

Clarence: A Mobile Application for Behavior and Wellness Tracking

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Abstract

This paper details the design, development and evaluation of Clarence, an Android application that allows users easy access to data pertaining to their physical and social behavior. All data is collected through smartphone sensors without any user effort beyond installing the application and turning on sensing capabilities. Data is then displayed with progress bars and line graphs that can be easily exported by email. Users can also choose to have a list of contacts alerted if they meet or fall below self-set goals and thresholds. This work builds on existing tools that have allowed smartphone users to track their daily behavior in order to better monitor their health, activities, and mood as well as on applications that have sought to give medical professionals more insight into their patients' behavior at home.

1. Introduction

One persistent struggle medical professionals have faced in providing optimum treatment is their inability to instruct or even accurately gauge patient behavior at home. While quality of medication and treatment is, of course, influential on outcomes, “it is apparent that the patient’s behaviour plays a profound role in health and illness” [12]. In particular, patient lifestyle and level of adherence to medical advice have long been identified as significant impactors of health outcomes that are beyond medical professionals’ control [12]. The dramatic effect of lifestyle on health can be clearly seen in a study analyzing United States mortality rates in 1990. The study found that the three most prominent contributors to mortality among Americans were all lifestyle related: tobacco use, diet and activity level, and alcohol consumption [10]. Additionally, the costs of non-adherence or an

individual's lack of cooperation with "health-related instructions or recommendations given by a healthcare provider . . . [which] may include medication regimens, dietary restrictions, exercise recommendations, preventive screenings, and other health behaviors" have been documented [4]. In addition to contributing to "illness complications and relapse [and] mortality" in individual cases, non-adherence is a global concern estimated to affect between 20% and 80% of all patients' treatment and costing \$300 billion dollars in unnecessary United States medical spending annually [4].

While medical professionals' inability to understand and instruct patients' lifestyles and level of adherence to treatment is fairly obvious, there also exist communication gaps in face-to-face meetings with patients that impact quality of care, particularly in mental health treatment. Research has found that language, race, and culture can affect patient-physician communication and lead to disparities in treatment across populations. One 2011 study found that patients' likelihood of having discussed their mental health needs with their physician differed according to race, ethnicity and language, although all groups reported a similar level of self-perceived need for mental health consultation [1]. Other studies have found communication difficulties between medical professionals and patients receiving mental health treatment generally. In 2014, researchers used linguistic analysis techniques on recordings of depressed patients meeting with their general practitioners and psychiatrists to discuss treatment plans. They found that patients were uncomfortable in the interactions, "[presenting] indirect expressions of shame and expressions suggesting alienation toward medical treatment" [8]. Furthermore, discussions on medication and dosages were somewhat stilted and one-sided. Ultimately, the authors concluded that "shared decision making," in which patients take an active role in their treatment, "did not take place because physicians did not explore patients' perspectives in depth" [8]. These studies and other literature on the topic suggest that even in face-to-face encounters, medical professionals are sometimes unable to get an accurate picture of patients' experiences at home and the effectiveness of treatment.

In recent years, technologies have been developed to help close this distance between medical professionals and patients. As will be elaborated in Section 2, new technology gives patients the

ability to track their lifestyle choices from their eating habits to their mood and provides physicians with accurate data on patient adherence. The Clarence Android application discussed in this paper combines several of the features of these technologies, including tracking, data visualization, and network notifications, in an attempt to address the communication gap between medical professionals and (particularly mental health) patients that persists in face-to-face appointments. When a patient finds it difficult to communicate medication side effects she has experienced or to make accurate and detailed statements of how her mood and activity level have been recently, she has the option of easily sending data from the application that could give objective insight to the medical professional. Furthermore, she can choose to keep her doctors up-to-date in between appointments by allowing Clarence to send SMS alerts about her health. In this way, Clarence, which takes its name from guardian angel Clarence Odbody of “It’s a Wonderful Life,” acts as a helpful intermediary between users and their support networks.

The remainder of this paper is organized as follows. Section 2 provides an overview of some existing tele-medical tools that enhance communication between patients and medical professionals and some of their common features. Section 3 describes several use cases of the Clarence application not supported by existing tools. Section 4 outlines the feature requirements of the application, while Section 5 elaborates on the design of the application as well as the methodology through which it was built. Section 6 includes screen shots of the application in progress, and Section 7 evaluates Clarence’s success using data produced by anonymous testers. Finally, this paper concludes in Section 8 by suggesting improvements and additional features to be implemented in the future.

2. Related Work

This section gives a brief overview of existing technical tools built to aid patients and medical professionals, and in many cases, facilitate communication between the two groups. Subsection 2.1 describes the introduction of new technologies to facilitate patient monitoring. Subsection 2.2 lists two features common among mobile health applications specifically. Subsection 2.3 introduces the concept of a digital social pulse and provides examples of its usage in mobile applications. Finally,

Subsection 2.3 describes which of these features Clarence supports and how Clarence builds on the existing tools discussed.

2.1. Introduction of Patient Monitoring Technologies

In the past, medical professionals' only knowledge of patients' home behavior was gleaned from "indirect – and often subjective – measures such as patient self-report and clinician judgment" [4]. While these methods are inexpensive, quick, and require no special technology, they are also frequently inaccurate. For example, research has found that these methods often lead to an underestimation of patients' non-adherence to treatment because of "retrospective recall biases, patient fears of rebuke, and patient-provider miscommunication" [4]. More objective alternatives to patient monitoring including "measuring drug metabolites in urine or serum" were too costly and required too much expertise to become widespread [4]. Similarly, interventions that allow complete patient monitoring such as hospitalization or interventions were also infeasibly expensive to implement on a large scale. The spread of personal devices including computers, smartphones, and tablets has revolutionized patient monitoring by providing methods that are inexpensive but also more accurate and detailed than traditional means. Specifically, four general types of patient monitoring technology have been introduced in recent years:

- mobile health applications
- home tele-monitoring systems equipped with medical devices and video and voice capabilities
- websites that connect patients and medical professionals
- patient portals hosting editable health records online [4]

Mobile health applications in particular have been successful in reaching a wide range of users and producing positive outcomes. Today, there are thousands of mobile applications designed to help patients manage their healthcare needs. Some of these applications aim to "remind/track medication dosing, monitor caloric intake (some by scanning bar codes of foods), provide access to medical reference information, record blood pressure and heart rate during fitness activities" among other goals [4]. The proliferation of mobile phones makes these applications easy to distribute to

patient groups. As of 2010, 82% of Americans owned a mobile phone and access is not restricted to Americans or traditionally well-served populations. In fact, mobile applications have been “utilized to reach underserved or access-starved individuals, particularly in developing countries” [4]. Furthermore, research has found that mobile applications are particularly well-suited to bridging the gap between patients and the medical professionals treating them. Patients typically approve of mobile health applications because they are easy to use and provide a “sense of anonymity” that allows them to be more honest than they might be in face-to-face meetings with practitioners [4]. Patient satisfaction has been backed up by studies on the efficacy of these applications; for example, one study found that an application helped to increase users’ activity levels over time [4]. The following subsection will give a general overview of the mobile health tools that have been built to enhance patient-practitioner communication and their features.

2.2. Typical Features of Mobile Health Applications

2.2.1. Notification Systems Many mobile health applications send automatic alerts to the patient and possibly his close contacts and doctors. These alerts are often delivered through short message service (SMS), but some are through interactive voice response (IVR) calls. Alerts to the patient typically query his behavior in order to provide information to medical professionals, or provide reminders. One such query might be whether he has taken his medication, if the application is designed to encourage or track patient adherence. An application targeted at smokers attempting to quit their habit might instead query users for the number of cigarettes they have had every few hours in order to provide feedback. A typical reminder message might prompt the patient to take his medication. Alerts sent to medical professionals and close contacts such as caretakers, family, and friends keep the patient’s support network up-to-date on any significant changes to his health. These alerts might contain data collected by wearables or other devices (e.g. blood glucose level) or allow patients “to share their results with other participants . . . for the purposes of social support, motivation, and competition” [4].

The SIMpill Medical Compliance System developed by technology consulting company Clinical

Technology Advisors is one example of an application that relies on SMS notifications [2]. As its name suggests, the system was designed to promote patient compliance. An application installed on the patient's cellphone is able to register when a pill bottle containing a SIM card is opened. When the application receives this notification, it records the event. If the patient fails to open the bottle, a reminder alert is sent to the patient. If the patient still fails to open the bottle, an alert is sent to the patient's designated caregiver. A study conducted by the SIMpill team on 155 tuberculosis patients yielded a compliance rate between 86-92% after 10 months of SIMpill usage. Furthermore, SIMpill's creators boast that the application successfully cut down on costly face-to-face time between patients and medical professionals, saying that it "frees up health workers from daily observation of patients taking their medication" [2].

2.2.2. Self-Management In much the same way that some mobile health applications query users to collect information to send to medical professionals and caregivers, some collect data to represent to users in simple graphics. This type of application aims to empower patients to better understand their health, make improvements to their lifestyles, and identify potential problems themselves.

The S Health application that comes pre-installed on Samsung phones functions as a self-management application. Samsung markets S Health as the user's "personal fitness coach" [5]. The application supports the tracking of many different aspects of user's health, lifestyles, and even environment. Built-in sensors in the device and integrated Samsung wearables are used to track the user's steps, heart rate, stress level, and ultraviolet light exposure among other measures. The user can supplement this data by manually entering in data such as her weight, calorie intake, and exercise habits. The user can review this data through "intuitive charts" generated by S Health [5]. Interestingly, S Health co-opts some conventions of video games in its design. In particular, it allows the user to set goals for herself (e.g. to walk 10,000 steps in a day) and then rewards her for reaching these milestones with positive alerts and virtual trophies. This design is aimed to "help [the user] accomplish [his or her] fitness milestones" [5].

2.3. Digital Social Pulse

Some researchers and developers are expanding on the tracking involved in self-management applications to include the user's "digital breadcrumbs" in an effort to construct a rich picture of the user's health [3]. These breadcrumbs are the data produced as the user interacts with technology throughout the day; "Answering e-mail; making phone calls; using GPS to find a post office; shopping for dinner; tracking our sleep and steps with a Fitbit" all produce digital breadcrumbs [3]. In a 2013 TEDMED Talk, Cornell Tech Computer Science Professor Deborah Estrin called for the development of mobile applications that leverage these breadcrumbs to supplement traditional medical treatment with "personalized, data-driven insights [. . .] such as early warning signs of a problem or gradual improvement in response to a treatment" [3]. Estrin believes that taken together breadcrumbs constitute a type of signature capturing the user's well being. Estrin terms the signature a "digital social pulse," saying, "[I]t's a single measure that I can look at over time that represents my well being, and social because it's something I can selectively share with a small number of friends and family" [3]. Furthermore, Estrin believes that capturing a user's digital social pulse so that she can use it to better understand their health and lifestyle constitutes "letting an individual have their data back" because this data is already being captured by "search engines, social networks, and mobile carriers" daily [3].

A growing number of applications and projects are already constructing users' digital social pulses in order to keep patients informed about their health. For example, an initiative Estrin co-founded, Open mHealth, aims to help detailed digital social pulses become a reality by facilitating data transfers between mobile health applications and devices. Open mHealth's website points out that although a huge amount of health data is collected and produced by various applications, this data is not commonly shared and is also "written in inconsistent formats" [11]. These factors pose significant challenges to integrating many sources of data into a single digital pulse. Consequently, Open mHealth works to create a "common language for health data" as well as a platform for developers [11]. One of mobile health application that builds on Open mHealth - and appears to be representative of other mHealth applications - is called MoodRhythm. This application targets

bipolar patients and "uses a phone's microphone, light sensors and accelerometer to monitor sleep and social patterns" as well as users' self-reports of mood to make lifestyle recommendations [13]. Emotion Sense is another project that utilizes digital social pulses. Built by four University of Cambridge researchers, is an Android application that collects a range of social and environmental data and relates the data to short self-assessments of mood. Aggregated user data is used in research on mood [14]. The creators of Emotion Sense also have published a collection of open source libraries that allow access to JSON-formatted data pulled from device sensors [14].

2.4. Clarence

Clarence makes use of the two common features of mobile health applications discussed above - notification systems and self-management - but builds on both of them. Following the typical model of SMS alert systems, users add contacts to be notified when there appears to be a significant change to their health. However, Clarence affords users more freedom to customize the level of information divulged than the applications previously discussed in an effort to support user privacy and independence. Specifically, users can specify which contacts receive which alerts and also add customized messages with more detail if they choose. Additionally, users have the option of easily sending visualizations of their data to any contacts by email. Clarence also adopts the design of self-management applications like S Health in allowing users to set goals for themselves, but adds to the model by also asking users to set thresholds or minimums, which may signal a health problem if they are not met. Additionally, Clarence tracks only data that can be collected automatically from the user's device unlike S Health, MoodRhythm, and Emotion Sense in order to reduce user effort.

Although Clarence currently supports the tracking of only four sensor measures and therefore does not produce a complete digital social pulse by any means, it attempts to construct the sketch of one. By tracking users' steps, Clarence attempts to gauge the user's physical health and activity level. This is supplemented by data on SMS messages and calls sent and received, which provides a window into the user's social behavior, and the amount of time the user spends on a Bluetooth-enabled devices such as a computer, which could correlate with stress if the user works on a

computer. In this way, Clarence tries to piece together a picture of the user's day-to-day physical, social and behavioral wellness to use in tracking progress and predicting health problems.

3. Use Cases

This section describes a few of Clarence's potential use cases.

3.1. Case 1: Alert Contacts for Negative Health Events

If a user becomes socially withdrawn or physically inactive due to physical or mental illness, the user's approved contacts should be notified. The change in the user's behavior should be noted automatically and without additional effort on the user's part through sensor data falling below previously set thresholds. SMS alerts would be sent only if the user has decided to add Contacts and changed her settings to allow these users to receive alerts when she misses thresholds. The user can choose to add additional context in these alerts.

3.2. Case 2: Aid Face-to-Face Patient-Medical Professional Communication

If the user is in an appointment with a medical professional and feels unable to honestly and objectively describe his experience on his current treatment regimen - a situation common among mental health patients, as described in Section 1 - he should be able to easily send the medical professional a representation of his health and behavioral data. Data transfer should be intuitive and data representation should be clear.

3.3. Case 3: Allow Users to Set Goals and Track Self-Improvement

If a patient has been struggling in a certain area, she should be able to set goals for her behavior and adjust these goals as they are met. For instance, if the user has noted that her computer usage is obsessive, Clarence should enable her to set a goal of only 300 minutes of Bluetooth-enabled device usage per day. While the user aims to meet this goal of 200 minutes and can set a more restrictive goal if she achieves it, she can also set an upper threshold of 800 minutes in order to be made aware if she has significantly over-used her computer.

4. Required Features

This section gives a brief overview of five of Clarence's features guided by the requirements of the above use cases.

4.1. Sensors

Currently, Clarence tracks four different values denoting user behavior through phone sensors:

- steps
- calls
- SMS messages
- minutes of Bluetooth-enabled device usage

Calls and SMS messages are aggregated as one value each regardless of whether the communication is outgoing or incoming. Minutes of Bluetooth usage keeps track of the amount of time the user spends in the vicinity of a Bluetooth-enabled device such as a computer. In future work, sensor tracking of hours the user spends driving, hours of television watching, and others might be easily integrated into the application by a process described in Section 5.2. As described in Use Case 1, sensing is done automatically so that the user can be sure that his contacts will be alerted of his progress regardless of whether or not he is entering in data regularly.

4.2. Goals and Thresholds

Clarence builds on the video game-inspired design of applications such as Android's S Health and other self-management tools. As discussed in the previous section, these applications allow users to set goals for themselves, such as a number of steps to walk in a day and award virtual medals when these goals are met. This design is engaging and also opens up the possibility of self-improvement through tracking; users can consistently set more stringent goals as past ones are met. Goals in this application work in the same manner as positive reinforcement or aids to becoming more social and active. Thresholds were added so that the user (and possibly other contacts) could be made aware if the user's behavior fell below some decided minimum. As in Use Case 3, a user could decide that

she would like to walk 10,000 steps and set it as a goal, but also decide that if she walks less than 1,000 steps this might be indicative of a health problem and set it as a threshold.

4.3. History

Users are able to view the complete history of their sensing data since they installed the application day-by-day. They can swipe backwards on the screen to move to the proceeding day and view a progress-bar representation of their steps, calls, SMS messages, and minutes of Bluetooth-enabled device usage for that day of sensing. For each sensor, the user's total for that day is displayed as well as his goal and threshold for that particular day. The progress bar's size is determined by the corresponding goal, except for the Bluetooth bar for which size is determined by the user's threshold. The user's total is displayed as a green progress with a second red progress indicating how far below the threshold that total falls. In order to differentiate between days easily, there is space for users to record notes about their day or mood for future reference. Finally, users can click the "Email" button in order to send a screenshot of that selected day's data. This supports Use Case 2 by allowing the user to quickly email a simple graphical display of data from a certain day to his doctor if need be.

4.4. Trends

Once at least one day's worth of sensing has been completed, users can choose to view long-term trends in their data. For each sensor, users can view and email screen shots of a simple line graph of their data since application installation. If the user from Use Case 2 would like to show his doctor a data collected since his last appointment, he can use the "Email" button to quickly transfer it.

4.5. SMS Notifications

Clarence makes use of a model supported by many existing mobile health tools: network notification. Like the SIMpill Medical Compliance System that sends messages to a patient's caregiver when the patient has failed to take her medication, Clarence allows users to specify contacts they would like to be alerted daily via SMS message when they reach their goals or fall below their thresholds.

Users add contacts and then choose one of four designations: Family Member, Medical Professional, Friend, or Other. They can then customize their settings by specifying whether each type of contact should receive goal alerts, threshold alerts or both. The aim of this feature is to keep members of the user's support network up-to-date and informed while still allowing the user complete control of his data and privacy. This feature enables the user from Use Case 1 to choose which contacts she would like alerted when she misses thresholds.

5. Architecture and Design

5.1. General Architecture

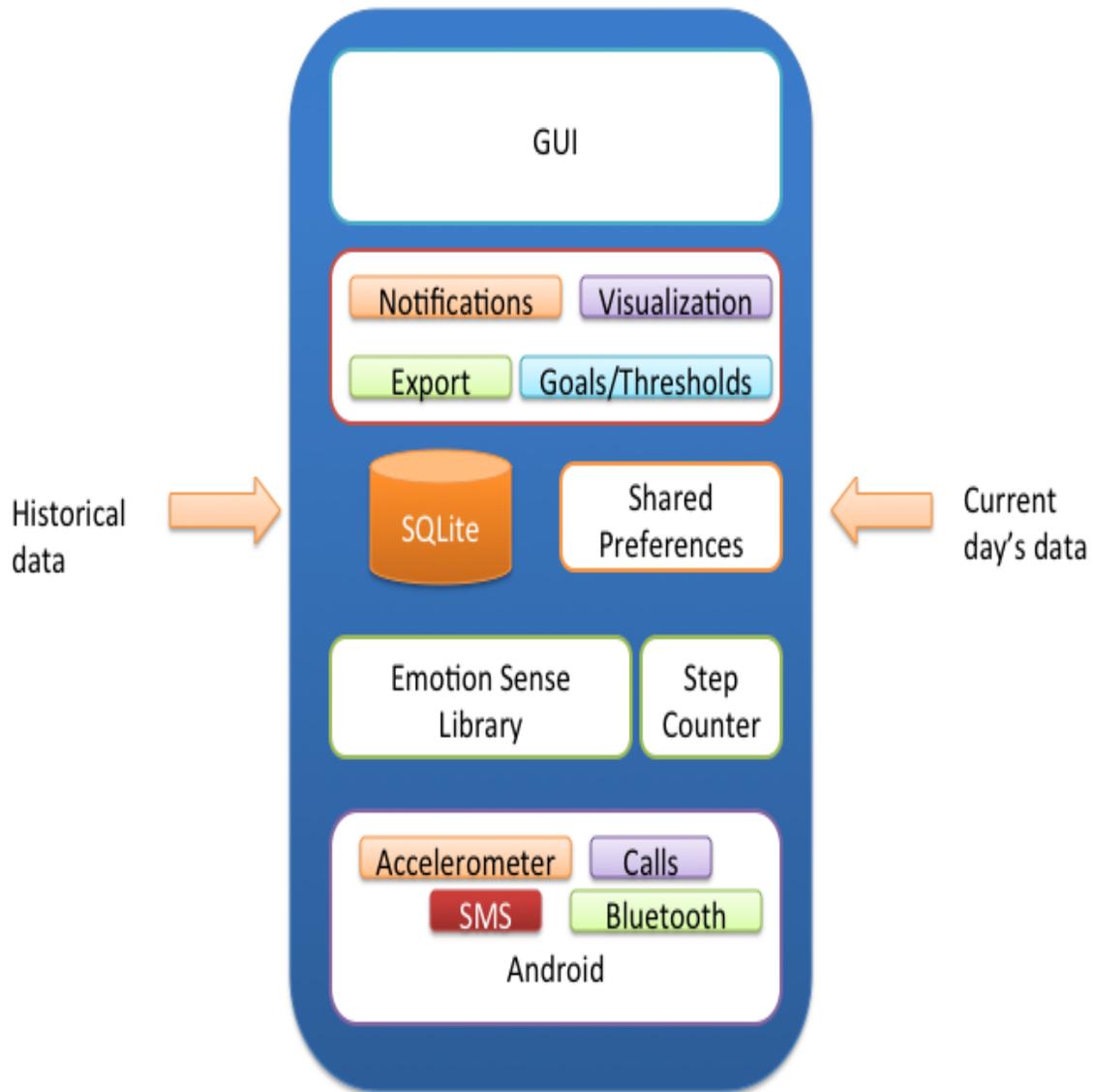


Figure 1: This figure gives a high-level overview of Clarence's architecture.

Figure 1 provides an overview of Clarence's basic architecture. The first layer from the bottom of the figure includes the hardware needed to install and properly run Clarence. As shown, the

application is built for Android. It can be run on tablets, but works best on smartphones because they can be unobtrusively kept with the user all day. Clarence relies on several built in sensors and applications pictured in this layer. Steps are sensed by the accelerometer and minutes of device usage are tallied by the Bluetooth sensor. Calls and SMS messages events are pulled from their built in Android applications. The next layer shows the sensor listeners through which Clarence accesses data pulled from these sensors and applications. Data on calls, SMS messages, and Bluetooth usage is subscribed to through the Emotion Sense Library discussed in Section 2.3, while user steps are listened for using the Android Step Counter Sensor [6]. The figure's third layer shows the storage of this data. The current day's data is stored within the application's Shared Preferences [7] where it is updated as new sensor data is received. At midnight each night, this running account of the sensor data is transferred into a local SQLite database. Internal storage was chosen so that users can be sure that their data will only leave their phone if they choose to send it to a contact or enable alerts. The fourth layer of the figure displays some of the features that access this data. The data is visualized to be displayed to the user in two ways: built-in Android progress bars and line graphs from the open source Android GraphView Library [9]. Data visualizations are exported through the user's preferred email application, while alerts triggered by sensor data meeting goals or falling below thresholds are sent via the built-in Android SMS application. Finally, goals and thresholds are stored along with the other data in Shared Preferences and in the database. These features are presented to the user through the top level of the figure, the graphical user interface (GUI). For screenshots of Clarence's GUI, see Section 6.

5.2. General Framework

While the Clarence application currently only supports four different sensors, it was designed as a general framework facilitating the addition of other sensors in the future. If, for example, a developer wanted to expand Clarence to track the number of steps the user runs, this could be done in the following steps. First, the local SQLite database where sensor data is stored would need to be updated to include a new column for storing running data. Additionally, a new key-value pair

would need to be added to the application's Shared Preferences. This pair would store the steps the user had run in the current day and be continually updated. A sensor listener class would also need to be implemented in order to register each step the user runs and update the Shared Preferences running total of steps accordingly. Finally, the various GUIs displaying sensor data would need to be slightly revised in order to display the running data. Beyond these three major steps, small adjustments must be made to the automated database storage service in order to properly record the running data and reset the current day's total stored in Shared Preferences to zero at midnight. This design was made deliberately generic so that a variety of sensors from different libraries can be added onto the application in the future or even customized to particular user groups, if need be, with little additional development.

6. Results

This section provides some screen shots of Clarence working followed by a brief description of the application's GUI.

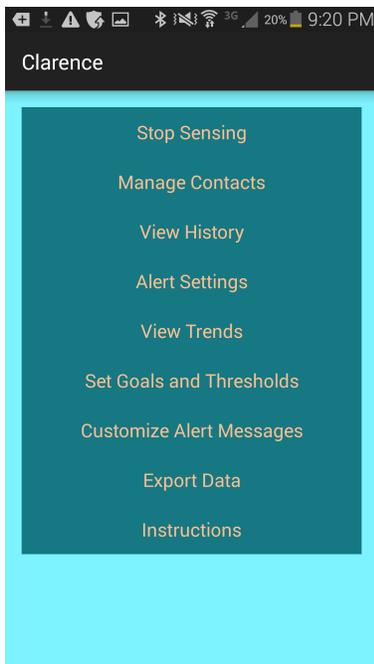


Figure 2: Clarence's home screen where the user can turn sensing on or off and navigate.

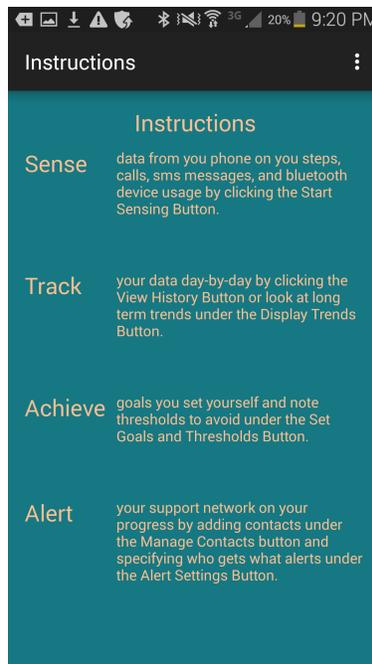


Figure 3: Instructions screen giving the user a brief introduction to Clarence's features.

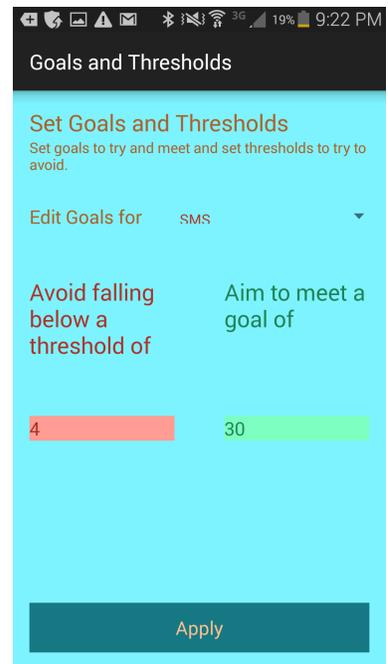


Figure 4: Screen in which users can update their goals and thresholds for each measure collected.

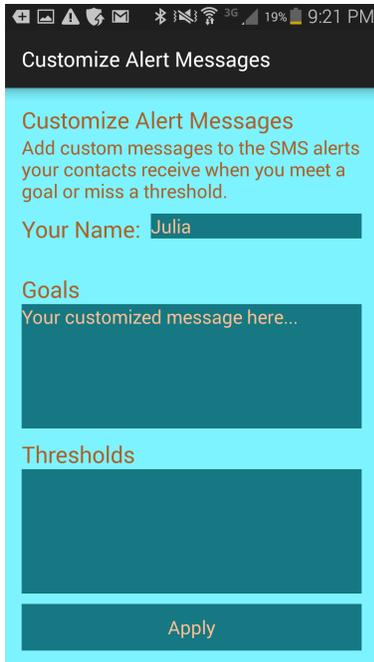


Figure 5: Users can add their own messages to alert notifications.

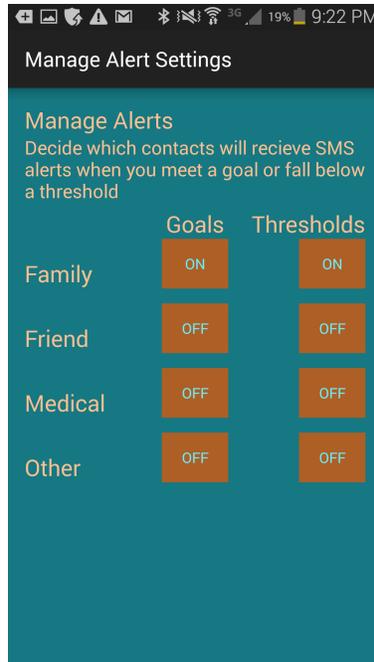


Figure 6: Users can customize which types of contact receive alerts.

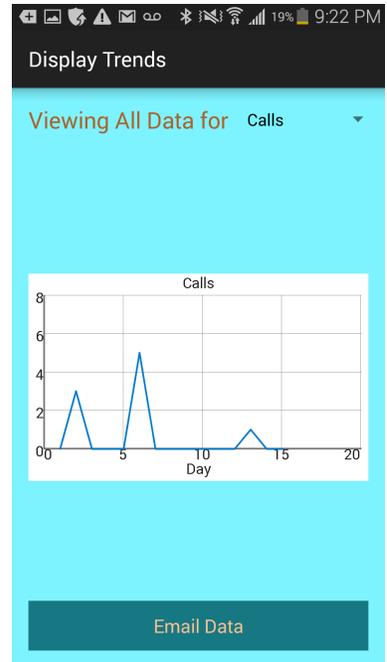


Figure 7: Users can graph historical data for a single sensor.

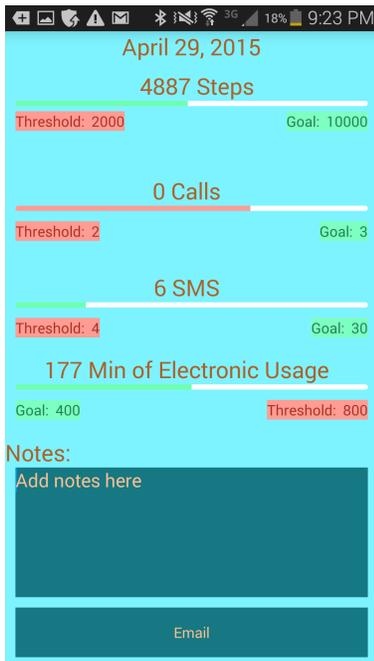


Figure 8: Data displayed for a single day of sensing.

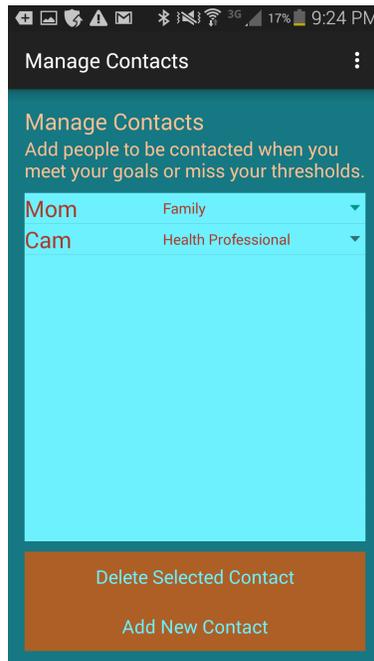


Figure 9: Screen in which user can add contacts from those stored in the device.

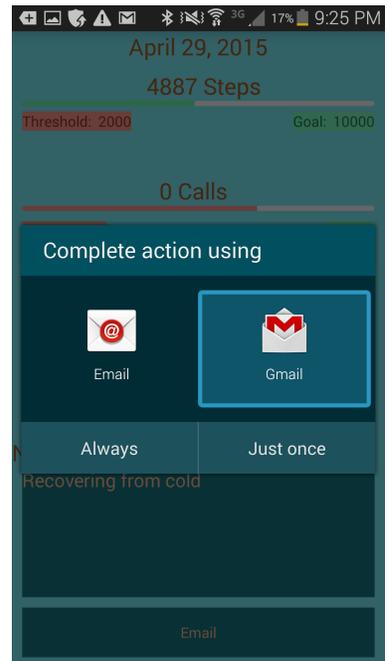


Figure 10: User is able to quickly email data.

Currently, Clarence’s GUI is very simple and captures user interaction through button clicks, swipes, and typing. Clarence’s home screen shown in Figure 2 allows users to turn sensing on and off and also navigate to other screens. The instructions shown in Figure 3 give new users a brief overview of Clarence’s features. Figures 4, 5, 6, and 9 allow users to set their own goals and thresholds, select which contacts will be alerted when they achieve or miss them, and customize the alerts that will be sent. Figures 7 and 8 show the visualizations Clarence produces of daily and long term data respectively. Figure 10 shows the user exporting one of these visualizations via email.

7. Evaluation

In order to evaluate Clarence’s success, an experimental version of the application was given to three testers. While the first tester to install the application did so on April 24th, with the other testers following a few days later, several bugs made data collection inconsistent. In fact, whole days of data were missed due to the author’s error. Nevertheless, data was produced by all testers during the testing period, which ended April 29th.

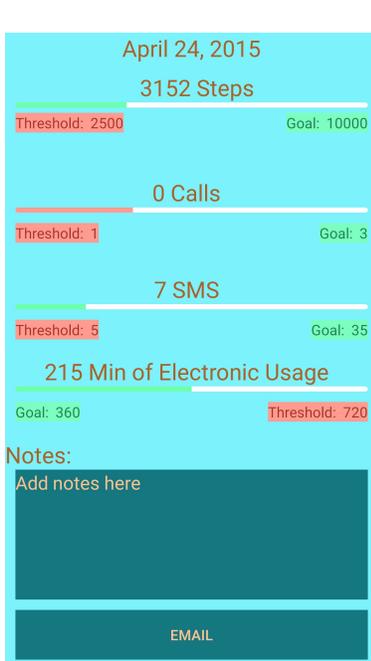


Figure 11

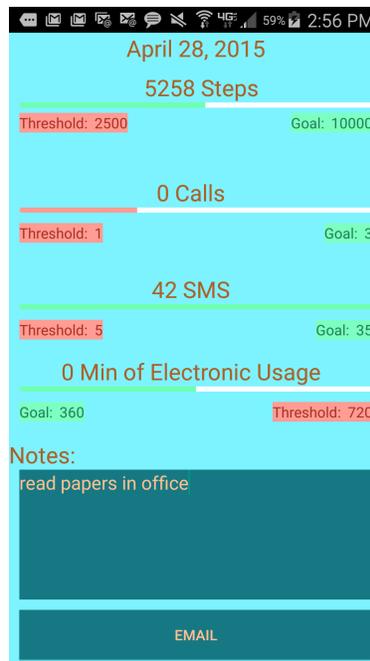


Figure 12

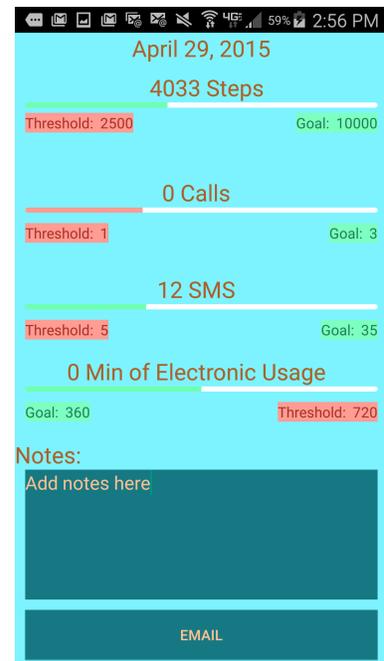


Figure 13

Figures 11, 12 and 13 show some of the tester data collected on various days of sensing. While the users’ steps, calls, and SMS message data appears accurate, it seems likely that the user whose

data is shown in Figures 12 and 13 did not have Bluetooth sensing enabled. In the future, this form of error could be corrected by alerting the user that Bluetooth sensing is not enabled, as Clarence alerts users if their device does not include an accelerometer. Additionally, the data collected seems to show that the default threshold of one call per day is perhaps too high as testers consistently missed it. In fact, no phone calls appeared in any of the testers' data which may indicate that calls are not as good of a measure of social behavior as the more popular SMS messaging, which varied considerably day-to-day.

In informal conversations with the testers, a persistent bug was brought up. Testers often found that Clarence had stopped sensing without their knowledge. In part, this seems to be due to users closing the application accidentally using the back button or the task manager. This problem could be easily fixed by adding an alert asking the user if he really intends to close the application. However, it appears that if left for long periods of time, Clarence stops sensing even when the user does not close it. This bug would need to be fixed in the future so that users could be sure data would be collected without having to monitor the application.

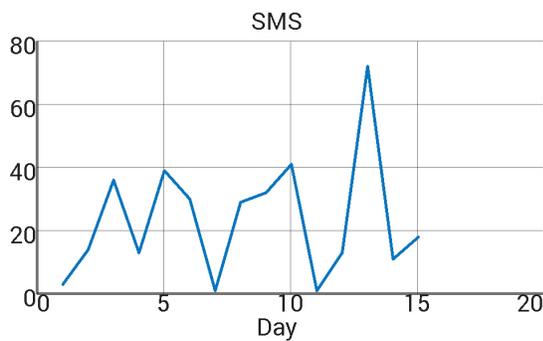


Figure 14: Author SMS data.

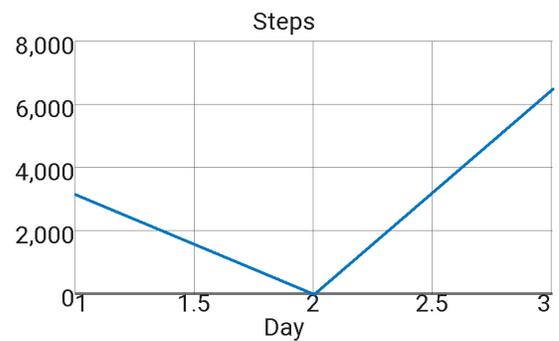


Figure 15: Tester steps data.

While tester data collected was spotty, as shown by the graph in Figure 15 displaying that the tester walked zero steps on their second day of sensing, SMS data collected by the author suggests that Clarence can be used to gain insight into users' social behavior. In particular, we can infer that day 13 of sensing was much more social than days 6 and 11.

8. Conclusion

The Clarence Android application was designed in an attempt to enhance patients' communication with the medical professionals treating them. Building on Deborah Estrin's model of the digital social pulse, Clarence pulls sensor information describing users' physical and social behavior as they go about their day and then allows them to use it for their own gain. While the experimental application distributed to testers was buggy and included only four sensors, Clarence provides a basic model that could be expanded into a more robust wellness tracker. After considerable future development, it could help give users and health professionals insights into home behavior based on untapped health indicators produced by technology use daily.

This future development might focus on several key areas. Most pressingly, Clarence needs to be debugged so that users can be sure sensing will not be unexpectedly interrupted. Along with this, it should undergo more lengthy and stringent testing. More testers combined with surveys used to gauge testers' moods and energy levels each day could be used to get a better picture of Clarence's success in providing a window into health. Additionally, its design could be made more attractive through a change of color scheme and more engaging through a more interactive user interface. For example, graphs could be made draggable and users could adjust their goals and thresholds on the graphs themselves. Clarence's data could also be formatted according to Open mHealth standards in order to be shared with other health applications. Finally, Clarence could be supplemented with additional sensors measuring other user behaviors such as running, driving, television watching, and noise levels, among others. In implementing these additional sensors using Clarence as a general framework, a much more complete digital social pulse of users could be built up and even personalized in order to more accurately gauge user health.

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10. Honor Code

This paper represents my own work in accordance with University regulations.

x Julia Johnstone

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