OnPoint: A Social and Mobile Platform for Optimizing Health Services for Complex Chronic Care Management

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OnPoint:
A Social and Mobile Platform for Optimizing Health Services for Complex Chronic Care Management
Master of Engineering Capstone Design Project Report

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1. Introduction

1.1. Chronic Disease In The US

As defined by Wikipedia, a chronic condition is a human health condition or disease that is persistent or otherwise long-lasting in its effects. Chronic disease includes hypertension, heart attack and stroke. (Chronic condition, wikipedia, 2016:3) Chronic diseases usually take more than 3 months to treat and some may even follow the patient till their death. Besides long time span and hard to fully cure, chronic disease usually comes with other complicated diseases which make the treatment process more complicated.

Based on the Centers for Disease Control and Prevention(CDC)'s data, Chronic diseases are responsible for 70% of the deaths in the US, and more than 85% of the nation's health care costs are spent on treating people with chronic diseases. (CDC : 2015) Even though to improve the chronic disease health care system, the department of health and human services has formulated and promulgated a whole array of regulations and code, due to the complexity of chronic disease and limited resources, most patients still fail to understand their symptoms or carry out their care plan correctly.

1.2. Problem Statement

Chronic disease treatment requires involvement of complicated medical system. There are 2 major problems: inefficient communication and complex task management.

It is a challenge for the care-giving team and the patient's family members to keep track of the patient's activities and communicate efficiently. In one case we studied, the nurse only calls the patient once every three months and asks him about his conditions orally. But most of the time the patient fails to remember his health condition history. Sometimes the patient may even remember his conditions wrongly which will mislead the diagnose of his disease. In another case, the 40 years old son is taking care of his 70 years old father. The son only visits his father once every two week in the weekend. During his visit, he will help his father fill the pillbox. But because of the lack of information exchange, by the time he notices that a certain type of medication needs to be refilled, it is too late to get the medication on time. Because usually it takes more than one week for the pharmacy to get the ordered pill.

Secondly, the tasks for carrying out the patient's care plan are very tedious and complicated for chronic disease patient. The patient not only needs to take medications based on the schedule, he or she also needs to log body readings regularly and health conditions, follow clinical goals such as exercise everyday and manage their appointments. One patient said that he feels overwhelmed during our interview.

1.3. Purpose Of The Project

The goal of our capstone project is to build an information system with a mobile application that allows chronic disease patients:

- to establish an efficient communication with the care-giving team and their family members.
- to take active charge of their health and to be able to follow their care plan more easily, leading to better task management to receive more adequate medical treatments

2. Design

2.1. Methodology

This capstone project has 2 big parts - deign process and implementation process. Since this is a user interface design project, we spend 3/4 of the time on the design process and the rest on the implementation process.

We went through three main design phases, each based on the work of the previous iteration. The first design phase - design phase 0 is from September 2015 to October 2015. We were mainly doing background research and communicating with our UCDavis collaborators to clarify the user needs. On October 27th, we held a tele-conference with 4 chronic disease patients and 6 specialists from UCDavis to discuss the function priorities and confirm the user needs about our assumption. In the second iteration - design phase 1, we were using Balsamiq wireframe tool to create the medium fidelity wireframes for these modules : medication management, symptom management,appointment management, goal module, and measurement module. After carrying out user test with one patient and having received feedback from our advisor and UCDavis collaborator, we launched our last design phase - phase 2. In this phase, based on the feedback, we refined the medication management module and created wireframes for on boarding module and the user's main dashboard - the timeline view. We were using keynote to create high fidelity module and carried out user testing on 4 patients and 4 specialists in UCDavis. Based on the feedback we received, we made some adjustment and created the final design.

It's worth pointing out that during the design process, everyone in the team contributed to every step equally. That is to say, we spent 6 hours on our capstone project each week together and

carried out the design of the project. More specifically, in the brainstorming step, all team members gathered together and tried to think on good project design ideas; in the wireframe implementation step, we split the tasks of making the wireframe. Each person was responsible for making one section of the prototype; in the user testing stage, we collaboratively carried out user testing and presented to our supervisor for feedback.

During the implementation phase, we divided our work based on functionality. I implemented the appointment module and commenting feature. Angela implemented the goals module and timeline module. Bill implemented the measurements module, medications module and backend integration. Me and Angela also collaboratively worked on the on boarding UX together.

In this paper, I will talk about the design of the medication management module, the symptom management module, the appointment management module and the commenting feature. Please refer to Bill Kim's paper for the design of the measurement module and the timeline view. Angela described the medication scheduling module and the goal module in her paper. Figure 1 demonstrates our work distribution in the implementation phase.

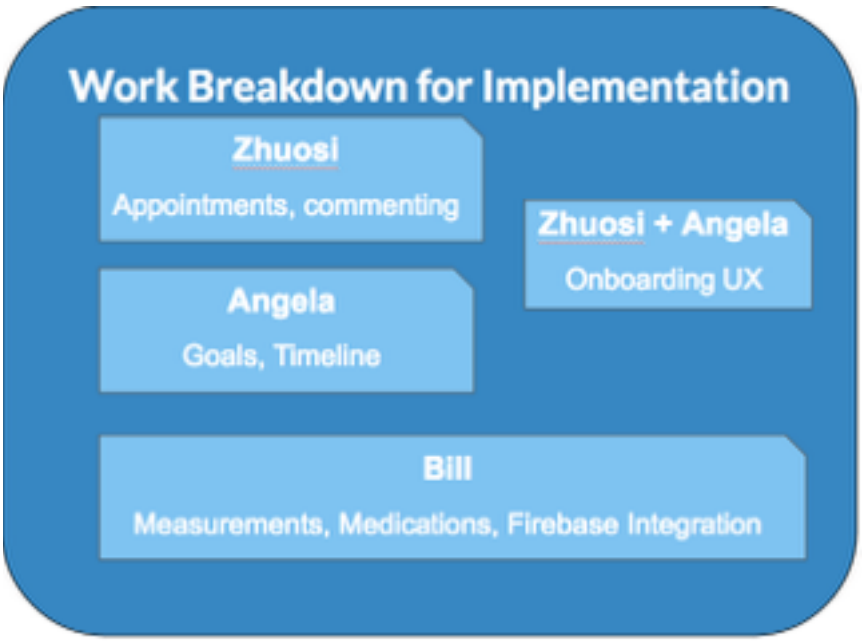
2.2. Phase 0 - Interview

This is the initial phase of our design process. In this phase, we first analyzed existing application's functionality and service. Based on our analyze result, we came out a rough functionality set we think should be integrated in our application. At the end, we held a tele-conference to finalize our design focus with patients and specialists.

2.2.1. Existing Application Analyse

The first goal of our application is to improve the communication between the patient's care giving team. After discussing with our UCDavis collaborator, we identified two key functionalities: messaging and shared timeline view. The shared timeline view serves as the main overview of relative event of the patient's health status. The messaging function is the tool to help everyone in the team to better communicate. In the traditional scenario, the patient's relatives and family members can only get to know the patient's status by actively calling the patient or visit the patient or the patient can call them and give them update. But this is very inefficient and unsynchronized as patient's care-giving team cannot get update of the patient status on time.

Figure 1. Work Breakdown for Implementation



The second goal of our application is to allow the patient to take active charge of their health and be able to follow their

care plan more easily. Based on this goal, we identified two other features: medication history recording and device integration. The medication history recording allows the patient to log their medication history so that during their visiting to specialist, they can have a precise, accurate full medication history record shown to the specialist. This record helps specialists better understand the patient's past condition and take proactive reaction. Traditionally, during the routing meeting for once every couple of months, the patient's medication intaking history is a fix question that the specialist must ask. But most of the patients just rely on their memory to answer this question. Their memory is unreliable and they often forget to mention important changes in their med or report their history incorrectly. Device integration is referring to integrate the patient's body measurement equipment with our application. For instance, most cardiovascular disease patients need to measure their blood pressure and heart rate and manually take note of the reading. If we can connect our application with their body reading hardware, the patient will be able to save the effort of taking log everyday.

Based on the 4 key modules (health timeline, messaging, medical record, device integration) we have identified, we cross-compared services provided by EPIC (Patient Engagement Epic 2016:5) , CRISP(The CRISp Integrated Care Network 2015:8), Caresync (Caresync 2016), Flow Health (Flow Health 2015), Caremerge (Caremerge 2016), and Qualcomm (Qualcomm Life 2015). Table 1 summarizes our conclusion.

Table 1: Current Care Management Applications' service analysis

		Service provided			
		Messaging	Health Timeline	Device Integration	Medical Records
Branch Name	Epic Suite	Yes	Yes	No	No
	CRISP	No	No	No	Yes
	Caresync	No	Yes	No	Yes
	FlowHealth	Yes	Yes	No	Yes
	CareMerge	Yes	Yes	No	Yes
	Qualcom Life	Yes	No	Yes	Yes

As we can see from the table, there does not exist one application / service that integrates all functionalities that are essential to the patient. Many solutions used by hospitals are geared towards providers to help manage patients. These are more focused on keeping a database of Electronic Health Records (EHR) and helping physicians query relevant patient information, rather than helping patients understand their health status. For example, EPIC is one of the largest providers of health software in the United States, but their products are focused on providing access to public health records. Patient-centered applications on the market that help people track their medical health are focusing on solving part of the problem. For instance, some are focusing on tracking patient's medication record like My Pillbox (My Pillbox 2015:06); some are focusing on sharing patient's Electric Health Record data like My Medical (My Medical 2015:08); some are focusing on educating people and offering them tips to prevent chronic disease like Preventing Chronic Disease (Preventing Chronic Disease 2014:07). Based on our research, even though some of them contain useful aspects such as managing appointment calendars, or keeping a checklist of medications, these services don't provide the deep level of engagement required for effective care coordination.

The services that are closest to our goal is provided by Qualcomm Life, a health-centric division of Qualcomm. They provide a HealthyCircles Platform which is a SaaS solution for communication and record sharing. However, they still lack the health timeline feature which we think is crucial for the patient to efficiently communicate with his care-giving team.

2.2.2. Finalizing Design Focus

On October 27th, 2015, we held a tele-conference with 4 chronic disease patients and 6 specialists from UCDavis to discuss the function priorities and confirm the user needs

assumption. After this meeting, our biggest takeaway was that those specialists confirmed our assumption that messaging feature, medication management module and shared care plan were very important to them and we agreed on detailed requirements about these modules. However, due to the time constrain and limited hardware background the group member had, we decided to not implement the device integration functionality.

For the medication management module, they pointed out that they were expecting more than just logging their medication history. The patients reflected that generating a customized medication schedule is often a hard task. One patient Mr. T said that he was currently on 17 medications and 1/3 were held twice a day and he had trouble with when to take medications, whether to take before / after meals and which pills go better with which pills. Another patient D also expressed that sometimes, he would accidentally forget to take certain pill but when he remembers it, he's not sure whether he should take the scheduled dosage or should he skip the pill or even reduce the amount. They also wanted to have access to detailed information of their drugs about substances, formulation, dosage and what/when/how it is given. And if the patient chooses to skip / reduce dosage / increase dosage, the application should track that action and let the patient note why they are doing that.

Even though we decided not to integrate the hardware device into our application, the patients still wanted to log their body readings like heart rate, blood pressure and body weight. On top of that, they hope this application can help them understand their health data by giving interpretations. For instance, when the blood pressure is too high or too low, the patient would want to be notified and given suggestions about what they should do next.

For the health timeline, they want it to be more intuitive, not just a place to access patient health record, but presented as a storyline that can be understood by their family. They all agreed that

the health timeline is an overview of the patient's shared care plan and is the key of this application.

As for the messaging functionality, the specialists enhanced that this messaging should not involve nurse and care givers. Because in some cases, one nurse is in charge of more than 100 patient's condition and it is unrealistic for them to view / reply all messages sent by every patient.

2.3. Phase 1 - Designing Different Modules

After getting feedback from phase 0, we made the following changes : instead of device integrating, we will create a measurement module where patients can log their measurement readings and get alert when their reading is out of a pre set range. As for messaging functionality, we should try to integrate our application with Apple's Messages because we thought that Messages has a mature messaging functionality and it can save the team effort to utilize it rather than create a functioning messaging application from scratch.

Our UCDavis collaborator expressed that a well defined patient's care plan should also include symptom management, goals and appointments. The symptom management module should send standard user symptom questionnaires based on the patient's disease two weeks before the scheduled appointment with specialists. The goals module should document personal goals as well as clinical goals. Appointments module is like a calendar application that reminds the patient of their scheduled appointment with specialists.

For phase 1, we used Balsalmiq wireframe tool to create low fidelity wireframe. Next in this section, I will talk about the medication management module and symptom management

module design in detail. Please refer to Bill's report for the description of the timeline module, measurement module and goal module.

2.3.1. Medication Management Module

- Description

Figure 2: medication module main page

Figure 3: pillbox image

We are using the pillbox metaphor in the module. In figure 2, the content is divided into three time slots (11Am, 2PM and 5PM). And there are medication icons that reflects corresponding medication's shapes and colors to represent medicines the patient need to take in each slot. Figure 3 is a picture of a three-time slot pillbox that the patient may use. This pillbox metaphor is intuitive and easy to use as it parallels patient's real life. The view of our application represents one column of the pillbox. i.e. the patient's one day medication schedule. Patients can check their other days' medication schedule by clicking the calendar icon next to the date and go to a different date.

We also used different icons to represent the medication status. For instance, the red exclamation icon next to Coreg represents that the patient has not taken this med and he should take it as soon as possible. The red ban icon next to Lasix represents that the patient has

chosen to skip this medication but he is not recommended to do so and he should not take it to make up. The green check mark next to Hydro represents that the patient has taken this medication. chosen to skip this medication but he's not recommended to do so and he should take it as soon as possible to make up. The green check mark next to Hydro represents that the patient has taken this medication.

We are also using color coding to represent the food constrain and time concept. For instance, Levo and Coumadin has blue background color, same as the fork and knife icon. This represents that Levo and Coumadin need to be taken with food. Similarly, Metformin also needs to be taken with food. Also the background of the first slot is gray which means that current time has passed the 11AM morning slot.

By clicking anywhere one time slot, the patient can enter the detailed view of one time slot. Figure 4 shows the detailed page of one time slot.

Figure 4: Detailed page of one time slot

Figure 5: Skip medication alert

The patient can view each medication's detailed information in this view by clicking that med's icon and choose to skip / take this medication. If the patient chooses to take this medication, a green check mark will appear next to this medication icon as shown in figure 2. If the patient chooses to skip a medication which is not suggested to take based on the instruction, then our application will display an alert to inform the patient as shown in figure 5.

- User Feedback

We got 3 pieces of user feedback on this module. Firstly, our user feels that it's not intuitive enough in the sense that once he takes the pill from his pillbox, his pillbox is empty while in our wireframe, that pill is still in the corresponding time slot even though it has a green check mark next to it. He suggested that it can be more realistic if the pill that has been taken could disappear from that time slot. Secondly, when he takes pill from his pillbox, he will simply pull all pills in the slot into his hand and eat at once. So to make our application less cumbersome, he suggested selecting all pills in the time slot by default when the patient enters the detailed page of time slot. The third piece of feedback is that we were using too many icon and colors to represent the medication status and constrains. He got confused when trying to figure out all the representations.

Overall, he expressed that this pillbox metaphor makes sense to him. And he's willing to use our application in his life.

2.3.2. Symptom Management Module

- Description

Our UCDavis collaborator pointed out that based on the patient's health condition, they have to take certain types of questionnaires in a regular basis. And UCDavis has a regulation of Remote Symptom Protocols for Individuals Undergoing Cancer Treatments, which defined 13 protocols such as Anxiety, Bleeding and Depression. These protocols are designed to provide information to assist decision-making. And the patient's answer should be interpreted by trained Registered Nurses (RNs). So our application will only send patients questionnaire when there is at least one trained RN in the patient's care-giving team. And our application will not give the patient any feedback regarding their answer. Instead, our application will simply transmit the patient's answer to the trained RNs.

Figure 6: Questionnaire example 1

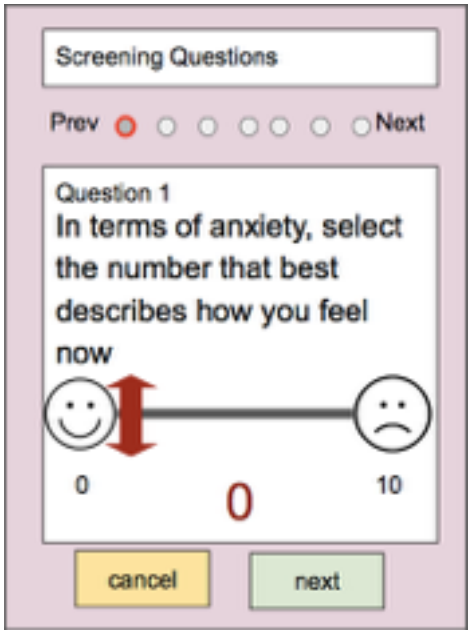
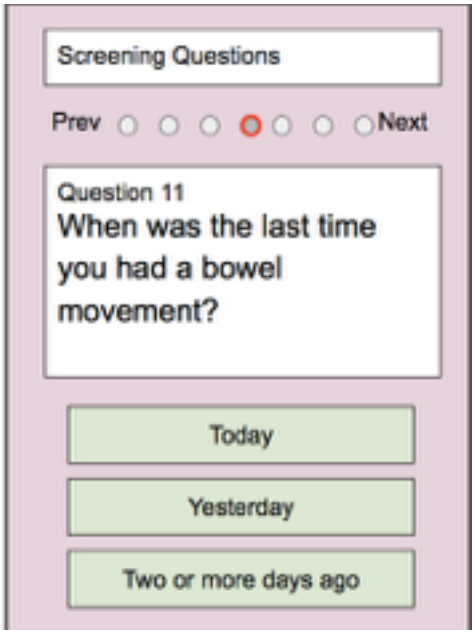


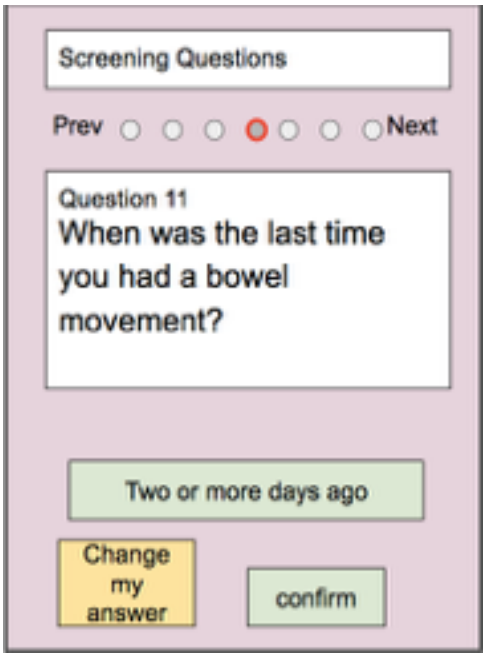
Figure 7: Questionnaire example



There are three types of questions in the questionnaire. The first type is to describe the patient's condition in a scale of 0 to 10. We used drag-bar representative to let the user choose their answer as shown in Figure 6. The second type of the question is multi-choice question. The patient should choose only one answer that best describes their condition as shown in Figure 7. The third type of the question is yes or no question, which has a similar layout as the multiple choice question while the available choices are yes and no.

Because the patient's answer is crucial to their treatment, we want to make sure that they have carefully read the question before making their decision. So we used the following design principles. Firstly, we created a clear, linear flow throughout the questions. As you can see from both figure 6 and figure 7, there are dots representing which question the user is currently on and users can navigate to different questions by clicking the pre / next button. Secondly, we provided immediate feedback to all user actions. For instance, after the user has made a choice in the figure 7 question, we offer two choices for the user "change my answer" or "confirm" as shown in figure 8. We also used the principle of making it easy to fix mistakes. The user can always go back to previous questions and change their choices by clicking the "prev" button. We also offered the user the option to change their answer when they finish every question.

Figure 8: Questionnaire example 3



- User Feedback

For the scales question, our UCDavis collaborators said that we should not use smile/sad face because that is unprofessional and not following standard. Instead, we should always display the numbers and interpretation about the number's meaning. For the multi-choice question, they said that pressing confirm should take the user to the next question. Because this way, the user won't need to manually press next button after clicking confirm button. They also pointed out that we should preserve the state of answering and if the user exist the application or go to another module before finishing the questionnaire, the answer can be saved and the patient don't have to start over again.

2.4. Phase 2

At the beginning of the spring semester, we launched our phase 2: high fidelity wireframe design, using keynote wireframe tool. In this phase, we refined our medication management module, designed the appointment module and introduced commenting feature. Because our advisors suggested that we should use ResearchKit to implement the symptom management module since it has well defined and standardized user interface, we did not keep refining our symptom management module. We will use the component ResearchKit provided during implementation. As we keep redesigning our main timeline view, we realized that a commenting feature can better serve our project goal which is to increase communication between care givers, compared to integrating messenger.

In this section, I will describe the design of medication management module, appointment module and commenting feature in phase 2. Please refer Bill's paper about the timeline view design detail and Angela's paper about the description of medication scheduling design.

2.4.1. Medication Management Module

- Description

After getting positive feedback on our pillbox metaphor, we kept using the same pillbox metaphor in phase 2. Figure 9 is the main view of medication management module. Instead of simply writing the time next to each slot, we allow user to give each slot a name, and to display the name as part of the time slot. For instance, in figure 9, the patient named the three time slots morning, afternoon and evening. Also based on the user feedback, the medication that have been taken will disappear from the time slot. So it can better reflect user's physical pillbox status. To help the user better understand the icon meaning, we displayed the meaning next to the icon. If the user clicked the medication with icon on it, instead of the detailed information of this medication, we will display the meaning of this icon as shown in figure 10.

Figure 9: Medication Management main view

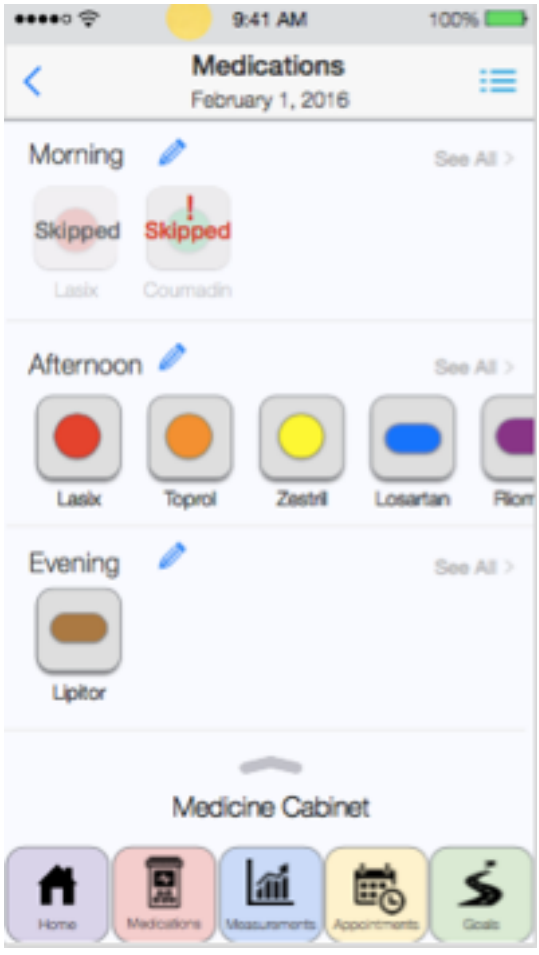
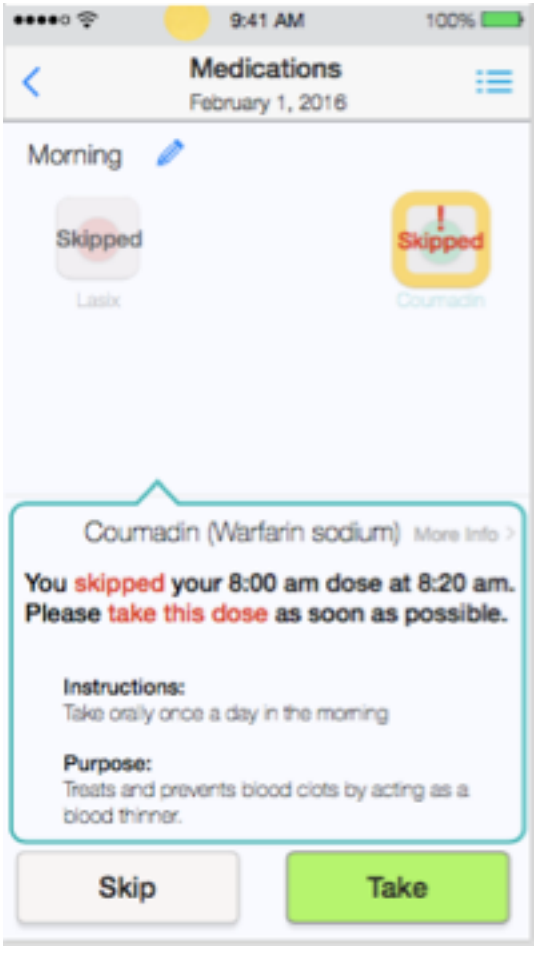


Figure 10: Skipped medication instruction



To help the user navigate through our application, after the patient clicked skip or take, we will notify them that the action has been completed and offer choice about next step. Figure 11 shows the view the patient will see after clicked skip / take.

We also introduced the medicine cabinet concept. Unscheduled medication i.e. medication that does not follow a daily routine will appear inside the medicine cabinet. The patient can access the cabinet medication by swiping the page up from the bottom. Figure 12 shows the view the patient will see when they swipe up. By selecting medication from the cabinet, the user can view the medication detailed information, log their take / skip action and input reason of taking that med as shown in figure 13. We also rephrased our change to the skip medication alert

Figure 11: Action complete notification

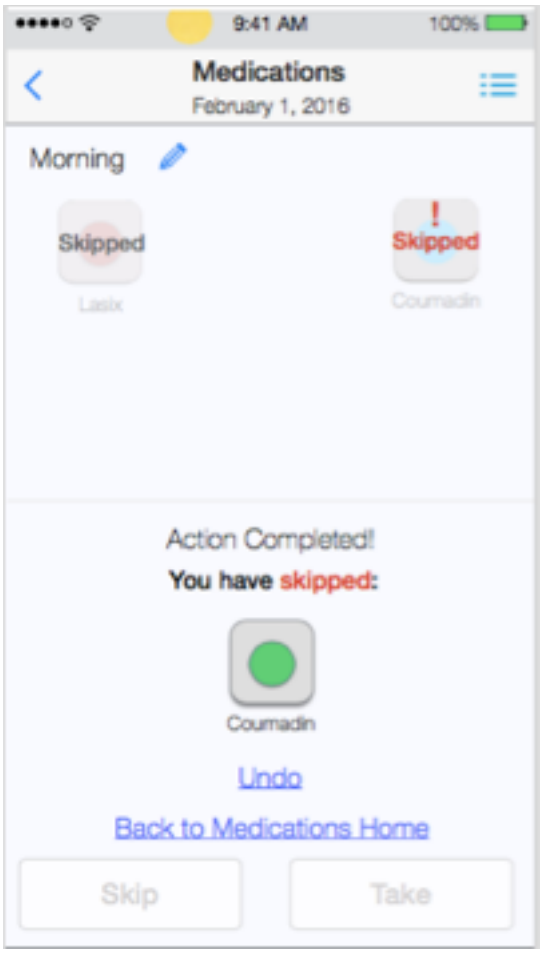
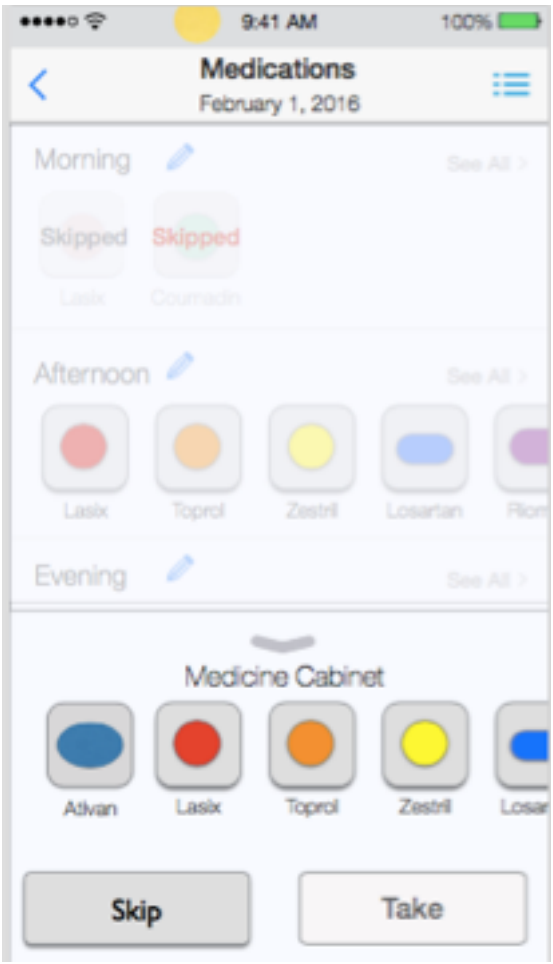


Figure 12: Medication Cabinet



message. So it's clear to the patient what is the suggested action. Please refer to figure 14 for the improved warning message design.

Figure 13: Take med in Medication Cabinet

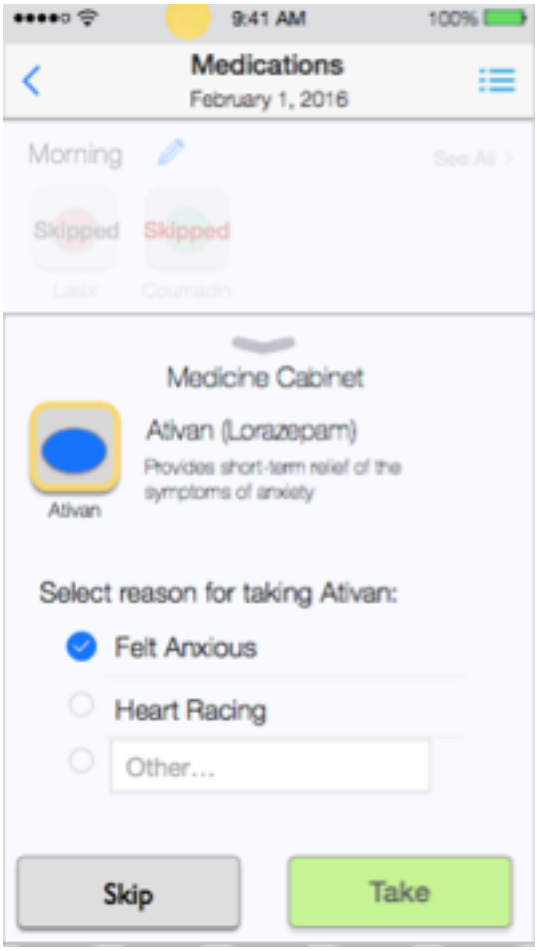
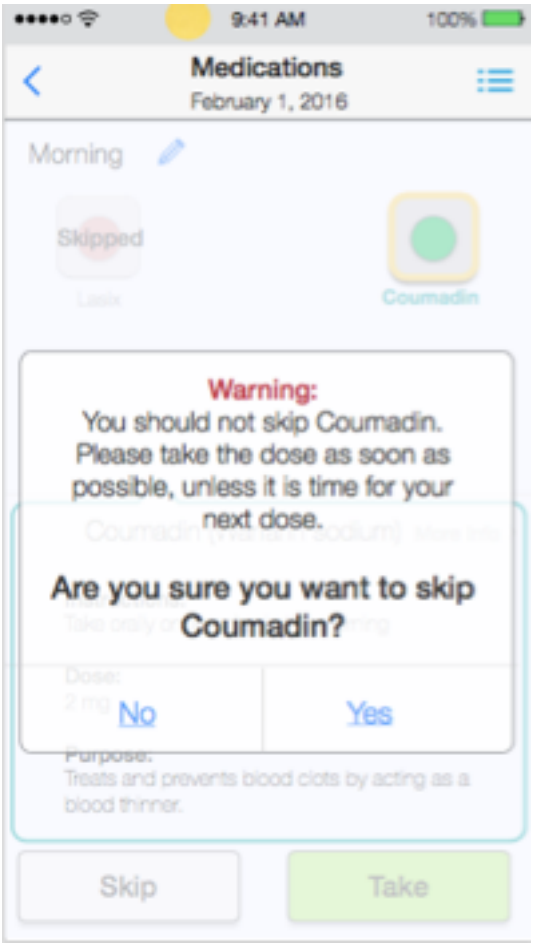


Figure 14: Alert message



- User Feedback

One patient expressed that they'd like to see the full history of their medication intaking condition, not just today's history. He also said that most of his cabinet medicines are scalable, i.e. the dosage may vary overtime he take it based on his condition. So it makes sense to let the user input the dosage information while taking the medication. Another patient said that the word "medication cabinet" is confusing for him. He suggested to use the word "as - needed meds".

2.4.2. Appointment Module

- Description

We view the appointment module as simple as a calendar view where dates with scheduled appointments are highlighted. And by clicking on that date, the patient can view the appointment detail in the lower half of that page. Figure 15 demonstrates the layout.

Figure 15: Appointment view

- User Feedback

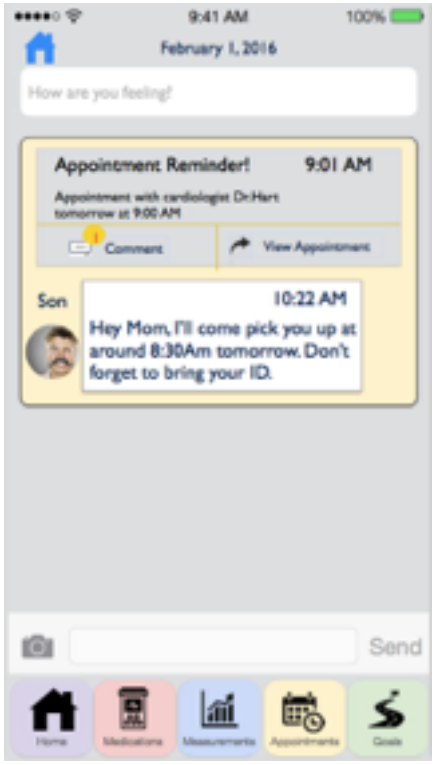
One caregiver said that she is using other calendar software to track her appointment. And it would be nice if she can import data from other calendar application. We didn't get much feedback about this module since this is a simple and straight forward module and most users went though this module very smoothly.

2.4.3. Commenting Feature

- Description

Instead of a separate messaging module, we introduced the commenting feature to the cards on our timeline. Please refer to Bill's report about the timeline view. By clicking the comment button on cards in the timeline, the patient can view other user's comment related to this card. Figure 16 is the view the user will see when clicking the comment button. The user can enter text in the input area and keep appending comment on the card.

Figure 16: Commenting Page



- User Feedback

Because this commenting on card function is very intuitive and is a well known process, none of the users had trouble figuring it out. And one patient's family really liked this function. She said it is nice to see the conversation associated with certain action / reminder / notification. In this example, the conversation is revolving around the patient's appointment with cardiologist.

2.5. Final Design

After three iterations, we started implementing the project during which we made some adjustment based on our phase 2 result. In this section, I will go over the medication management module, appointment module, on boarding module and commenting feature of our final user interface. All figures used in this section are screen shots of the interface from the final software application.

2.5.1. Medication Management Module

We split the medication management module into three segments : medication status segment, medication detailed info and fill pillbox.

Figure 17: Medication Main Page

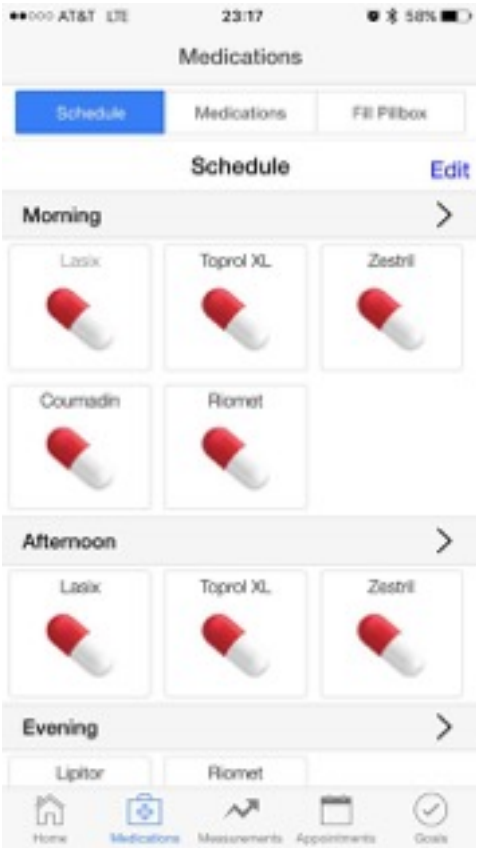
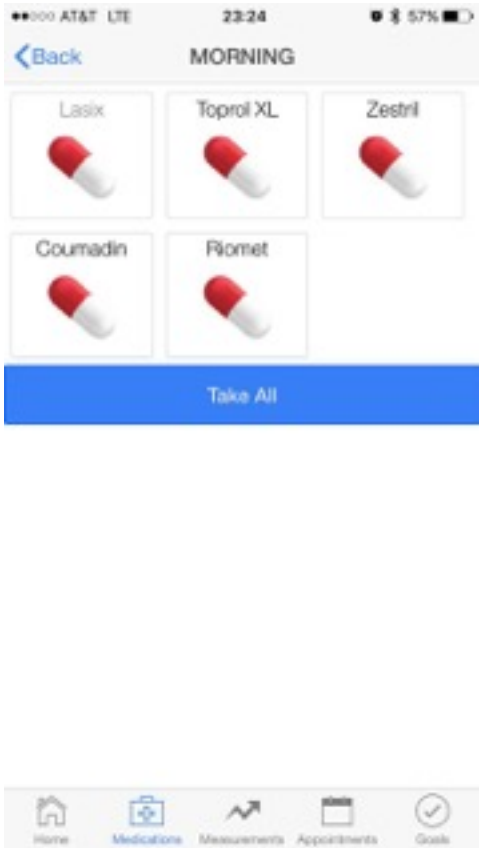
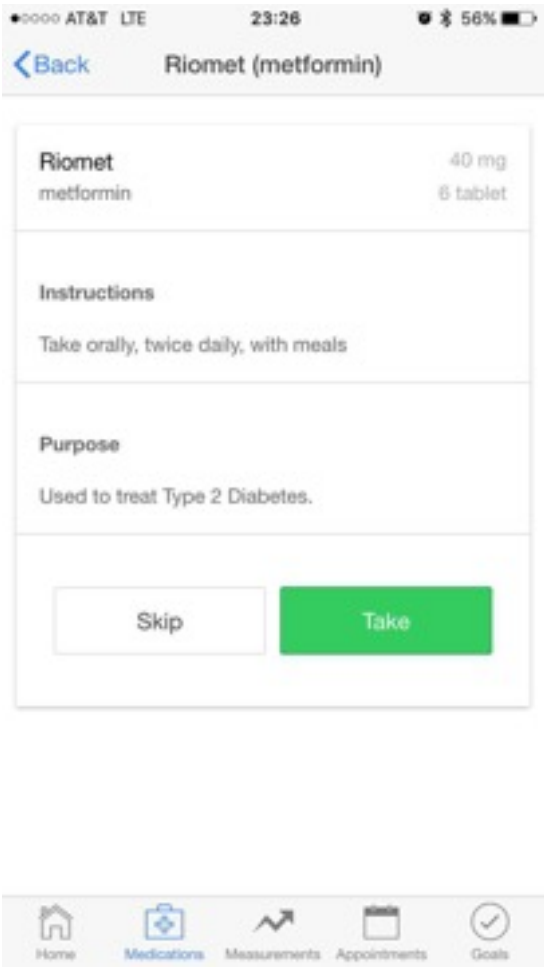


Figure 18: Medication Time slot Page



The medication status segment represents the user's current day's medication pillbox condition. And user can view medication detail and log their medication intake in this module. As shown in figure 17, the medication main page is still using the pillbox metaphor and representing each medication with icon. Because currently we are only using fake medication data, the icon for each medication is the same. But later it can easily be replaced with real medication icon. By clicking the title bar of a time slot, the user can enter the detailed page of that time slot as shown in Figure 18. As you can see, we have added the take all button on this view. Clicking the medication icon will lead the user to medication detail page. Where user can view the medication detailed information and log skip / take as shown in Figure 19.

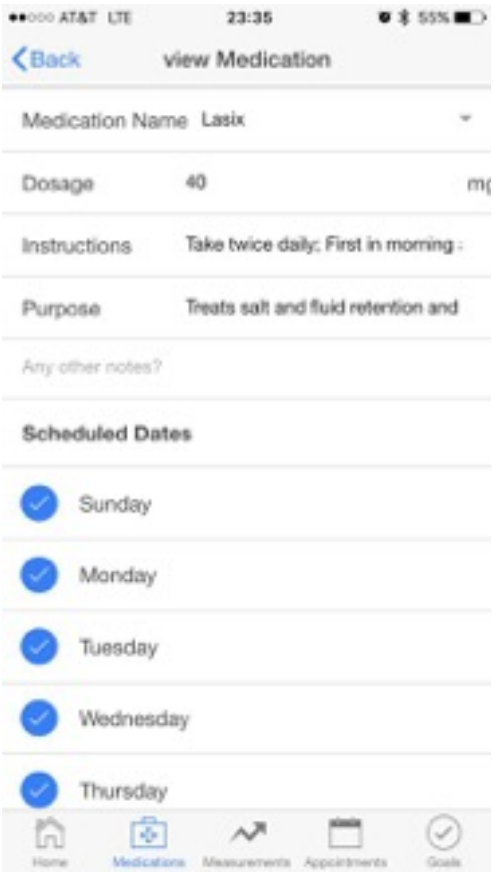
Figure 19: Detailed medication info



The medication detailed info segment is a place for the user to edit medication information and make adjustment to their medication schedule. Figure 20 is the main page of this segment. It displays the medication name of both scheduled med and as needed med. Clicking the black arrow next to the medication will lead user to the medication editing page where user can change the medication information as shown in figure 21.

Figure 20: medication detailed info main Page

Figure 21: editing medication Page



The Fill pillbox segment is a place for the user to refill their pillbox as needed. Figure 22 shows the view of this segment. The table on the upper half of the page is the mapping of the user's physical pillbox. By clicking the medication icon on the lower half of the page, the patient can view how many tablet of that type of medication should be put into their pillbox slot. Medicines that the user is currently on has green background color; medicines that has been selected before has gray background while medicines that have not been selected yet has white background. The page will be refreshed every time the user enters the fill pillbox segment.

Figure 22: fill pillbox Page

2.5.2. Appointment Module

The appointment module is a place where user can check their appointment and add a new appointment. Figure 23 is the main page of this module. It displays each appointment in the order of time with a card format. Clicking the blue plus sign on the top right corner of this page will lead the user to add a new appointment page where user can add a new appointment as shown in Figure 24.

Figure 23: appointment main page

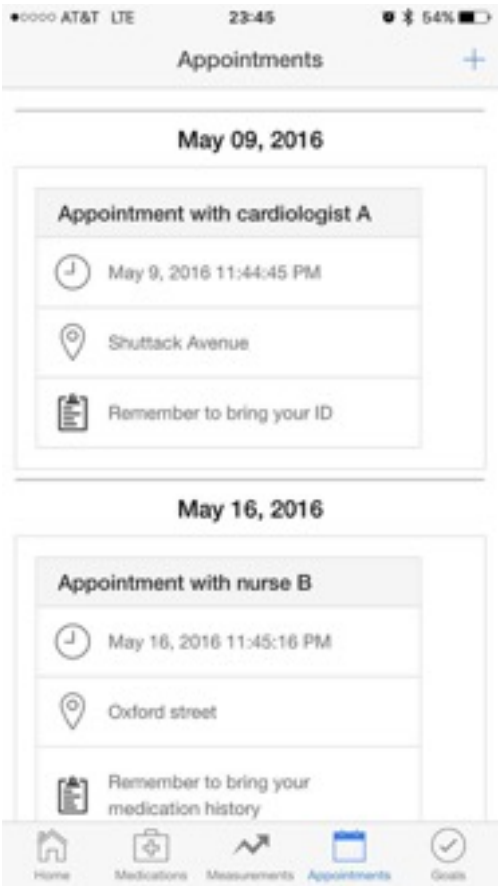
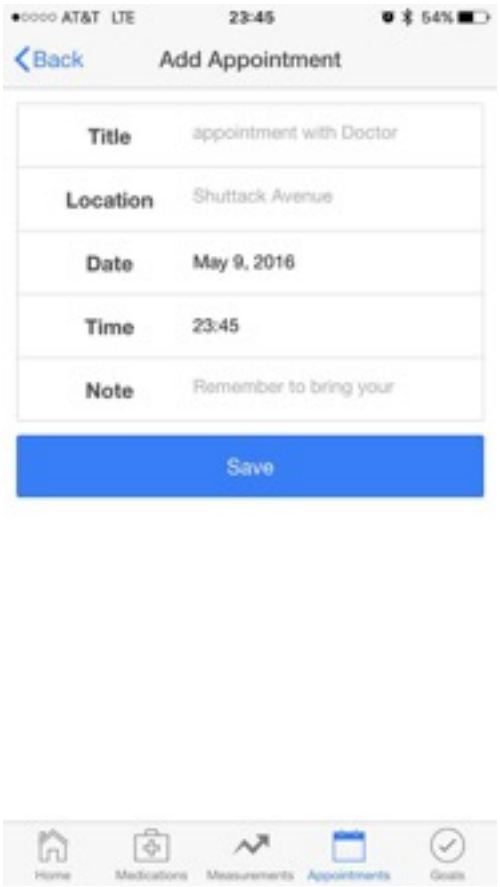


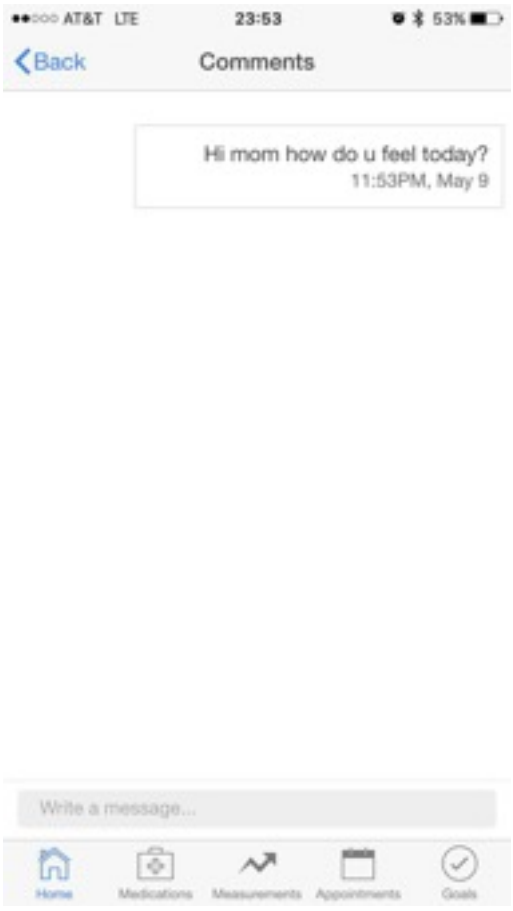
Figure 24: add an appointment page



2.5.3. Commenting Feature

This module deviated from the design in phase 2 by removing the card content. Clicking the comment button will enter the commenting page where a user can view all comments associated with this card as shown in figure 25.

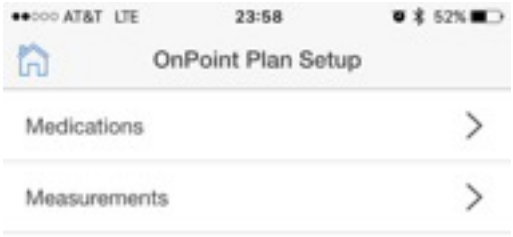
Figure 25: commenting page



2.5.4. On Boarding Module

The onboarding procedure refers to setting up patient's care plan process. After the user finish registration, he will be redirected to the onboarding's main page (Figure 26) where he can choose to set up medication plan / measurement plan. If the patient choose to setup his medication plan, he will manually input each medication information (Figure 21), then make adjustment to the generated schedule by drag and drop motion and fill his pillbox (Figure 22) in the last step. Please refer to Angela's paper about the medication schedule generation and editing description. If the patient choose to setup his measurement plan, he will manually enter his measurement schedule information. Please refer to Bill's paper about the description of this section.

Figure 26: on boarding main page



3. Implementation

3.1. Framework Choice

3.1.1. Front-end : Ionic wrapped with Cordova

Hybrid apps are basically small websites running in a browser shell in an app that has access to the native platform layer. And Ionic is a front-end HTML5 mobile development frameworks targeted at building hybrid mobile apps. In order to run as a native app, Ionic, as an HTML 5 framework, needs a native wrapper which is Cordova in our project. Even though HTML5 is mainly been used on website development, Ionic apps aren't meant to be run in a mobile browser app like Chrome or Safari, but rather the low-level browser shell like iOS's UIWebView or Android's WebView, which are wrapped by tools like Cordova/PhoneGap. (Welcome to Ionic 2016)

There are mainly four reasons we choose Ionic. The biggest reason is that the learning curve of web development technologies is much smoother compared to other native iOS application development tools such as swift and objective C. Given the team's lack of experience in iOS programming, web development leads to a much faster development cycle. Secondly, Cordova can provide us with the necessary native iOS plugins such as access to the camera, ResearchKit and HealthKit which we were planning on using in our application. Thirdly, web development technologies such as HTML, CSS, and Javascript have a much stronger community compare to swift due to swift's recent launch. Lastly, ionic framework is a cross platform tool. Which means it can compile the application to both Android and iOS operating system. This saves the team lots of efforts. Later if we want to broaden our software platform, we can relatively easy deploy onto Android platform.

3.1.2. Backend

We choose firebase, a real-time NoSQL database to store and synchronize our application's data. It can power the application's backend, including data storage, user authentication and static hosting. (Firebase 2016:04)

In our application, the commenting feature is one example of this case. Every user in the care-giving team can comment on card, which is to say, the messages attached to the card is constantly being changed by multiple users. And every user's view needs to be updated in real time. And firebase is good at handling cases where data is constantly changing by multiple users (all accessing the same database stored in the cloud). Because in the firebase, all data are stored in the cloud so it's readily available everywhere and firebase server is capable of handling the real-time data updates between devices.

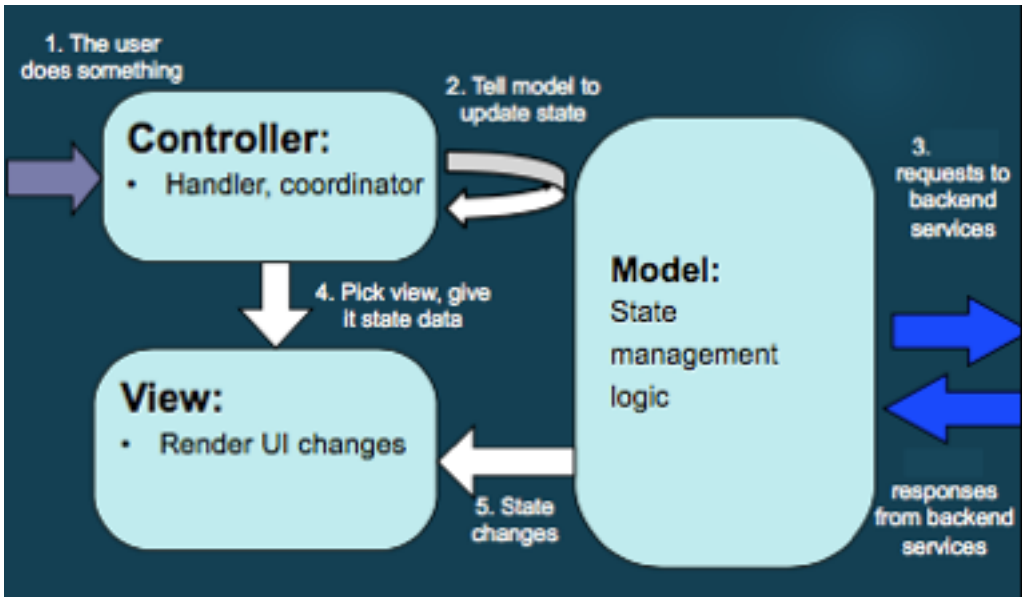
Because Ionic uses AngularJS, a JavaScript framework which binds data to the HTML view, and Firebase provides a Angular version called AngularFire, so developers can use AngularFire to easily wire up Firebase with an Ionic app.

3.2. Code Architecture

3.2.1. Front-end - MVC

Because the essence of ionic framework is the same as web application development, we are using the Model-view-controller (MVC) software architectural pattern to implement the front-end interface. Model, view and controller are three interconnected parts. Model is where the data is stored and it is responsible for pick / update the presentation of the state. View is the html interface page that the user is directly interacting with and it is responsible for display information as well as receive commands / instructions. Controller is where the main computation / logic is carried out and it is responsible for read / compute / update the state. Please refer to Figure 27 as an general MVC work flow demonstration.

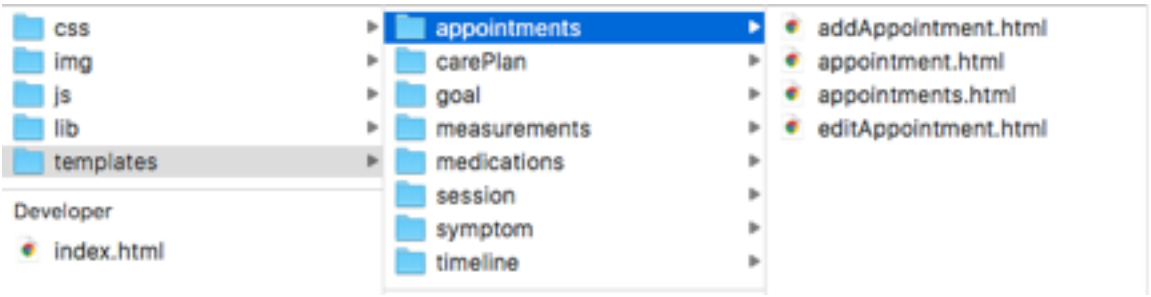
Figure 27: MVC structure



As an well established framework architecture, MVC has lots of advantages. The biggest advantage of separating the presentation (view) and the state management logic (controller) apart is that it's relatively easy to move our software onto a different platform / screen size. For instance, some aged patients has less finger dexterity and they use a bigger screen. A fine tune on the view can satisfy their needs. As mentioned in 3.1.1, ionic framework can compile our application onto Android platform. To make our application match the Android layout convention, we simple needs to replace the component we used in the view without touching the code in the module or controller.

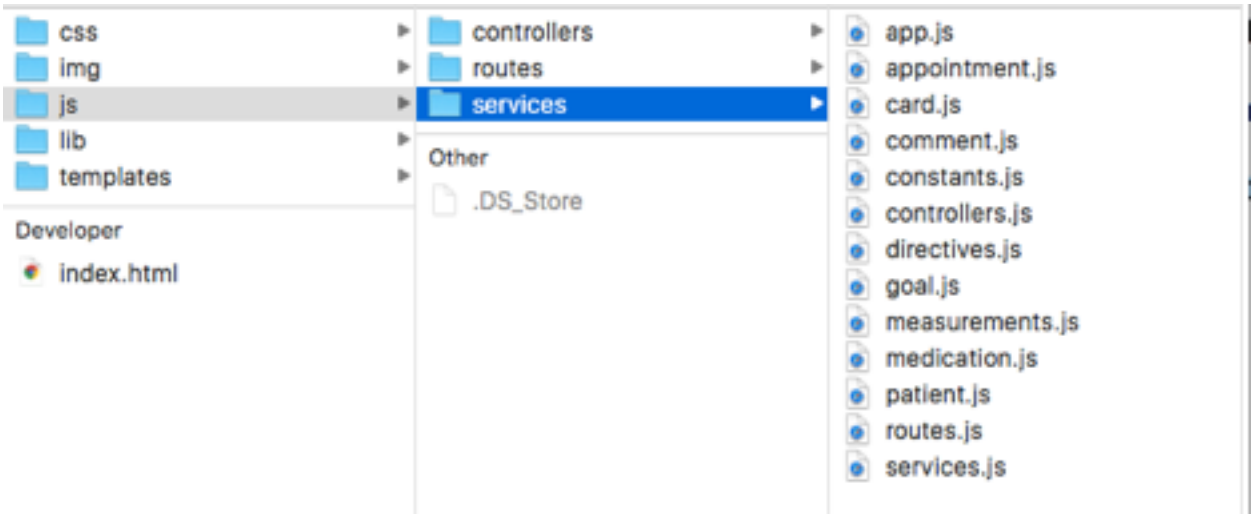
Following MVC, the outer layer has 5 folders as shown in Figure 28. The css folder is where the format of the html files are stored, the img folder holds image resources been used, the js folder contains the module and controller, the lib folder contains libraries this application is depending on such are ionic library. We can get a sense of how the templates folder is organized from figure 28. It contains all html files that compose the user interface (i.e. the view folder). Under this folder, html files for each module are enclosed in the corresponding subfolder.

Figure 28: templates folder layout



As shown in figure 29, the “js” folder has three subfolders : controllers, routes and services. Each view file in templates is corresponding to one controller while one controller can map to more than one template file. Routes folder has one js file which stores the above mentioned mapping relationship between templates file and controllers file. Services is the model file. It communicates to backend and stores data in model. As we can see from figure 29, each self contained data component is stored in a separate model file.

Figure 29: js folder layout



3.2.2. Backend

As mentioned in 3.1.2, we used Firebase framework to support our backend. Because Firebase can smoothly link with ionic front end, we did not need to implement our own server. In other words, we are using the Firebase's default server service. As an NoSQL database, Firebase data is stored as JSON objects rather than tables or records. Adding data to the JSON tree will become a key in the existing JSON structure. (Firebase, understanding Data 2016:04)

In our database, the root is patients and it contains an array of users. As we can see from figure 30, each unique 36 character long hexadecimal number is the key to a patient. Data associated with each patient are stored under corresponding keys. For instance, patient's personal information (including name, email address, age etc) are stored under the profile node. While patient's medication information is stored under medications. Figure 31 demonstrates the layer under medications node. Medications key contains an array of medication objects each stores the corresponding medicine's detailed information in a key - value format. Please refer to Bill's paper about a detailed description of the backend implementation.

Figure 30: root layer of database

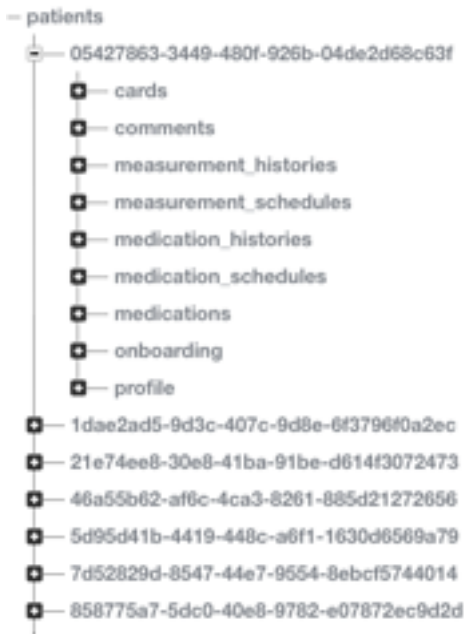


Figure 31: medication node structure

4. Future work

Due to the limited resource and time constrain, we did not put some features and functionalities as our development priority. But based on the design plan, some features ought to be included in this application. In section 4.1, I will describe all missing features. And in section 4.2, I will talk about improvement that can be made to improve the user experience.

4.1. Adding Missing Features

4.1.1. Integration With ResearchKit

As mentioned at the beginning of phase 2, we decided to use ResearchKit in our symptom management module to create the questionnaire. Quote from Research Kit website : “ResearchKit is an open source framework introduced by Apple that allows researchers and developers to create powerful apps for medical research. Easily create visual consent flows, real-time dynamic active tasks, and surveys using a variety of customizable modules that you can build upon and share with the community.” (ResearchKit 2016:05) Ionic also provides Ionic ResearchKit, an open source plugin equivalent of Apple’s ResearchKit framework built on Ionic. (Ionic ResearchKit 2015)

4.1.2. Multi-role Management

One of the main goals of this application is to increase the communication between people in the patient’s care giving team. Which means that users of different role (patient, patient’s family, caregiver) should have different interfaces and functionalities. For instance, only patient can log

their medication / measurement history. Care-givers should be able to edit the patient's clinical goals while others can edit the patient personal goals. And they should share the same timeline view which reflects the patient's care plan status.

4.1.3. Auto Generate Patient's Medication Schedule

For the testing purpose, we are using hardcoded medication schedules. Our application does not have the capability to generate an optimized medication schedule given medication information. This application is build on the assumption that a reasonable medication schedule has been generated by someone in the care giving team. To make this application useable for the variety of other users, this is the crucial functionality that this application should include. Please refer to Angela's paper about medication scheduling module detail.

4.1.4. Taking Note Of Patient's Own Health Status

In our main timeline view, there is an input text allowing the user to input their health status that are not directly related to a card. For instance, the patient may not feel well because they have eaten too much salty food at night. They should be able to log that status in the input area and that status should become a note card and been shared in the timeline view. In the current version, we only implemented the HTML view of that input area. We have not implemented the logic behind it.

4.1.5. Archive Past Schedule

Even though patient can change their medication and measurement schedule as they want, currently there is no way for them to roll back to previous schedule. That is to say, the new schedule will overwrite the past schedule and there is no record in our database about their past

schedule. For the purpose of monitoring patient's health conditionaaa, this function should be included.

4.1.6. Generate PDF Record

As mentioned in 2.2.1, to fulfill the second goal of this application and empower the patient, the patient should be able to get their full care plan history through our application. This history should be in the format of a pdf which integrates all of the user generated data. With a easy to read and well organized history, we can save the time of both specialist and patient and it can enhance the active communication between the patient and specialist.

The firebase backend has all of the raw data needed to generate such history. Extra logic is needed in the controller to generate a well formatted report.

4.1.7. Integrate Appointment Module with Other Calendar Application

As mentioned in 2.4.2, one care-giver expressed that it would be nice to import appointment data from her other calendar application. Further work is need to invest into how to integrate other calendar applications such as Google Calendar into ionic framework.

4.1.8. Alert System (red dot) Notification

As part of the multi-role management functionality, other users should receive notification while the patient's care plan status has changed once they open our application. For instance, if care-giver A replied to a card, the patient should receive notification about this event. If another care-giver B replied to A's message under the same card, then A should also receive notification. Because the patient may have more than 5 cards been generated daily, it's easy for other users

to ignore important patient status update. With a notification system, everyone in the care giving team could been effortlessly updated with the patient's latest status.

4.2. Improving User Experience

4.2.1. Scanning the Prescription to Input the Medication Information

Currently the user has to manually input medication information. We believe the user experience will be significantly improved by letting the user input medication information through taking photos of their prescription. This functionality requires to incorporate image recognition technology for the purpose of extracting medication information. On the market, CareZone (CareZone 2016), a health management application, has implemented the functionality of extract medication information from the photo of pillbox.

4.2.2. UI Design

Even though we implemented most of the user interfaces as designed, some fine interface detail needs to be further ironed out. For instance, from the design phase 0, we envisioned that the medication icon should be auto-generated based on the medicine's shape and color as shown in figure 2. On the market, My Pillbox, a pill reminder and meds tracker application has realized this functionality. This function will help the user better map their physical pillbox to our medication module's pillbox metaphor.

5. Conclusion

We believe that this application can satisfy regular needs of patients with chronic disease by tightly bringing the whole care-given team into the same page and assist them to better collaborate. At present we have a minimum viable product with basic functionalities and we are able to carry out user testing with preconfigured settings. Even though further work is needed, given the limited time and human resource, it is safe to say that this capstone project is a real success.

6. Acknowledgements

I would first like to thank my capstone advisor Professor Bjorn Hartmann. He always devotes as much time and effort as possible to help us in the past year. Without his guidance and persistent help this project could not have been possible.

I would like to express the deepest appreciation to my committee member Dan Gillette. He managed to attend almost every meeting in the past year. Whenever I ran into a trouble or had a question about my project, he is always there to help.

I would like to thank my teammates Angela Hsueh and Bill Kim. We worked closely on this project. We spend more than 6 hours every week work on this project. They are like my brother and sister. We had lots of great memories together. It is my honor to work with them.

I would like to thank our UCDavis collaborator Kathy Kim and Sarah Haynes. Without their timely and high quality feedback and help in organizing user testing, this project would not progress so smoothly.

In addition, many thanks go to Dimitri Skjorshammer, who was involved in the implementation phase for this capstone project. Without his passionate participation and input, the implementation could not have been so fast.

Lastly, I want to express my thanks to CITRIS which funded this project.

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FlowHealth <https://www.flowhealth.com/>

CareMerge < http://www.caremerge.com/web/chronic-care-management/ >

Qualcomm Life <http://www.qualcommlife.com/wireless-health>

My PillBox (Meds & Pill Reminder) < https://play.google.com/store/apps/details?id=com.tobeamaster.mypillbox&hl=en >

My Medical < https://play.google.com/store/apps/details?id=com.hyrax.mymedical&hl=en >

Preventing Chronic Disease - PCD < https://play.google.com/store/apps/details?id=gov.cdc.topical.pcd&hl=en >

Welcome to Ionic < http://ionicframework.com/docs/guide/preface.html >

Firebase < https://www.firebase.com/features.html >

Firebase - understanding data < https://www.firebase.com/docs/web/guide/understanding-data.html >

ResearchKit < http://researchkit.org/ >

Ionic ResearchKit < https://market.ionic.io/plugins/ionic-researchkit >

CareZone < https://carezone.com/home >

Chapter 2: Engineering Leadership Paper (Team-Written)

1. Introduction

Chronic disease is the greatest challenge facing the healthcare system in the United States. It is the leading cause of death, accounting for 7 out of 10 deaths each year, and over half of all Americans have at least one chronic condition (Chronic Disease Prevention and Health Promotion 2015, Gerteis, Izrael and Deitz 2014:4). In order to address the challenges and long-term nature of chronic illness, the healthcare system is evolving from a reactive system to a more proactive system aimed at preventative care and patient self-empowerment. Chronic diseases require a diverse range of medications, appointments, caregivers, and specialists to effectively manage the disease and the patient. This poses significant challenges for patients as they are left to self-manage their care between office visits. Furthermore, a patient who suffers from one chronic disease also typically suffers from multiple comorbidities such as depression, hypertension, and obesity. The varying number and magnitude of diseases a patient suffers from further complicates the delivery of efficient and effective care (Kim 2015:1). The management of such chronic conditions requires complex interactions between multiple health care specialists, multiple transitions between physical locations and different degrees of maintenance and surveillance (Kim 2015:1). Our project is a collaborative mobile platform for patients to engage in their care and more effectively manage their complex health conditions. We will analyze how our project fits into the industry landscape, our approach to marketing, and the challenges we face regarding health data regulations.

2. Industry Analysis

The healthcare landscape is constantly evolving as it adapts and transforms to best serve the needs of an ever increasing population. Our capstone project is at the center of an emerging

industry within healthcare: the disease management industry. The number of people with chronic diseases is projected to grow over the next few decades as the baby boomer generation ages and becomes more susceptible to chronic illness. (Anderson 2010:7) Moreover, the Patient Protection and Affordable Care Act has brought wellness and long-term patient care to the forefront (Curran 2015:5-6). The potential market for a comprehensive chronic care management system is huge with such a high demand from the increasing population of potential buyers.

The current state of solutions for chronic care management pales in comparison to the alarming rate at which the need for such a system is rising. Current care management revolves around infrequent checkups from a care manager and relies heavily on family members as well as self care. The disease management industry, however, has rapidly grown due to the digital revolution and technological advancements. E-patients, healthcare consumers that have taken a more active role in their own care by researching various topics online, have been a direct result of the internet and information age, (Ball and Lillis 2001:2-3). The rise of the electronic health records and the e-patient has contributed to improving information flow between doctors, patients, and caregivers. Furthermore, the propagation of medical devices and smartphone applications that pair with these devices in the realm of preventative medical care have

empowered patients to monitor their own health, and have also improved communications between patients and their care network as well as strengthened patient self-care.

With the rapid pace of technological developments, there is no shortage of developers or engineers who can invent a solution for chronic care management. The disease management industry has experienced a flurry of new entrants such as CareZone, FlowHealth, Caremerge, and CareSync, which increases the rivalry within the industry. All of these companies provide smartphone solutions to lighten the load of managing the patient's chronic disease. The disease management industry, however, is still looking for a comprehensive solution that can increase coordination and collaboration without significantly impeding the natural flow of a patient's life.

3. Market Analysis

Our project is designed to help chronic care patients understand their care plan and make the behavioral lifestyle changes necessary to improve their health outcomes; this is a central tenet to the evolving healthcare paradigm that healthcare professionals are struggling to effectively address through patient and provider training. Thus, our strategy to introduce our product to the market will be to first target healthcare professionals, who in turn, can recommend our app to their patients who have chronic diseases. Since we are partnering with the UC Davis School of Nursing, we can leverage the credibility of our partnership and proven deployment in the UC Davis Health System to market our app to healthcare professionals, and also take advantage of any network effects and connections of our partners at UC Davis. With the goal of increasing adoption rate, our product is developed on the iOS platform and will be offered in the Apple AppStore for free.

4. Regulation and Ethics

The proliferation of health-related smartphone applications, of the standalone variety and also those which pair with medical devices, has brought to the spotlight regulatory concerns over such technologies. The US Food and Drug Administration (FDA) has regulatory authority over the safety of mobile health applications and stipulates that

> "apps acting as medical devices or as accessories to medical devices will require FDA approval, whereas apps that provide users with the ability to log life events, retrieve medical content, or communicate with clinicians or health centers will not be regulated under its jurisdiction [...] the FDA has focused on safety, it has largely left the review and certification of apps to the marketplace" (Powell et al. 2014:1851).

The explosion of smartphone applications that are aimed at the healthcare industry provides convenience and ease of use for patients but also comes with various risks and security concerns. Since we are not creating a medical device, which comes with risk of liability and also requires a lengthy and complicated process of FDA approval, we must be careful to distinguish ourselves as a non-medical health management application which aggregates health data and facilitates communication and collaboration. Our challenge lies in providing enough guidance to help patients organize their health care, without crossing the line to becoming a medical device by providing diagnoses or medical recommendations. Instead, all medical advice and suggested adjustments of a patient's care plan will come from the health care professionals within the patient's healthcare team. In a nutshell, our application is an information channel, not an information generator.

Since our project centers around patient medical data, we must be mindful of regulations and laws concerning privacy. In the United States, the Health Insurance Portability and Accountability Act (HIPAA) Privacy and Security Rules establish standards governing patient health data. According to the HIPAA Privacy Rule, any “individually identifiable health information” must be protected. This includes the individual's past, present, or future physical or mental health or condition; the provision of health care to the individual; the past, present or future payment for the provision of health care to the individual and other common identifiers that could be used to identify the individual (Office for Civil Rights 2003:3-4). Because our application will aggregate various factors that describe the patient's health status and present it in a timeline view with searchable past history, we must be vigilant in the transmission and security of the information collected by the application. We will provide data privacy by creating user accounts and only giving read and write permissions to specific users designated by the care plan and the patient. Furthermore, all information transfer, such as screening questionnaire and symptom protocol results, will be encrypted. Through these precautionary steps we will safeguard the patient's health-related data and ensure their privacy is secure.

5. Conclusion

The healthcare industry is on the cusp of a digital revolution as technology empowers patients to take charge of their own health. With the ever increasing human population combined with the aging of the baby boomer generation a more efficient and effective healthcare system is a challenge that is evident now more than ever before. Our capstone group will leverage expert advice from the UC Davis School of Nursing and CITRIS to maneuver around patient data privacy concerns and create an application to meet the rising demand for a comprehensive chronic care management system. Our focus on fostering and improving collaboration and

communication will distinguish us from current solutions and will serve as the key ingredient to the solution of chronic care management.

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