Improving user engagement and insight through Contextualized Quantified Self

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Definition of the selected challenge related to the interaction between humans and data-analytic systems
The proliferation of smartphones and commoditization of health sensors (including step trackers, heart rate sensors, and blood pressure monitors) has enabled a process of self-digitization known as the "quantified self" (QS).[1] The QS movement has caught the attention of the research community seeing in self-quantification systems (SQS)[2] an opportunity to tackle P4 Medicine issues (i.e. predictive, preventive, personalized and participatory)[3] by exploring the unique datasets generated by QS users.[4,5] Companies such as Fitbit, Jawbone, Misfit, Withings, Apple, and others sell a range of reliable health and lifestyle tracking sensors[6] and accompanying applications which have been met with sales exceeding 43 million units[7] in 2015 and predicted to reach over 100 million by 2017.[8] Coupled with health apps such as MyFitnessPal, Moves, and Lifesum, this ecosystem promises to combine lifestyle data and analytics to derive insights into health and suggestions for improvement.[9]

However, a recent study highlights the striking reality that half of activity tracker owners stop using their devices, and one-third stop after only six months.[10] The early-stage venture fund Rock Health recently suggested one of the potential reasons for this drop: wearable devices makers usually leave the use cases of their product to the imagination of their customers.[9] Among the many challenges that need to be addressed, building software that identifies meaning in lifestyle data and can close the loop to provide actionable suggestions is critical. In addition, the market is very fragmented with apps and devices that are either single-purpose or so oriented towards the general market that they end up providing no insights at all. A population of core users called Quantified-selfers has overcome the multiple barriers discouraging many users[11] but several pitfalls remain unaddressed. These include poor interface design (e.g. complicated data entry menus) and insufficient analytics in determining lifestyle patterns that are predictive of phenotypes important to the user.[12] Apps often strive for entry granularity that is so high that it creates a burden on users, leading to less data collected than if the entry process were streamlined.[13] Additionally, current data visualizations are limited to progress bars and individual plots for each dimension of data, making it challenging to observe trends in lifestyle data and opportunities for changes.[14] Users often view their data in a vacuum with no context, making algorithmic suggestions for improvement unclear and further contributing to issues with user acceptance.[15]

We propose an interactive user interface for Contextualized Quantified-Self (CQS). This interface puts quantitative and qualitative user data in the context of the user's activities (e.g. meetings), environment (e.g. weather, pollution), and other users. By representing a user's day with a unique visualization, it is possible to go beyond the "what to do" and break it up into actionable tasks to guide the user on "how to do it" when associated with a Learning Health System (LHS).[16]

We present this visualization system's ability to compare a day between users and between a user and a group using high blood pressure (HBP) as a case study.

Identified health problem
According to the American Heart Association, roughly 78 million American adults have high blood pressure (BP),[17] only half of which have their high BP under control.[18] What is more shocking is that in 2010 alone, more than 362,895 American adults died from high BP-related major cardiovascular disease,[19] leading to an estimated cost of over $69.9 billion dollars.[20] High BP can be diagnosed by a healthcare provider at a hospital, clinic or even at a local health fair. While the health risks of untreated high BP are concerning, it can be prevented and controlled. In fact, roughly 46,000 deaths each year could be prevented if 70% of adults with high BP received appropriate treatment.[21] The American Heart Association made hypertension a primary focus of its 2014-2017 strategic plan and is hoping to improve cardiovascular health by 20% through reducing cardiovascular disease and stroke by 20% by 2010.[22]

The Healthcare Effectiveness Data and Information Set (HEDIS) quality indicator is measured by determining, "the percentage of members 18 years of age and older who had a diagnosis of hypertension (HTN) and whose BP was adequately controlled during the measurement year using the following criteria".[23]

We believe that such an interactive system can have an impact on this type of quality indicators by displaying both recommended measurements and encouraging self-tracking. A versatile platform able to support a LHS for wellness is more likely to engage a patient to monitor his/ her physiological parameters and could help hospitals reach out to their outpatient population.

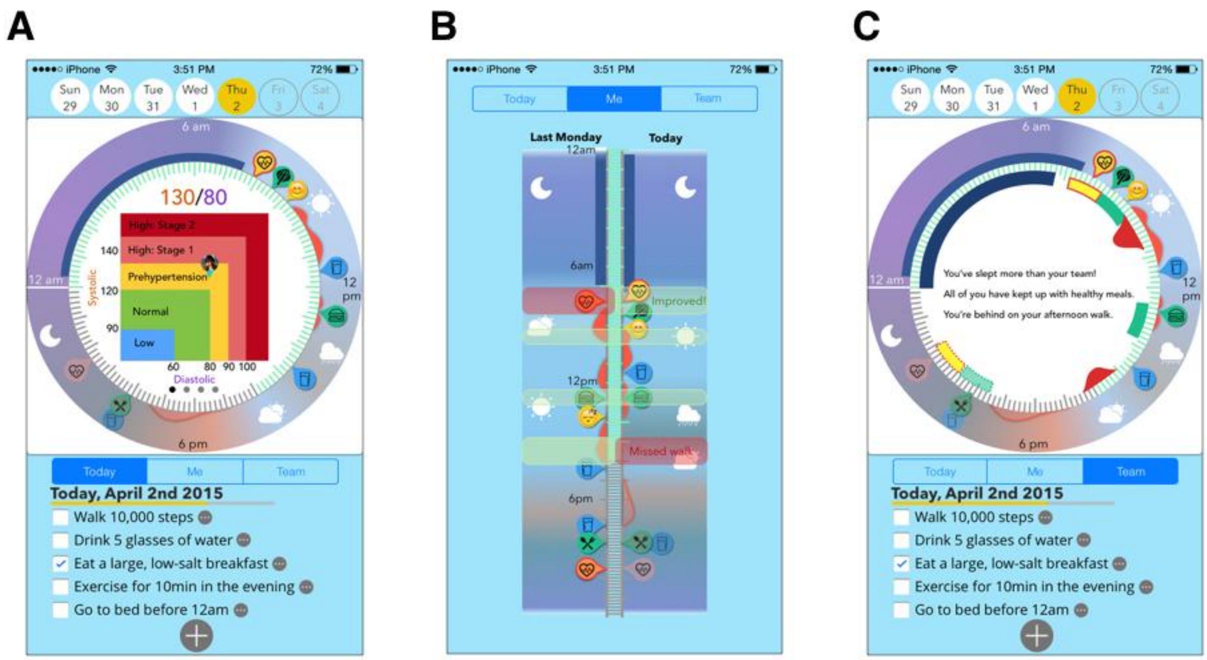

Figure 1: Overview of *Contextualized Quantified Self* (CQS) visualization. (**A**) User interface displaying calendar (top), Day Ring (center), and Goals Panel (bottom). Each entry is added to the user's timeline (*Blue arc*: sleep; *red curves*: steps with exercise intensity; *pins*: blood pressure measurement, meals, mood, water). The user's day is surrounded by environmental information (e.g. weather). Personalized daily goals generated using a Learning Health System aggregating many users' data are presented as a checklist, and the user can tap on the button to the right of each goal to see its justification. Remaining goals are listed as "ghost entries" on the timeline providing a suggested time for completion. Detail View in center displays additional information. (**B**) One vs. one comparison view allowing a user to compare him-/herself against their activity on a previous day. Green bars indicate lines of agreement; red bars indicate discordant times and opportunities for improvement. (**C**) One vs. many comparison view. Inner circle displays time range during which team has completed activities. Textual summaries are also included for motivation.

Description of the proposed solution

We designed this interface to work with a Learning Health System (LHS) providing personalized *goals* leading to a long-term *objective*, and suggested *time-dependent tasks* on the visualization as guides toward goal completion. While the specifications of the LHS are beyond the scope of this design challenge, we will generate personalized daily goals for each user by comparing him or her against similar users to find lifestyles that are predictive of improved outcomes for the given objective. We then wish to display the results of these analytics in a clear and consolidated way. To do this, our interface is composed of three elements: the central Day Ring, the calendar at the top, and the Goals Panel at the bottom (Figure 1).

The central Day Ring contains several elements that allow the user to quickly see their data in context, view temporal relationships between their data, and see remaining goals for the day. A 24-hour clock contains the user's timeline for a given day. Instead of treating each data type as its own isolated graph, we acknowledge and highlight the temporal relationships between different data types by displaying each actively or passively logged entry (including sleep, steps, meals, drinks, mood, and blood pressure measurements) sequentially on the timeline (Figure 1A). A user can tap on any entry to view more detail. Remaining goals from the LHS and suggested times for their completion are displayed on the user's timeline as "ghost entries" that summarize the context-driven goals generated from many users back onto each individual user's timeline.

The Day Ring supports three types of comparison: one versus one (e.g. one user against a previous day or one user versus another user), one vs. many (e.g. one user against the day of their team), and many vs. many (e.g. their team compared to the entire user population). In the center of the Day Ring is a Detail View that allows the user to see progress towards completing their goal, detailed measurement information, and environmental data such as the weather forecast.

Above the Day Ring is a calendar from which users can elect to display their previous days. At the bottom of the page, a panel displays the goals for that day. Unlike many QS apps where users must laboriously keep a diary, our interface represents goals using a checklist format that automatically updates when they have been reached. This rationale conveys more closure, and each goal can be expanded to get access to its algorithmic justification. The ability to expand goals to view the analytic basis for their inclusion will help relieve symptoms of the "black box" models and invite users to understand the rationale for suggested lifestyle changes.[15]

Using our case study of monitoring blood pressure, our goals would take into account common recommendations for blood pressure measurement (e.g. consistent time of day for measurement, frequency of measurement, leaving adequate time after awakening and before meals and exercise to measure blood pressure) as well as diet and exercise suggestions. We will also be able to leverage environmental factors such as weather or pollen levels to suggest appropriate times for achieving exercise requirements for the day. Finally, lifestyle patterns identified using our LHS for both a user over time as well as multiple similar users would be summarized in the daily goals and ghost entries.

Discussion of alternative solutions considered

As alternatives we considered bar graph solutions as well as different shapes for the timeline. Bar graphs would entail having an individual chart for each data type collected. We also considered alternate shapes for the timeline as well as simplifications such as grouping times into morning, afternoon, and evening. Finally, we iterated on the proposed solution, beginning with just the timeline before adding the Detail View and environmental data. This was inspired by our realization that it was necessary to correlate a user's activities with external factors such as environment.

Discussion of the strengths and weakness of the chosen solution as compared to the alternatives

The major strength of our design is that it can be adapted to a variety of screen sizes including smartphones and smart watches. The concentric design is adapted to concisely visualize multiple layers of information (e.g. physical activity, meals, sleep, mood, beverages, schedule, and environment). The weakness is that users may not be familiar seeing data visualized in this way compared to standard visualizations such as bar graphs. However, we believe that seeing many dimensions of data consolidated together will facilitate better understanding of the emergent trends our LHS finds in the data.

Proposed implementation and dissemination plan

As mentioned above, this interactive visualization interface is designed to directly interact with a LHS that, for a given objective, compares one user to many similar users to provide personalized daily goals broken up into time-dependent tasks displayed on the Day Ring. To this end, we are actively implementing the presented design in the form of an iOS app.[24] Users will contribute both passively collected data (e.g. steps and sleep from wearable devices that communicate with HealthKit) and actively collected data (entered using a majorly optimized and simplified data entry menu also beyond the scope of this abstract). The data generated by users will be stored on a HIPAA-compliant server. This implementation is scalable since both the data storage and computing power necessary to support the LHS will grow with the user base. We will disseminate the app through Apple's App Store.

Proposed evaluation plan
This interactive visualization interface aims to be objective-agnostic and therefore fulfill the expectations of a wide variety of profiles. We identified three different sub-populations for evaluation: users with no chronic medical conditions and not used to practicing self-tracking, core quantified-selfers already engaged in one or several SQS, and users with high blood pressure who require frequent monitoring. The recruitment of these users will go through an IRB protocol and they will sign a consent form to agree on sharing their data after de-identification.

Supplementary video demoing the visualization features can be found at:
https://drive.google.com/file/d/0B6sloU_tAHOgYWdUNUp3cENHTWM/view?usp=sharing

References

1. Mcfedries P. Tracking the quantified self [Technically speaking]. Spectrum, IEEE. IEEE; 2013 Aug 1;50(8):24–4.
2. Almalki M, Gray K, Sanchez FM. The use of self-quantification systems for personal health information: big data management activities and prospects. Health Inf Sci Syst. 2015;3(Suppl 1 HISA Big Data in Biomedicine and Healthcare 2013 Con):S1.
3. A personal view on systems medicine and the emergence of proactive P4 medicine: predictive, preventive, personalized and participatory. 2012 Sep 15;29(6):613–24.
4. Hood L, Lovejoy JC, Price ND. Integrating big data and actionable health coaching to optimize wellness. BMC Med. BioMed Central Ltd; 2015;13(1):4.
5. Kim J. Analysis of health consumers' behavior using self-tracker for activity, sleep, and diet. Telemed J E Health. Mary Ann Liebert, Inc. 140 Huguenot Street, 3rd Floor New Rochelle, NY 10801 USA; 2014 Jun;20(6):552–8.
6. Dontje ML, de Groot M, Lengton RR, van der Schans CP, Krijnen WP. Measuring steps with the Fitbit activity tracker: an inter-device reliability study. J Med Eng Technol. Informa UK Ltd. London; 2015 May 27;:1–5.
7. Wearable band shipments set to exceed 43.2 million units in 2015 [Internet]. Canalys. Available from: http://www.canalys.com/static/press_release/2014/canalys-press-release-20140911-wearable-band-shipments-set-exceed-43-2-million-units-2015.pdf.
8. Wearable technology worldwide projected total unit shipments from 2013 to 2018 (in millions) [Internet]. MarketsandMarkets. In Statista - The Statistics Portal. Available from: http://www.statista.com/statistics/302500/wearable-technology-worldwide-unit-shipments/
9. The Future of Biosensing Wearables [Internet]. Rock Health Partner. 2014 Jun. Available from: http://fr.slideshare.net/RockHealth/the-future-of-biosensing-wearables-by-rockhealth.
10. Ledger D. Inside Wearables [Internet]. Endeavour Partners. 2014 Jan. Available from: http://endeavourpartners.net/assets/Endeavour-Partners-Wearables-White-Paper-20141.pdf
11. Li I, Dey A, Forlizzi J. A stage-based model of personal informatics systems. the 28th international conference. New York, New York, USA: ACM; 2010. 10 p.
12. Van den Bulck J. Sleep apps and the quantified self: blessing or curse? J Sleep Res. 2015 Apr;24(2):121–3.
13. Choe EK, Lee NB, Lee B, Pratt W, Kientz JA, Lee NB, et al. Understanding quantified-selfers' practices in collecting and exploring personal data. the 32nd annual ACM conference. New York, New York, USA: ACM; 2014. 10 p.
14. Larsen JE, Cuttone A, Lehmann S. QS Spiral: Visualizing Periodic Quantified Self Data. *CHI'13*. Apr 27–May 2, 2013.
15. Bell MZ. Why Expert Systems Fail. *The Journal of the Operational Research Society*. 1985 Jul 1;36(7):613–9.
16. Friedman C, Rubin J, Brown J, Buntin M, Corn M, Etheredge L, et al. Toward a science of learning systems: a research agenda for the high-functioning Learning Health System. 2015. pp. 43–50.
17. Keeping High Blood Pressure Under Control [Internet]. The American Heart Association. August 14, 2014. Available from: http://www.heart.org/HEARTORG/Conditions/HighBloodPressure/PreventionTreatmentof HighBloodPressure/Keeping-High-Blood-Pressure-Under-Control_UCM_460131_Article.jsp.
18. The Centers for Disease Control. Vital signs: awareness and treatment of uncontrolled hypertension among adults—United States, 2003–2010. *MMWR*. 2012;61:703-9.
19. Go AS, Mozaffarian D, Roger VL, et al. Heart disease and stroke statistics—2014 update: a report from the American Heart Association. *Circulation*. 2014;63:1230-8.
20. Heidenreich PA, Trogdon JG, Khavjou OA, et al. On behalf of the American Heart Association Advocacy Coordinating Committee; Stroke Council; Council on Cardiovascular Radiology and Intervention; Council on

Clinical Cardiology; Council on Epidemiology and Prevention; Council on Arteriosclerosis, Thrombosis, and Vascular Biology; Council on Cardiopulmonary, Critical Care, Perioperative and Resuscitation; Council on Cardiovascular Nursing; Council on the Kidney in Cardiovascular Disease; Council on Cardiovascular Surgery and Anesthesia, and Interdisciplinary Council on Quality of Care and Outcomes Research Forecasting the future of cardiovascular disease in the United States: a policy statement from the American Heart Association. *Circulation*. 2011;123:933-44.

21. Patel MM, Daru B, Roman D, et al. Progress of health plans toward meeting the Million Hearts Clinical Target for High Blood Pressure Control – United States, 2010-2012. *MMWR*. 2014;63:127-30.
22. Lloyd-Jones DM, Hong Y, Labarthe D, et al. On behalf of American Heart Association Strategic Planning Task Force and Statistics Committee Defining and setting national goals for cardiovascular health promotion and disease reduction: the American Heart Association's Strategic Impact Goal through 2020 and beyond. *Circulation*. 2010;121:586-613.
23. The Healthcare Effectiveness and Data and Information Set [Internet]. *Proposed Changes to Existing Measure for HEDIS 2015: Controlling High Blood Pressure (CBP)*. March 19, 2015. Available from: http://www.ncqa.org/Portals/0/HomePage/CBP.pdf.
24. WELL by Plurl Health [Internet]. Available from: http://www.plurlhealth.com.