Visualizing Diabetes data in Mobile contexts

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MobileVis '18 Workshop at CHI 2018}, April 21, 2018, Montreal, QC, Canada. https://mobilevis.github.io/

Abstract
Type one diabetes is a serious long-term condition involving the manual control over a person's blood glucose levels. Mobile smartphones have introduced new possibilities for smart digital decision support systems. Recent research has suggested that while diabetic users were able to read standard visualizations of blood glucose data they were unable to convert these into actionable insights. This paper is position paper on ongoing investigations into alterative visualisations for continuously monitored blood glucose data in an effort to create actionable interfaces, or ones that support strategic thinking and lifestyle diagnostics.

Author Keywords
Health; chronic conditions; mHealth; apps; mobile ; pervasive computing; ubiquitous computing; quantified self; personal informatics; Internet of Things; visualisation.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Among Among major health conditions, diabetes is one of the most common and costly. It is believed to affect 380 million people worldwide, and numbers are rising.

Figure 1 mySugr Logbook/ Connected Plot

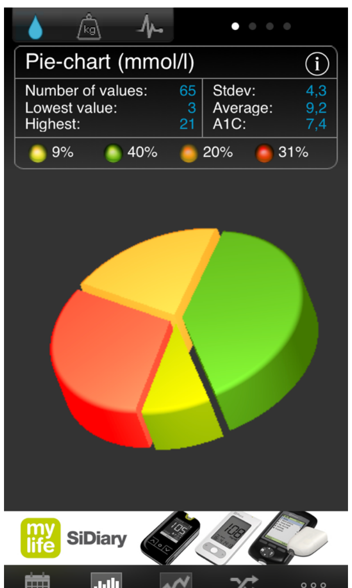

Figure 2 SiDiary Pie Chart

In the United States, spending on diabetes management was close to 550 billion USD in 2013, approximately 11% of total health spending on adults [1]. Type 1 diabetes (T1D), which affects roughly 5-10% of people with diabetes, is an autoimmune disease and necessitates daily injections of the hormone insulin in order to control blood glucose levels.
While short and long-term complications can be severe, diabetes can be successfully managed, blood glucose levels stabilized and complications minimized with a carefully controlled lifestyle and the correct use of medications.
Self-monitoring and self-management practices are essential for good diabetes outcomes, as the majority of care is by necessity self-care [2]. While glycemic control is a clear objective, it can also be tremendously demanding; it is a multivariate task, affected not only by diet, exercise, and insulin dosages, but also hard to control factors such as stress, illness, natural variability, and even the weather. At the core of modern diabetes self-management is the ability to monitor blood glucose (BG) levels, and to dynamically adjust medication and other factors accordingly. People with type 1 diabetes (PWT1D) were early adopters of mobile digital technology, in the form of the BG meter, which gives a glucose reading in a few seconds from a small drop of capillary blood.
More recently, the continuous glucose monitor (CGM) has become available as a mobile T1D technology. It has a small sensor most often inserted into subcutaneous fat in the abdomen that can be worn for between one and three weeks, although many labs are researching how to extend the life of these devices. This evolving technology allows not only for an automatically updated BG reading every few minutes, but can also alert users when they are exceeding or falling below preset threshold levels. These systems are starting to incorporate cloud connectivity, to allow for real-time data display to connected devices like smartphones and smart watches, as well as to share health data remotely with others. Along with wearable insulin pumps that can track injected doses of medication, these increasingly connected T1D devices are moving diabetes into the era of pervasive cloud connected personal computing, or an Internet of Things for personal health.

The user problem is to Monitor the current blood glucose levels and make regular decisions about the timing, choice of insulin type, and dose based upon a number of factors including a recent history of blood glucose levels and likely, and expected, carbohydrate intake and levels of future exercise and energy expenditure. All of this has to be done in a non-burdensome way and whilst being sensitive to the emotional impact of blood glucose levels and, at the same time, avoiding stigmatizing the PWT1D**.**

Current assistive approaches

Historically it was common that PWT1D would carry a notebook and make written notes about blood glucose levels. These notes could then be used to identify regularities in the glycaemic control. For example, identifying a temporary high glycaemic level just after waking up in the morning which would, without any active intervention, return to normal.

With the creation of the smartphone there has been a great number of applications which are designed to facilitate and automate this notetaking process. One of the abilities, that such digital recording has facilitated, is the use of visualization to present the blood glucose

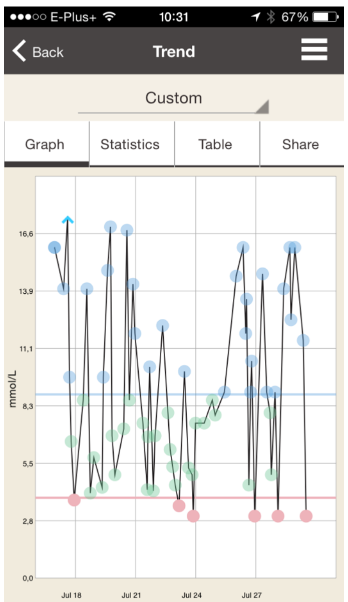

Figure 3 Accu-Chek connected Plot

data back to the user in a variety of formats (figures 1 to 3). One objective for this kind of visualization is for long-term strategic thinking. Recent research [3] has suggested that many of these apps have been used and then abandoned by PWT1D. More recent research [4] took a selection of diabetes applications and performed a study where identical information was entered into each App. The primary finding was that while users were capable of interacting with the data and visualizations used, it was difficult for them to convert the information presented into actionable advice. One factor which could have contributed to this was the small size of screen on the mobile devices. Diabetes data fluctuates radically throughout the day removing any clear trends in the noise of data.

Currently diabetes management is on the edge of a significant change. Traditionally the PWT1D would take and entere the blood glucose level into a notebook or smart app. Recently the technology for continuous blood glucose monitoring has allowed the potential for very high-frequency samples for blood glucose levels. This in turn has been supported by small and very popular visualizations (see Fig 2) on the blood glucose level device itself. These devices have proved to be very popular act the tactical level. Instead of injecting 3 to 4 times per day, users will now inject smaller amounts but with more careful timing. This has led to an informal formal self-management called 'sugar surfing'.

This increase in data and the ability to automatically collect other information (for example using gate analysis to collect information about the user's activity) leads to a new visualization problem of how to present to users, very dense data of blood glucose levels in combination with other contextual information.

The challenge

This creates one clear question for the design of mobile visualization(s). Is it possible to create an actionable interface using some alternative form of visualization? Such a visualization(s) and associated user interface would have to be able to create a quick, 'glanceable' interactions. This visualization would also have to be readable by non-data specialists indeed it would have to be usable by those between nine and 90 with with no assumptions about their numerical skills. Although the PWT1D might be expected to become familiar with use (i.e. be an expert user) it is clear from current app usage that the application would have little more than a couple of months to prove legible to the user.

Such user interfaces have many constraints which are not common to many other mobile visualization contexts. Along with the very broad user base, the users are not self-selecting (they didn't choose to have diabetes). They are not using your app out of choice but out of necessity. Additionally, one complication for long term diabetes can be a failure or degradation of vision. There are many emotional impacts for examining one's own blood glucose levels. When the user has knowledge that if they exceed the maximum recommended blood glucose level they are damaging their body, then being reminded daily of them failing to do this can lead to emotional stress which, in turn, can be attributed to the messenger. Reviewing one's own information in public can potentially be quite stressful.

Also, dropping below the recommended blood glucose levels can lead to collapse and in rare cases death. In

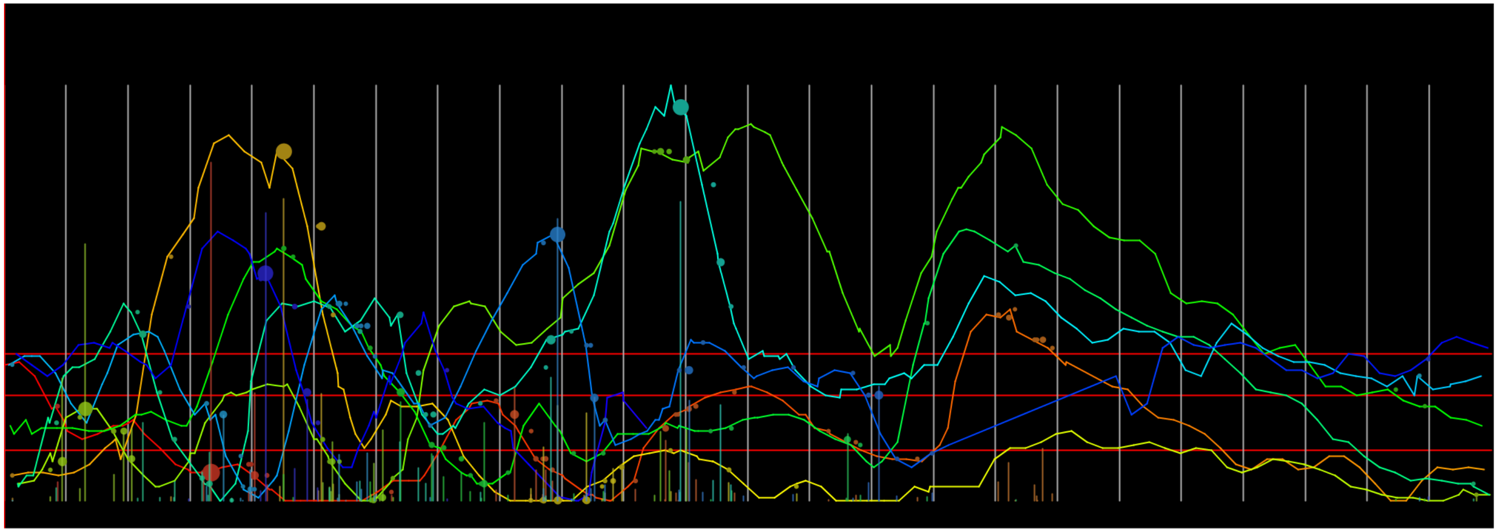

Figure 4 plot of 24 hour period each line indicates different date period. Red horizontal lines indicate 'ideal' range of BG level

these cases, the misreading of the visualization or the false formulation of action can lead to the death of the user. Under low blood sugar levels, cognitive impairment is common. This raises the bar in terms of clarity and legibility of the visualization. Especially when dealing with real-world data such as data errors caused by the sensing needle becoming 'old' (sensor insert sites have to be changed every 2-3 days) with errant data being identified and removed from the larger statistical picture.

Current Work in Progress

Continuous blood glucose monitoring devices have also shown the value for tactical level decision support. The current work seeks to challenge conventional apps/charts by creating a number of alternative specialist visualizations designed to maximize insights into the blood glucose data. The first of these (figure 4) represents multiple 24-hour periods plotted over the same time period. Here repeating daily patters may be identified. The color of lines represent the day, the circles represent exercise and the colored vertical lines represent insulin injections. Red horizontal lines represent recommended minimum and maximum blood glucose values. Figure 5 represents the whole 7-day time period showing information and using a standard line chart.

Figure 6 attempts to show the blood glucose levels in 'phase space' here. The BG values of two consecutive time periods are plotted. Here the horizontal axis represents the BG value 15 minutes ago and the

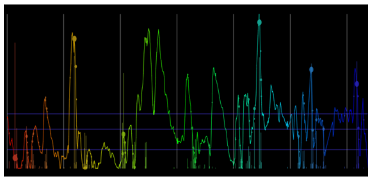

Figure 5 line plot of whole date period

vertical axis represents the BG value 30 minutes ago. The pale and white lines represent the ideal range of BG values. The colors represent the third value – white for 'in range'. Orange for beyond the ideal range and blue for below the range. Green outlines indicate points were exercise or insulin injections.

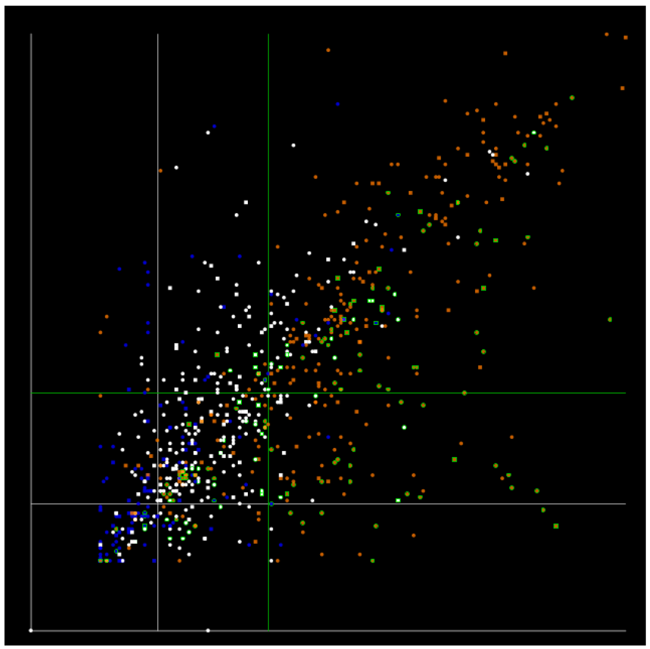

Figure 6 'phase' plot of BG values.

While no proposed visualization has been found to be ideal, the process is seen as an iterative cycle spanning visualization and user evaluation. Generated simulations (see fig 7) which can be used to initate user feedback and analysis.

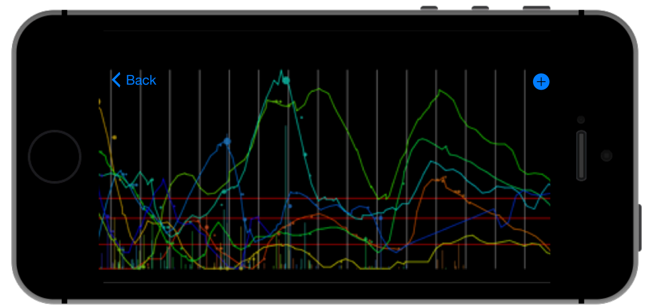

Figure 7 Simulated screen showing overlapping days.

Conclusions

The contention of this research is that alternative forms of visualization could be created which highlight different aspects of the data permitting visual enquiry

to identify repeated patterns of positive or negative behavior. By visually presenting data it is thought possible to graphically highlight patterns which the user could then use to compare previous strategies and actions with their outcomes. The essence of these visualizations would be to compact a large amount of relevant information into a small space.

Once relevant visualizations are identified it is proposed it should be possible to create tools which would display the current and recent live BG values in the context of

historical precedent giving users a new way to test their self-dosages against previous dosages in that context.

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