Exploring a Theory-Guided Path to the Design of Personal Informatics and Intervention Technologies

Elizabeth L. Murnane
Information Science
Cornell University
elm236@cornell.edu

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Abstract
At a high level, my goal is to design and deploy behavioral coaching and intervention systems that better complement individual users' unique characteristics. I am motivated by the idea that a person's innate attributes and current contexts interact in ways that produce idiosyncratic behaviors that generic interventions may not suit. Using domain knowledge as a guide, my research develops lightweight profiling methods that leverage people's digital footprints in order to passively sense pertinent psychological, physiological, and behavioral characteristics – and ultimately tailor personal informatics and intervention tools accordingly. I argue that such a theoretically-informed approach that is able to robustly mine, model, and accommodate personal variability will lead to technological solutions that better meet individual needs and produce more positive outcomes.

Author Keywords
Personalization, Personal Informatics, Intervention

Introduction
Research is increasingly exploring the value of technology for behavioral awareness and intervention, for instance via personal informatics tools that help users collect and reflect on personal data [7] or persuasive technologies that promote certain attitudes and behaviors [5].

Theory-Driven Technology Design

Advocates for theory-driven approaches argue that theory can inform system design and evaluation [6] and that the efficacy of technology-mediated interventions depends on theoretical understandings of the mechanisms behind behavior [8]. One of the earliest and perhaps most well-known examples of theory-guided persuasive design is the UbiFit system for monitoring and maintaining physical activity [4], and other more recent systems have been similarly designed on theoretical premises (predominantly goal-setting), for instance to encourage sustainable behaviors, social activism, and physical activity.

While such work has legitimately benefited individuals striving to make behavioral changes, most systems do not make similar efforts to incorporate relevant theory into designs, or theories are only given a cursory mention and leave details ambiguous as to how constructs were actually translated into design elements [13]. Also, most take a generic approach and offer one-size-fits-all interventions – even though idiosyncratic differences can influence the efficacy of an intervention and successful behavior change depends on personalized solutions [3].

Personalization

One personalization strategy is for users to self-report relevant traits. As the quantified-self movement grows, people are increasingly using technology to measure and record personal data, but such user-driven collection is burdensome nonetheless. In addition, it is increasingly infeasible for individuals to capture the amount and granularity of information necessary to produce a comprehensive behavioral profile comprised of multiple personal variables and behavioral determinants. Further, an approach dependent on self-report is especially problematic for some contexts such as when self-assessment is compromised (e.g., for people with sleep deprivation or certain mental health conditions).

Thus, interest arises in system-driven personalization, for instance by passively measuring and modeling individual characteristics from behavioral trace data. Such methods have rapidly progressed as technology ownership and usage levels grow and as devices' sensor capabilities become increasingly extensive. However, we again encounter shortcomings – namely, sensing is not theoretically informed but rather takes a more data-driven approach based mostly on intuition or trial and error [12]. This is understandable given the wealth of available user-specific data and considering the effort required to reach out to domain experts or to independently investigate and assimilate relevant theories – understandable, but not desirable.

First, such systems may simply have a veneer of robustness, where success has been achieved in fitting a model – but where the appropriate constructs may not have been captured or modeled in the first place. Similarly, exhaustive approaches face computing power limitations; for instance, battery drain can plague even simple continuous sensing toolkits. A theory-driven approach that is more targeted towards capturing features likely to hold relevant information can both help prevent important facets of data from being overlooked as well as avoid unnecessary processing. Finally, though these systems may be capable of identifying statistical patterns from sensed behaviors, without a theoretical foundation we may easily misinterpret such behaviors or fail to control for confounding factors that actually underlie them. A theory-driven approach allows us to more confidently interpret observations and also speak back to and refine existing theories.

My Research To Date

My research aims to close these gaps among theory, personalization, and design. To date, I have focused on the following domains that exemplify the value in pursuing theory-driven, personalized approaches to the design of personal informatics and intervention technologies.

Case Study: Smoking Cessation

There are nearly 44 million smokers in the U.S. alone, where tobacco smoking is the leading cause of preventable death and the leading form of chemical dependence. Importantly, over 68% of smokers report a desire to quit and over 50% have attempted to do so for at least one day. However, relapse is common, and only a minority of smokers are able to permanently maintain abstinence [2].

Digital cessation tools, such as mobile monitoring and assistance applications, hold tremendous potential to empower users at a broad scale with information, strategies, and self-awareness when attempting to quit. However, studies of existing tools find they have low adherence to established clinical practice guidelines for treating tobacco use and dependence and also do not provide support that is personalized, based on individual motivations, or adaptive during the cessation process, for instance to detect or preempt relapses.

In this study [10], we analyzed tweet and network data over a two-year window from a sample of 653 Twitter users trying to quit smoking. Guided by extant theory, we derived predictor variables related to posting activity, sentiment, and social network structure and interactions in order to compare users who abstain vs. relapse. Among other results, we showed that those who fail in their smoking cessation are far heavier posters and use relatively less positive language, while those who succeed are more social in both network ties and in directed communication. We further qualitatively unraveled the cessation process to identify users' motives, preparedness, and strategies – finding that Relapsers were far more likely to procrastinate before cessation; quit for more casual, shallow, and unrealistic reasons; and chose a cold turkey strategy rather than effective treatment methods.

Our findings' consistency with clinical evidence suggests that tweets about smoking can be leveraged by intervention systems to diagnose and monitor cessation status. Such personalized behavior change tools could use these signals to tune the level of assistance based on whether a new user is more or less likely to maintain abstinence; tailor the content, timing, and audience of information and reminders based on the different motives and mindsets of a user; and monitor relevant activities and behavioral changes for relapse warning flags.

Case Study: Predicting Psychological Traits

Self-efficacy has been shown to fuel motivation, influence effort put towards tasks, and overall improve performance outcomes [1]. Such qualities make it stand out as a potential predictor of positive outcomes across domains such as online contribution or health behavior change.

In this study (under review), we aimed to identify self-efficacy through linguistic markers in online text, with an eye towards an automated, broadly deployable method for detecting psychological signals from technology-mediated behavioral traces. Guided by theory from social science, psychology, and linguistics, we constructed language features representative of salient characteristics of self-efficacy in order to operationalize traits including perseverance, confidence, sentiment, executive skill, self-regulation, critical thinking, and social competency.

Comparing individuals with high vs. low self-efficacy, we demonstrated ways in which self-efficacy manifests. Specifically, posting volume and length were positively associated with self-efficacy as were features related to optimism, executive skill, and sociability, while impulsivity and negativity were associated with low self-efficacy. Attempting binary classification of high/low self-efficacy, our approach outperformed multiple baseline algorithms – including more exhaustive and data-driven techniques, which further bolsters the notion that a theoretically informed approach may genuinely enhance performance.

Case Study: Sleep

Sleep has gained considerable recent interest, leading to the development of tools to help users track sleep patterns and duration, evaluate sleep quality, and adopt healthy sleep and wake schedules. However, these systems tend to present generic recommendations rather than provide support that is personalized and accommodates individual variability, both contextually and biologically speaking. For instance, consider the blanket recommendation, "End caffeine consumption 8-14 hours before bedtime" even though caffeine does not affect everyone equally.

Guided by a theoretical understanding of the biology behind sleep and wake behaviors, this research [9] aimed both to better understand the interplay between internal rhythms and technology-based external factors and to develop novel sensing techniques that incorporate such awareness of chronobiological variables to more accurately assess neurobehavioral functions and misalignments.

Using data from 9 participants' phone and social media logs, survey instruments, sleep diaries, and interviews, we first analyzed temporal trends in technology use along with associations between use and sleep timing. We then leveraged these usage patterns to infer sleep onset and wake events (with an accuracy comparable to approaches that are more obtrusive on users and less feasible to deploy on a mass scale) and to detect chronobiological phenomena such as "social jet lag" related to imbalances in sleep duration between work days and free days.

Applying this sleep sensing technique, we next explored the impacts of sleep on neurobehavioral functions known to exhibit strong circadian patterns and suffer substantially after sleep loss and interruption: attention, cognition, and mood. Our analyses revealed significant differences in these variables following nights of adequate vs. inadequate sleep – specifically that lack of quality sleep manifests in cyberloafing behaviors (based on increased amount, frequency, and burstiness of technology usage the following day), diminished cognitive performance (based on the expression of complex thought in text-based social media content), and more negative mood (based on sentiment analysis).

Overall, this work demonstrates how relationships and phenomenon well known in a domain of study can be made apparent through analysis of technology use, which we can leverage as part of more personalized behavioral assessment and intervention appropriate for that context.

Case Study: Bipolar Disorder

Beyond developing theoretically-guided profiling methods that leverage technology-mediated behaviors to model user characteristics, my research also aims to gain insights into how and why people use technology in particular ways. I have therefore undertaken research in a domain where pre-existing theory is lacking – the self-monitoring practices, attitudes, and needs of individuals managing mental health – in order to recommend design principles for user-driven and system-driven monitoring technologies that are suitable for this context.

In particular, bipolar disorder has been recognized as one of the ten most debilitating illnesses worldwide [11]. The condition is characterized by drastic swings between opposing mood states, which necessitates more personalized support capable of handling individual differences – in this case, even at the level of intra-individual variability. Recent research suggests the efficacy of non-pharmacologic based treatments that target the tracking and stabilization of behavioral, social, and sleep-wake routines. One promising approach is ubiquitous, technology-based tracking through both wearables and mobile applications.

For this study (under review), we administered a survey of closed and open ended responses to 552 individuals with bipolar disorder, which we analyzed with descriptive statistics and qualitative methods. We found that for nearly two thirds of respondents, self-monitoring positively changed their overall approach to maintaining health by imparting behavioral, psychological, and social benefits. Most notably, tracking helped individuals self-enforce behavioral consistency; increased their self-awareness of BD patterns, triggers, and effective coping strategies; enabled development of stronger senses of self-efficacy and self-compassion with respect to their condition; and facilitated the conveyance of information with caregivers. However, problematic experiences related to tracking were also reported. Challenges included remembering or maintaining tracking routines, especially during times of emotional instability; difficulties extracting patterns from paper-based logs or interpreting aggregated reports from some digital tools, including during interactions with doctors; and frustrations related to unintuitive or unreliable experiences with technology-based trackers.

Translating findings into design guidelines, we additionally provided recommendations for how technology could be more condition-oriented, intuitive, and flexible in order to support the positive aspects of self-monitoring, while attempting to overcome current challenges. Further reporting on respondents' technology-mediated warning signs and symptom manifestations, we also provided evidence for the feasibility of leveraging usage patterns to develop more proactive and automated forms of symptom tracking, episode detection, and personalized intervention.

Future Work

In the sleep domain, I am continuing to study relationships among technology usage, sleep, and cognitive performance – specifically, how peaks and dips in alertness manifest through mobile application use, linguistic markers in online text, and technology-mediated social interactions. Using interview data from the aforementioned sleep study and a follow-up study focusing on daily alertness trends, I am also exploring a tension wherein technology for delivering circadian-attuned recommendations can itself be a disruptor to sleep and neurobehavioral functioning, and I am deriving design implications for tools that strike a balance between adherence and overuse.

Regarding bipolar disorder, I am building on my findings of how aspects of technology usage (e.g., amount, timing, type, and linguistic features) reflect bipolar symptoms in order to develop models for detecting and predicting the onset and remission of manic and depressive episodes.

While most of my work to date has focused on system-driven approaches to personalization, I am also exploring novel forms of user-driven data capture by developing game-based ecological momentary assessments that promote adherence, data fidelity, and user enjoyment.

Finally, to pursue my ultimate goal of creating end-to-end informatics and intervention systems, I am developing games that use personal data (e.g., email, Facebook) as input to explore a novel medium for supporting awareness and reflection of patterns, activities, and sociality.

Doctoral School – Personal Objectives

I will appreciate feedback and guidance about what puzzle pieces I should pursue for the remainder of my PhD program, and I hope the Doctoral School will help me determine how I can convey or adjust my research to make it a valuable contribution to the UbiComp community. Specifically, I am focusing on the domain of health and well-being but could expand this scope; I typically utilize web and text data but could incorporate alternate sensor streams; and I primarily devote energy towards modeling user characteristics and deriving design implications but could turn attention to instantiating those computational methods and design principles in deployable systems.

Biographical Sketch

I entered the Information Science PhD program at Cornell University in August 2011 and plan to graduate in August 2016. I am advised by Dan Cosley (Chair) and also work closely with Geri Gay (1st minor committee member).

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