

# **+ Linked Living**

**2015 Master's project**

**School of Information, UC Berkeley**

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# Abstract

In a rapidly aging society like the US, supporting older adults to stay healthy is an important social and economical issue. They have strong personal desire to stay healthy and live independently for as long as possible but most elderly people currently lack effective tools to track and monitor their health and they remain concerned about future health risk, especially heart disease risk. We designed and developed Linked Living to address the issue. Linked Living is a product consisting of wearable sensors and a web platform. It continuously collects heart rate and activity data, processes the data with additional contextual information and communicates findings to seniors and their family members in a digestible and visually appealing manner.

We researched needs of our target users and explored available solutions. Starting with exploratory research, we collected users' data by using Samsung Gear S smartwatch, analyzed patterns, designed the interface, developed algorithm for data processing and activity detection, and implemented them on the web. Our product aims to provide tools for health monitoring and enable information sharing among family members, ultimately contributing to seniors' healthy independent living.

# Introduction

## Problem:

The US population of 65 years or older adults has more than tripled since 1900. There were 43.1 seniors (65+ adults) in 2012 and this population segment is expected to grow rapidly. By 2060, the population of 65+ adults is projected to be more than 92 million.<sup>1</sup> There is a growing concern about lack of support system for this rapidly growing population segment.

It is said that at least 90% of them have one or more chronic conditions. While the society struggles to expand existing resources to care for older adults to match the speed of this demographic change, there is an opportunity for technological solutions to assist independent living and health maintenance of older people. Although seniors are not often as tech savvy as younger generations, more and more of them are using mobile devices and Internet services recently.<sup>2</sup> Now is the time when technology based solutions have become viable and realistic to help them.

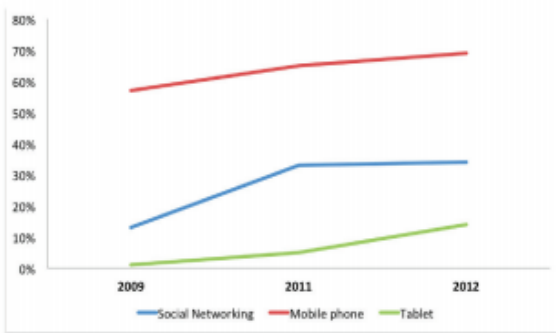


Fig 1: Trends in technology use by older (65+) adults (Pew Internet Research report 2009-2012)

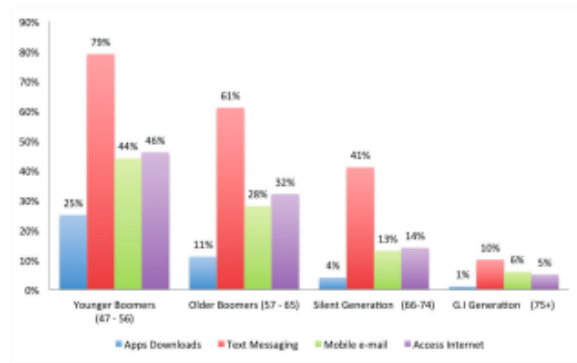


Fig 2: Mobile phone use by age groups (Pew Internet Research report 2012)

<sup>1</sup> Administration on Aging, Administration for Community Living, & U.S. Department of Health and Human Services. (2014). A profile of Older Americans: 2013. Retrieved from [http://www.aoa.acl.gov/Aging\\_Statistics/Profile/2013/docs/2013\\_Profile.pdf](http://www.aoa.acl.gov/Aging_Statistics/Profile/2013/docs/2013_Profile.pdf)

<sup>2</sup> Center for Technology and Aging. (2014). The New Era of Connected Aging. Retrieved from <http://www.techandaging.org/ConnectedAgingFramework.pdf>

## **Objective:**

We aim to provide a solution that supports older adults and people around them (e.g. family members) in monitoring health and well-being of the older adults more effectively by taking advantage of recent advancement in wearable devices, quantified-self technology, automated systems, and information visualization.

## **Team members and roles**

Kiki Liu - Front end developer

Derek Kuo - Back end developer

Noriko Misra - UX researcher and designer

# Exploratory research

We started the project with a broad idea of using wearable technology to support independent living of older people. We were strongly interested in assisting communication among stakeholders such as family members and caregivers. To deepen our understanding of the problem space and narrow down the project scope, we conducted exhaustive literature review and secondary research, interviewed various stakeholders, and also analyzed survey results collected by another group in a similar problem space.

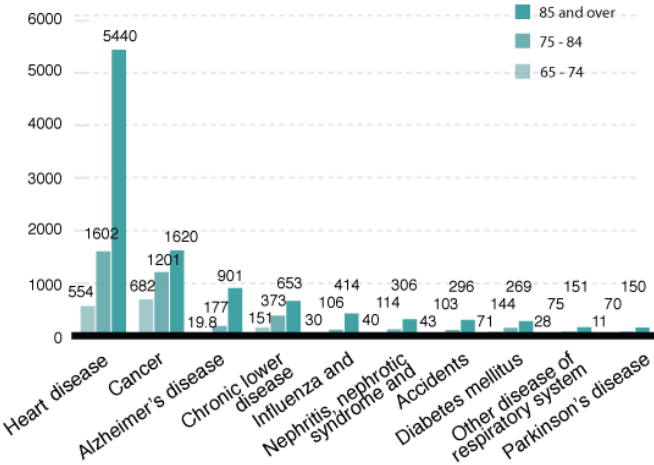
## Problem space / landscape:

Literature review and secondary research helped us understand conditions and needs of American older adults, their use of technology, and emerging landscape of technological solutions for them.

< General concerns and needs of seniors today >

Majority of older adults want to live in their home as long as possible. According to study conducted by AARP Research and Strategic Analysis in 2010, 73% of respondents (1616 people at age 45+) strongly agreed with the statement, “What I’d really like to do is to stay in my current residence for as long as possible.”<sup>3</sup>

Fig 3: Death rates for 10 leading causes in different age (2009)



<sup>3</sup> Keenan, Teresa A. (2010). Home and Community: Preferences of the 45+ Population. AARP Research & Strategic Analysis.

How is it possible when people are getting older and require support to maintain such lifestyle? It often depends on availability of family caregivers, especially when the health conditions or physical capacities of elderly persons are deteriorated. However, caregiver support ratio<sup>4</sup> is projected to decline significantly as baby boomers (people born between 1946 and 1964) start to become care recipients from caregivers. The ratio is estimated to continuously drop, from 7.2 in 2010 to 4.1 in 2030.

In such a demographic trend, staying healthy for as long as possible is crucially important for both elderly family members and their potential caregivers. Many seniors today are said to have one or more chronic conditions; heart diseases such as arthritis have been the most common among them<sup>5</sup> and heart diseases are a leading cause of death among people age 65+ (Figure 3). To prevent heart diseases, the followings are recommended by U.S. National Institute of Health. <sup>6</sup>

- Know your blood pressure and keep it under control
- Exercise regularly
- Don't smoke
- Get tested for diabetes and if you have it, keep it under control
- Know your cholesterol and triglyceride levels and keep them under control
- Eat lots of fruits and vegetables
- Maintain a healthy weight

Early intervention are highly recommended, but it is not always clear to elderly people and their family members the ways of monitoring heart conditions and practicing prevention measures effectively.

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<sup>4</sup> Defined by AARP Public Policy Institute as the number of potential caregivers at age 45-64 for care recipients at age 80+

<sup>5</sup> Administration on Aging, Administration for Community Living, & U.S. Department of Health and Human Services. (2014). A profile of Older Americans: 2013. Retrieved from [http://www.aoa.acl.gov/Aging\\_Statistics/Profile/2013/docs/2013\\_Profile.pdf](http://www.aoa.acl.gov/Aging_Statistics/Profile/2013/docs/2013_Profile.pdf)

<sup>6</sup> U.S. National Library of Medicine. (n.d.). Heart Diseases--Prevention: MedlinePlus. Retrieved from <http://www.nlm.nih.gov/medlineplus/heartdiseasesprevention.html>

< Technology use by seniors today >

According to Pew Research Center (2014)<sup>7</sup>, use of technology is steadily increasing among American seniors. 77% of people at age 65+ are now using a cell phone. Although there is still a gap compared to younger people, only 59% of older adults go online today but the trend is upward (Figure 4). Generally speaking, more and more older adults started to have access to technology products and services. In coming years, when more seniors start to use smartphones, we will see more applications available for them.<sup>8</sup>

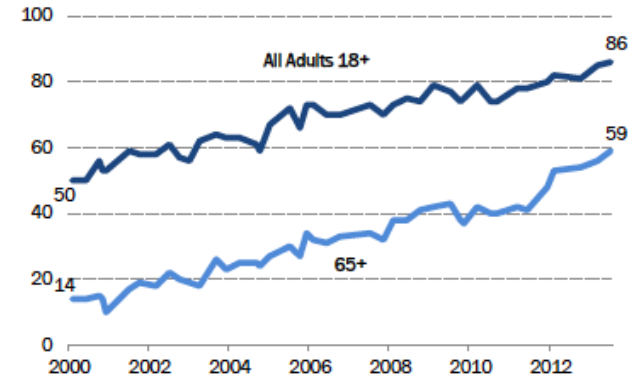
Age 65+ is a large and diverse population segment; are there differences among them in adopting a new technology? We commonly guess that older people may be more reluctant to it, but is this true?

Adoption of technology, especially

internet and broadband, is more prominent among younger, higher-income and more

#### Internet adoption over time, seniors vs. all adults

*% of seniors/all adults who go online, 2000-2013*



Pew Research Center's Internet Project tracking surveys.

PEW RESEARCH CENTER

Fig 4: (Source: Pew Research Center (2014))

#### Internet and broadband adoption among seniors

*% of seniors (ages 65 and older) who ...*

|                          | Go online | Broadband at home |
|--------------------------|-----------|-------------------|
| Total for all 65+        | 59%       | 47%               |
| <b>Age</b>               |           |                   |
| 65-69                    | 74        | 65                |
| 70-74                    | 68        | 55                |
| 75-79                    | 47        | 34                |
| 80+                      | 37        | 21                |
| <b>Education</b>         |           |                   |
| High school grad or less | 40        | 27                |
| Some college             | 69        | 57                |
| College graduate         | 87        | 76                |
| <b>Household Income</b>  |           |                   |
| <\$30,000                | 39        | 25                |
| \$30,000-\$49,999        | 63        | 51                |
| \$50,000-\$74,999        | 86        | 73                |
| \$75,000+                | 90        | 82                |

Pew Research Center's Internet Project July 18-September 30, 2013 tracking survey.

PEW RESEARCH CENTER

Fig 5: (Source: Pew Research Center (2014))

<sup>7</sup> Pew Research Center. (2014). Older Adults and Technology Use. Retrieved from [http://www.pewinternet.org/files/2014/04/PIP\\_Seniors-and-Tech-Use\\_040314.pdf](http://www.pewinternet.org/files/2014/04/PIP_Seniors-and-Tech-Use_040314.pdf)

<sup>8</sup> Mobi Health News. (2012). Elderly still not using apps for health, but tomorrow's seniors might | mobihealthnews. Retrieved from <http://mobihealthnews.com/18726/elderly-still-not-using-apps-for-health-but-tomorrows-seniors-might/>



highly educated people. This trend is also observed in other subgroups of older adults, those 80+, those with low income, and those without higher academic degrees (Figure 5). It can indicate that early adopters of technology among seniors are likely characterized by age, income and education levels.

The study points out three major obstacles that seniors face in adopting new technologies: difficulty in learning, physical constraints, and unconvinced attitude to new technologies. Many seniors need more support in learning to use a new technology. Some have physical or health conditions that make reading or use of technology more challenging while others remain skeptical about advantages of using new technologies. These characteristics must be taken into account when they are introduced to a new technology.

< Emerging landscape of technological solutions for seniors >

Though the market size is still smaller than regular consumer products, many technology products and services specifically targeting older adults have been introduced in recent years. Many of these products are categorized in the following areas<sup>9</sup>:

| Areas                                    | Examples   |
|--|--|
| Health and wellness tracking and logging | vital sign, activity, sleep, and mood monitors, emergency response devices, medication adherence support, smart toilet |
| Living environment                       | fall detection, environment sensors and video monitoring   |
| Communication support                    | social networking and contribution, physical and cognitive games and training  |

<sup>9</sup> Center for Technology and Aging. (2014). The New Era of Connected Aging. Retrieved from <http://www.techandaging.org/ConnectedAgingFramework.pdf>

|                                 |  |
|---------------------------------|--|
| Support system for stakeholders | caregiver platform, care coordination platform |
|---------------------------------|--|

As prices of wearable devices, especially those with simple functions, are declining, health and wellness tracking devices are becoming increasingly popular even among older adults. Today, one in nine (55+ adults) owns some kind of wearable fitness devices<sup>10</sup>. However, most of available services target people aged 25 to 34 and seniors don't always find a device or an application usable. According to a recent study about older adults' use and attitude with activity monitoring technology (Fausset et al, 2013)<sup>11</sup>, senior participants gave the following feedback on tested wearable devices (Fitbit, Striv, MyFitnessPal, and Nike+ FuelBand).

- No participant mentioned problems with perceived ease of use.
- More than half participants liked being able to track and see achievements of the day.
- Some expressed disappointment on data accuracy, especially of counted steps.
- Some wanted to know information such as sleep period and quality, which was not available with tested services.
- Some disliked manual data input about their diet.
- Some felt uncomfortable wearing the devices.

In this study, three out of eight expressed their intention to continue using the technology. We view the results of this study hopeful and examine factors that can motivate or demotivate seniors in continuously using wearable technologies.

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<sup>10</sup> Senior Care Corner. (n.d.). Wearable Health & Fitness Devices Can Help More Seniors & Family Caregivers | Senior Care Corner. Retrieved from <http://seniorcarecorner.com/wearable-health-fitness-devices-seniors-family-caregivers>

<sup>11</sup> Fausset, C. B., Mitzner, T. L., Price, C. E., Jones, B. D., Fain, W. B., & Rogers, W. A. (2013). Older Adults' Use of and Attitude toward Activity Monitoring Technology. Retrieved from <http://pro.sagepub.com/content/57/1/1683.full.pdf>

## **Our assumptions:**

After the secondary research, we brainstormed and developed the following assumptions. We further examined them through interviews and analysis of survey results collected by another group.

1. The care and assistance needs are diverse among seniors depending upon their life stages. These also correlate with age groups.
2. Many of healthy seniors worry about deterioration in their health in the future, especially cardiovascular diseases.
3. Encouragement from family members such as children and grandchildren can be a great motivation for seniors in monitoring and maintaining health.
4. Seniors who had experience in using computer or some kind of technology at work are more open to continue using them. However, starting to use something completely new can be overwhelming experience for them.
5. Seniors who are in higher income, highly educated group are more motivated to maintain health and are willing to use new technologies for it.
6. Exercise activities that are popular among seniors are simpler and more slow-paced compared to those popular among younger generations.

## **Interview results:**

We interviewed four senior people, three people with elderly family members, and one cardiovascular surgeon for about one hour<sup>12</sup>.

< Senior people >

We recruited four senior people through our personal connections and conducted interviews in January and February 2015. The following is information about interviewees.

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<sup>12</sup> Interview guide is available in Appendix 1

|   | Sex | Age      | Education | Living condition | Technology use             | Occupation  |
|---|-----|----------|-----------|------------------|----------------------------|---|
| 1 | M   | 72       | College   | With wife        | Windows<br>phone<br>Laptop | Retired   |
| 2 | F   | 70       | College   | Alone            | iPhone<br>Macbook          | Retired   |
| 3 | M   | late 60s | College   | With wife        | iPhone<br>Desktop          | Retired, but actively involved in volunteering activities |
| 4 | F   | late 60s | College   | With husband     | iPhone<br>Desktop          | Retired, but actively involved in volunteering activities |

Finding 1: Needs and motivation of tracking health conditions and activities change depending on people’s current health conditions.

Three out of four interviewees pointed out that their interest in the concept of tracking health conditions and exercise can change over time. One said, “I have a friend who suffers from a kidney disease. He must take care of his health with more attention and he must be more interested in this (using a wearable device and monitoring heart rate and exercise) than us, probably.” Another person said, “Right now, I am healthy, so I don’t feel I should spend time to track my health conditions. But later when my health deteriorate, I will definitely check this kind of services.” One interviewee who had obesity expressed very strong interest in the idea of monitoring her diet and weight. These comments indicate high correlation between usage and current health conditions rather

than usage and age. It was clear that concern about deterioration in health would generate incentives for seniors to track their conditions.

We were also intrigued by seemingly-little interest in health monitoring among healthy. How confident are those people? Is there any information need among these segments, which we may be able to support? Considering the importance of early intervention to prevent chronic diseases, understanding needs of currently healthy seniors is as important as those of with health problems. To our question of how much they know about their current health risk, they were not entirely confident to answer. One participant said, "I take annual medical check up and currently don't really recognize any symptoms. So I just assume I am OK now..." Another person told that he believes he is all right because he never had serious diseases before and feels fit now. But he also mentioned his concern that things can possibly change in the near future. Although all of them said that they own blood pressure measurement devices at home, none of them use it or log data regularly. They see it as extra trouble. Current ways of judging their health conditions is rather subjective, which leaves most seniors anxious.

Finding 2: Family involvement and encouragement can motivate seniors to track their health and exercise.

All of our interviewees have children with whom they communicate regularly. They usually communicate via phone calls and texts. One person said that she likes checking photos on her daughter's' Facebook page. All the interviewees usually talk about recent life experiences in general (e.g. where they went, who they met recently) with their children, but share health information only when they find something serious. Two of our interviewees said that they don't want to make their children worried unnecessarily. They said that they are happy to share more information if it helps their children stay worry-free. One person said, "Actually, my daughter in law would check such information more than my own son. He is too busy at work." Another interviewee who survived from breast cancer said, "I hope my son is interested in my health. He is my only child and I hope he cares." All of them said that they don't feel negatively when

their children try to encourage them to exercise. One person mentioned that she would feel happy to hear praise and encouraging comments from her daughter.

Finding 3: Simplicity and automation are key factors to keep seniors using wearable devices.

Two interviewees said that they own Fitbit, but no longer use them because they didn't feel immediate benefits by checking the collected data. One person told us with emphasis, "It has to be very simple and easy to use. If it's complicated or I have to enter lots of information, I will stop using it." Another interviewee mentioned the importance of capturing data that is important to users. She said, "I swim everyday, so I want a device that can track my swimming. It's my main exercise." These comments are similar to findings by Fausset et al (2014).

Finding 4: Sense and need of privacy protection are more situational and changeable.

Although all of the interviewees were open and positive to the idea of sharing information logged by wearable devices, one interviewee mentioned that he might not feel comfortable to share locational data with his family. He also said that he might feel like sharing more information when he is sick. He said, "If I am sick, I may need my son's closer attention to my health." He told us that privacy setting should be flexible enough so that he can easily adjust depending on the situations. Another interviewee also said, "I don't care much about privacy. I share everything with my daughters and I have no problem. But I understand that it may be different with other people."

< People who have elderly family members >

We recruited three people who have elderly family members through our personal connections and conducted interviews in December and January in 2015. The following is information about interviewees.

|   | Sex | Age | Situations of elderly family members | Ways to communicate with family  |
|---|-----|-----|--------------------------------------|----------------------------------|
| 1 | M   | 40  | Parents in 60s living by themselves  | Phone call, emails, skype        |
| 2 | F   | 34  | Parents in 60s living by themselves  | Skype, emails, text messages     |
| 3 | F   | 38  | Parents in 60s living by themselves  | Phone call, skype, text messages |

Finding 1: Young adults living far away from their elderly parents want to understand both physical and mental health of the parents.

All the interviewees said that they usually ask questions in their regular calls to parents to find out how healthy and happy their parents are. Those who call more frequently feel more confident in their knowledge.

Finding 2: Asking information from older parents is not always an easy task for young adults.

A male interviewee said, "I cannot keep asking my parents all the time how much exercise they did and what they ate, so it's not easy. I don't want to pressure them." A female interviewee said, "I try to guess how happy or stressed they are based on their recent social activities such as who they met and where they went. It's kind of like probing and sensing how they really are."

Finding 3: Children are interested in nutritious intake, exercise, vital signs (blood pressure, heart rate, body temperature) and sleep quality.

Interviewees typically ask questions in these areas to understand overall health conditions of their parents. A female interviewee, who was a nurse, said that she could understand health conditions based on vital signs. However, she said, "I can understand

things by looking at numbers, but most people may not be able to do so. They need help in determining whether the vital sign is good or bad."

Finding 4: Young adults want to see general patterns and changes.

All the interviewees were interested in seeing change. A female interviewee said, "I know their routine, typical conditions and activities. When hearing how my parents are, I am subconsciously checking what are different from normal, typical things."

Finding 5: Technology app may be able to find problems that older parents are not aware.

An interviewee said, "It will be harder for older people to even notice small physical problem. Say, my mother didn't recognize she had a slight fever. I found out when she finally used thermometer."

Finding 6: Communication with grandchildren can be a great motivation for older people.

An elderly interviewee said, "That'll be great, my 2 years old granddaughter reads my story... I'm more interested to see what her day looks like." Although data input is a big challenge for most older people due to lack of familiarity and limited physical capacity, allowing users of older people to communicate with their grandchildren can be an incentive for them to use our system.

Finding 7: Privacy can be a sensitive issue.

A female interviewee said, "I don't want to spy on my parents. I don't feel right about it and it may deteriorate relationship between us. I know that there are services such as putting camera inside the house to monitor. But I don't like it. It should be mutually agreed between young children and older parents about what information they collect and share."



< Cardiovascular surgeon >

We interviewed a cardiovascular surgeon to understand what data he pays attention to and how he analyzes them.

Finding 1: Continuous data log is not a very common practice for patients in early stage of cardiovascular diseases.

He mentioned three common heart rate examinations, namely regular electrocardiogram monitor, holter monitor, and insertable cardiac monitor. Only the insertable cardiac monitor can provide long-term 24-hour data, but they are mainly for severe heart disease patients. He said that continuous data log over a long period from a wearable device can be a great additional information to identify heart diseases. He also mentioned that collecting data of physical state (i.e. exercise) is valuable because he can understand contexts that impact heart rate level.

Finding 2: There are variations among individuals and setting a strict target range is not easy.

To our question whether he uses particular matrix and ranges to interpret heart rate data, he answered that he doesn't so much. He rather pays attention to beats and waveforms for a certain amount of time and tries to identify irregular patterns. He said that it is difficult to define normal range of heart rate unless it is very low or high (e.g. less than 40, or higher than 200). He pointed out that each individual has a certain variation and someone can be completely healthy even if s/he often has slightly higher range of heart rate than average of other people. This indicates that setting reference points to help interpret heart rate data is not easy.

Finding 3: Early feedback is valuable even if data accuracy is not perfect.

He was overall positive to our idea, understanding that heart rate sensors in wearable devices are not medical level quality. He said that what he can do for patients at a hospital is often for short, limited duration. Heart rate data from wearable sensors can contribute to better understanding of patients' heart conditions if he analyzes them in

combination with other data he collects. He also emphasized the importance of contextual data from wearable devices.

Finding 4: Analysis of aggregated data of large group of people may be able to provide new insights.

He mentioned that he is interested in analyzing aggregated data of large group of healthy people over time. He said that he never saw such data and may be able to find new patterns or insights if data is available.

## **Survey analysis:**

We had an opportunity to discuss with a startup company, who are creating a product to support communication between seniors and their family members, and learn from their recent large-scale survey with seniors. They collected over 600 responses from people over 55 years old and shared it with us. We found interesting results as follows.

- 33% of respondents don't regularly exercise.
- Money management, games, online shopping, and social networking are popular activities among respondents using Internet.
- Over 50% of respondents use smartphones. Phone usage is concentrated on making or receiving phone calls or sending or receiving emails and text messages.
- 97% of respondents don't have any emergency response device.
- In addition to phone calls, text messages, social networking services, and emails, in-person meeting is a common way of communication among family members (58%).

## Synthesis and what we learned:

Through our exploratory research, we learned that seniors have different needs depending upon their life stages (Figure 6). We identified that their health condition is a key factor in defining their mindset and needs in terms of health tracking and monitoring. Many at older age are aware and concerned about future health risk, especially that of cardiovascular diseases. They are in the transition stage shown in the Figure 6.

Fig 6: Needs in different life stages



Most people don't have effective ways to identify heart problems early. Some do light exercises such as walking and swimming regularly, but intensive exercise seems rare among them. In addition to it, their family members often have sense of responsibility to pay attention to seniors' health. However, current common practices of health monitoring and information sharing often lack data and rely on self-reporting by seniors, which makes early detection and intervention difficult. Depending on quality of relationship and situations, seniors can be greatly motivated by encouragement from

their family members. Privacy and data ownership are important and sensitive issues while there is no simple solution to address these issue.

To provide a new technology to solve the problem, simplicity of interaction and process automation are important. Wearable devices, which can automatically log certain types of physiological data without manual data input, have great potential as a supporting tool. Older adults who used to have exposure to technologies and use computers/phones/internet even after retirement are potential users because they are more open to the idea of using a technology solution. Although heart rate data from wearable sensors are not of medical level quality, long-term continuous data, which is not always collectable in regular medical practices, can be a great data source to identify heart problems.

# Our solution

## Scope and features:

After exploratory research, we brainstormed and defined target users, main features, a use case, and system of our project. We understand that seniors and their family members are interested in various health related data including heart rate, exercise, sleep, nutritious intake, blood pressure, weight etc. We decided to mainly focus on heart rate and exercise data. This is because our priority in this project was to find ways to simplify and automate data logging process, effectively communicate and help interpret collected data to promote healthier life of seniors rather than improvement in signal detection with raw sensor data. As we also decided not to focus on hardware development, we picked Samsung Gear S smartwatch, which has various kinds of built-in sensors and basic API for heart rate and pedometer data.

### < Target User >

| Types of users  | Technology                                  |
|---|---|
| Older adults who are currently healthy but are concerned about future cardiovascular risk | Smartwatch for data logging<br>Web platform |
| Their family members who want to understand and monitor heart conditions of seniors       | Web platform                                |
| Caregivers of the older adults  | Web platform                                |

We decided not to include medical professionals in the scope of beneficiaries for our project although we are aware of their potential information needs.

< Main features >

| Features                 | Types of data or information  |
|--------------------------|---|
| Data-logging             | <ul style="list-style-type: none"> <li>● heart rate data and certain types of exercise data without user input (i.e. walking and running)</li> <li>● sleep data with user input (user will label starting time of sleep)</li> </ul>   |
| Processing and detection | <ul style="list-style-type: none"> <li>● activities with contextual information (indoor/outdoor, weather and temperature of the location)</li> <li>● heart rate data for various heart rate matrix</li> </ul>   |
| Providing interface      | <p>&lt;Daily Digest&gt;</p> <ul style="list-style-type: none"> <li>● data visualization of daily heart rate data and activity data</li> <li>● visual storytelling timeline for a day by combining heart rate, activity, and contextual data</li> </ul> <p>&lt;Trends&gt;</p> <ul style="list-style-type: none"> <li>● data visualization of long term trends with various heart rate and activity matrix</li> <li>● filters for users to manipulate view of long term trend data</li> </ul> <p>&lt;Communication&gt;</p> <ul style="list-style-type: none"> <li>● commenting features for seniors, their family members and caregivers</li> </ul> |

< Use case >

Mary is 78 years old, living alone far from her daughter. Her daughter visits her twice a year although she calls her almost every day. Her caregiver visits her 4 times a week to help her with general checkup and minor housekeeping chores. Both of them want to understand more about how Mary is doing especially when they are not around, but she

often just says, “I’m fine, it’s the same as usual.” She doesn’t remember all the details and wouldn’t tell much until a problem emerges.

Since Mary started using our product, her daughter and caregiver start to learn more about Mary’s life and heart rate levels. It enables her daughter and caregiver to communicate with her more effectively. First, they are more proactive about her health problems; they recently identified an increasing trend of Mary’s heart rate at rest. They also noticed that Mary hardly exercises. So they encourage her to take a walk for 15 minutes everyday in the morning. They can see in our web platform that Mary is doing walking exercise on some days. Her daughter posts praises for Mary’s behavioral change and hopes that heart rate level also gradually improves over time. Everyone feels not only more effective, but also more connected.

< System >

|                        |   |
|------------------------|---|
| Device                 | Samsung Gear S (we don’t include full scale smartwatch application in this project)   |
| Sensors                | heart rate, pedometer, light sensor, and gps  |
| Input Data from sensor | <ul style="list-style-type: none"> <li>● heart rate:<br/>An attribute to indicate the heart rate in beats per minute.</li> <li>● pedometer:<br/>Current activity - Running, Walking, Not Moving<br/>Speed<br/>Cumulative distance - Cumulative distance traveled since last start<br/>Cumulative total step count - Cumulative walking and running step count since last start.</li> <li>● light sensor:<br/>Ambient light level in lux.</li> </ul> |

|                   |  |
|-------------------|--|
|                   | <ul style="list-style-type: none"> <li>• gps:<br/>Latitude, longitude, speed, timestamp</li> </ul>   |
| Other data source | Weather and temperature data from open data source   |
| Output            | Providing seniors, their family members and caregivers summary of heart condition, overall mobility, and exercise with visual storytelling UI in our web platform. |

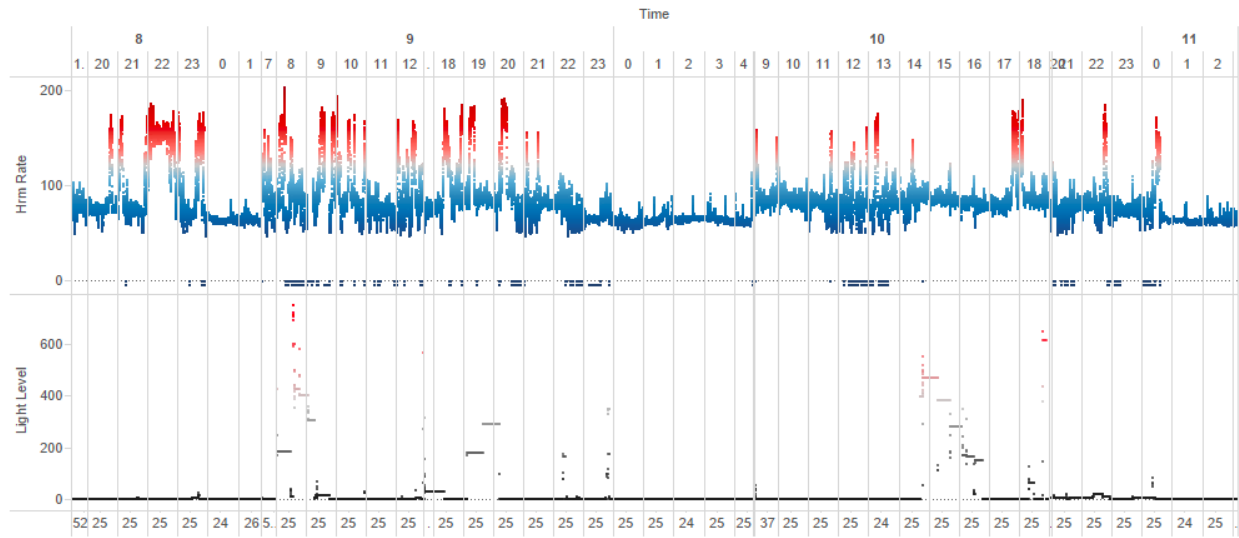
**Initial exploratory data analysis:**

To deepen our understanding and to identify important matrix for heart rate and activities, we collected three types of data (resting, walking, and running) from 13 people including 10 people at age 25-35 and 3 people at age 65-70. We visualized them in Tableau and Figure 7 is a sample from the dataset.



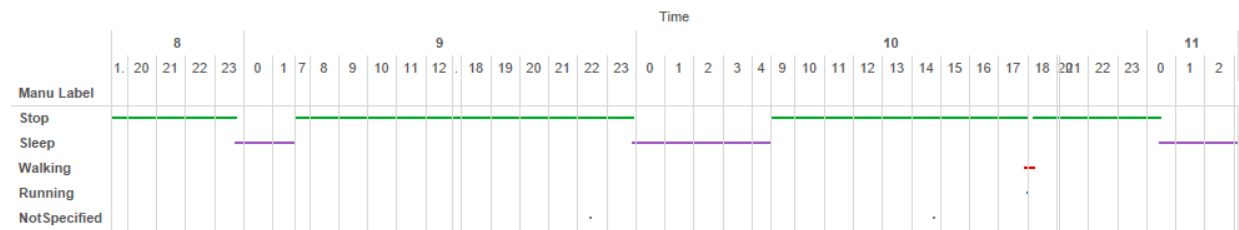
Fig 7: Tableau visualization of heart rate, light level, manual activity label, and pedometer data

HR&Light

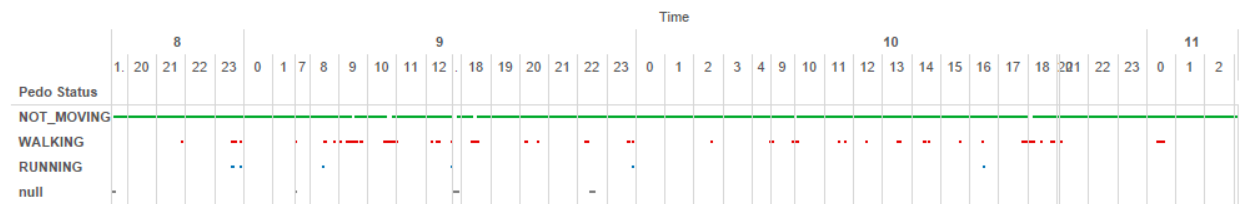


Manu\_label

Manu\_label



Pedo\_status



With heart rate data, we found various patterns listed below.

- People usually have fewer fluctuations in their heart rate during sleep.
- Heart rate tends to rise during the exercise period.
- Heart rate at rest data has peaks, which is probably caused by arousals from other physiological or pathological conditions. (Heart rate at rest is defined as “heart rate when you are not physically exercising but awake.”)

- There are days when people have higher maximum heart rate and/or higher levels of heart rate than other days. We cannot figure out whether it comes from positive or negative stress/arousal or pathological conditions, but it is reasonable to think that their heart is experiencing higher pressure on these days.

We also reviewed recent medical research on heart rate and analyzed types of data researchers use and their interpretation methods. Many studies use resting heart rate and maximum heart rate as matrix. It is said that higher resting heart rate correlates with higher mortality rate even among people without cardiovascular diseases. Risk of heart attack also increases when heart rate rises for people with cardiovascular diseases.<sup>13</sup>

On the other hand, we observed the following patterns with pedometer data:

- Pedometer API returns status data every second. It fluctuates as people stop time by time while walking or running. We need to process the data and detect activities based on our definition of activities.
- Unlike running, walking can be either an exercise or a general move. Since people continue to walk for longer time when it is an exercise, we need to distinguish based on duration.
- Heart rate can stay high whether it is exercise walk or general move walk because arousal can be caused by psychological factors, too. It is not easy to distinguish different kinds of walks based on heart rate.

Although it is difficult to completely understand the difference between younger and older adults' data with such a small sample size, we observed following:

- Older adults' heart rates tend to have lower range. It is observable in heart rate levels during sleep, exercise, and rest.
- When older adults start to have mobility issues, their walking speed is likely to decline and frequency of stops may increase. It can make activity detection

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<sup>13</sup> Wikipedia. (n.d.). Heart rate - Wikipedia, the free encyclopedia. Retrieved May 7, 2015, from [http://en.wikipedia.org/wiki/Heart\\_rate#Maximum\\_heart\\_rate](http://en.wikipedia.org/wiki/Heart_rate#Maximum_heart_rate)

harder. In our project, we decided not to analyze this further as we focus on healthy seniors who are concerned with heart risk in the future.

Based on these findings and data collected by our device, we decided to focus on the following matrix for visualization in trend view.

|            |   |
|------------|---|
| Heart rate | <ul style="list-style-type: none"><li>● Heart rate during sleep</li><li>● Heart rate at rest</li><li>● Daily maximum heart rate</li><li>● Percentage of time with heart rate above certain levels (e.g. 180, 100)</li></ul> |
| Exercise   | <ul style="list-style-type: none"><li>● Hours of sleep</li><li>● Minutes of exercise</li><li>● Minutes of intense exercise (intense exercise is defined as exercise with average heart rate above 120)</li></ul>            |
| Mobility   | <ul style="list-style-type: none"><li>● Total steps (including steps from both exercise and general move)</li></ul>   |

## Design:

< Persona >

Based on research findings and project scope, we created three personas. We used them as a guide in iterative product design process.



Persona 1: Joe

Age: 55

Occupation: Business management in a tech company

Current Health Concern: Risk of diabetes

Hobby: Tennis

Family: Wife, daughter and son (age of 20 and 23), parents (age 80)

Familiarity with Technology: High

Joe is a successful businessperson who plans to retire in a few years. He is currently healthy, but is concerned about risk of diabetes. His mother became diabetic at age of 61. Although he likes eating high calorie Chinese food and drinking alcohol, he has started to think that he probably should refrain to maintain his health. He plays tennis with his wife and his friends on weekends, but he is not sure whether he is exercising sufficiently.



Persona 2: Maggie

Age: 68

Occupation: Retired

Current Health Concern: Risk of heart disease

Hobby: Knitting

Family: Two daughters (age of 38 and 44)

Familiarity with Technology: Medium

Maggie retired 8 years ago and stays at home alone. She doesn't have on-going serious diseases, but feels weak in her knees in recent years. Her concern is risk of heart disease because she sometimes feels her heart is beating very fast just after a bit of walk. Although she hasn't been diagnosed as having any major problem, she is afraid that it may happen in near future. She likes sitting inside and knitting, but feels that she

may need to go outside and exercise more to stay healthy. Her daughters call her almost everyday and ask about her well being, but feel that they don't really know about her conditions. They also communicate via Facebook.



Persona 3: Harry

Age: 75

Occupation: Retired

Current Health Concern: Heart disease (occasional pain)

Hobby: Reading

Family: Wife, son (age of 45) and grandchildren (age 15 and 12)

Familiarity with Technology: Low

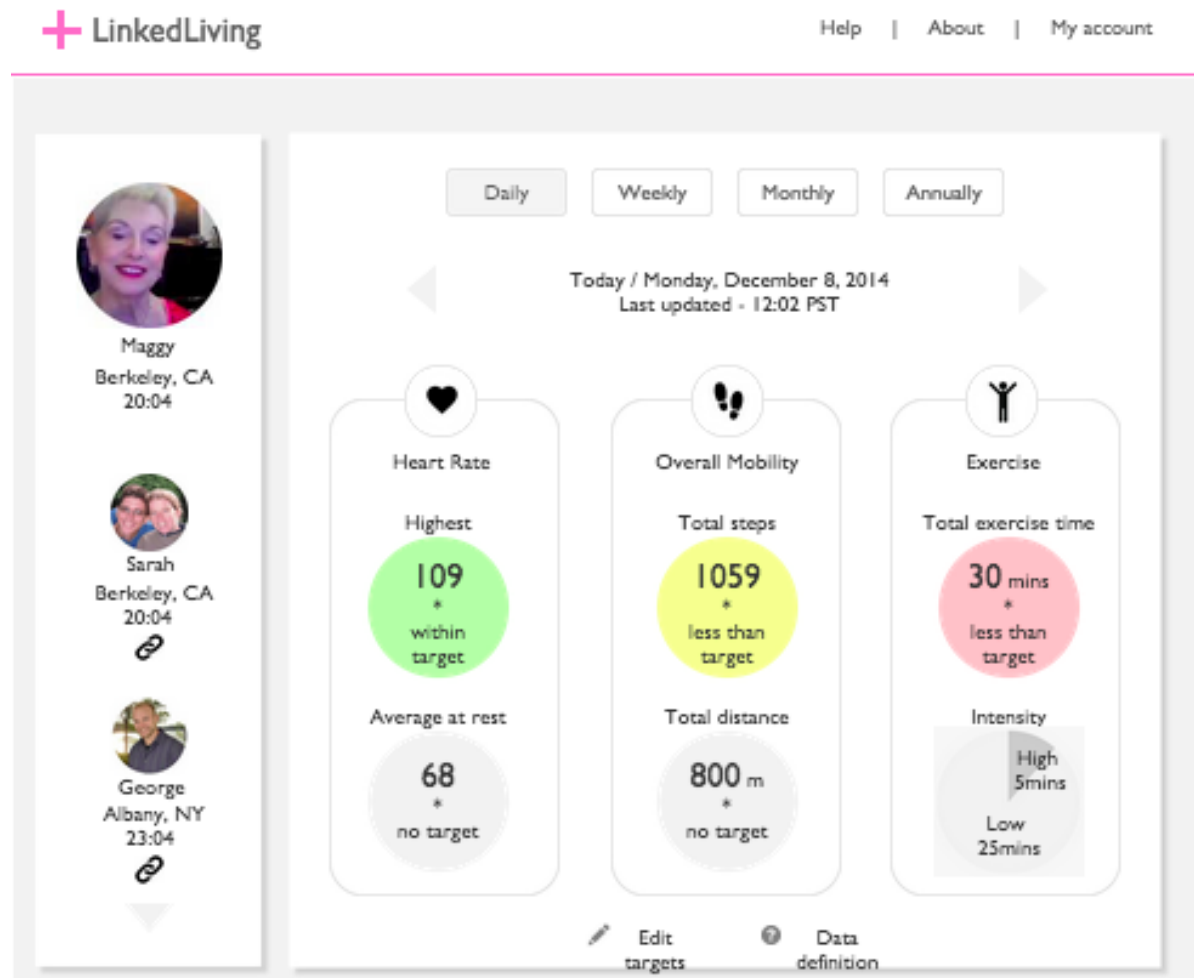
Harry lives with his wife in a suburb. He was diagnosed with cardiac angina and had an operation a few years ago. He has home sphygmomanometer and sometimes checks his heart condition. But he often forgets to log the data and doesn't really know whether he is getting better or worse until he sees a doctor. He has a cell phone but doesn't use it more than calling or occasionally texting. He loves talking to his grandchildren and looks forward to their visit twice a year. Harry feels very happy when his son sends some photos of them. His son and daughter-in-law as well as his wife worry about his health, but don't really know what they should do.

< UI Design >

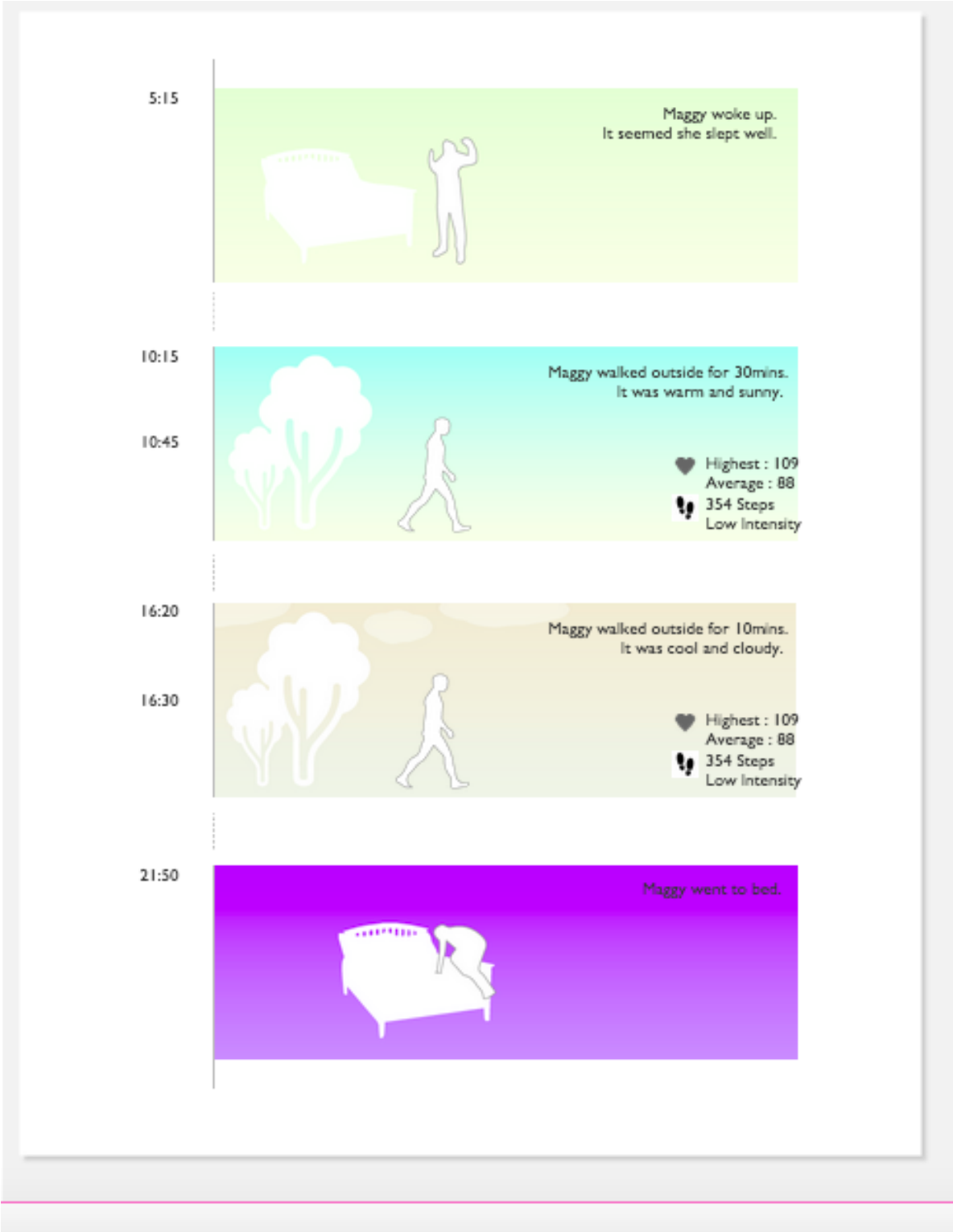
We designed UIs including daily data summary and trend view through iterative process. To get feedback from someone with a fresh eye, we conducted think-aloud sessions with a few people for each component.

- First iteration and interactive mockup

We designed data dashboard for daily view. Colored circles intend to communicate whether the data is within a target range. Users can move to previous or next day by clicking triangles near the date title. On the left, we display people who have access to the information.

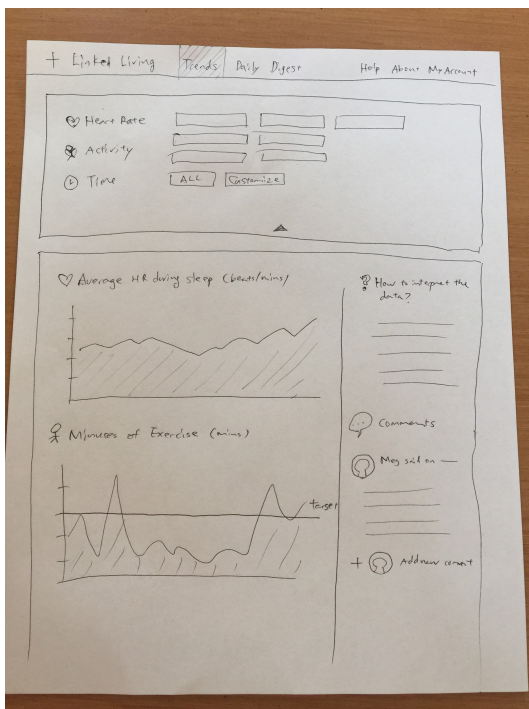
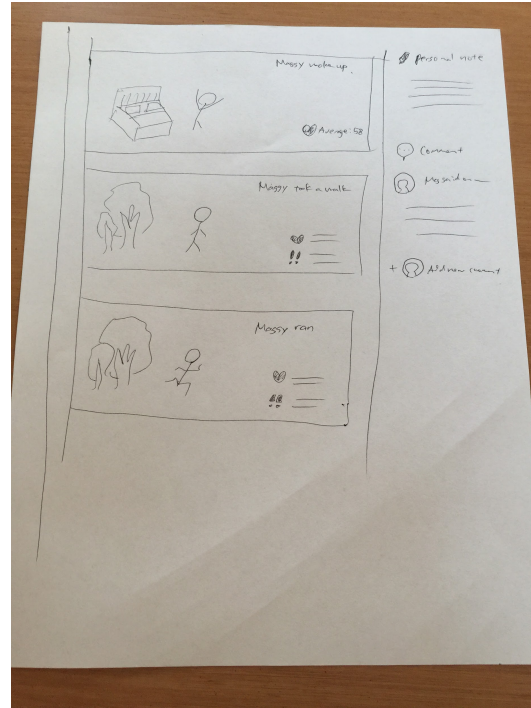
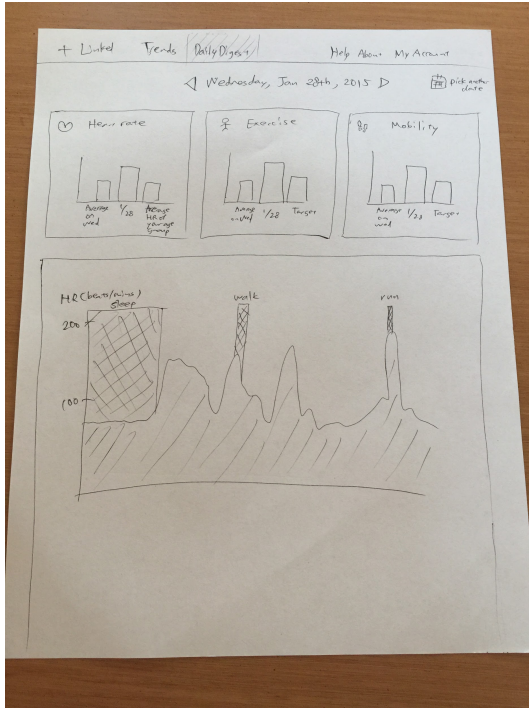


Users can see visual timeline to understand how a senior user wearing a watch has spent time during a day. We create images of multiple layered that are generated based on data.



- Second iteration and paper prototype

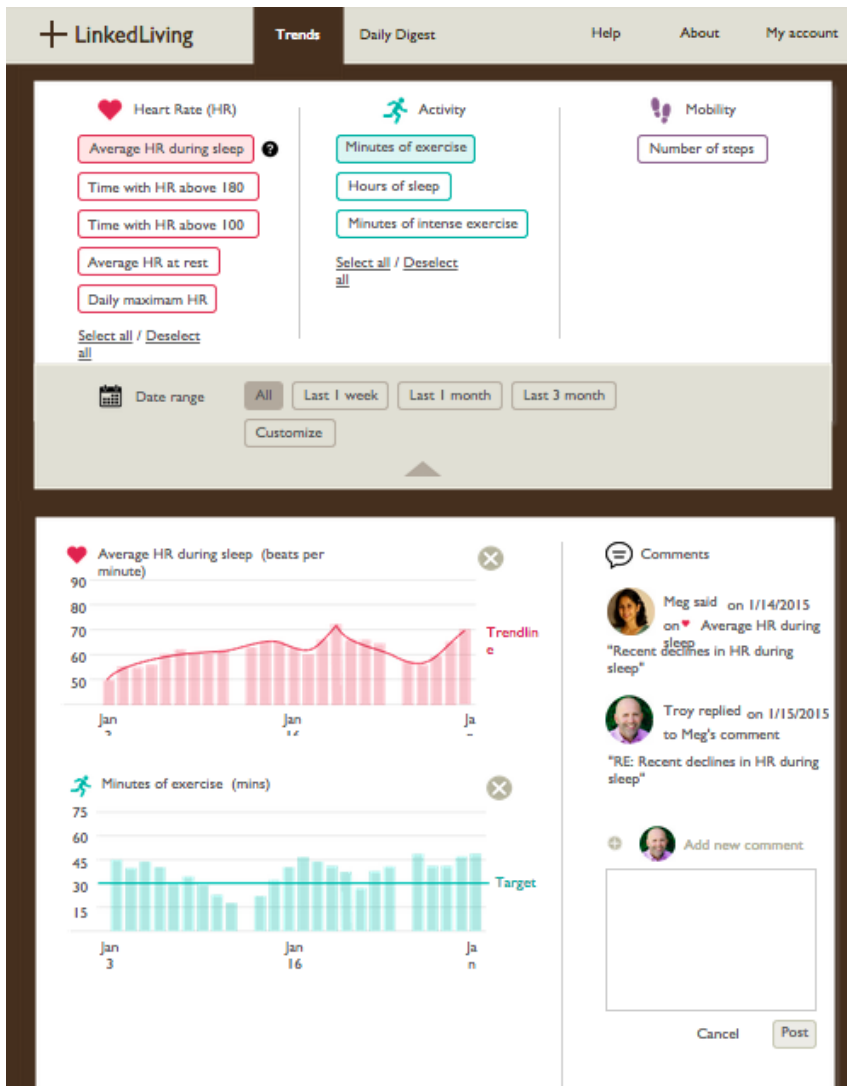
After receiving feedback from a couple of people and organizing information and features, we developed a paper prototype for the next iteration. This time we tried to use more graphs and reference points so that users can compare different numbers easily.



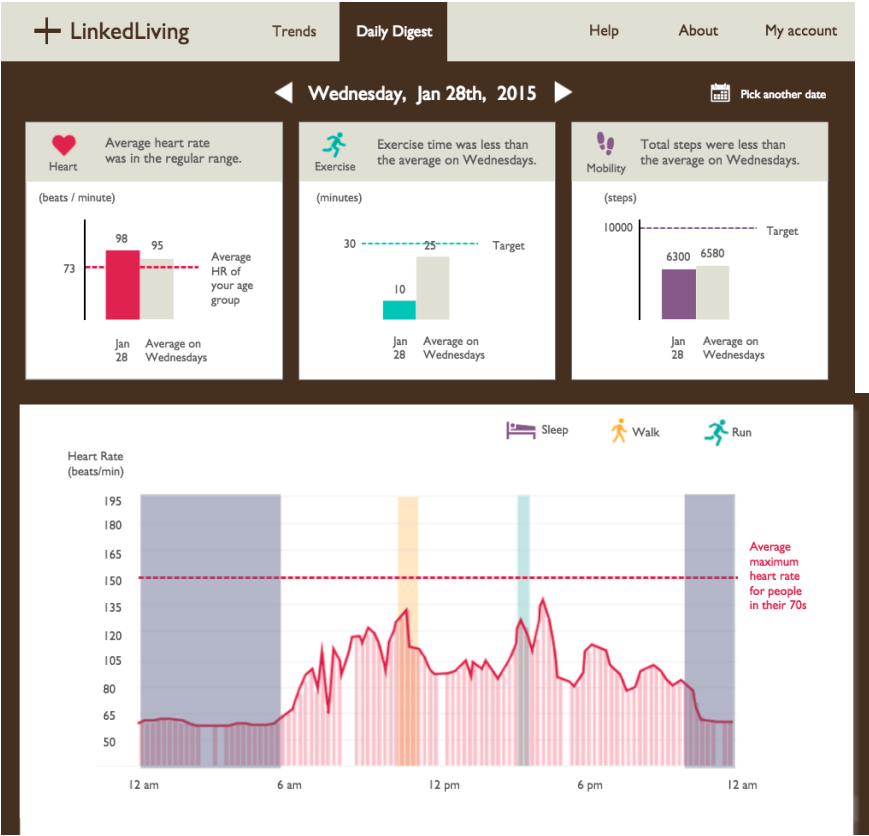


- Final UI

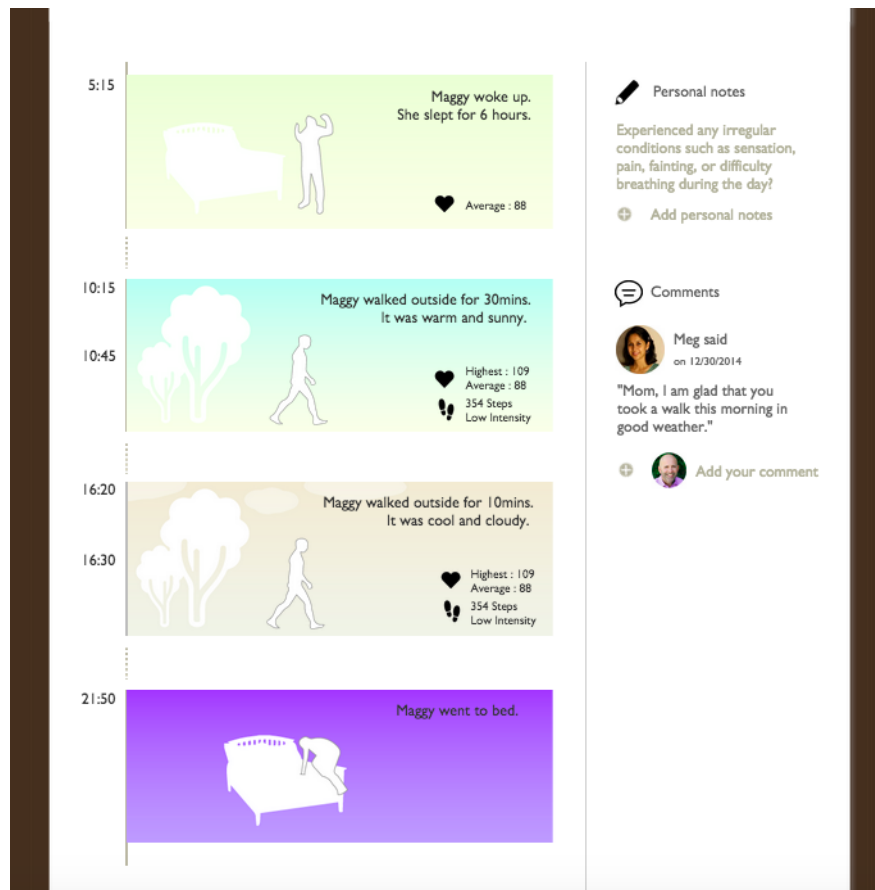
In our final version of UI design, we created two kinds of view; trends and daily digest. Trends view shows graphs of different matrix that can be manipulated by the top filters. On the right of graphs, we provide a comment function for communication among family members.



In daily digest view, there are three graphs with heart rate, exercise and mobility data on the top. Users can compare data of a day with average of the same weekday and self-defined target. Below the three graphs, we display a chart containing heart rate per minutes. We provide one reference point, which is average heart rate of elderly users' age group. Time of activities is highlighted by colored background so that users can identify them at a glance and understand relationship between heart rate and activities. We highlight three kinds of activities: sleeping, walking, and running.



Based on positive feedback on visual timeline, we maintain it in daily digest view. On the right side, we provide personal notes to log self-identified symptoms and comment features for communication among family members.



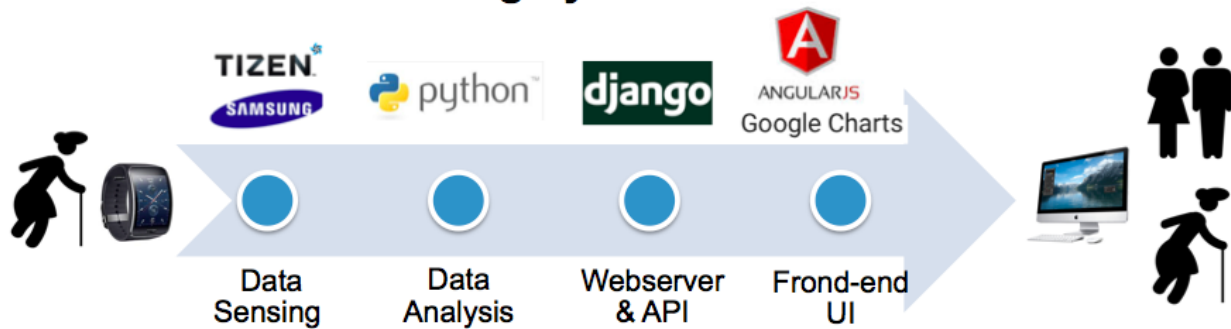
## Privacy:

We understand that privacy control and protection is an important topic but we decided not to set it as the main focus of our project. We do not implement particular privacy features in this project, but believe that flexible privacy control is crucial to achieve usability especially for seniors. We discuss data ownership under "Future Work" in this report.

## System Architecture:

The chart below displays the end-to-end system architecture of our solution. It started with our target users wearing a smart watch with multiple sensors on it.

## LinkedLiving System Architecture



1. Data sensing: Our application includes a data sensing app on the smartwatch which is developed using the Tizen Wearable IDE. It monitors and records users' heart rate, mobility, ambient light condition and geolocation information.
2. Data analysis: After collecting the data, we applied Python analysis framework, pandas and numpy in particular, to perform data fixing, activity detection and data aggregation tasks. The output tables are used for front-end charts through API calls.
3. Web Server & APIs: Our website and web server are built on django framework. The front-end UI can retrieve the data by API calls.
4. Front-end UI: The front-end infographics and charts are built using Google Charts Development Package. We designed the application for seniors and their family members to quickly review and catch-up on the long-term trend and daily activities.

### Data Sensing:

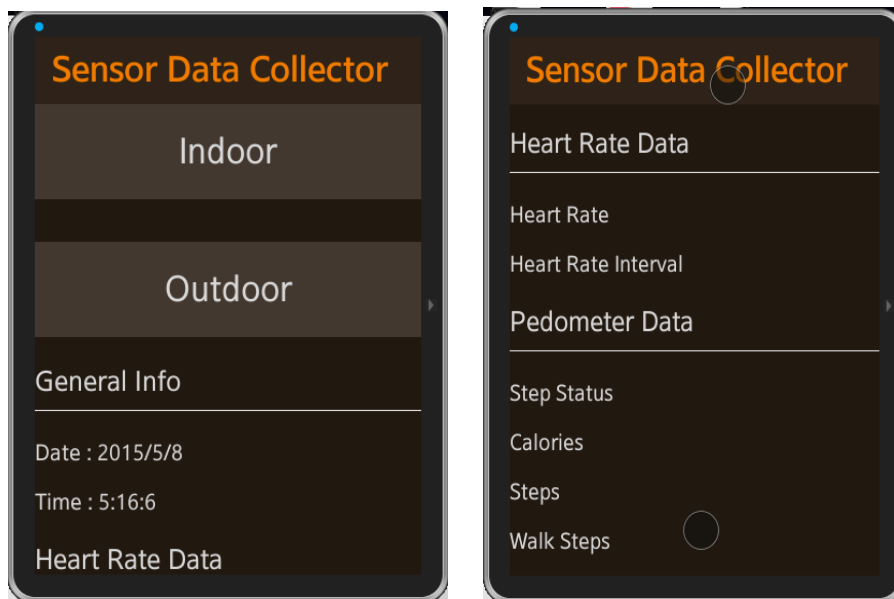
< Device Selection >

We selected Samsung Gear S smartwatch as our data collection device based on two main factors. First, it contains various sensors including accelerometer, gyroscope, light sensor, heart rate sensor, UV sensor, pedometer, barometer, magnetic sensor, and gps. The second, It has Tizen IDE which is an easy-to-use development toolkits that can

be used to develop applications on Gear S. It allows access to all sensors and file system to collect data.

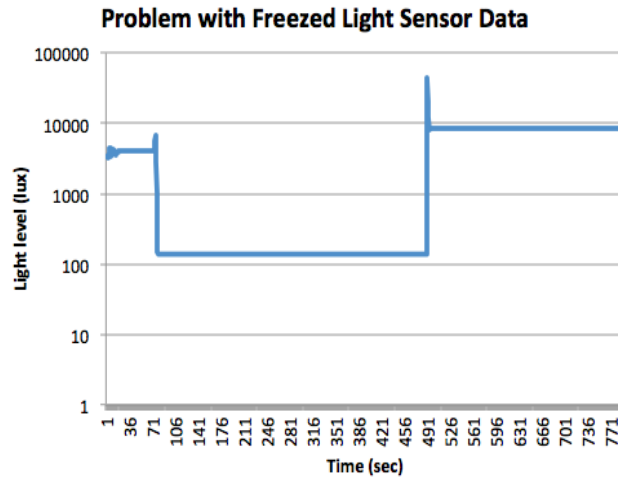
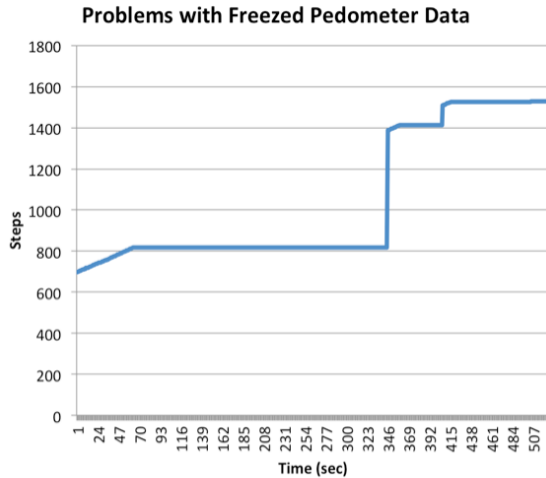
#### < Data Collection App >

Our app on Gear S has been used for everyday activities. It provides a very simple UI for users to start and stop recording data. It also allows input of manual labels such as Indoor/Outdoor, Walking/ Running/ Sleep. The manual labels are used in developing our exercise detection and indoor/outdoor detection algorithms. We recorded the sensor data for every second. Sample views of our app are shown as below:



#### < Problems on irregular functionality of pedometer and light sensor >

When checking the data, we found that pedometer and light sensor cannot work for a longer period of time. The sensors automatically stop recording after a certain period of time even when screen and CPU are ON. After exhaustive research and investigation, we found that this is a limitation of the device and there is no solution provided by the manufacture. We illustrate the problem in the charts below:



To overcome this problem, we decided to carry the freezed data to next phase and try to solve it by gap bridging algorithms (will discuss in next section).

## Data Analysis:

< Exercise Detection >

We are interested in determining the periods when the users are doing actual exercise activity (e.g. walking and running) and differentiate it from other movements (e.g. occasional commute or regular movements). We develop the exercise detection algorithm based on four phases.

### 1. Gap Bridging for freezing data

As we mentioned in the sensor section, the pedometer as well as light sensor cannot continuously record data for long period of time, i.e. “freezing mode”. It requires us to bridge the gap for the “off” period. We used following algorithm pseudocode to recover the result.

$$\text{Gap Ratio} = (\text{Steps After} - \text{Steps Before}) / \text{Time}$$

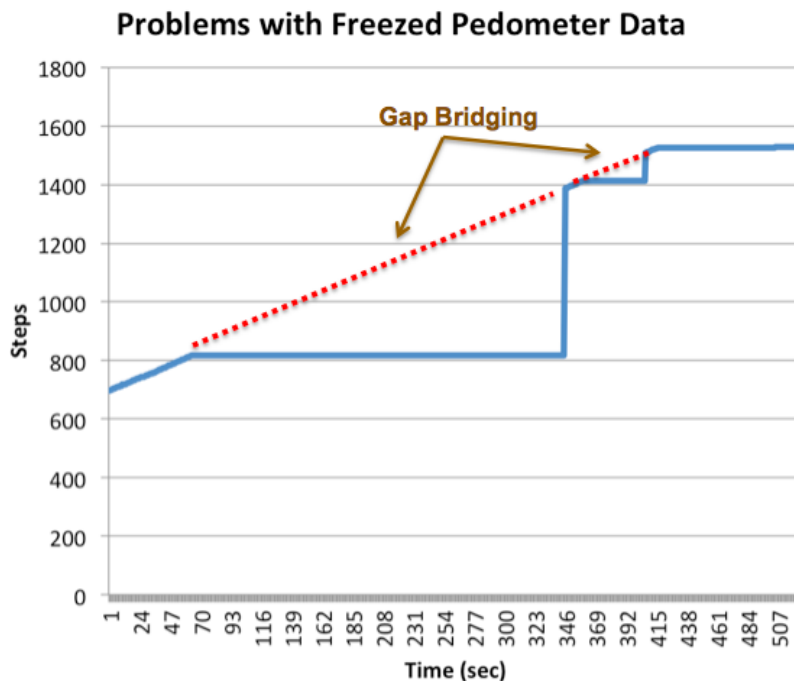
$$\text{NewSteps}(t') = \text{Steps Before} + (t' - t) * \text{Gap Ratio}.$$

If Gap Ratio > 2.0: flip the activity label to “Running”

If Gap Ratio > 1.0 but <=2.0: flip the activity label to “Walking”

If Gap Ratio < 0.3: flip the activity label to “Stop”

For example. If the steps before freezing = 600, steps after freezing = 900, time = 120 (s), the gap ratio =  $(900-600)/120 = 2.5$  , which means we will rewrite the steps using NewSteps(t) and flip the activity label to “Running” during the freezing time. The following charts show the pedometer data after gap bridging.



## 2. Minute Label Clustering

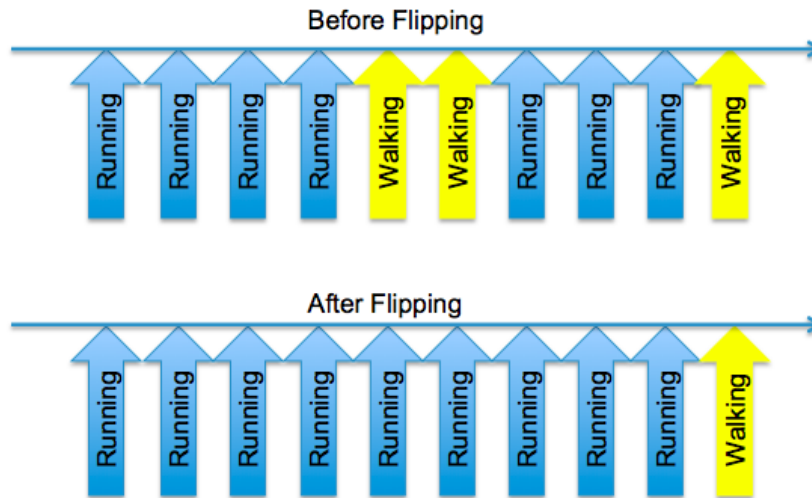
After recovering the raw data, we use the minutes cluster to format the aggregated label per minute. For each data point, we clustered them based on the minute they belong. Ideally each minute will have 60 data points. We use the majority rule to decide which activity label represent the minutes. For example, if # of running label is 5, # of walking label is 35, # of stop label is 20, we select walking to present the minute cluster. We also did small adjustment which favors running label a bit. (Select running if # of running label is greater than 20).

### 3. Activity Flipping

We applied rules to flip the minute's activity label based on neighbors.

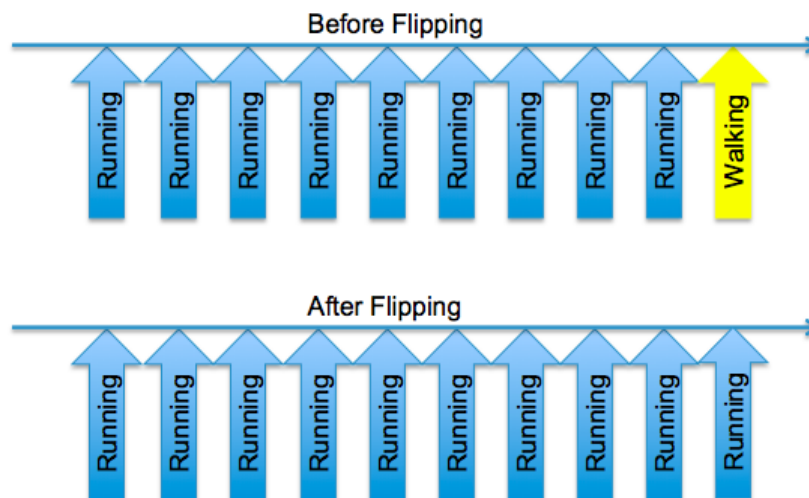
Rule #1: Two running within 5 mins should count continuously running.

Reasoning: People are tempted to take rest a bit before running again.



Rule #2: Running followed by Walking within 2 mins should count as running.

Reasoning: People are tempted to rest a while after running before walking back





#### 4. Exercise formation

Finally, the algorithm extracts the activities that have identical walking or running data for more than ten minutes and creates output as exercise.

#### 5. Accuracy Validation

The algorithm has been tested on 10 actual users' data. We asked each of them to wear the watch and perform walking and running activities for about 10-15 minutes. We then applied the algorithm to determine the activity output. As the table below shows, the algorithm effectively reduces the noise and extracts the activity period.

#### *Algorithm Output Example:*

| Date    | Time  | User Manual labeling | Data Aggregation (w/o data fixing) | Data Aggregation (w/ data fixing) | Activity Gap Bridging | Final Result |
|---------|-------|----------------------|------------------------------------|-----------------------------------|-----------------------|--------------|
| 3/25/15 | 14:46 | RUNNING              | RUNNING                            | RUNNING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:47 | RUNNING              | RUNNING                            | RUNNING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:48 | RUNNING              | WALKING                            | WALKING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:49 | RUNNING              | NOT_MOVING                         | WALKING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:50 | RUNNING              | RUNNING                            | RUNNING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:51 | RUNNING              | RUNNING                            | RUNNING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:52 | RUNNING              | RUNNING                            | RUNNING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:53 | RUNNING              | WALKING                            | WALKING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:54 | RUNNING              | RUNNING                            | RUNNING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:55 | RUNNING              | WALKING                            | WALKING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:56 | RUNNING              | RUNNING                            | RUNNING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:57 | RUNNING              | RUNNING                            | RUNNING                           | RUNNING               | RUNNING      |
| 3/25/15 | 14:58 | RUNNING              | RUNNING                            | RUNNING                           | RUNNING               | RUNNING      |

#### < Data Aggregation >

##### 1. Activity Data Aggregation

We have identified following metrics as important activity indicators for the users.

| Key metrics       | Explanation   |
|-------------------|---|
| Activity Type     | The activity that the users are performing, i.e. Walking, Running, Taking Nap, Sleeping |
| Activity Duration | Total time of the activity in minutes   |

|                    |   |
|--------------------|---|
| Max Heart Rate     | The 95% percentile of heart rate during an activity to exclude device error or outliers |
| Average Heart Rate | The average heart rate during the activity  |
| Total Steps        | Total steps recorded during the activity  |
| Time of the Day    | When was the activity happened, i.e. Morning, Afternoon, Evening                        |
| Weather            | Weather data gathering from external weather API.                                       |

## 2. Daily Data Aggregation

We have identified following metrics as important daily indicators for the users.

| Key metrics                        | Explanation   |
|------------------------------------|---|
| Max Heart Rate                     | The 95% percentile of daily heart rate to exclude device error or outliers.                                 |
| Average Heart Rate at Sleep        | The average heart rate during sleep, it is calculated based on sleep data after 0:00 am and before 11:59 pm |
| Average Heart Rate at Rest         | The average heart rate excluding the exercise time.   |
| Percentage of Heart Rate Above 180 | Time of heart rate above 180 divided by total time collected by the device.                                 |
| Percentage of Heart Rate Above 100 | Time of heart rate above 100 divided by total time collected by the device.                                 |

|                         |  |
|-------------------------|--|
| Exercise Time           | Total time of exercises during the day including walking and running   |
| Sleep Time              | Total time of sleep during the day. It is calculated based on sleep data after 0:00 am and before 11:59 pm         |
| Intensive Exercise Time | Total time of intensive exercise of the day. We counted the exercise as intensive if the average heart rate > 120. |

## Web server and APIs:

We applied django framework as our web service infrastructure. In our application, there are four APIs supporting the inquiries sent from the front-end:

### 1. Get Activity API

It returns a list of activity data within a certain time period used for narrative UI.

=> Sample API call for 2015/04/01 00:00:00 PST to 2015/04/01 23:59:59 PST

*http://127.0.0.1:8000/api/get\_activity/?user\_id=123&start\_datetime=1427871600&end\_datetime=1427957999*

| Attribute           | Datatype | Sample value | Explanation                        |
|---------------------|----------|--------------|------------------------------------|
| start_activity_time | [time]   | 1417968027   |                                    |
| end_activity_time   | [time]   | 1417968027   | Optional                           |
| activity_type       | [int]    | 1            | used for showing icon on timeline: |

|                 |       |  |   |
|-----------------|-------|--|---|
|                 |       |  | 0 wake-up<br>1 go to sleep<br>2 walk<br>3 run<br>4 take a nap   |
| story_line      | [str] | Maggy woke up. She seemed to have a good sleep |   |
| max_hr          | [int] | 109  | -1 n/a  |
| avg_hr          | [int] | 80   | -1 n/a  |
| intensity       | [int] | 1  | 1 high intensity<br>0 low intensity<br>-1 n/a   |
| steps           | [int] | 100  | -1 n/a  |
| background_flag | [int] | 1  | Use in image layers. More refer to content variation form:<br>-1 not applicable, no background returned<br>1 sunny<br>2 rainy<br>3 cloudy<br>4 snow |
| time_flag       | [int] | 1  | -1 not applicable, no   |

|  |  |  |   |
|--|--|--|---|
|  |  |  | background returned<br>1 morning<br>2 afternoon<br>3 evening<br>4 night<br><br>(base on start time) |
|--|--|--|---|

### 2. Get Daily API

It returns a list of heart rate per minutes used for the daily heart rate chart.

=> Sample API call for 2015/04/01 00:00:00 PST to 2015/04/01 23:59:59 PST

*[http://127.0.0.1:8000/api/get\\_daily/?user\\_id=123&start\\_datetime=1429081200&end\\_datetime=1429167599](http://127.0.0.1:8000/api/get_daily/?user_id=123&start_datetime=1429081200&end_datetime=1429167599)*

| Attribute  | Datatype   | Sample value | Explanation   |
|------------|------------|--------------|---|
| time_stamp | [datetime] | 1417968027   | indicate the time stamp of a particular heart_rate data point |
| avg_hr     | [int]      | 80           | -1 if no data found   |

### 3. Get Trend API

It returns a list of heart rate and mobility data per day used for trend charts.

=> Sample API call for 2015/04/01 00:00:00 PST to 2015/04/15 23:59:59 PST

*[http://127.0.0.1:8000/api/get\\_trend/?user\\_id=123&start\\_datetime=1427871600&end\\_datetime=1429167599](http://127.0.0.1:8000/api/get_trend/?user_id=123&start_datetime=1427871600&end_datetime=1429167599)*

| Attribute | Datatype | Sample value | Explanation |
|-----------|----------|--------------|-------------|
|           | pe       |              |             |

|                                     |            |            |  |
|-------------------------------------|------------|------------|--|
| time_stamp                          | [datetime] | 1417968027 | indicate the time stamp of a particular day point  |
| max_hr                              | [int]      | 109        | Max heart rate of one day.<br>-1 if no data found in given range.<br>Show as Daily maximum HR                          |
| max_hr_baseline                     | [float]    | 105        | The baseline will show either one of below:<br>1) k-day average if $k < 7$<br>2) previous 7-days average if $k \geq 7$ |
| avg_hr_rest                         | [int]      | 80         | -1 if no data found  |
| avg_hr_rest_baseline                | [float]    | 78         | The baseline will show either one of below:<br>1) k-day average if $k < 7$<br>2) previous 7-days average if $k \geq 7$ |
| avg_hr_sleep                        | [int]      | 80         | -1 if no data found  |
| avg_hr_sleep_baseline               | [float]    | 82         | The baseline will show either one of below:<br>1) k-day average if $k < 7$<br>2) previous 7-days average if $k \geq 7$ |
| percent_of_time_above_high          | [float]    | 1.2        | % of time with HR above high threshold(ie.180), by minutes   |
| percent_of_time_above_high_baseline | [float]    | 0.5        | The baseline will show either one of below:  |

|  |         |      |   |
|--|---------|------|---|
|  |         |      | <ul style="list-style-type: none"> <li>1) k-day average if <math>k &lt; 7</math></li> <li>2) previous 7-days average if <math>k \geq 7</math></li> </ul>  |
| percent_of_time_above_low                  | [float] | 25.1 | % of time Time with HR above low threshold(ie. 100)   |
| percent_of_time_above_low_baseline         | [float] | 20.2 | <p>The baseline will show either one of below:</p> <ul style="list-style-type: none"> <li>1) k-day average if <math>k &lt; 7</math></li> <li>2) previous 7-days average if <math>k \geq 7</math></li> </ul> |
| exercise_duration_minutes                  | [int]   | 20   | Minutes of exercise   |
| exercise_duration_minutes_baseline         | [int]   | 20   | Target time that user set before  |
| sleep_duration_hours                       | [float] | 8    | Hours of sleep  |
| sleep_duration_hours_baseline              | [float] | 7.5  | Target time that user set before  |
| intense_exercise_duration_minutes          | [int]   | 5    | Minutes of intense exercise   |
| intense_exercise_duration_minutes_baseline | [int]   | 10   | Target time that user set before  |
| total_steps                                | [int]   | 3113 | Total steps in the day  |
| total_steps_baseline                       | [int]   | 2500 | Target total steps  |

#### 4. Get Health Info API

It returns the daily summarize data with comparison benchmark data used for benchmark charts.

=> Sample API call for 2015/04/01 00:00:00 PST to 2015/04/01 23:59:59 PST

***[http://127.0.0.1:8000/api/get\\_trend/?user\\_id=123&start\\_datetime=1427871600&end\\_datetime=1429167599](http://127.0.0.1:8000/api/get_trend/?user_id=123&start_datetime=1427871600&end_datetime=1429167599)***

| Attribute                    | Datatype | Sample value | Explanation   |
|------------------------------|----------|--------------|---|
| avg_hr                       | [int]    | 68           | avg heart rate for the day<br>0 if no data found  |
| avg_hr_weekly_benchmark      | [int]    | 66           | avg heart rate for whole period<br>0 if no data found   |
| avg_hr_target                | [int]    | 80           | target heart rate for the age group.<br>Fixed to 80 now   |
| total_steps                  | [int]    | 1000         | total steps for the day<br>0 if no data found   |
| total_steps_weekly_benchmark | [int]    | 1000         | Avg total steps for the same day every week. Ex. If the day is Wednesday, it shows avg total steps for Wednesdays<br>0 if no data found |
| total_steps_target           | [int]    | 2500         | target total steps set by user<br>Fixed to 2500 now   |
| exercise_time                | [int]    | 30           | Exercise duration for the day<br>0 if no data found   |

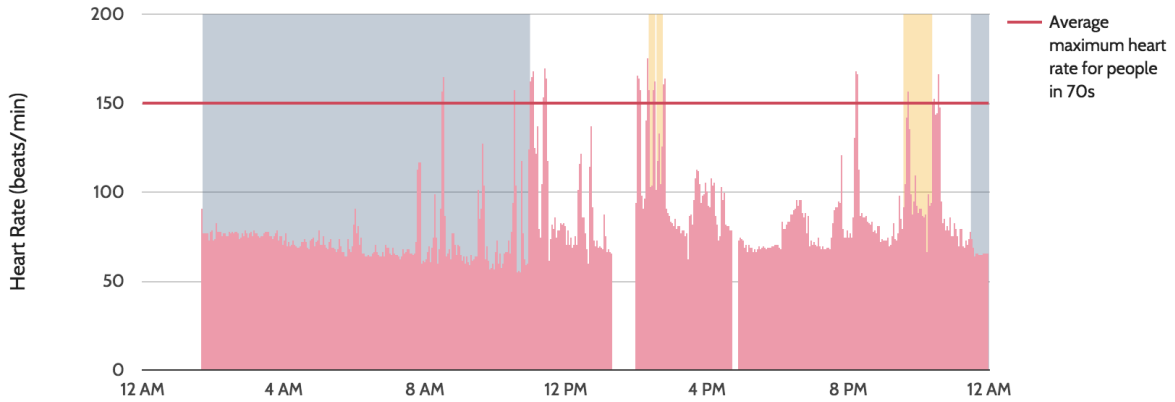


|                                |       |    |  |
|--------------------------------|-------|----|--|
| exercise_time_weekly_benchmark | [int] | 25 | Exercise duration for the same day last week. Ex. If the day is Wednesday, it shows Exercise duration for Wednesdays<br>0 if no data found |
| exercise_time_target           | [int] | 20 | Target exercise duration set by user.  |

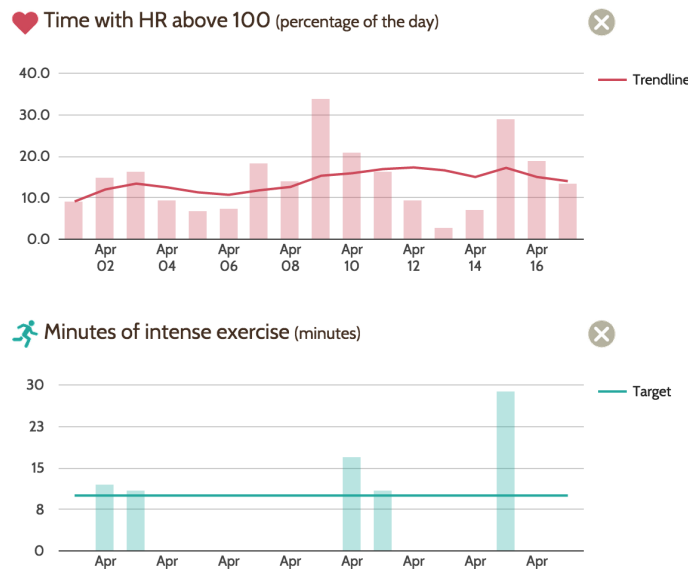
**Front-end Development and Data Visualization:**

Our platform is built to interpret the seniors’ key health information and other contextual data in a meaningful way.

Below chart shows one-day heart rate information collected from a real user. We do observe that the heart rate peaks around the time the user takes a walk. On the other hand, the user suffers from unexpected high heart rate at the later stage of the sleep in that morning. The user recalls that he did stay up late the night before and the sleep quality was poor in the morning. We also observe some spike around 8pm where no exercise is detected. It turns out that high arousal in emotion could also contribute to high heart rate. In the future, we would integrate more contextual information (e.g. calendar, tv schedule) to help understand the unusual pattern in heart rate and other health indicators.



In order to discover long period of information and find trend or pattern across days, we also designed day-to-day comparison on summarized metrics. The selectors panel showed below enables the users to easily compare within or across the heart rates, activities or mobility information over self-defined time period. Therefore, heavy data exchanges are required in our web application. We apply AngularJS to declare our dynamic views for seamless user experience.



We compare different approaches for data visualization (High Chart, Metrics Graphics, D3.js, Fusion Charts etc.) and eventually adopt Google Charts for its flexibility and cost (free even for commercial use). Specifically, we customize the attributes from combo chart template and enable varied charts (bar chart, line chart and area chart) working smoothly within one SVG.

# User feedback and final design

## Results of usability test:

We obtained feedback from three people at age 60-70 and five people at age 25-35 for usability test<sup>14</sup>. We tested the design shown as “final mockup” in the previous chapter. We asked participants to fill a questionnaire using likert scale for the following statements.

|             |  |
|-------------|--|
| Statement 1 | The tasks were easy to complete.                           |
| Statement 2 | I felt lost after given the tasks.                         |
| Statement 3 | I understood the navigation system throughout the website. |
| Statement 4 | I found information on this website useful.                |
| Statement 5 | I found the experience of using this website enjoyable.    |

Answer options for all the statements were (1) Strongly disagree, (2) Disagree, (3) Not sure/undecided, (4) Agree, (5) Strongly agree.

Fig. 8: Answers to questionnaire (older adults)

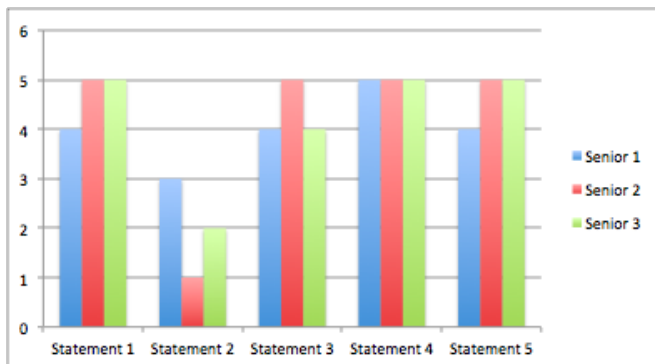
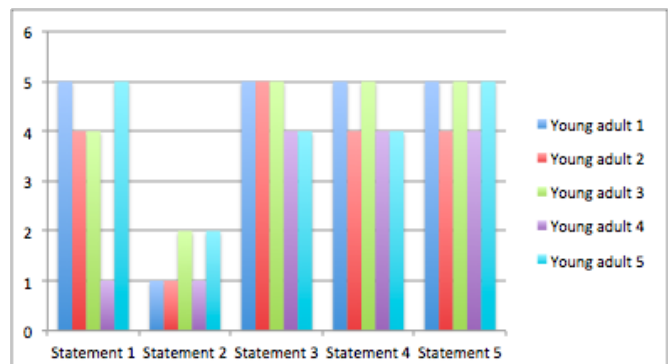


Fig. 9: Answers to questionnaire (younger adults)



<sup>14</sup> Usability test guide is available in Appendix 2.

As shown in Figure 8 and Figure 9, most older and young adult participants gave positive feedback to difficulty of task, navigation system, usefulness of information, and overall experience. Only one young adult strongly disagreed with statement 1. However, his feedback through the session and written comments did not mention difficulty of task. He might have mistakenly chosen the answer option 1 for statement 1.

< Seniors >

We recruited three senior people through our personal connections and conducted usability test in April. The following is information about participants.

|   | Sex | Age      | Education | Living condition | Technology use    | Occupation  |
|---|-----|----------|-----------|------------------|-------------------|---|
| 1 | F   | 70       | College   | Alone            | iPhone<br>Macbook | Retired   |
| 2 | M   | late 60s | College   | With wife        | iPhone<br>Desktop | Retired, but actively involved in volunteering activities |
| 3 | F   | late 60s | College   | With husband     | iPhone<br>Desktop | Retired, but actively involved in volunteering activities |

Feedback 1: Communication feature can be a great source of motivation.

Participants liked functionality to show comments from family members. Most said that they feel encouraged to be involved in health monitoring.

Feedback 2: Information such as sleep quality, consumed calorie, and blood pressure are desired.

While they were happy to see available data, participants mentioned that they wish they could see more information relevant to their current health concerns. All of them said that they want to see sleep quality. A person with obesity problem was interested in calories consumption while another participant taking medication for high blood pressure was more interested in blood pressure level.

Feedback 3: Tutorial for use is necessary especially for non tech savvy users.

One participant said, “Some parts were not clear when I started, but it was better after reviewing information. It’d be helpful if audio, video tutorial is available for first time user.”

Feedback 4: (About wearable device, not UI) Smaller, lighter device is preferable for 24-hour use.

Although people who are used to wearing a watch or accessory said that they feel less uncomfortable with a wearable device, all of them said that the size and weight of a wearable device should be minimal to use during sleep.

< Younger adults >

We recruited five people who have elderly family members through our personal connections and conducted usability tests in April. The following is information about participants.

|   | Sex | Age      | Situations of elderly family members | Ways to communicate with family |
|---|-----|----------|--------------------------------------|---------------------------------|
| 1 | M   | late 20s | Grand parents living by themselves   | Phone call, occasional visit    |

|   |   |          |   |                                 |
|---|---|----------|---|---------------------------------|
| 2 | F | late 20s | Grandmother in 80s living close to her son  | Phone call, occasional visit    |
| 3 | F | late 20s | Parents in 60s living by themselves and aunts with health issues living with their own children | Skype                           |
| 4 | F | late 20s | Parents in 50s living by themselves   | Phone call, frequent visit      |
| 5 | M | late 20s | Grand parents living in a foreign country   | Occasional phone call and visit |

Feedback 1: Visual representation of data and interface aesthetic work well.

Participants generally liked the look and feel of interface. One said, “I like the warm color choice, look and feel wasn’t intimidating.” Another person told, “I like the aesthetics and also the large visual emphasis on the timeline, showing the persons' activities throughout the day.”

Feedback 2: Data should be displayed in more action-oriented manner.

During the session, we repeatedly observed participants asking question, “Is this good or bad? Do I need to tell or do something for my parents/grandparents?” Most participants didn’t recognize supporting information for data interpretation in the right part of the trend view. One person said that she wishes the system could tell her what has to be done. Although we provided reference points such as average heart rate of the same age group or self-defined targets, they were not completely sure how to interpret the data.

Feedback 3: Different scale for each graph in the trend view can confuse users.

Three people pointed out that graphs in trend view use different scale, which could be a bit confusing. One person suggested using one graph with multiple lines.

Feedback 4: Filter in the trend view takes too much space and makes chart invisible.

Three participants could not clearly see graphs below the filter section in the trend view. One person said that a different composition might work better.

Feedback 5: Mechanism of displaying particular comments is not always clear.

One participants said, “I am not sure whether he can see all the comments if I select different graphs in the trend view or move to another date in daily digest view.”

## **Modifications for the final design:**

Based on the feedback, we reflected the following modifications.

- Set typeface at a slightly larger size
- Display supporting information for data interpretation together with matrix and graphs.



# Future work

## **Design a collaborative platform by including human experts:**

One of the hardest problems in the design process was to support users' data interpretation. Although we adopted reference points such as trend line, average and self-defined target, participants in the usability test still struggled to interpret the graphs. Our system is not to diagnose and tell users what to do, but rather to communicate trends and contexts in general. However, as soon as they see graphs, people almost automatically try to judge whether they or their family members are all right or not. This is not easy because we need to take various factors into account including information that cannot be captured by a wearable device.

As we heard in the interview with cardiovascular surgeon, there are variations among individuals and this data is very useful in combination with other information. We came to realize that humans are a lot better at doing such a job than automated machines. We researched approaches adopted in businesses that have similar problems and found an interesting mobile app. Rise, a mobile app for diet control, uses nutrition experts who review users' meals and give one to one advice. We believe that we can take similar approach and include human experts (e.g. nurse practitioners) who can play a role of a coach for seniors and their family members and support data interpretation. Our platform can be a collaborative space where users and experts have effective monitoring and communication with actual data. We believe that this is a promising idea and hope to conduct further study.

## **Expand data coverage to other health information:**

Another big challenge in our project was the scope of data collection. Seniors expressed interest in data points that cannot be collected or easily provided by a wearable device. Due to limited resources, we did not include such data in this project. However, we believe that it is beneficial to eventually take data from other technology products such

as Nest, digital blood pressure measurement device and digital weight scale. There are already many products that can send data through Bluetooth. We envision that data in our platform should satisfy users' information needs much better by connecting to other devices and incorporating in activity detection algorithms.

## Decide the data storage mechanism: cloud or local?

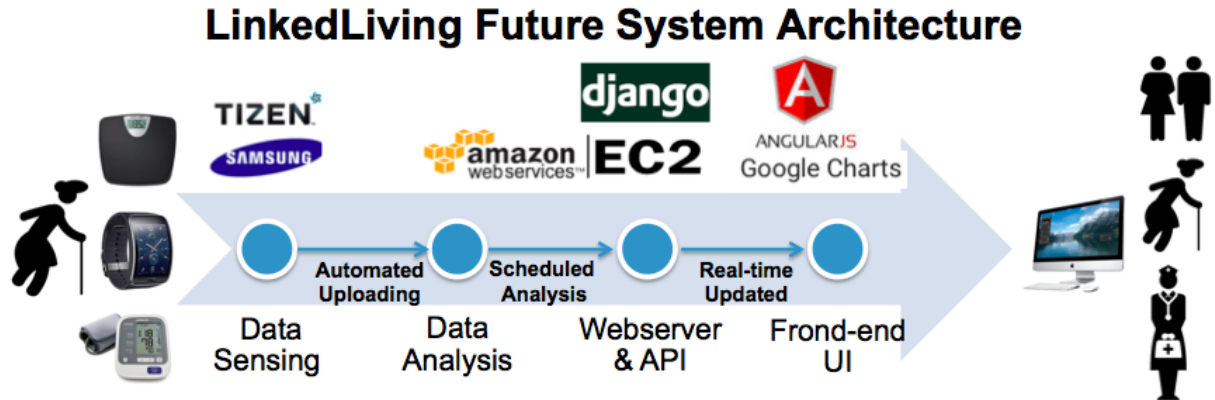
Storage of personal health data is a sensitive topic. People have debated on where it should be stored on cloud or just locked on personal devices. Although there is no correct answer to those questions, we analyzed the strength and weakness of two approaches:

| Where to store data | Cloud server   | Personal devices   |
|---------------------|--|--|
| Data Security       | Lower security due to security attack.   | Higher security. Only the user can access the data.                            |
| Data Usefulness     | More useful for general public by aggregating users data to perform suggestions. | Less useful due to the scarcity of data. Can only use self data for benchmark. |
| Data Consistency    | Support fault recovery. Guarantee the data can never be lost.                    | Data could be lost due to device issues.                                       |
| Data Ownership      | Complicated. It's hard to define when, where, and how to use the data.           | Simple. The data has been used only for the user.                              |
| Maintenance Cost    | Higher. Extra expense on cloud   | Low. Store the data on   |

|  |         |                |
|--|---------|----------------|
|  | servers | local devices. |
|--|---------|----------------|

### Implement real time data collection/analysis pipeline:

In the future, we want to automate the data processing flow as an end-to-end process. To begin with, we will send data directly from the data collection app to database via Internet connection. Furthermore, we will make data analysis process run as daily schedule on Cloud using SQL or MapReduce. The result can be directly shown via current Web UI without any manual work.



# Conclusion

Current demographic trend is making it increasingly important to support older adults to stay healthy for longer independent living. But most people don't have effective tools to do it, sometimes blindly believing that they would be OK. Linked Living is our attempt to provide a solution to the problem.

We created Linked Living by applying various disciplines that we learnt at I School. We successfully practiced important principles in areas such as user centered design, web architecture, information visualization, and data science. Taking advantage of recent advancement in wearable technologies, our product provides a new way to monitor older adults' heart health risk and share information among family members and other stakeholders.

While working on the project, we also re-discovered large potential in this area. Technologies such as physiological sensors and Internet of Things can make more valuable information available in real time. Our work highlights the importance of using these technologies not only for regular consumers but also for people in need. We hope to see more technological solutions become available to address challenging problems faced by our society.

# Appendix

## 1. Interview guide

If interviewees are over 55 years old, refer to 1.

If interviewees are less than 55 years old and have elderly family members, refer to 2.

Basic format:

- Introduce ourselves:
  - Hi, my name is \_\_\_\_\_. I am a UC Berkeley graduate student and now working on a class project to support communication between senior citizens and their family members living away.
  - We would like to hear senior people's opinions and insights and wondering if we can talk to you.
    - (If positive) Thank you very much for your interest. Is now a good time to talk to you for about 30 mins? (if yes, start. if not, schedule a meeting)
    - (If negative) We totally understand. Thank you very much, anyway.
- Get approval for audio recording and inform that this is confidential:
  - With your permission, we would like to audio record our talk so that we can review it if we miss something. Would you mind if we take audio recording? (if they mind, don't record. Ask them whether we can take notes on paper.)
  - I would like to emphasize that whatever we discuss here is completely confidential. You don't have to answer our questions if you don't want to. Please feel free to stop us whenever you want to.
- Ask interview questions
  - First, start chatting about their family. Try to connect with the person.

- Ask where they live, whether they live with their family members, how often they meet their family members
- Ending remarks:
  - I think we have learned a lot from you. Again, we really appreciate your time and your insights. With your valuable input, we will further examine how we could help communication between senior citizens and their family members. Thank you very much.

## 1. Interview with senior people

### 1-0. Background and family situations

- Do you mind if I ask your age group? 50s, 60s, or 70s?
- Are you working currently?
- Are you married?
- Do you live alone now? If not, whom do you live with?
- Do you have any family members living near by? Who are they?
- How often do you communicate with your family members?
- How do you do so? Telephone? Letter? Email? Text? or Skype or any software?
- Do you have any grandchildren? How do you communicate with them? How often do you reach out to them?
- What do you usually talk about? What do you like sharing with them?
  - What kinds of questions do your family members often ask you? How do you answer them?
  - Do they ask any health related questions? If yes, how do you answer them?

### 1-1. Tech and wearable device

- Which phone do you use? Do you use a smartphone?
  - If yes, how comfortable are you to use smart phone?

- If now, do you use any mobile phone? Which mobile phone do you use?
- Do your family members use smart phones?
- How often do you use Internet? Which device do you use?
- Have you ever used any self-tracking device or emergency response device? (e.g. fitbit)
  - If yes:
    - What are the things you like about it?
    - What are the things you dislike about it?
  - If no:
    - Have you ever considered using them? What did you think at that time? What stopped you from using it?
- How do you like wearing a watch type device to collect data?
  - (After asking general opinion) What makes you feel that way?
  - How does it feel like? Positive or negative? Why?
  - If the device could be useful to you somehow, what kind of features should be there?

### 1-2. Health monitoring

- Do you measure and keep records of any health conditions at home? e.g. blood pressure
- Do you talk about health concern with your family sometimes?
- Do you share lab data with your family?
- What are the main issues in maintaining your health?
- Do you have any caregivers currently? What kind of services do you receive?

### 1-3. Privacy

- How do you feel about sharing information generated based on the data from the watch with your family members?

- What kind of information could be useful for you and your family members to share?
- What kind of information would you want not to share?
- Out of the following items, which one do you feel uncomfortable to share? (card sort: OK to share, Don't want to share, Depending on the situations / places to visit, exercising (walking, running, cycling etc), sleeping, heart rate, falling (emergency), wandering (emergency), anything else you wanna add)

#### 1-4. Feedback on our project

- What would your first reaction if your daughter/son suggests using this watch to keep track of your health conditions?
- If you would use the service, what could be benefits?
- If you would use the service, what could be disadvantages or things you would not like?

## 2. Interview with "children"

### 2-0. Background and family situations

- Do you mind if I ask your age group? 50s, 60s, or 70s?
- Where does your parents live? Do they live with someone?
- Is there any family members living near by? Who are they?
- How often do you communicate with your parents?
- How do you do so? Telephone? Letter? Email? Text? or Skype or any software?
- Do you have any children? How do they communicate with grandparents? How often do they reach out to them?
- What do you usually talk about? What do you like sharing with them?



- What kind of questions do you often ask your parents? How do they answer them?
- Do you ask any health related questions? If yes, how do they answer them?

### 2-1. Tech and wearable device

- Which phone do you use? Do you use a smartphone?
  - If yes, how comfortable are you to use smart phone?
  - If now, do you use any mobile phone? Which mobile phone do you use?
- Do your grandparents use smart phones?
- How often do you use Internet? Which device do you use?
- Have you ever used any self-tracking device or emergency response device? (e.g. fitbit)
  - If yes:
    - What are the things you like about it?
    - What are the things you dislike about it?
  - If no:
    - Have you ever considered using them? What did you think at that time? What stopped you from using it?
- How do you like wearing a watch type device to collect data?
  - (After asking general opinion) What makes you feel that way?
  - How does it feel like? Positive or negative? Why?
  - What do you think of idea letting your parents wearing them?

### 2-2. Health monitoring

- Do your parents measure and keep records of any health conditions at home? e.g. blood pressure
- Do your parents talk about health concern with you sometimes?
- Do they share lab data?

- What are the main issues in maintaining their health?
- Do they have any caregivers currently? What kind of services do you receive?

### 2-3. Privacy

- How do you feel about sharing information generated based on the data from the watch of your parents?
  - What kind of information could be useful for you and your parents to share?
  - What kind of information would you want not to see?
  - Out of the following items, which one do you feel uncomfortable to see? (card sort)

### 2-4. Feedback on our project

- This is the website you would see while your parents are wearing the watch. What are your thoughts?
- How do you think about the idea of using this watch to keep track of your parents' health conditions?
- If you would use the service, what could be benefits?
- If you would use the service, what could be disadvantages or things you would not like?

## 2. Usability test guide

Introduction

Hi NAME of test participant,

Thank you again for participating in our usability activity. My name is \_\_\_\_\_.

I'll be giving you a few tasks to complete with a prototype that we are testing today. While you work to complete the tasks, I'd like you to think aloud about what you're doing during this activity. Just narrate what you're doing, sort of as a play-by-play telling me what you're doing and why you're doing it. This evaluation should take about or less than 30 minutes.

During the activity, you might ask me questions. If these questions are about the task I've asked you to complete, I will attempt to clarify the task. If the questions are about the application, I'm less likely to answer those types of questions, since I'm really interested in finding out what you would do if you had those questions and didn't have someone available to answer those questions. Please do ask those questions, because it's good for me to know what questions you're having as you're going through the activity. If, however, you feel as if you've reached a point when you would stop working on the task if you weren't in the activity, please let me know, as that's very important information for me to have.

Please be straight and honest. We really want to hear and know what you're thinking. You're not going to hurt our feelings if you say things that are positive or negative about the product.

Also, to clarify: we're studying this application, not you. There are no right or wrong answers as we go along. No matter what you do, you cannot make a mistake.

With your permission, we would like to record this session so that we can go back and review it in case we miss something. We will not use the record for any other purpose than analysis. Is it OK for us to video record this session?

Now I'd like to read you what's called a statement of informed consent. It's a standard thing I read to everyone I interview. It sets out your rights as a person who is participating in this kind of research. As a participant in this research:

You may stop at any time.

You may ask questions at any time.

You may leave at any time.

There is no deception involved.

Your answers are kept confidential.

Before we begin, do you have any questions?

Initial questions

1. Any family members over 65?
2. Do you know how healthy they are? Do they have any cardiovascular problems?  
Do you feel you'd like to know more?
3. What's the common ways for you and the family member rot communicate?
4. Do you have any wearable device? If so, what is it?

Tasks

1. Here is the prototype we would like you to test. Please do \_\_\_\_\_.

Probe:

- If there's any language you feel weird or confused, please point them out.
- Do you have any feedback?
- (For the troubled part) Can you tell me what you were trying to do here?

**Daily digest**

- Could you tell me what this screen is about?

- Please look at the top three boxes on the screen. What do you think they are? Could you tell me how this senior was on this day based on information?

- Now please look at the chart. What do you think this is? Could you tell me what this senior did on this day based on the chart?

- Could you tell me how this senior's heart rate was on this day based on the chart?

- Please look at the area below the chart. What do you think this is?

- Could you tell me how this senior was on this day based on the information in the timeline?

- Could you add comments for the senior person?

- How do you see data of the previous day?

- Is there anything that you wish you could do in this screen?

- Is there anything else that you would like to comment on?

### **Trends**

- Could you move to a screen where you would be able to check trends in longer term?

- Could tell me what this screen is about?

- Please look at the top part on the screen. What do you think this is?

- OK, this is .... Now you would like to see daily maximum heart rate. Please manipulate the screen to see it.

- Now please look at the graphs. What can you tell based on the graphs on the screen?

- Could you look at the section on the left? What do you think they are? Does this info help you to interpret the data? How?

- Could you add comments for the senior?

- Is there anything that you wish you could do in this screen?

- Is there anything else that you would like to comment on?

2. Please provide us feedback on these questions. (pass the questionnaire)

3. Please do \_\_\_\_\_ in this application (test for a control condition).

General probe question during usability test on each task (ask whenever appropriate)

1. What draws the evaluators' attention?
2. Do the names and icons of navigation elements make sense?
3. What are their expectations for the behavior/content of any given element/screen?
4. Do the interface elements function as the evaluator had expected?
5. Are there places where the evaluator would like additional information?
6. What are the most important elements in any given feature?

#### Wrap-up

That was the last task that I have for you today. We'll wrap up with a couple of questions.

- How would you describe this product in a couple of sentences to someone with a level of computer and web experience similar to yours?
- Is this an interesting service? Is this something that you would use?
- Is this something you would recommend? Why/Why not?
  
- Have you ever said, "I wish this program would do X for me"? What was it?
  
- Do you have any final thoughts or comments about the session that you just went through?

Okay, this wraps up the session and I'd like to thank you for your time today. If you have any other thoughts or ideas on your way home or tomorrow, or later, please feel free to send email to \_\_\_\_.

## Qualitative Questionnaire

Indicate how much you agree or disagree with the following statements regarding the user interface design of LinkedLiving.

1) The tasks were easy to complete

(1) Strongly Disagree (2) Disagree (3) Not Sure/Undecided (4) Agree (5) Strongly Agree

2) I felt lost after given the tasks

(1) Strongly Disagree (2) Disagree (3) Not Sure/Undecided (4) Agree (5) Strongly Agree

3) I understood the navigation system throughout the website

(1) Strongly Disagree (2) Disagree (3) Not Sure/Undecided (4) Agree (5) Strongly Agree

4) I found information in this website useful

(1) Strongly Disagree (2) Disagree (3) Not Sure/Undecided (4) Agree (5) Strongly Agree

5) I found the experience of using this website enjoyable

(1) Strongly Disagree (2) Disagree (3) Not Sure/Undecided (4) Agree (5) Strongly Agree

6) What task was the most frustrating to you and why?

7) What did you like the most about this website?

8) What did you like the least about this website?