipd.cis` access the data layer through mediator entity classes, whose names match those of the database tables to which they provide access. As the diagram shows, these

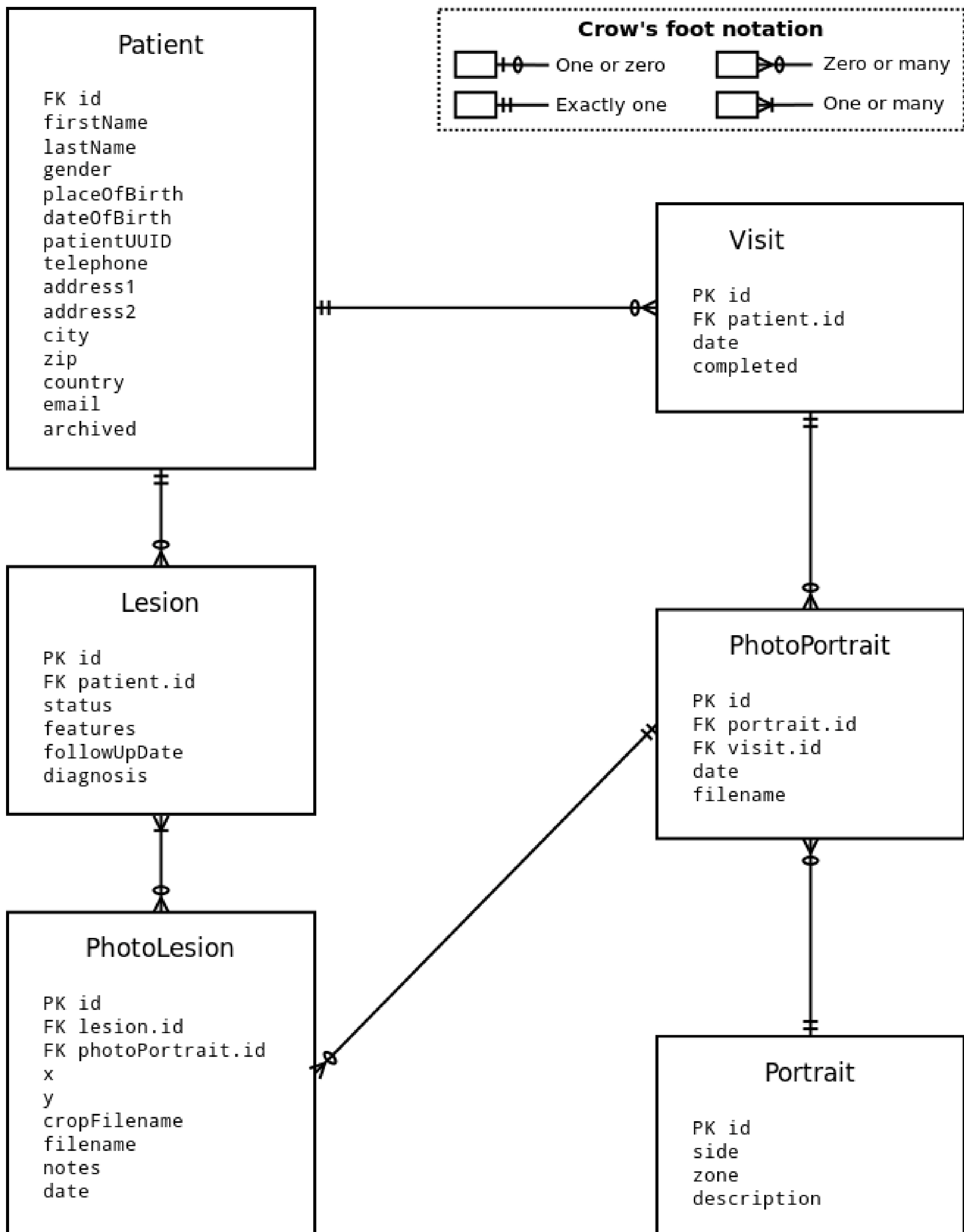

Figure 34: The database schema.

mediator classes use object composition to contact the database through their respective accessor classes, while hiding them from the requester outside of the package.

The database schema is dynamically generated by the application when it is first installed. Every entity class is paired with a `Contract` class named after it–for example, `Lesion` is paired with `LesionContract`, `Patient` is paired with `PatientContract`–that defines the translation between fields in the entity Java object and their equivalent columns in the database. A single class, called `SchemaManager`, controls whether the database schema needs to be defined, and uses information retrieved from the `Contract` classes to initialize it when needed. The `SchemaManager` class is also responsible for updating the tables definitions whenever needed. Its current implementation simplistically relies on executing SQL `ALTER TABLE` commands provided by the developer through external text files.

Future versions of `SchemaManager` may use more sophisticated ways to compare the existing table definitions with those dictated by the updated `Contract` classes, and could possibly make use of database versioning tools such as Liquibase [Vox15] or Flyway [Gmb15a]. These open-source libraries maintain dedicated metadata tables to automatically update the database schema definition. Whenever changes are needed, they can be communicated to the library through either Java calls or SQL commands. Every update is associated with a version number, so that it is always possible to migrate a database from an older schema to a more recent one, by simply applying all changes that were defined for the versions in between.

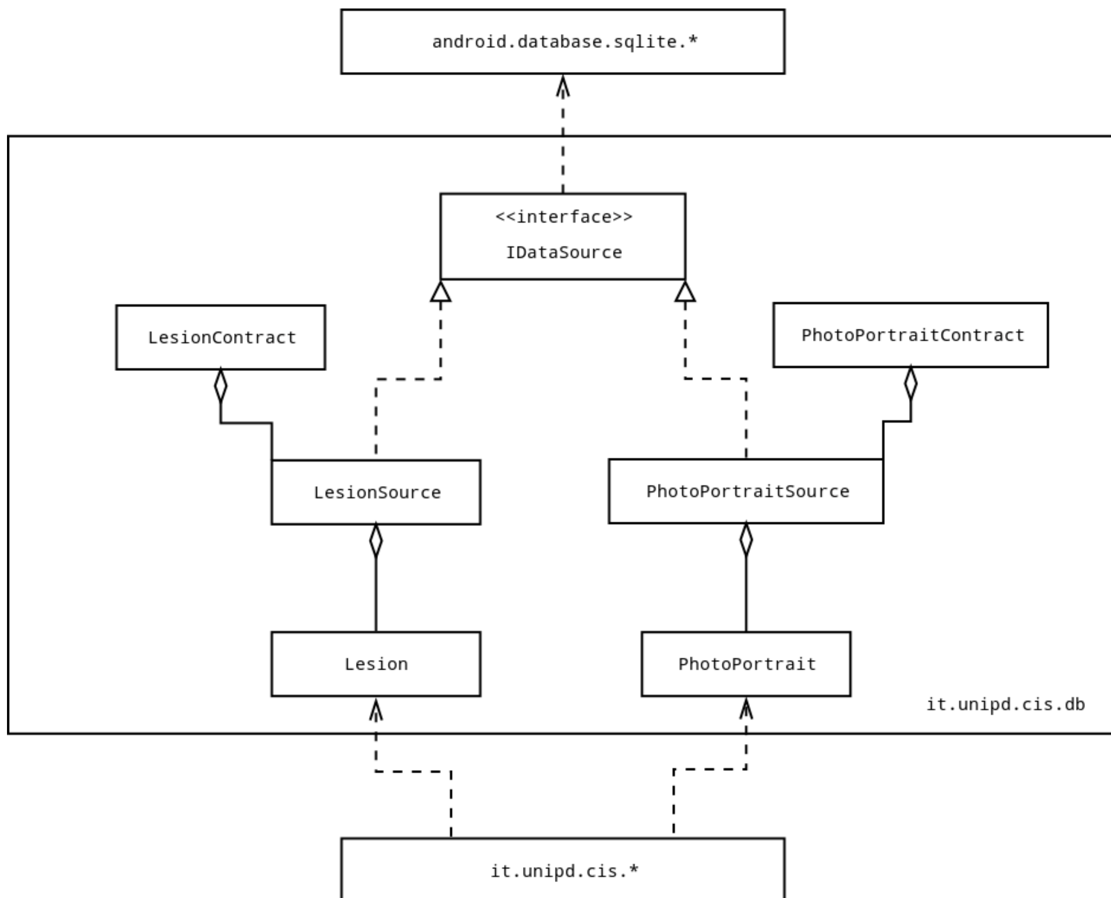

Figure 35: Diagram of implementation classes for the Data Access Layer.

5.3 CODE ORGANIZATION

What follows is a description of the code organization within MoleMapper, according to two different dimensions. Section 5.3.1 describes how classes are organized into packages, providing a quick reference for navigating the source code of the application. Section 5.3.2 analyzes how the two main types of components in the Android framework, activities and fragments, interact with each other in MoleMapper.

5.3.1 Package structure

In its most recent incarnation, MoleMapper is composed of 254 Java classes organized in 62 packages and subpackages. Instead of providing an extensive list containing descriptions of the role of every package, this section will only focus on packages at the higher levels of the hierarchy. The package hierarchy tree was purposely kept small, in order to facilitate navigation. The height of the tree is 4 levels.

The root package, used by the Android OS to identify the application, is called `it.unipd.cis`, following Java's `country.organization.project` naming convention. This package contains all activities for the application, which will be discussed in the next section. The root package also contains these subpackages:

- `adapters` contains adapters used by components in the UI. Adapters are classes that convert low-level representations of data, such as arrays, lists, or maps, into widgets that can be included in the UI. As an example, `AdapterListViewNaevi` converts lists of `PhotoLesion` items coming from the database into lists of widgets, each containing a dermatoscopic picture.
- `camera` contains classes that control the tablet's camera. Inside this package, `CameraPreview` and `CameraManager` are the two most notable classes.

The former displays the video feed coming from the device to the UI. The latter manages all parameters for the camera, such as image quality or auto-focus mode, and acquires pictures when the shutter is activated.

- `db` is the package described in the previous section, containing the Data Access Layer for the application. Every entity in the database is paired with a subpackage with a matching name (in plural form). For example, package `db.lesions` contains `Lesion`, `LesionSource`, and `LesionContract`, among the others.

- `fragments` contains all fragments used throughout the application. Fragments will be discussed in the next section, along with activities.

- `layout` contains MoleMapper's custom layout managers, such as `TabManager`, which is the class that manages switching between multiple tabs in the lesion and portrait screens.

- `opengl` contains code that uses the Open Graphics Library (OpenGL [sgi15]). MoleMapper uses OpenGL for high performance 2D graphics to maximize responsiveness when high-resolution pictures are on screen. For example, the `cameras.gesture` subpackage contains classes that interpret touch events when portrait or dermatoscopic pictures are shown. The phrase "Cameras", in this case, refers to OpenGL-specific language where a scene is rendered from the point of view of the camera.

- `util` contains utility classes used throughout the application, such as `FileManager`, a class that provides an abstraction over Android's file I/O system, or `BitmapWrapper`, a class that provides access to bitmap files, which automatically adjusts the sampling coefficient used by Android when loading the image, according to the amount of native memory currently available.

- `views` contains MoleMapper's custom views. Views are Android's basic building blocks for user interface components. For example, a `TextView` is used to display text to the user, and an `ImageView` is used to display im-

ages. Among the custom views, we can find for example `VerticalTextView`, or `ViewLesionComparison`, whose names are self-explanatory.

- `workflow` contains all classes that manage the application's workflow. These will be discussed in detail in Section 5.4.3.

5.3.2 Activities and fragments

Android applications are built on the concepts of activities and fragments. An activity is an application component that provides a screen with which users can interact. A fragment represents a behavior or a portion of user interface in an activity. Multiple fragments can be combined into a single activity, and they can be reused across different activities. Only one activity at the time is ever active in the system, whereas multiple fragments can be running in the foreground at the same time. Activities define the layout of every screen by either loading definitions from static XML files that follow an Android-specific format, or by dynamic generation through Java calls. Fragments define their own layout, which is included in the parent activity's layout. Fragments were introduced in Android 3.0. They provided several benefits, such as allowing developers to create modular and reusable activity components, supporting flexible UI designs on tablet screens, and helping to minimize code duplication in applications.

Activities and fragments are also involved in defining the behavior of an application. Figure 36 describes the *activity lifecycle*, which rules the interaction between the OS and the application. Gray rectangles contain methods declared in `android.app.Activity`, which is the base class for all activities in an application. Subclasses can override each of these methods to provide code to be executed on activity state transitions, which are shown as arrows in the image. The application's entry point is, therefore, represented by the `onCreate()` method of one of its activities, depending on which was launched. Applications can, in fact, declare multiple launcher activities in their `AndroidManifest.xml` files,

which is parsed by the OS at installation time. Fragments follow a similar life-cycle, which includes 4 additional methods that are triggered by callbacks in the parent activity. For a more in-depth description of the life cycle of fragments, please refer to the Android specification [Inc15d].

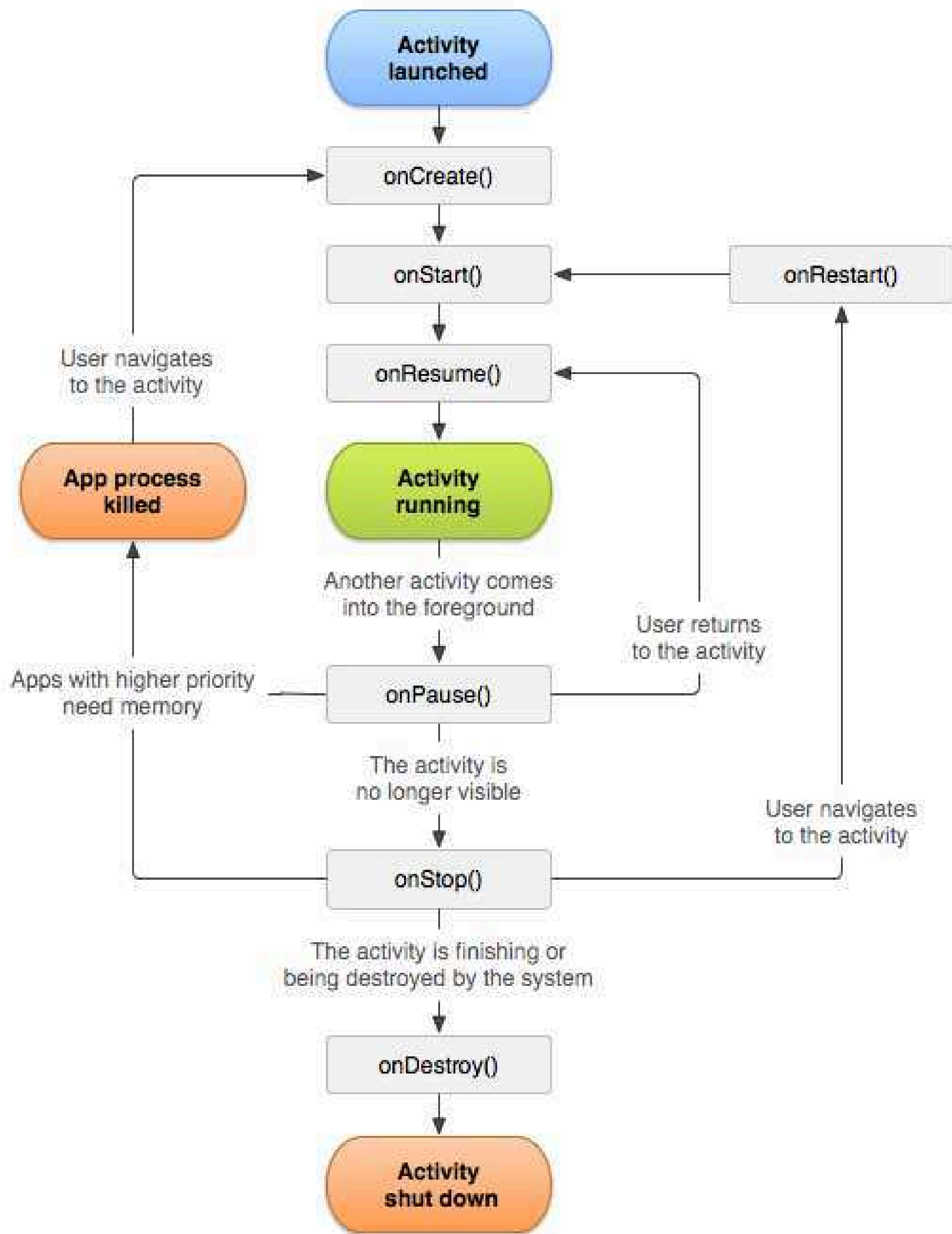

Figure 36: Android's activity lifecycle, as illustrated in the Android API Guides available at `http://developer.android.com/guide/components/activities.html`.

Activities

Every screen in MoleMapper is defined by an activity whose class name begins with the "Act" prefix. Because most XML files use fully qualified package names when referencing activities, we chose against creating a dedicated `activities` package, and we dropped the naming convention of using the full "Activity" prefix in favor of the shorter, 3-letter one.

The following list contains a brief description of MoleMapper's activities. Since activities are implementations of the screens described in Section 4.4, every item in the list contains a reference to the (capitalized) screen name that was used in that context.

- `ActHome` – implementation of the Home screen. From this screen, users can either access data about recent visits, or start a new one. Additionally, they can access the settings page for the application
- `ActPreference` – contains application-level settings. Following a standard pattern common to most Android applications, settings can always be accessed via the context menu on the top right of the screen. The class extends `android.preference.PreferenceActivity`, a subclass of `Activity`, which is Android's base implementation for activities that show a hierarchy of preferences to the user.
- `ActPatient` – implementation of the Patients screen. From this screen, users can search for patients, and access their records from the database.
- `ActVisit` – implementation of the visit screen. The activity's layout contains 2 tabs, providing an overview of the current progress of the visit in taking portrait and dermatoscopic pictures, respectively.
- `ActPortrait` – implementation of the portrait screen. The activity's layout contains 3 tabs, used to take, mark, and side-by-side compare portrait pictures, respectively.

- `ActLesion` – implementation of the dermatoscopic screen. The activity's layout contains 3 tabs, used to take, evaluate, and side-by-side compare pictures, respectively.
- `ActReport` – implementation of the visit screen's Report and dermatoscopic overview sections. In the first version of MoleMapper, the content of this activity was stored in tabs of the visit screen. During supervised tests, all dermatologists reported that the position of the Report tab made it poorly accessible. Doctors expected to find a dedicated screen containing a summary of the visit, and were confused by seeing it displayed as a tab. We therefore moved the Report tab to an activity that follows the lesion screen in the workflow. The new position of the Report received positive feedback in the following rounds of supervised tests, and was therefore kept in all versions thereafter.

Fragments

All fragments in the application are stored in the `it.unipd.cis.fragments` package, and for the same considerations that were discussed for activities, their class names begin with the compressed "`Frg`" prefix. MoleMapper's UI uses fragments in two ways. They're either used as aggregators of views that can be reused by different activities, or as containers for other fragments. For example, every tab in MoleMapper is implemented as a container fragment that is dynamically replaced with another one when the associated tab selector changes state.

The following list contains a description of the fragments used in the application.

FrgCamera, FrgPortraitCamera, and FrgLesionCamera

`FrgCamera` is the base class containing code that is shared between its two subclasses: `FrgPortraitCamera` and `FrgLesionCamera`. These two fragments are used as the leftmost tab in `ActPortrait` and `ActLesion`, respectively, and guide the user in taking full-scale, or dermatoscopic pictures. The parent class contains methods to manage the image acquisition process, which includes: (1) showing the user a grayscale version of the latest available picture of the same area, to facilitate alignment for the new shot, (2) displaying the camera's video feed with the outline of the previous picture overlaid, and (3) after the picture is taken, displaying it while giving the user the option to take another. The subclasses define the location of saved files, and update the database using classes from the `it.unipd.cis.db` package.

Figure 37 shows the state of `FrgPortraitCamera` before the user taps on the shutter button. On the top-right, indications on how the portrait should be aligned are provided (in this case, the portrait's top border must be aligned above the patient's shoulder line, and the bottom must be aligned above the

patient's elbows). The most recent picture available for the region is displayed in grayscale to highlight that it was taken in a previous visit.

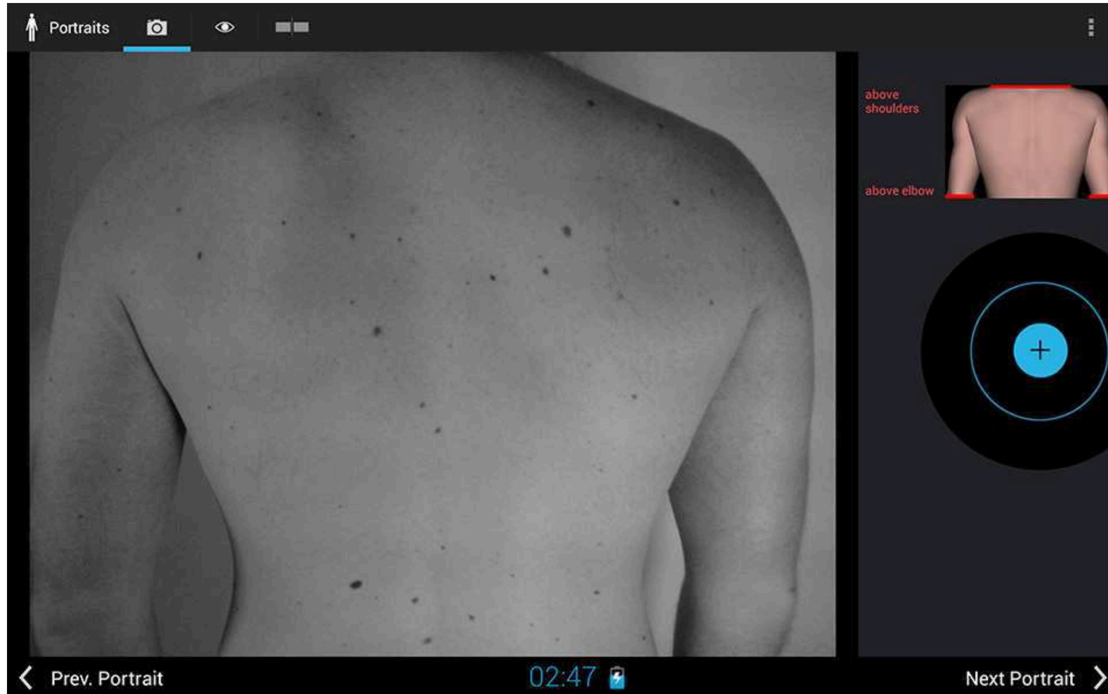

Figure 37: `FrgPortraitCamera` before a new portrait picture is taken.

FrgPortraitManikin

`FrgPortraitManikin` is the fragment that implements contextual navigation. Shown on the left side of Figure 38, this fragment contains clickable regions shaped after the subdivisions of the body into portraits. Swiping horizontally changes the displayed pose among the 4 available (front, back, left, and right). Clicking on any region takes the user to a screen that is defined by the parent fragment containing `FrgPortraitManikin` through a callback function. This fragment executes the callback, passing it the id of the selected region as parameter. The callback is then responsible to load the appropriate screen.

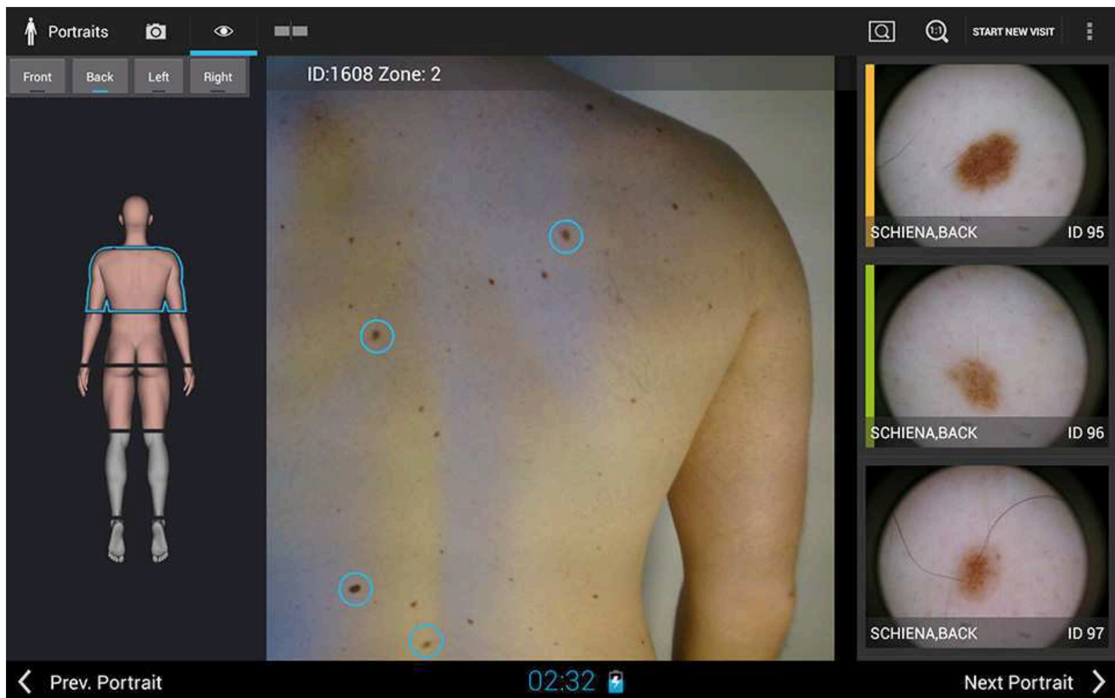

Figure 38: Contextual navigation for portraits. On the left, `FrgPortraitManikin`.

FrgPortraitMark

`FrgPortraitMark` is the central tab in `ActPortrait`, and is used to mark interesting lesions in a portrait, so that they can be photographed with the dermatoscope later. The fragment can be seen in Figure 39. Whenever users tap on the portrait, a circle appears around the touched point, and an entry is added to the rightmost list, which contains all lesions marked for the current portrait. The new entry is shown using a clipping of the portrait picture as preview, and can be deleted by clicking a semi-transparent "X"-labeled button on its top right. Contrary to the initial design, we decided to show circles around lesions even in previews, so that ambiguous cases involving neighboring lesions can be easily solved by looking at the circle's center. Whenever a dermatoscopic picture of the marked lesion is available, it is used as preview. For example, in Figure 39, the three dermatoscopic pictures on the right are mapped to the portrait picture. Tapping on entries from the list on the right of the screen makes the corresponding marker highlighted.

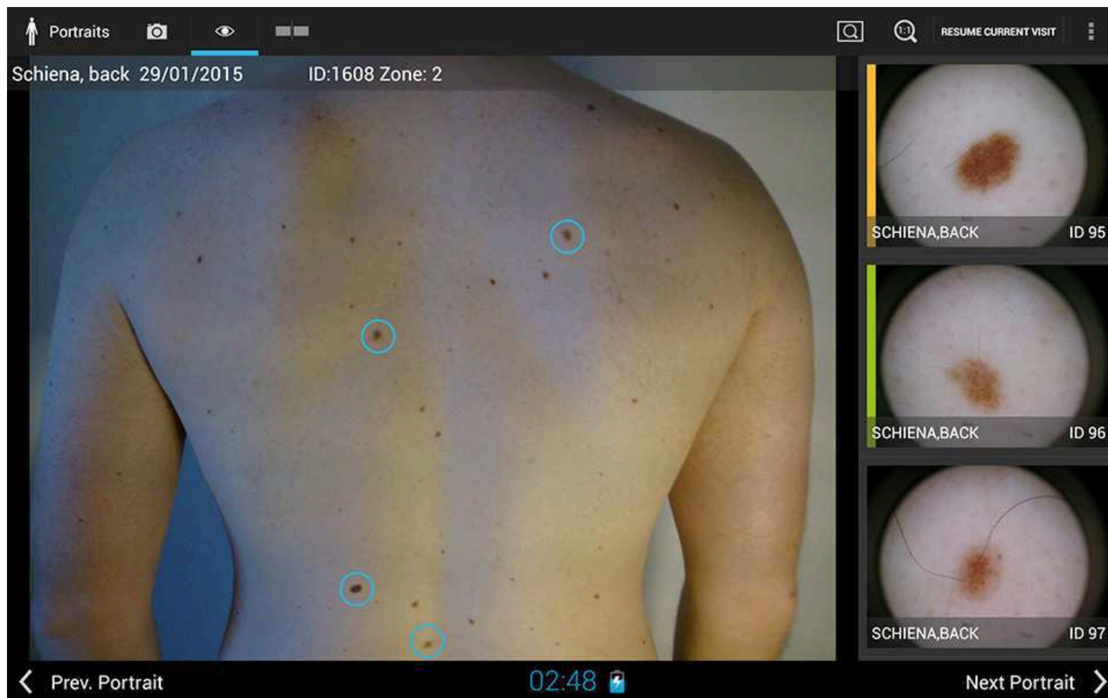

Figure 39: `FrgPortraitMark` shown after dermatoscopic pictures were taken.

FrgLesionDetail

`FrgLesionDetail` is the central tab in `ActLesion`, and is used to evaluate all lesions in a portrait. The fragment faithfully reproduces the original design, and includes a new experimental feature, which may not be part of future versions of MoleMapper. A 3-dimensional representation of dermatoscopic pictures can be accessed by pressing the "3D"-labeled button in the top-right menu. An example of this view in action can be seen in Figure 40. The Z-axis denotes intensity of a given pixel's red component, using its RGB color value. This way, darker lesions appear as elevated zones that stand out against the level ground represented by the lighter healthy skin. This visualization originated as a byproduct of the development team's experiments with OpenGL, but it was kept as part of the application by user request. However, although the red component of a dermatoscopic picture is often useful in detecting melanoma, it needs to be evaluated in relation to the associated green and blue values, and not in isolation [SMVS+03; SGS+05].

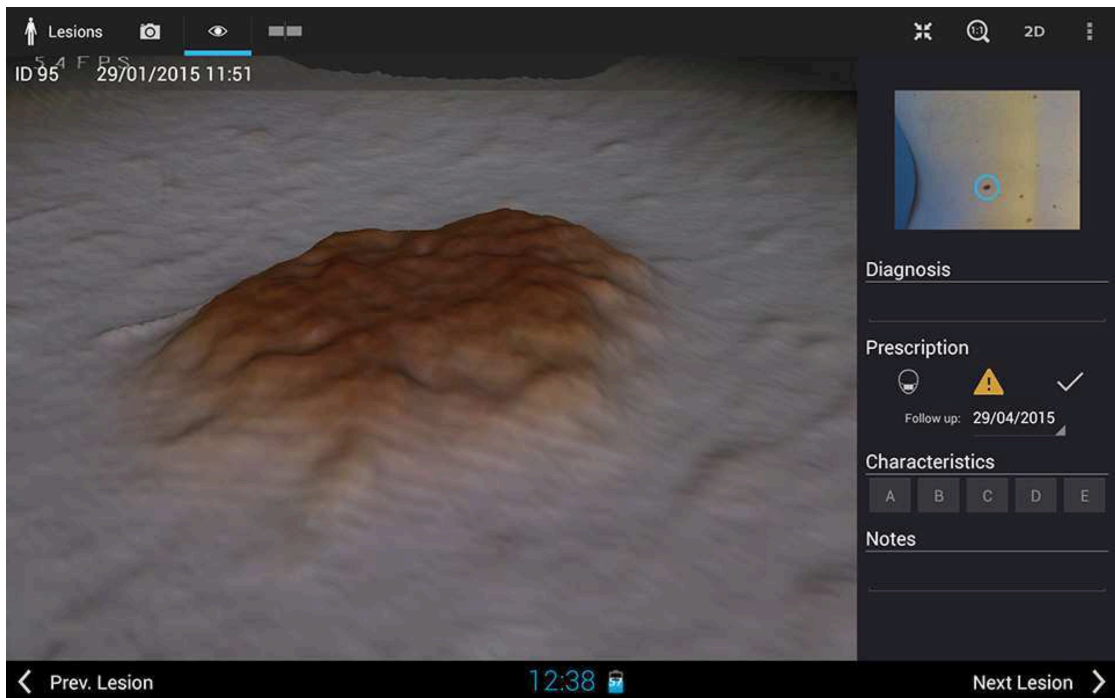

Figure 40: 3D view of a dermatoscopic picture shown in fullscreen mode.

FrgPortraitComparison and FrgLesionComparison

`FrgPortraitComparison` and `FrgLesionComparison` are used as the rightmost tab in `ActPortrait` and `ActLesion`, respectively. These fragments show two pictures side-by-side, and let users pan, zoom, and rotate the views using a novel interaction that deviates from the original design.

The first implementation of the comparison screen used an external toggle button to lock the two views together, so that moving, scaling, or rotating either of the two pictures would apply the same transformation to the other. We tested the interaction by having all team members try to align pairs of pictures of the same portrait that were purposely taken at different distances and angles. The solution worked, but all testers found the constant mode switch between locked and unlocked views tedious. However, we noticed a recurring pattern in how we aligned pictures: most of the times, one of the two pictures was used as reference, and we would only move it when the two

views were locked. Hence, we designed an alternative solution that exploits this pattern.

In the current implementation, shown for `FrgLesionComparison` in Figure 41, there is no toggle button to lock the two views together. Controlling the image on the left simultaneously applies the changes to both, whereas moving the image on the right only affects that image. The team tested the new interaction, and found it more effective. At the same time, we dedicated particular attention to feedback from the dermatologists about this non-standard solution, which will be discussed in the next Chapter.

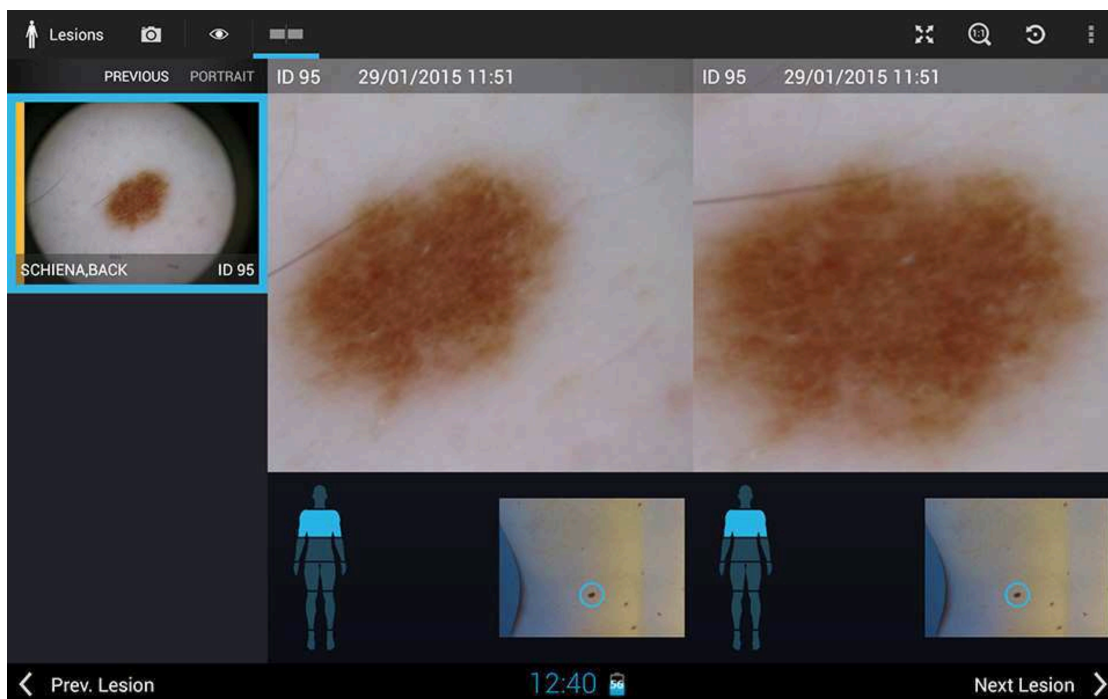

Figure 41: `FrgLesionComparison` in action.

FrgPortraitRemap

`FrgPortraitRemap`, visible in Figure 42, is used to map lesions marked in previous versions of a portrait to their exact positions in the most recent picture. Whenever MoleMapper detects lesions marked for follow-up from the previous visit, it warns the user by adding a warning sign to the header of the new

portrait, containing the number of lesions that need to be remapped. Tapping on the warning sign, or on the "REMAP" button in the top-right menu, replaces the currently displayed `FrgPortraitMark` with a `FrgPortraitRemap`.

In the first design, press-and-hold was used to select markers in the picture on the right. This action conformed with the "data selection" metaphor included in the Android interaction design pattern manual [Inc15e]. Once selected, markers could be dragged to a new position. Lifting the finger from the tablet's surface would confirm the new position for the marker. The left-hand side picture could only be used as an uneditable reference, so touching its markers would not trigger any action.

Supervised tests showed that this approach performs poorly in practice. This happened for two reasons: (1) whenever two or more lesions need to be remapped–which, according to dermatologists, is likely to happen in practice–, the slowness of the press-and-hold gesture makes remapping a time-consuming operation, and (2) press-and-hold is not self-discoverable. Users tried to move markers by simply dragging them without waiting, which triggered panning instead. Furthermore, doctors reported that there are cases in which they may not want to remap all lesions from the previous portrait picture. Such cases can occur when, for example, a lesion was excised, or a different doctor marked a lesion that the current one does not find suspicious. With the original implementation, users would have needed to first remap all lesions, and remove them from the portrait in a following phase.

The design of the comparison fragments inspired the new interaction. The left picture maintains a one-to-one mapping to the right. Panning or zooming it results in the same transformation being applied to the picture on the right. All markers from the reference picture are replicated on the other, and are initially shown in black. Users can select which lesions need to be remapped by touching their markers on the left, which results in the corresponding marker on the right picture to become blue. When a marker is selected, it can be repositioned by dragging it with one finger. A button in the top-right menu labeled "MAP ALL" lets users select all lesions from the reference picture for

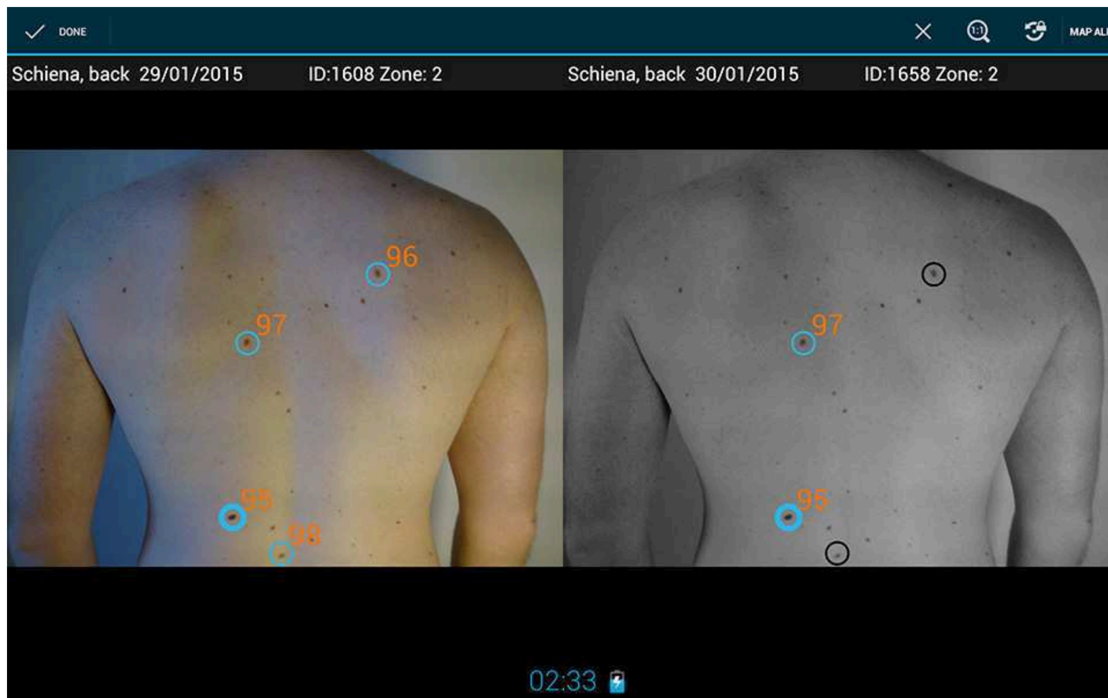

Figure 42: `FrgPortraitRemap` in action.

remap, so that fewer clicks are needed in case all lesions must be remapped. Users can remove a lesion from the selection by tapping on its marker on the left-hand side picture. As an example, in order to select 7 lesions out of 8 for remap, users must (1) click "MAP ALL", which makes all markers on the right-hand side image turn blue, and then (2) tap on the lesion to be excluded on the left-hand side image, which makes the corresponding marker on the right turn black, leaving the other 7 highlighted in blue.

FrgPortraitSummary

`FrgPortraitSummary` shows the current progress of a visit in terms of portrait pictures taken. As Figure 43 shows, regions can be in one of 3 states, according to whether they were photographed in the current visit (region displayed as fully saturated), photographed in the previous visit but not in the current (shown with 50% saturation), or never photographed (shown in grayscale).

Tapping on any region takes the user to the corresponding `FrgPortraitSummary` fragment.

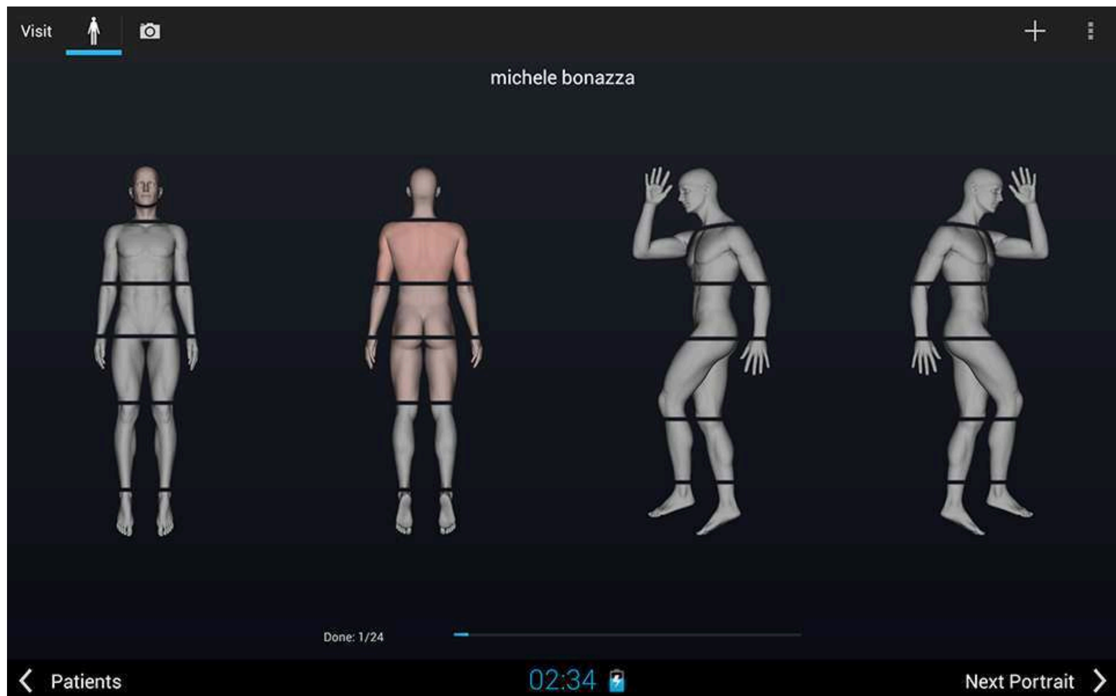

Figure 43: `FrgPortraitSummary`. Every region in the four manikins is colored according to the availability of a photograph for it.

FrgLesionSummary

`FrgLesionSummary` shows the current progress of a visit in terms of dermatoscopic pictures taken and lesions evaluated. Depicted in Figure 44, the fragment contains all lesions that need to be analyzed in the ongoing visit, grouped by lesion state. Color coding is used to label the four lists: red for lesions that need to be excised, yellow for lesions in follow-up, green for benign lesions, and dark gray for lesions that have not been evaluated. Lesions for which a dermatoscopic picture is not available are shown using a clipped version of the portrait photograph in which they appear.

After supervised tests, we added the option to delete lesions from the current visit directly from this screen. Doctors used the overview to apply the ugly

duckling principle, and made decisions accordingly. On occasion, they would need to remove entire groups of lesions that presented the same uncommon feature because they deemed the possibility of all being melanomas unlikely. Since these lesions can and likely do appear in different parts of the body, discarding them directly from `FrgLesionSummary` saves users from navigating to all the affected portraits, increasing the theoretical efficiency of dermatologists.

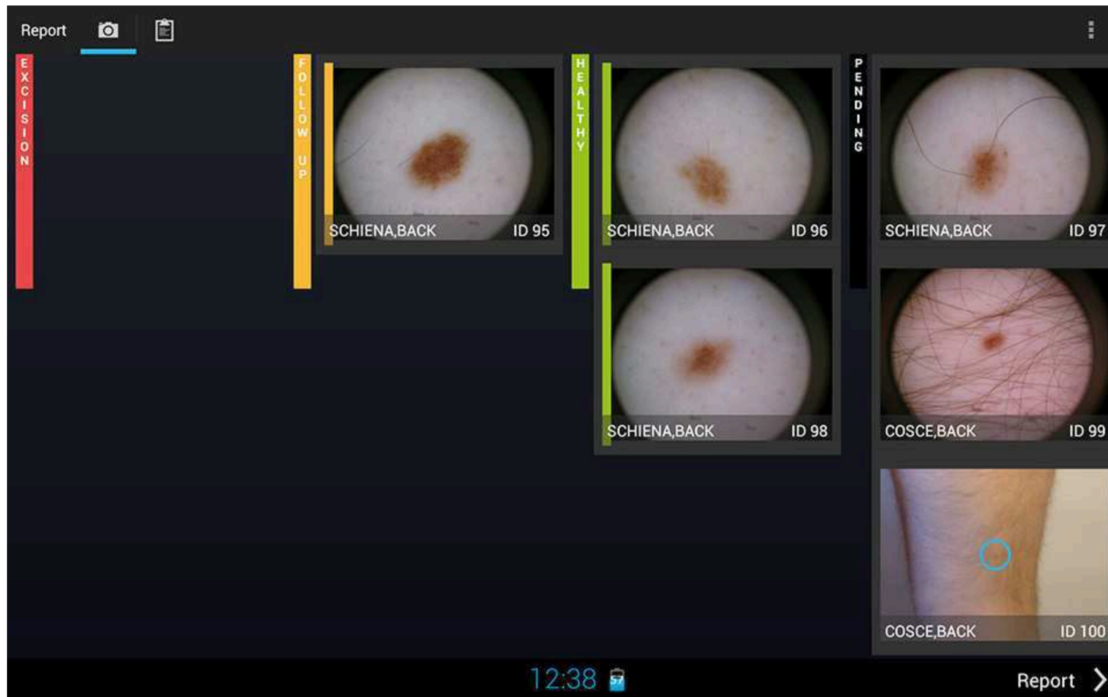

Figure 44: `FrgLesionSummary`. Dermatoscopic pictures are grouped according to lesion state.

FrgVisitReport

`FrgVisitReport` is used when producing the report that a patient receives at the end of every visit, and is depicted in Figure 45. The fragment closely matches the original visit-report screen design, with an additional feature. Tapping on any of the images shown on the report takes the user to the associated `FrgPortraitMark` or `FrgLesionDetail`, according to the type of image that was selected.

This new feature was introduced because we noticed that doctors would sometimes use reports from previous visits as quick summaries of the patient's status. When they encountered lesions that they found particularly interesting, they would use the displayed information to navigate to the appropriate screen, which was time-consuming. The updated version of the `FrgVisitReport` fragment allows them to accomplish their goal in one click.

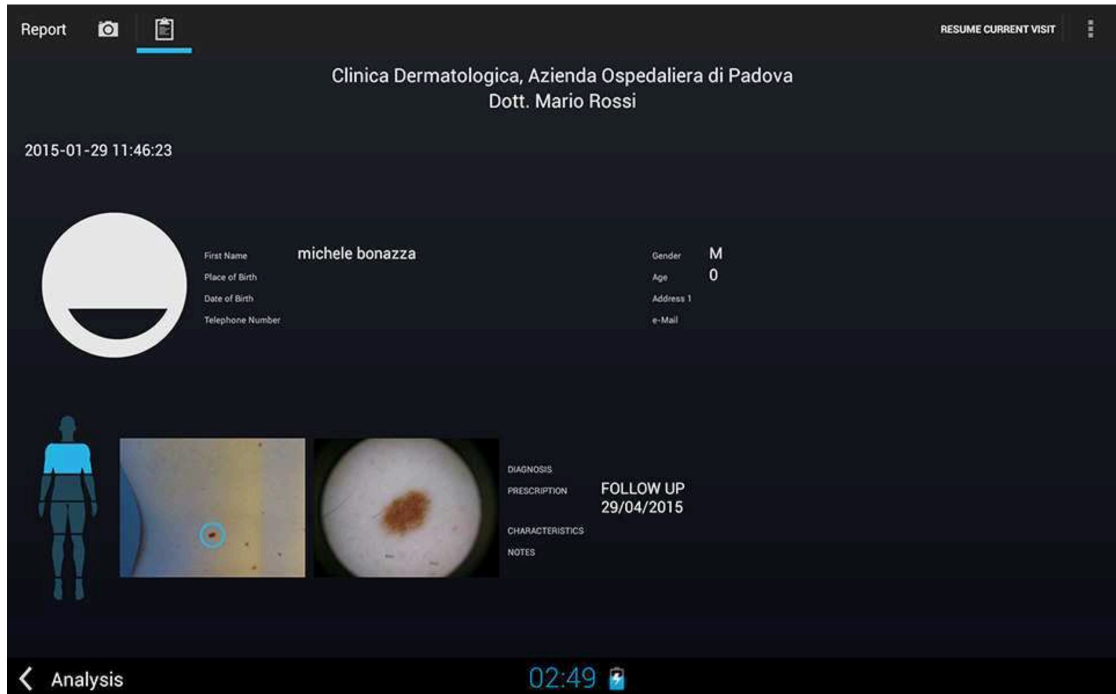

Figure 45: `FrgVisitReport`. Details of the patient were hidden using a photo editor.

5.4 IMPLEMENTATION OF COMPONENTS

This section presents the non-trivial code design choices that we made while implementing MoleMapper. In many cases, the existing Android architecture did non provide an out-of-box solution, leading to the need to invent new algorithms, or overcome limitations of the Android API. This section explains how we overcame those challenges.

5.4.1 Image processing

Since image processing is a topic that requires a level of in-depth analysis that falls outside the scope of this dissertation, this subsection will only provide a brief description of the goals of the algorithms that were implemented, and will state how they are used in MoleMapper. For a more detailed description of these algorithms, please refer to [Per15]. We designed algorithms for edge detection, digital hair removal, and image segmentation and registration.

Edge detection is used to create an outline of the most recent picture available for a portrait, which is overlaid on top of the camera video feed to help dermatologists align newly taken pictures. Stronger edges, such as those of the subject's outline against the background, are displayed with thicker lines.

Digital hair removal is a technique used by MoleMapper to replace body hair in dermatoscopic pictures with estimates of the underlying occluded skin. The resulting images are almost indistinguishable from those of hair-free skin [FPS11], and help dermatologists focus on the lesion by removing the distraction represented by the presence of hair.

Image segmentation is a process that partitions pixels in a picture into contiguous regions, called segments. We developed MEDS [PBB+13b; PBB+13a], an image segmentation algorithm that identifies the shape of melanocytic lesions. It does so by defining two sets of pixels in each dermatoscopic picture,

one for the lesion and one for the surrounding healthy skin. Once the outline of a lesion is defined, it can be compared with its previous ones in order to detect dangerous changes in shape or size.

Image registration is needed to perform comparisons between dermatoscopic pictures and provides a coordinate system to align different pictures of the same subject against a shared frame of reference. Registration depends on segmentation, as pictures of a lesion are aligned according to the outline of the lesion itself, which is the output of our segmentation algorithm.

5.4.2 Status bar

MoleMapper's UI is based on the Wizard design pattern, as mentioned in Section 4.3.1. The pattern requires users to click on buttons labeled "Next" and "Previous" to navigate through the application's screens. As mockups showed, we chose to place these buttons in a horizontal navigation bar at the bottom of the screen. Unfortunately, Android does not let applications change the content of its system navigation bar, which is positioned at the bottom of the screen. This led to the need to replace the navigation bar with our own layout.

The Android system did not provide a reliable method to hide the navigation bar. Android 4.0 introduced a flag called `SYSTEM_UI_FLAG_HIDE_NAVIGATION` which can be programmatically set to hide the default navigation bar. However, as soon as a touch event is detected, the navigation bar is restored, which makes the flag useless for MoleMapper. Starting with Android 4.4, applications can use the whole screen surface by setting the `SYSTEM_UI_FLAG_IMMERSIVE` flag. Android 4.4 was released in November 2013, and has only been available for the Xperia Tablet Z since September 2014. At the time of writing, it is still not available for the ASUS Transformer Prime. Hence, we needed to implement a custom solution to overcome this issue.

The only (undocumented) way to hide Android's navigation bar in versions prior to 4.4 is to kill a system service, which can only be done for "rooted" devices. A device is said to be rooted when its applications can be executed with administrative privileges, thus giving them "root access" to the Linux kernel on which Android is based. Sony and ASUS officially provide instructions on how to enable administrator access on their devices, at the cost of potentially voiding their warranty [Son15; ASU15].

MoleMapper hides the navigation bar upon application launch, and restores it when terminated. To achieve this, we defined `it.unipd.cis.CiS`, a subclass of `android.app.Application` that overrides its parent's `onCreate()` method, so that the `updateStatusBarVisibility()` method shown in Listing 1 is called. The method uses the `service` command-line utility to stop the `com.android.systemui` activity, and hide the navigation bar. To restore it, the method uses Android's activity manager command-line utility (`am`) to start the UI service again.

Listing 1: Excerpt from CiS.java

```java
public static final String[] SHOW_STATUSBAR_CMD = new String[] { "am",
    "startservice", "-n", "com.android.systemui/.SystemUIService" };

// code omitted

private void updateStatusBarVisibility(boolean isVisible) {
  if (isVisible == statusBarVisible)
    return;
  Process proc;
  try {
    if (isVisible) {
      proc = Runtime.getRuntime().exec(SHOW_STATUSBAR_CMD);
    } else {
      pid = PID_HONEYCOMB_AND_OLDER;
      if (VERSION.SDK_INT >= VERSION_CODES.ICE_CREAM_SANDWICH) {
        pid = PID_ICS_AND_NEWER;
      }
      proc = Runtime.getRuntime().exec(
          new String[] { "su", "-c",
              "service call activity " + pid + " s16 com.android.systemui" });
    }
    proc.waitFor();
    statusBarVisible = isVisible;
  } catch (IOException e) {
    Log.w("system", "can't hide status bar");
  } catch (InterruptedException e) {
    Toast
        .makeText(getApplicationContext(), e.getMessage(), Toast.LENGTH_LONG)
        .show();
    e.printStackTrace();
  }
}
```

Aside from the navigation buttons, our custom bottom bar layout includes two widgets. A clock widget, which is simply a `TextView` whose content is updated every minute through a `java.util.Timer`, and a battery widget. The current charge level is shown using the default battery icon, which is part of the image library available to Android applications. MoleMapper registers a `BroadcastReceiver` to receive events regarding the battery status broadcast by the OS, and changes the icon according to the type of event that was received. Android broadcasts an event every time the battery is either charged or discharged by 1%, or is attached or detached from a charger.

5.4.3 Layout management

All activities in MoleMapper share a part of their layout: the status bar described in Section 5.4.2. Hence, we decided to create a base class called `CisActivity` from which all activities in MoleMapper derive. This class also contains methods that manage the transition between activities. As an example, a connection with the SQLite database needs to be established when activities start, and it needs to be closed when they terminate. The parent class has code that operates these transactions when the OS calls its `onPause()` and `onResume()` methods.

Further, `CisActivity` controls other parts of the layout that are shared among its subclasses. These include the tab selector in the top bar, the "Now loading" dialogs displayed when activities take longer than half a second to load, the contextual navigation panel, and the transparent active regions at the lateral edges of the tablet that trigger workflow stepping on swipe. Subclasses communicate which of these parts need to be managed by the parent class by implementing *marker* interfaces. An interface in Java is called marker whenever it does not declare any method, and classes implementing it are associated with a behavior simply by virtue of including it in their class declaration. A classic example is the `Serializable` interface: objects in Java can be serialized if their class implements `Serializable`, which does not contain any

method. Therefore, in MoleMapper, an activity that uses tabs will implement the `Tabbed` interface, whereas one that can take a long time to load will implement `LongLoading`. An activity that uses swipes to move in the workflow will implement `Steppable`, while one activity that contains the contextual navigation panel will implement `WithCollapsiblePanel`. When `onCreate()` is called, the parent class checks which of the markers are implemented by the subclass through a sequence of `instanceof` calls, and decorates the layout accordingly.

5.4.4 Workflow

From its inception, MoleMapper was designed to allow for quick changes to the workflow it enforces. Our plan was to iteratively adjust the order of its steps to incorporate feedback from the dermatologists as they used the tool. With this goal in mind, we implemented a solution that lets developers change the workflow of the application by editing a single class.

First, we defined the `State` enumeration, which lists all possible steps in a workflow, and maps them to the activity that implements them. Listing 2 shows the definition of the first 5 states. With the exclusion of the `SHUTDOWN` state, which is an artificial step that is used to save the state of the application and restore the system navigation bar upon termination, all states provide a link to the activity class of reference, and two IDs of *resource strings*. A resource string is a sequence of characters stored in a file named `strings.xml` which is made accessible at compile time by the Android pre-processor. In this case, the first reference is to the string to be used in labels for buttons pointing to the state, such as "Next Portrait" or "Previous Lesion". The second is the string to be used as title for the state's screen, such as "Portraits" or "Lesions".

Listing 2: Excerpt from Workflow.java

```
public static enum State implements WorkflowState<State> {
  /**
    * The null state that is used as a placeholder to indicate that an
    * activity's previous state is the shutdown state.
    */
  SHUTDOWN(null, -1, -1),
  /**
    * The home screen, the first screen displayed when the application is
    * loaded. Currently the same as {@link ActHome}.
    */
  HOME(ActHome.class, R.string.workflow_home_label, R.string.title_activity_home),
  /**
    * The screen where all patients are listed and can be searched for.
    * Currently the same as {@link ActPatient}.
    */
  PATIENTS(ActPatient.class, R.string.workflow_patients_label,
      R.string.title_activity_act_patients),
  /**
    * The screen where a picture of a 1X-zoom portrait can be taken. Currently
    * the same as {@link FrgPortraitCamera}, a fragment inside
    * {@link ActPortrait}.
    */
  PORTRAIT_CAMERA(ActPortrait.class, R.string.workflow_portrait_camera_label,
      R.string.title_activity_act_portraits_camera),
  /**
    * The screen where lesions marked on a previous portrait can be mapped to a
    * new picture of the same area. Currently the same as
    * {@link FrgPortraitReMap}, a fragment within {@link ActPortrait}.
    */
  PORTRAIT_MAP(ActPortrait.class, R.string.workflow_portrait_map_label,
      R.string.title_activity_act_portraits_map),
```

`CisActivity` makes use of this mapping between workflow steps and activities to provide a method for changing the current screen in the application. The method, called `changeScreenTo()`, has two signatures: one accepts a `State` as argument, while the other accepts a `Condition`. Cases exist in which the following step in the workflow is not uniquely defined. For example, since users can move between screens with the contextual navigation panel to quickly jump to a specific portrait, the step that follows taking a picture of the last portrait in the sequence depends on whether all other pictures were already taken. In these cases, `changeScreenTo()` can be passed a `Condition`, which is an inter-

face that declares a single method, `getNextState()`, that returns the state to be shown next, according to some custom logic.

As Listing 3 shows, workflows can be defined by connecting states through a sequence of `setPrevious()/setNext()` method calls, letting developers provide custom logic for resolving ambiguous cases. The simplicity of this class suggests that a graphical tool could be developed to re-arrange steps in a workflow, which could be given to end-users to let them customize their process. However, we have not investigated this option at this stage, so it is left as future work.

Listing 3: Excerpt from PrototypeWorkflow.java

```
/*
 * (non-Javadoc)
 * @see it.unipd.cis.prototype.workflow.Workflow#updateStatesMap()
 */
@Override
public void updateStatesMap() {
  State.HOME.setPrevious(State.SHUTDOWN);
  State.HOME.setNext(State.PATIENTS);

  State.PATIENTS.setPrevious(State.HOME);
  State.PATIENTS.setNextCondition(Condition.PATIENT_SELECTED_CONDITION);

  State.VISIT_PORTRAIT.setPrevious(State.PATIENTS);
  State.VISIT_PORTRAIT.setNextCondition(Condition.PORTRAIT_TAB_CONDITION);

  State.PORTRAIT_CAMERA
      .setPreviousCondition(Condition.PORTRAIT_TAB_CONDITION);
  State.PORTRAIT_CAMERA.setNextCondition(Condition.PORTRAIT_TAB_CONDITION);

  State.PORTRAIT_MARK.setPreviousCondition(Condition.PORTRAIT_TAB_CONDITION);
  State.PORTRAIT_MARK.setNextCondition(Condition.PORTRAIT_TAB_CONDITION);
```

6 EVALUATION

In the previous chapter, we presented the details of how MoleMapper was built, and the implementation choices made when building it. This Android application includes the lessons learned from our interviews with dermatologists in Chapter 2, and provides an interface that encourages a consistent workflow for its users, automating many of the required steps. In this chapter, we present an evaluation of the MoleMapper Android application in the form of a case-study.

Given the ambitious goal of attempting to improve the way that dermatologists work and the investment required of doctors to participate in the study, we chose to perform a longitudinal case-study to evaluate the tool. The application targets a specialized audience, and is intended to help guide the workflow of professionals in their daily practice. For this reason, gathering enough dermatologists to form a sample size useful for quantitative analysis is a challenging task. We chose to perform a case-study involving 5 dermatologists in which we trained the doctors in the usage of the tool, asked them to use it in their daily practice, and collected their feedback over a several month period. The small sample size of doctors allowed us to personally respond to questions that they had about MoleMapper, or to administer emergency technical support in the rare cases that MoleMapper did not behave according to expectations. From that, we received personal accounts from the doctors about the effectiveness of MoleMapper in encounters with patients, and received insight that would help us answer our research hypothesis.

The rest of the chapter is organized as follows: Section 6.1 describes how we collected and analyzed data about usage of the application. Section 6.2 presents the data that we gathered through interviews. Lastly, Section 6.3

discusses the results and proposes potential solutions to the issues that were highlighted.

6.1 METHOD

We evaluated MoleMapper in two different settings, both taking place at the Dermatology Clinic of the University of Padova. All participants received training in the form of a one-hour presentation of the tool in a classroom setting, followed by a demonstration of a complete mole mapping visit performed using the application. Additionally, each doctor was paired with a member of the development team to perform two assisted mock visits to familiarize with the interface.

The first setting consisted of a total of 15 mole mapping visits performed by 3 dermatologists in a supervised environment. One developer played the part of the patient, while another took notes of the behaviors he observed, and of the considerations voiced by the doctor. Because of scheduling constraints, neither of the two rooms in the clinic dedicated to mole mapping could be used for the experiments. Visits took place in a third room having an identical layout. All participants were female, and included the following: a professor with several years of mole mapping experience, a dermatologist with one year of mole mapping experience, and a recently graduated dermatologist with six months of mole mapping experience. The tablet used to execute MoleMapper was the ASUS Transformer Prime.

The second setting involved 2 dermatologists conducting a total of 87 visits on 16 patients. MoleMapper was used in the context of an experimental study that involves monitoring patients every two weeks to collect detailed data on the variability of skin lesions. Visits took place in the same environment that regular mole mapping visits do. Two female dermatologists were involved, one having two years of mole mapping experience, and the other having one year

of experience. The tablet used to execute MoleMapper was the Sony Xperia Tablet Z.

6.1.1 Data collection and analysis

We conducted semi-structured interviews with dermatologists at the end of each study. We started each interview by asking doctors about their perceived the usefulness of MoleMapper, and if they felt comfortable in following the workflow it enforces. We would then ask questions about the subdivision of the patient's body used by the application, focusing on the ergonomic factors involved, such as the feasibility of taking the proposed portrait pictures, and the comfort of the patient in assuming the proposed poses. Then, expanding on the ergonomics topic, questions pertaining to the tablet's form factor would naturally follow. We asked about the device's physical size, its camera quality, and its maneuverability. From there, we would then move to the usability of MoleMapper's user interface, which would typically lead doctors to discuss specific parts of the application. The interviews ended with a series of questions about the usability of specific features that were implemented in non-standard ways, such as the picture comparison interaction, or the lesion remap screen.

Data collected from interviews was grouped by topic, and the analysis of that data is presented in Section 6.2. Results are discussed in Section 6.3, where we address the research question and describe how some of the issues reported by dermatologists could be solved in future versions of the application.

6.2 RESULTS

In the following, we group the feedback obtained from the dermatologists by topic.

6.2.1 General feedback

By the end of the study, all dermatologists felt at least as confident in using the application as they were in using their regular digital dermatoscopy tools. Two doctors reported that visits conducted with MoleMapper feel less stressful than what they would otherwise do. All participants reported that they found MoleMapper useful, and that they saw it as an improvement over the tools that they were using at the time. One participant emphatically stated that "it solves *a lot* of the issues I have with [the tool I use for mole mapping]". Specifically, they thought that our tool let them produce higher quality analyses within the same amount of time, and that performing a visit using MoleMapper was a less laborious process than the one they typically followed.

Overall, doctors did not think that MoleMapper enabled them to perform mole mapping visits in shorter time. Three dermatologists argued that the duration of a visit is affected by a combination of the time they have available and the patient's mole count, and only marginally depends on the tools that they use. Therefore, they saw no difference in the time they spent in performing visits that could be attributed to MoleMapper. One dermatologist revealed that the streamlined approach followed by the application helped her "get rid of [the] full-body photography [phase] fast", reducing the overall time spent in a visit. One participant reported that she felt slightly faster when working with the software tool in use at the Dermatology Clinic, but attributed the difference to her prolonged experience with her existing tools.

6.2.2 Workflow

Overall, the workflow encouraged by the application received positive feedback from the dermatologists. They appreciated the sense of structure that it conferred to visits, with one doctor stating that "it's probably due to the fact that I'm a very methodical person". However, four participants disliked that MoleMapper proposed the full-body photography phase for every visit. They would skip taking new pictures of portraits for which an image was already available. Two doctors attributed this choice to the considerable time investment required by taking all 24 pictures. One conceded that "it is useful to compare multiple pictures of the same area, so it may be worthwhile taking them every time, even if it takes forever". The other two stated that the information carried by the new pictures is "scientifically irrelevant, if not misleading". The dermatologist who supported retaking all portrait pictures every time specified that she "would never skip a portrait [picture], unless a patient comes back shortly after the previous visit to have a single melanocytic lesion checked". One doctor also questioned the usefulness of pictures of regions of the body devoid of lesions, remarking that she "will never take all portrai[t picture]s of a patient in my whole life".

Doctors had different opinions about what lesions should be proposed by the application to be included in new visits. Three doctors agreed with MoleMapper's approach of showing all lesions from the previous visit that were either marked with the "Follow-up" status, or were not evaluated. The other two would have preferred to see only those that were given the "Follow-up" status, automatically archiving the others.

6.2.3 Standard subdivision of the body

All dermatologists found merit in the proposed subdivision of the human body. They explained that, after some practice, they were able to quickly map lesions on the patient's skin, and retrieve the associated dermatoscopic pictures.

According to doctors, the four poses that the patients needed to assume during the full-body photography phase did not cause discomfort. In general, the doctors considered the poses easy to capture with the tablet's camera. However, one participant noted that, when photographing patients with larger than average body structures, it could be hard to frame portrait pictures and she would need to either use a footboard or stretch her arms. Similarly, two dermatologists reported that, on some occasions, they relied on adjusting the examination table's height in order to take portrait pictures. One of them added that adjustable-height examination tables are "standard equipment that every reasonably equipped clinic should always have, regardless of the type of visits/exams that are performed in that room".

6.2.4 Tablet form factor

The tablet form factor was unanimously seen as an improvement over the PC + external camera combination. The opinions of dermatologists on image quality ranged from "very good" to "excellent" for both tablets. We asked whether an external higher resolution camera could be an interesting addition to the system, but all participants found it unnecessary. Two dermatologists revealed that the image quality of the device's camera and screen were high enough to replace their hand-held dermatoscopes. The other three preferred to use their traditional dermatoscopes when first inspecting the patient. This was because the doctors were already adept at using their existing dermatoscopes, and they considered them ergonomically superior since the dermatoscopes easy to hold.

Two of the three doctors that used the ASUS Transformer Prime found it “a bit on the heavy side, especially when the dermatoscopic lens is attached”. One of them explained that “at first, I found [the ASUS Transformer Prime] a bit cumbersome compared to the dermatoscope I usually use, but with some practice, you learn what’s the best grip to handle it”. The two doctors who used the Sony Xperia Tablet Z found it easy to handle, even when the dermatoscopic lens was mounted.

Attaching and detaching the dermatoscopic lens to the ASUS tablet were regarded as straightforward operations. On the other hand, while attaching the lens did not cause any issue, dermatologists found detaching the dermatoscopic lens from the Sony tablet a strenuous operation. The device snapped into place using pressure, but created a seal that was difficult to remove. Doctors reported using either their nails or a nail filer-like device to pry it open.

6.2.5 UI usability

Three participants found MoleMapper’s user interface self-explanatory. One of them pointed out that it was “probably due to my experience with tablets”, and warned that “older doctors may have a harder time figuring out what every button does, [...] or use a touch interface when they are used to mouse and keyboard [interfaces]”. The other two participants thought that in order to become proficient with the application’s interface, doctors would need to gain practice with it for two weeks. All participants appreciated that the UI provided guidance on how to take portrait pictures, and found the overlaid outline of the previous picture helpful in aligning the new photograph.

Dermatologists requested changes to some parts of the interface. Specifically, one user asked for “bigger icons, or icons that make more sense for a doctor”. Another thought that the tab layout is not intuitive, as “it’s not always clear which tab contains the information I’m looking for”. Nevertheless, doctors made it clear that these suggestions were intended to help new users of the

application, as they learned what the icons meant, or what each tab contained, by using the tool.

Two participants requested that MoleMapper provide a more explicit visualization of the current progress of a visit. They found the color difference between the states of portraits too subtle to be captured at a glance. To show progress, the interface showed fully saturated images for portraits photographed in the current visit, 50% saturated for those photographed in the previous visit, and grayscale for those that were never photographed. In practice, changing saturation was difficult to notice.

6.2.6 Working with pictures

The majority of the time doctors spent using MoleMapper was dedicated to image manipulation. All participants found performing the three gestures involved in navigating pictures (pinch-to-zoom, pinch-rotate, and one-finger-drag) natural, as well as tapping on the area occupied by a lesion to mark it. One doctor remarked how "the ability to zoom in solves the issue of images being [physically] small because of the size of the tablet's screen".

We seeked confirmation on the usability of the novel interactions that were introduced in MoleMapper, namely the lesion remap feature, and the picture comparison interaction. Dermatologists found remapping lesions from previous pictures of a portrait to the most recent ones simple. However, four of them wished it was made more automatic. One doctor suggested merging lesion remap to the lesion mark phase, "so I could mark all lesions that I want to further analyze in one take, [...] regardless of whether it's the first time [that they are being analyzed]". Another would have liked MoleMapper to automatically remap all lesions from the previous visit with one click, letting the user decide on which needed to be aligned in the new picture in a following step.

Another new feature included in MoleMapper was the ability to compare multiple dermatoscopic pictures at the same time, in the dermatoscopic overview screen. Early feedback from dermatologists convinced us to duplicate the position of the screen, so users could access it at two different steps in the workflow, at the beginning and at the end of a visit. Two doctors accessed the dermatoscopic overview exclusively at the beginning of a visit as a way to understand, at a glance, the current status of a patient. Two others used it exclusively at the end of a visit "because it gives a good, immediate summary of what has been done". The other participant accessed the screen at both times. All dermatologists liked the organization of the overview, and used it extensively to apply the ugly duckling principle.

6.3 discussion

This section presents an interpretation of the data obtained from interviews that were presented in Section 6.2. We analyze the feedback using the same grouping that was defined for the previous section, and we summarize our observations to address the research question posed in Chapter 1.

6.3.1 General feedback

Overall, dermatologists felt positive about MoleMapper because they perceived it as improving the quality of their results. This was because they saw usefulness in the comparison tools provided by the application, and they were able to focus on analyzing lesions in detail.

In addition to the doctor's comments, we believe the professed increase in quality of the visits could be attributed to three factors: (1) doctors could take advantage of more tools dedicated to picture comparison, including the all-to-

all view provided by the dermatoscopic overview, (2) the information about the previous visit was made immediately accessible when analyzing lesions, and (3) dermatologists could focus on one task at the time. Three dermatologists, included the two involved in the second study, gave partial validation to factor (3) with their feedback about visits being less stressful and less laborious when using MoleMapper.

A second insight was that the perceived improvement did not extend the time taken per patient. We parsed the log files saved by the application to verify whether the perceived duration of a visit corresponded to the actual measurements. The average duration of visits performed using MoleMapper was 30.7 minutes ($\pm$15.7, median: 25), which corresponded with the estimate of 30 minutes given by dermatologists in preliminary interviews.

Both participants involved in the second study confirmed that this was true in their use when they reported an improvement in the quality of their analyses, without a difference in average visit time.

6.3.2 Workflow

A notable result of the two studies was that no doctor rejected the workflow proposed by the application. This was a surprising result given the variety of approaches available in the discipline and also reported by the doctors themselves that we interviewed. However, all participants requested to partially modify the workflow to better match their style of work.

Full-body photography was a step in the workflow that was considered as excessive by dermatologists, who instead preferred to only capture pictures they considered important. Doctors did not see the value in taking all full-scale pictures for every new visit, and considered it an annoying waste of time. Since two doctors questioned the scientific relevance of showing recent full-scale photographs of the patient, we should reconsider the choice of the

default portrait to be displayed for comparisons. Because of the disagreement between dermatologists on the subject, a promising solution seems to be letting users define their own choice through a settings page.

While doctors considered this step as excessive, there is an opportunity to further aid the workflow by automating this step. The motivation to do this and capture all portrait pictures with each visit is grounded in the following three observations: (1) detecting new lesions in areas of the body not covered by photography is impossible, (2) newly appearing lesions must be detected as soon as possible, as they are associated with high risk of melanoma [BKE+05], and (3) portrait pictures will be taken automatically by FullBodyScanner, so the whole workflow step will eventually be processed in one click. Early results from a pilot laboratory experiment suggested that all portrait pictures could be taken in approximately 5 minutes. Unfortunately, results showed that dermatologists did not share our point of view. Automating this step will be a crucial part of our future work, as change detection algorithms depend on the availability of pictures to be compared.

6.3.3 Standard subdivision of the body

Dermatologists internalized the proposed subdivision of the human body and proficiently used it to navigate through dermatoscopic pictures. The adoption of the new system was essential towards a standardization of the results produced by the doctors.

The proposed poses were considered comfortable for both the patient and the doctor. Preliminary interviews reported in Chapter 2 revealed that one of the reasons for which dermatologists did not frame full-scale pictures consistently in their practice had to do with the demographics involved. Older patients could not stand for long times, and would find some poses difficult to assume. In those cases, doctors would either not take pictures, or take them from a different angle. When using MoleMapper, instead, participants confirmed that

the set of poses that we devised could be used regardless of the patient's age, which is a requisite for standardization.

6.3.4 Tablet form factor

The choice of implementing MoleMapper as an Android application was a well received decision, and achieved our design goals. All participants saw the single point of control as a major improvement over the repeated context switches required by the traditional PC and external dermatoscope environment. The image quality of the tablet's camera received unanimous appreciation. It is worth noting that the digital dermatoscopy tools that the participants used in their daily practice were equipped with cameras whose resolutions ranged from 1.2MP to 2MP, compared to the 8MP resolution of the Android tablets.

The hardware upgrade that occurred between the two studies resolved the weight issue that affected the first prototype. However, the issue for which the dermatoscopic lens from the Sony tablet was difficult to detach indicated that the revised solution that we implemented still had room for improvement. This issue was outside of our control because the lens mount was provided by the dermatoscopic lens vendor. In future work, we may consider designing an alternative mount for the DL3 dermatoscope. One of the ideas that was discarded for the bulkier FOTO dermatoscope employed a rail to make the lens slide over the tablet's camera when dermatoscopic pictures needed to be taken. The reason why that design was abandoned was that it implied adding the weight of the dermatoscopic lens to that of the tablet even when it was not needed. Since both the new tablet and the new lens weigh significantly less than their predecessors, that solution could again become viable.

6.3.5 UI usability

The main goal in designing MoleMapper's UI was to provide simple access to all of its functionality. Interviews indicated that the doctors were able to use all views without issue, and the features were self-discoverable. In the case of the two dermatologists who did not consider the application's interface straightforward, they believed that two weeks was enough to become proficient with the tool. Self-discoverability was a secondary goal. MoleMapper's primary objective was to support a dermatologist's daily practice, hence simplicity in repeated usage was more important than immediateness in first usage. For this reason, the suggestions from the two participants about changing the tab organization or providing bigger icons should be followed only in case the revised designs do not interfere with the experience of expert users. In addition, the other three participants found the existing UI to be self-discoverable.

Interestingly, the two users who reported color saturation to be a bad choice for discriminating between the three portrait statuses were those involved in the second study. Prolonged use of the application might have helped them notice this issue, which should be addressed in future work. A possible solution makes use of three different colors to highlight the portraits, although it would introduce a new arbitrary color code into the application. Another alternative is to move to a two-state representation in which portraits photographed in the previous visits are also shown in grayscale. In this fashion, the visual difference between portraits photographed in the current visit, shown with full saturation, and those that were not, shown in grayscale, would become more pronounced.

6.3.6 Working with pictures

Since all participants had experience with touch interfaces, we were confident that they would have found the main image-manipulation gestures natural. Interviews confirmed our intuition.

The side-by-side interaction used in comparisons and remapping received a positive feedback that exceeded our expectations. We knew from our internal tests that the interaction had the potential to be used effectively, but its novelty constituted an unknown for its usability. By default, MoleMapper requires dermatologists to take new dermatoscopic pictures of all lesions that they marked in the previous visit. This default choice differed from the way some dermatologists were used to work. We learned from interviews that some doctors prefer to ignore previous data about lesions to avoid being biased. On the other hand, some other doctors consider previous evaluations to be informative and would, therefore, prefer the application to automatically remap lesions from previous visits. Our choice of showing the lesions that could be remapped, letting the user decide which ones to remap, seemed to satisfy neither group. A solution to this problem could be to provide an option to let users set the policy that MoleMapper should follow.

The dermatoscopic overview was another feature that was more appreciated than we expected. We thought that dermatologists would have preferred a more compact view to compare all lesions with each other, regardless of their existing classification. Instead, when explicitly asked, doctors did not express a need for such a screen, and declared themselves satisfied with the existing one.

6.3.7 Summary

We now address the research question introduced in Chapter 1, *can dermatologists be more effective in detecting early-stage melanoma?*

A definitive answer to the question would require a multiple-year study comparing results from a group of dermatologists using MoleMapper and another using a different tool. However, after analyzing the results of our case study, it is at least possible to assert that doctors *feel* more effective when using MoleMapper. The workflow it enforces helps them focus on their main activity so they can provide more in-depth analyses of suspect lesions. Further, the segmented representation of the human body to capture photos created a modularized workflow. This has several benefits–for example, easy tracking of progress–, and it is a task that could be performed by multiple people if one is interrupted. The move from using multiple devices to a single point of control also helped doctors focus on their tasks, removing the distractions that constant context-switching was causing. MoleMapper's user interface enables doctors to carry out their work without incurring in the cognitive effort needed by deciding on the better step to be taken next. Finally, dermatologists benefit from more immediate interaction patterns when working with pictures, which is essential in detecting subtle changes in melanocytic lesions.

7 CONCLUSIONS AND FUTURE WORK

Detecting melanoma in its early stages is essential to reduce the risk associated with the disease. Because of its similarity with benign melanocytic lesions, recognizing early-stage melanoma is a challenging task for dermatologists. While digital dermatoscopy has helped doctors improve their effectiveness in finding melanoma for the last two decades, no standardized process has emerged to consistently guide mole mapping visits. Each dermatologist thus follows a personal workflow, dedicating a considerable cognitive effort to decisions on the best sequence of actions to perform. This lack of a consistent, repeatable pattern in the way visits are conducted prevents doctors from allocating time to their most important activity, analyzing lesions.

In this dissertation, we addressed this issue and made the following five contributions:

Contribution 1: A summary of the different workflows practiced by dermatologists that was revealed in interviews with 7 dermatologists.

Although dermatologists do not consistently adhere to a fixed sequence of steps when performing mole mapping visits, interviews revealed a recurring set of patterns that emerged when considering the workflow across many doctors. We analyzed accounts from 7 dermatologists from the Dermatology Clinic of the University of Padova and presented the results in Chapter 2. This summary represents an overview of the typical courses of actions that doctors take when visiting their patients, and may serve as a reference for any future application or research that seeks to improve on the process performed by dermatologists.

Contribution 2: A standard subdivision of the human body that can be used when taking full-scale pictures of a patient.

In current practice, dermatologists use full-scale photographs of the patient to map lesions. Once a full-scale picture is taken, it is typically reused in all following visits for the patient. When taking these pictures, doctors neglect the use of consistent framing, focusing instead on centering what they consider the most interesting area at the moment. This inconsistency leads to difficulty in retrieving data about lesions, as there is no clear way to establish a priori where a lesion is mapped.

We introduced a standard subdivision of the human body to overcome these limitations that is thorough and found acceptable by both dermatologists and their patients when used in practice. Interviews with dermatologists confirmed that the proposed subdivision eliminated uncertainty in retrieving lesions in the application. Further, visits performed by different doctors produce results that are more easily compared when the standard subdivision is used.

Contribution 3: A consolidated proposed workflow for dermatologists that would bring thoroughness and consistency to their practice.

Based on the analysis of the workflows practiced by dermatologists, we designed a sequence of steps that doctors can follow to perform mole mapping visits. The devised workflow introduced a repeatable process that dermatologists can internalize to reduce the cognitive effort required each visit. Tests with 5 dermatologists from the University of Padova showed that the proposed workflow could easily be followed, and that doctors felt proficient in performing visits according to it within a few weeks.

Our proposed workflow encourages doctors to take new full-scale pictures each time a patient visits their office. The additional information associated with new versions of a picture was intended to help doctors detect newly appeared lesions, which are often indicators of melanoma [BKE+05]. However, feedback from our interviews with the dermatologists made clear that the time investment required to perform full-scale photography for every visit was too

high. Nevertheless, the information is crucial to allow automated detection of new lesions, so we plan to address this issue by introducing a system that takes all full-scale pictures at once, with a single click.

Contribution 4: An Android application to perform the proposed workflow.

We developed MoleMapper, an application for Android tablets that enforces and automates components of the proposed workflow. One of the main strengths of MoleMapper is its single-device approach. Digital dermatoscopy tools used in current practice are designed for PCs, and rely on the dermatologist switching between a hand-held dermatoscope and the computer's mouse and keyboard. MoleMapper lets doctors hold a single device at any time, engaging the dermatoscopic lens when needed through a custom designed system.

Aside from its improved ergonomics, MoleMapper was appreciated by all the dermatologists we interviewed for the simplicity of its user interface. Doctors felt confident in using it in their daily practice after two weeks of usage, and saw it as an improvement over their existing tools.

Contribution 5: An evaluation in the form of a case study for the application and workflow being used by dermatologists in-the-field.

We evaluated MoleMapper through a case study involving 5 dermatologists from the Dermatology Clinic of the University of Padova. The study was composed of two phases, a first laboratory experiment involving 3 dermatologists performing a total of 15 mock visits, and a second in-the-field deployment of the application involving 2 dermatologists performing a total of 87 visits on 16 patients. We ran a series of semi-structured interviews involving all participants in the experiments in order to gather feedback on the usefulness and usability of MoleMapper, and on the applicability of the workflow it enforces. Overall, the application and its proposed workflow received positive feedback by all dermatologists who declared themselves proficient with the tool after two weeks of usage.

7.1 FUTURE WORK

This section discusses three directions in which we plan to expand the work that was presented in this dissertation, which are data synchronization, integration with FullBodyScanner, and providing further validation.

7.1.1 Data synchronization

In its current implementation, MoleMapper does not provide data synchronization tools other than a simple data export module. Users can download full-scale and dermatoscopic pictures to an external SD card, or through a USB connection. Images are organized in a hierarchy of folders that mirrors the structure of the application's data model. Hence, exported files are organized in a set of top-level folders labeled after the full name of the patient, which contain a folder for each visit, which in turn contain two folders, one for full-scale and one for dermatoscopic pictures.

When implementing the application, we decided to use a SQL-based inmemory database to make future synchronization with external databases trivial. However, we preferred to first focus on the local functionality of the tool, leaving data synchronization as a feature to be implemented in a following stage. Data should be synchronized with external sources to accomplish four goals: (1) to provide backup in case of failures, (2) to make data available to all users of the application, regardless of the tablet they use, (3) to integrate with external systems for medical record organization, and (4) to integrate with PersonalScreener. Goals (1), (2), and (4) could be accomplished by using a cloud model to store data, providing an API layer that lets both MoleMapper and PersonalScreener upload pictures and metadata through authenticated HTTP calls. However, the issue of ownership of data should be carefully examined, as interviews exposed a considerable level of uncertainty on the matter, and may need to comply with data privacy and security laws. Goal (3) will require

implementing ad-hoc solutions depending on the medical record organization system in use, which in the case of the University of Padova is the Galileo system [Sol15].

7.1.2 Integration with FullBodyScanner

The workflow we proposed includes the full-scale photography phase for every visit. Our choice was motivated by the fact that, in order to detect newly appearing lesions, or subtle changes in existing ones, image processing algorithms need to compare the two most recent pictures of any given area of the body. Unfortunately, dermatologists reported that they would never include that phase in their daily practice. Hence, making the full-scale picture acquisition phase automatic is a more urgent task than originally planned, as our belief that doctors would be willing to manually substitute FullBodyScanner proved unfounded.

An interesting result of the case study was that two doctors would have preferred not to see the most recent full-scale pictures available. They considered older pictures to be more informative when compared with the patient's current state. We should therefore allow users to decide on the policy for showing previous images, and even if new pictures are automatically taken by FullBodyScanner, they could be hidden if the users so decide.

7.1.3 Further validation

The case study we conducted provided initial insight to our research question. It involved a low number of participants, but its significant incidence number allowed us to build the insights provided in this dissertation. However, this should be followed up by both a full qualitative analysis and quantitative analysis.

A qualitative analysis involving at least 18 doctors across different organizations to use the tool should be provided to build a larger story of how MoleMapper would be used in practice, both in how well it is received, and in how well it improves diagnosis. The insights built from this qualitative analysis should be followed up by an email questionnaire that targets a large audience (on the order of hundreds of dermatologists) to verify that the assertions made are generalizable to a larger population.

A further longitudinal initiative would also be necessary to evaluate if MoleMapper does indeed lead to better diagnosis by tracking the progress of patients over a course of 5 to 10 years, and compare their early detection rates compared to statistics collected of existing practices.

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BIBLIOGRAPHY

[ABS+07] Giorgio Annessi, Riccardo Bono, Francesca Sampogna, et al. "Sensitivity, specificity, and diagnostic accuracy of three dermoscopic algorithmic methods in the diagnosis of doubtful melanocytic lesions: the importance of light brown structureless areas in differentiating atypical melanocytic nevi from thin melanomas." In: *Journal of the American Academy of Dermatology* 56.5 (2007), pp. 759–767.

[AFC+98] Giuseppe Argenziano, Gabriella Fabbrocini, Paolo Carli, et al. "Epiluminescence microscopy for the diagnosis of doubtful melanocytic skin lesions: comparison of the ABCD rule of dermatoscopy and a new 7-point checklist based on pattern analysis." In: *Archives of Dermatology* 134.12 (1998), pp. 1563–1570.

[ASC+03] Giuseppe Argenziano, H Peter Soyer, Sergio Chimenti, et al. "Dermoscopy of pigmented skin lesions: results of a consensus meeting via the Internet." In: *Journal of the American Academy of Dermatology* 48.5 (2003), pp. 679–693.

[ASU15] ASUSTek. *EEEPad Transformer Prime Support*. Jan. 2015. URL: http://www.asus.com/it/Tablets/Eee_Pad_Transformer_Prime_TF201/HelpDesk_Download/.

[BGS+09] Charles M. Balch, Jeffrey E. Gershenwald, Seng-jaw Soong, et al. "Final Version of 2009 AJCC Melanoma Staging and Classification." In: *Journal of Clinical Oncology* 27.36 (2009), pp. 6199–6206. DOI: 10.1200/JCO.2009.23.4799. eprint: http://jco.ascopubs.org/content/27/36/6199.full.pdf+html. URL: http://jco.ascopubs.org/content/27/36/6199.abstract.

[BKE+05] Jeremy P Banky, John W Kelly, Dallas R English, et al. "Incidence of new and changed nevi and melanomas detected using baseline images and dermoscopy in patients at high risk for melanoma." In: *Archives of dermatology* 141.8 (2005), pp. 998–1006.

[BMJ13] Paul K Buxton and Rachael Morris-Jones. *ABC of Dermatology*. John Wiley & Sons, 2013.

[BSG+01] Charles M Balch, Seng-Jaw Soong, Jeffrey E Gershenwald, et al. "Prognostic factors analysis of 17,600 melanoma patients: validation of the American

Joint Committee on Cancer melanoma staging system." In: *Journal of Clinical Oncology* 19.16 (2001), pp. 3622–3634.

[BSK+03] I. Bogdan, J. Smolle, H. Kerl, et al. "Melanoma ex naevo: a study of the associated naevus." In: *Melanoma Res.* 13.2 (Apr. 2003), pp. 213–217.

[CEG+89] Wallace H. Clark, David E. Elder, DuPont Guerry, et al. "Model Predicting Survival in Stage I Melanoma Based on Tumor Progression." In: *Journal of the National Cancer Institute* 81.24 (1989), pp. 1893–1904. DOI: 10.1093/jnci/81.24.1893. URL: http://jnci.oxfordjournals.org/content/81/24/1893.abstract.

[Che76] Peter Pin-Shan Chen. "The entity-relationship model—toward a unified view of data." In: *ACM Transactions on Database Systems (TODS)* 1.1 (1976), pp. 9–36.

[CKU+07] M Emre Celebi, Hassan A Kingravi, Bakhtiyar Uddin, et al. "A methodological approach to the classification of dermoscopy images." In: *Computerized Medical Imaging and Graphics* 31.6 (2007), pp. 362–373.

[Coo95] Alan Cooper. *About Face: The Essentials of User Interface Design*. 1st. New York, NY, USA: John Wiley & Sons, Inc., 1995. ISBN: 1568843224.

[CRG+78] Wallace H Clark, Ronald R Reimer, Mark Greene, et al. "Origin of familial malignant melanomas from heritable melanocytic lesions:The BK mole syndrome'." In: *Archives of dermatology* 114.5 (1978), pp. 732–738.

[Des15] UNITiD Interaction Designers. *Contextual Navigation Design Pattern*. Jan. 2015. URL: http://unitid.nl/androidpatterns/uap_pattern/contextual-navigation.

[DHFETAG00] United States. Department of Defense. Human Factors Engineering Technical Advisory Group. *Human Engineering Design Data Digest*. United States Department of Defense, 2000.

[EGG+80] David E Elder, Leonard I Goldman, Susan C Goldman, et al. "Dysplastic nevus syndrome: a phenotypic association of sporadic cutaneous melanoma." In: *Cancer* 46.8 (1980), pp. 1787–1794.

[EKR+01] Marek Elbaum, Alfred W Kopf, Harold S Rabinovitz, et al. "Automatic differentiation of melanoma from melanocytic nevi with multispectral digital dermoscopy: a feasibility study." In: *Journal of the American Academy of Dermatology* 44.2 (2001), pp. 207–218.

[FDM04] N.E. Feit, S.W. Dusza, and A.A. Marghoob. "Melanomas detected with the aid of total cutaneous photography." In: *British Journal of Dermatology* 150.4 (2004), pp. 706–714. ISSN: 1365-2133. DOI: 10.1111/j.0007-0963.2004.05892.x. URL: http://dx.doi.org/10.1111/j.0007-0963.2004.05892.x.

[FH12] Laura K. Ferris and Ryan J. Harris. "New Diagnostic Aides for Melanoma." In: *Dermatol Clin* 30.3 (2012). 22800557[pmid], pp. 535–545. ISSN: 0733-8635. DOI: 10.1016/j.det.2012.04.012. URL: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3623959/.

[FPS11] M. Fiorese, E. Peserico, and A. Silletti. "VirtualShave: automated hair removal from digital dermatoscopic images." In: *Conf Proc IEEE Eng Med Biol Soc* 2011 (2011), pp. 5145–5148.

[FRK85] Robert J Friedman, Darrell S Rigel, and Alfred W Kopf. "Early detection of malignant melanoma: The role of physician examination and self-examination of the skin." In: *CA: a cancer journal for clinicians* 35.3 (1985), pp. 130–151.

[FSFLT+13] J. Ferlay, E. Steliarova-Foucher, J. Lortet-Tieulent, et al. "Cancer incidence and mortality patterns in Europe: Estimates for 40 countries in 2012." In: *European Journal of Cancer* 49.6 (2013), pp. 1374 –1403. ISSN: 0959-8049. DOI: http://dx.doi.org/10.1016/j.ejca.2012.12.027. URL: http://www.sciencedirect.com/science/article/pii/S0959804913000075.

[GB98] JJ Grob and JJ Bonerandi. "The 'Ugly Duckling'Sign: Identification of the Common Characteristics of Nevi in an Individual as a Basis for Melanoma Screening." In: *Archives of dermatology* 134.1 (1998), pp. 103–104.

[Gmb15a] Boxfuse GmbH. *Flyway – Database migration made easy*. Jan. 2015. URL: http://flywaydb.org/.

[Gmb15b] FotoFinder Systems GmbH. *Medical Imaging for your Success: FotoFinder*. Jan. 2015. URL: http://www.fotofinder.de/1/startseite/.

[Hap95] R Happle. "What is a nevus." In: *Dermatology* 191.1 (1995), pp. 1–5.

[HKG+14] N. Howlader, M. Krapcho, J. Garshell, et al. *SEER cancer statistics review, 1975-2011, National Cancer Institute. Bethesda, MD*. Apr. 2014. URL: http://seer.cancer.gov/csr/1975_2011/.

[HMB+03] Allan C Halpern, Ashfaq A Marghoob, Thomas W Bialoglow, et al. "Standardized positioning of patients (poses) for whole body cutaneous photography." In: *Journal of the American Academy of Dermatology* 49.4 (2003), pp. 593–598.

[Inc15a] Apple Inc. *Mac basics: Multi-Touch gestures*. Jan. 2015. URL: http://support.apple.com/en-us/ht4721.

[Inc15b] Google Inc. *Android Design Principles*. Jan. 2015. URL: https://developer.android.com/design/get-started/principles.html.

[Inc15c] Google Inc. *Creating Single-pane and Multi-pane Layouts*. Jan. 2015. URL: http://developer.android.com/guide/practices/tablets-and-handsets.html#Fragments.

[Inc15d] Google Inc. *Fragments*. Jan. 2015. URL: http://developer.android.com/guide/components/fragments.html.

[Inc15e] Google Inc. *Gestures*. Jan. 2015. URL: http://developer.android.com/design/patterns/gestures.html.

[Inc15f] Microsoft Inc. *Touch: Swipe, tap, and beyond*. Jan. 2015. URL: http://windows.microsoft.com/en-us/windows-8/touch-swipe-tap-beyond.

[Ins15] Derma Instruments. *Derma medical systems*. Jan. 2015. URL: http://www.dermamedicalsystems.com/index.php?menu_id=104.

[Jai12] Sima Jain. *Dermatology: illustrated study guide and comprehensive board review*. Springer, 2012. ISBN: 9781441905246. URL: http://site.ebrary.com/lib/iupui/docDetail.action?docID=10539517.

[KPW+02] Harold Kittler, H Pehamberger, K Wolff, et al. "Diagnostic accuracy of dermoscopy." In: *The lancet oncology* 3.3 (2002), pp. 159–165.

[Mac90] Rona M MacKie. "Clinical recognition of early invasive malignant melanoma." In: *BMJ: British Medical Journal* 301.6759 (1990), p. 1005.

[MF03] F. Mazzeo and P. Forestieri. *Trattato di chirurgia oncologica*. Piccin, 2003. ISBN: 9788829916542. URL: http://books.google.it/books?id=gUMeO1h0H3EC.

[Mil56] George A Miller. "The magical number seven, plus or minus two: some limits on our capacity for processing information." In: *Psychological review* 63.2 (1956), p. 81.

[Org07] World Health Organization. *WHO Growth Reference 5-19 years*. [Online; accessed 1-January-2015]. 2007. URL: \url{http://www.who.int/growthref/hfa_girls_5_19years_per.pdf?ua=1}.

[PBB+13a] Francesco Peruch, Federica Bogo, Michele Bonazza, et al. "Simple, fast, accurate melanocytic lesion segmentation in 1D colour space." In: *VISAPP, Computer Vision Theory and Applications, International Conference on*. 2013, pp. 191–200.

[PBB+13b] Francesco Peruch, Federica Bogo, Michele Bonazza, et al. "Simpler, Faster, More Accurate Melanocytic Lesion Segmentation Through MEDS." In: *IEEE transactions on bio-medical engineering* (2013).

[Per15] Francesco Peruch. "(Semi)-automated analysis of melanocytic lesions." PhD thesis. via Gradenigo 6, Padova: Università degli Studi di Padova, Jan. 2015.

[PSW87] Hubert Pehamberger, Andreas Steiner, and Klaus Wolff. "In vivo epiluminescence microscopy of pigmented skin lesions. I. Pattern analysis of pigmented skin lesions." In: *Journal of the American Academy of Dermatology* 17.4 (1987), pp. 571–583.

[RC00] Darrell S Rigel and John A Carucci. "Malignant melanoma: prevention, early detection, and treatment in the 21st century." In: *CA: a cancer journal for clinicians* 50.4 (2000), pp. 215–236.

[Res15a] Hwaci Applied Software Research. *Internal versus external BLOBs*. Jan. 2015. URL: `https://www.sqlite.org/intern-v-extern-blob.html`.

[Res15b] Hwaci Applied Software Research. *SQLite's home page*. Jan. 2015. URL: `http://www.sqlite.org/`.

[RFK+05] Darrell S Rigel, Robert J Friedman, Alfred W Kopf, et al. "ABCDE—an evolving concept in the early detection of melanoma." In: *Archives of dermatology* 141.8 (2005), pp. 1032–1034.

[Rob05] JK Robinson. "Sun exposure, sun protection, and vitamin D." In: *JAMA 2005* 294 (2005), pp. 1541–1543.

[RRF10] Darrell S Rigel, Julie Russak, and Robert Friedman. "The evolution of melanoma diagnosis: 25 years beyond the ABCDs." In: *CA: a cancer journal for clinicians* 60.5 (2010), pp. 301–316.

[Sam12] Mattia Samory. "Design and implementation of a high productivity user interface for a digital dermatoscope." MA thesis. Università degli Studi di Padova, 2012.

[SC90] Anselm Strauss and Juliet M Corbin. *Basics of qualitative research: Grounded theory procedures and techniques.* Sage Publications, Inc, 1990.

[Sch11] Gerald Schaefer. "Interactive navigation of image collections." In: *Future Generation Information Technology*. Springer, 2011, pp. 30–36.

[Sci15] MELA Sciences. *Melanoma detection: see below the skin to better diagnose melanoma*. Jan. 2015. URL: `http://www.melafind.com/dermatologists/about-melafind`.

[sgi15] sgi. *OpenGL – The industry standard for High Performance Graphics*. Jan. 2015. URL: `https://www.opengl.org/`.

[SGS+05] W. V. Stoecker, K. Gupta, R. J. Stanley, et al. "Detection of asymmetric blotches (asymmetric structureless areas) in dermoscopy images of malignant melanoma using relative color." In: *Skin Res Technol* 11.3 (2005), pp. 179–184.

[SM92] Helen M Shaw and William H McCarthy. "Small-diameter malignant melanoma: a common diagnosis in New South Wales, Australia." In: *Journal of the American Academy of Dermatology* 27.5 (1992), pp. 679–682.

[SMVS+03] R. J. Stanley, R. H. Moss, W. Van Stoecker, et al. "A fuzzy-based histogram analysis technique for skin lesion discrimination in dermatology clinical images." In: *Comput Med Imaging Graph* 27.5 (2003), pp. 387–396.

[SMZ+14] Rebecca Siegel, Jiemin Ma, Zhaohui Zou, et al. "Cancer statistics, 2014." In: *CA: A Cancer Journal for Clinicians* 64.1 (2014), pp. 9–29. ISSN: 1542-4863. DOI: 10.3322/caac.21208. URL: http://dx.doi.org/10.3322/caac.21208.

[Sol15] eHealth Solutions. *eHealth Solutions Galileo web page*. Jan. 2015. URL: http://www.noemalife.com/index.php?id=41&L=1.

[Son15] Sony. *Unlockbootloader*. Jan. 2015. URL: http://developer.sonymobile.com/unlockbootloader/unlock-yourboot-loader/.

[stu12] DAZ studio. *DAZ Studio homepage*. Apr. 2012. URL: https://www.daz3d.com/get_studio.

[SWJG92] DL Shriner, RF Wagner Jr, and JR Glowczwski. "Photography for the early diagnosis of malignant melanoma in patients with atypical moles." In: *Cutis* 50.5 (1992), pp. 358–362.

[TRS98] Hensin Tsao, Gary S Rogers, and Arthur J Sober. "An estimate of the annual direct cost of treating cutaneous melanoma." In: *Journal of the American Academy of Dermatology* 38.5 (1998), pp. 669–680.

[Vox15] Nathan Voxland. *Liquibase – Database refactoring*. Jan. 2015. URL: http://www.liquibase.org/.

[VWVDVE01] Martijn Van Welie, Gerrit C Van Der Veer, and Anton Eliëns. "Patterns as tools for user interface design." In: *Tools for Working with Guidelines*. Springer, 2001, pp. 313–324.

[Wik15] Wikipedia. *Holy Grail (web design)*. Jan. 2015. URL: http://en.wikipedia.org/wiki/Holy_Grail_(web_design).