Towards Circadian Computing: A Sensing & Intervention Framework for BodyClock Friendly Technology

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Abstract
Human physiology and behavior are deeply rooted in the daily 24 hour temporal structure. Our biological processes vary significantly and idiosyncratically throughout the day. Continued disruption of biological rhythms often has serious consequences for physical and mental well-being, causing cardiovascular disease, cancer, obesity, and mental health problems. My research goal is to advance a vision for "*circadian computing*" — designing, developing and deploying novel technology that helps to maintain our innate biological rhythms. Towards that vision, I focus on developing technologies for detecting circadian disruptions and providing in-situ interventions. My approach involves passive and automated sensing of behavioral traits to model body clock patterns that can be used to support varying needs of users over time. One strand of my research focuses on developing tools that can adapt to our individual rhythms and provide more biologically attuned support in the areas of physical and cognitive performance, sleep, and wellbeing. The other aspect of my research focuses on mental health — preventing relapse by identifying disruptions and providing circadian interventions for bipolar and schizophrenic patients.

Author Keywords
Circadian Computing; mHealth; mobile sensing; chronobiology

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Introduction

Like nearly every organism on Earth, our physiology varies significantly over the course of a day. Within our bodies there are hundreds of biological clocks, controlled by a "master clock" in our brain — the Suprachiasmatic Nucleus or SCN [6]. These body clocks vary between individuals, from "early birds" (early types) to "night owls" (late types) and control oscillations in our biological processes resulting in circadian rhythms. "Circadian" means about (*circa*) a day (*diem*). It refers to any biological cycle that follows a roughly 24-hour period, including regular changes in our blood pressure, cortisol, and melatonin levels. These fluctuations affect when we sleep, eat, and also have an impact on our physical and mental performance.

But, in our modern mobile world, with its always-on ethos, circadian disruption — often exemplified by sleep discrepancy — is becoming increasingly wide-spread. Indeed, a recent study found that around 80% of the population live against their innate rhythms [15], mostly by adhering to work schedules that demand waking up earlier than our internal clock dictates. Sleep pathologies are reaching an epidemic level, with sleep disorders affecting around 70 million people in United States[1] alone.

Such persistent disruption of biological rhythms can have serious consequences for physical and mental well-being [7]. For example, constant changes in daily routine due to shift work has been shown to increase risk factors for cancer, obesity, and type-2 diabetes [17]. In particular, circadian misalignment can have a debilitating impact on mental health. For patients with bipolar disorder [9] and schizophrenia [4], circadian disruptions might result in relapse onset with devastating consequences.

While computational approaches are increasingly focusing on personalization and context-awareness, they have yet to factor in consideration of our internal body clock. As a result, we are surrounded by devices and technologies that make incomplete assumptions about the steady capabilities and fixed requirements of their users throughout the day. As examples, current technologies do not support or adapt to individualized variations in sleep onset, working memory, alertness, and cognitive and physical performance. The goal of circadian computing is to provide technology with this predictive power, so it can play to our biological strengths (and weaknesses), instead of requiring users to adapt to the 24/7 steady hum of machines.

Towards that goal, I focus on developing technologies for detecting circadian disruptions and providing in-situ interventions. My approach involves passive and automated sensing of behavioral traits to model body clock patterns that can be used to support varying needs of users over time. One strand of my research focuses on developing tools that can adapt to our individual rhythms and provide more biologically attuned support in the areas of physical and cognitive performance, sleep, and wellbeing — for instance, suggesting daily schedule that aligns with the natural oscillation of alertness throughout the day. The other aspect of my research focuses on mental health — preventing relapse by identifying disruptions and providing circadian interventions for bipolar and schizophrenic patients. Such technologies can help transform existing approaches to mental health care

[1] http://www.cdc.gov/sleep/about_us.htm

from being reactive to preemptive.

Overall, my research strategy combines techniques from mobile sensing, machine-learning, ubiquitous computing and chronobiology to (1) develop low-cost and scalable methods that can cheaply, accurately, and continuously collect real-time behavioral data to identify biological rhythm disruptions; (2) design and build novel computing systems that help people to realign with their individual rhythms by employing circadian interventions ("fixing the broken clock"); and (3) deploy and evaluate these systems among target populations.

Current research

Scalable assessment of circadian disruptions
While in recent years there has been a growing attempt for detection of circadian disruption and its impact, such studies have been often conducted in artificial settings. Understandably, these methods are not scalable to large population. Subjective assessments and surveys have been used to investigate the relations between environmental factors, circadian systems, and sleeping patterns in large scale [16]; but as these are dynamic processes that change over time, chronobiologists have pointed out the need for *in situ* and broad data-collection strategies that can record real-time data over a large population spanning various time zones and geographical locations [14].

Towards that, in our recent UbiComp paper [1], we focused on detecting and inferring behavioral traits of circadian biomarkers in a manner that is low-cost, reliable, and scalable. Our study with 9 participants over 97 days show that low level smartphone usage patterns can be used to detect and predict individual daily variations indicative of temporal preference, sleep duration, and deprivation. Such a low-cost and unobtrusive way of inferring these cues of circadian disruptions could help people understand and diagnose sleep issues and enable adoption of individualized work schedules.

Circadian Rhythms for Modeling Cognitive Performance
Cognitive performance is known to vary significantly across the day as a result of multiple individual factors including circadian variations, sleep pressure, and stimulant intake (e.g., caffeine). Being able to assess the biological basis of performance continuously and unobtrusively has significant implications for context-aware computing and UbiComp systems. Tailored feedback and actionable suggestions based on cognitive performance would impact how we schedule our lives, how we work, and when we sleep. Combined with other forms of context, an understanding of the user's mental state and present capacities has the potential to change how we approach diverse application areas such as scheduling, education, and accident prevention.

Towards this vision, we focused on collecting reliable, in-situ data on cognitive performance with low user burden. For this, we used a smartphone based app that implements Psychomotor Vigilance Task (PVT), a reaction time test commonly used to measure alertness performance [10] by showing a visual stimulus at random intervals to the user, who responds by touching the screen. Use of smartphone based measurement also allows us to employ extensive sensor systems for passively collecting contextual data that might be useful in predicting alertness level. From recent study spanning 5 weeks over 13 participants, we are focusing to develop personalized models capable of detecting individualized trends in performance. Being able to predict the dynamics of alertness would lay the foundation for a new class of circadian-aware technology — technology that can adapt to dynamic variations in individuals' cognitive ability.

Preemptive care in the context of mental health
Maintaining circadian stability including sleep-wake cycles are particularly important in the context of mental health. Disruptions in circadian rhythms can result in relapse and psychosis onset for a number of mental illnesses including bipolar disorder (BD) and schizophrenia [3]. Being able to monitor behavioral trends indicative of such disruptions can enable early warning systems for more effective intervention. This can result in transforming existing mental health care from being reactive to preemptive — with a focus on detecting and preventing relapse even before it happens.

Bipolar Disorder
Bipolar disorder is a serious mental illness (SMI) that has been recognized as one of the eight leading causes of years lived with disability worldwide [12]. It has been associated with poor functional and clinical outcomes [11] and high suicide rates [2]. It also induces huge societal cost — the direct and indirect cost associated with bipolar disorder I and II in 2009 has been estimated to be $\$151$ billion in United States alone [5].

Figure 1: A watch face showing best hours for specific tasks.

While there is no cure for bipolar disorder, clinical evidence indicates that interventions targeting circadian stability including social rhythms, sleep–wake rhythms, and light–dark exposure may markedly improve outcomes [13]. For that, patients use Social Rhythm Metric (SRM) to establish and keep track of daily routines, mood and energy [8].

While the SRM has been proven effective for assessing stability and rhythmicity of social routines, its paper-and-pencil format has multiple disadvantages as a clinical tool. Longitudinal self-tracking is difficult particularly in light of the inherent characteristics of bipolar disorder. Even well-intentioned patients often forget to complete it. Additionally, in certain stages of illness, momentary and retrospective recall can be particularly challenging for patients with severe psychiatric disorders, and are sometimes unreliable.

In our recent work (*in review*), we focus on using smartphone-based sensing to overcome the limitations of existing self-report methods in helping individuals with bipolar disorder to maintain stability and rhythmicity. From our study over 4 weeks with 7 bipolar patients, we found that passively collected behavioral (e.g., speech, activity, sms and call log) and contextual data (e.g., location) using smartphone sensors can be used to infer rhythmicity as assessed from SRM score with high accuracy (precision: 0.85 and recall: 0.86).

Schizophrenia
Schizophrenia is a severe psychiatric disorder characterized by psychotic symptoms including hallucinations, delusions and cognitive deficits. It is one of the leading causes of years lost to disability that affects around 1% of the world's population. Sleep and circadian rhythm disruption is one of the most common and consistent features of schizophrenia [4]. So, being able to detect such disruptions can enable early intervention lowering the risk of relapse onset significantly. Towards that I am collaborating with system builders and clinical researchers for scalable, unobtrusive and automatic behavioral patterns monitoring for schizophrenic patients using smartphone to develop personalized early warning systems. So far, we have finished 6 weeks of trial and currently deploying for a large scale study.

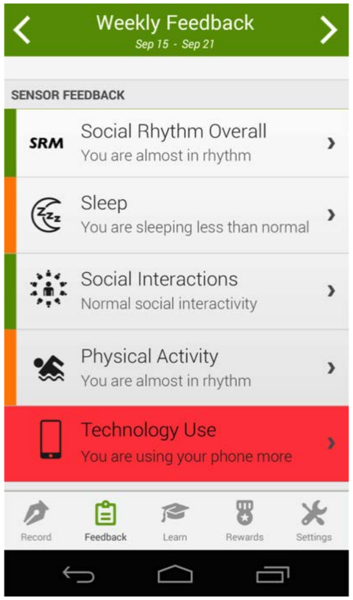

Figure 2: Feedback about daily routines to help bipolar patients maintaining stability.

Future work

Towards the vision of circadian computing, so far, I have been working towards assessment and detection of trends that might indicate disruptions. Future work will focus on making use of innate rhythm information in multiple contexts. In particular, I would like to build and deploy systems and applications that take circadian aspects into consideration.

Continuing on our work on assessing daily oscillation of cognitive performance, I am planning to build a scheduling and calendar system that better aligns with individual bodyclock pattern. In other words, if we are able to infer internal body clock and alertness pattern of a user, how can we design interventions that would suggest tasks more appropriate for a given hour (e.g., see Figure 1). Such a system can also enable better collaboration in a distributed team setting by pairing colleagues who are more synchronized with each other according to the sensed alertness profiles.

The other domain of application I am planning to work on is to help synchronize with one's internal rhythms. As our body uses environmental cues like exposure to sunlight for stabilizing bodyclock, it is possible to design interventions striving to minimize circadian disruptions. Being able to "fix broken clock" would be particularly important in the context of mental health. In particular, given the importance for bipolar patients to maintain stability, I am planning to design and develop a system that would focus on increasing adherence to daily rhythms for this population. One way of doing it might be through automated sensing to detect anomalies in daily trend and providing actionable and instantaneous feedback (see Figure 2).

Objective for attending the DS

The Doctoral School program in UbiComp 2015 would be a great opportunity for me to get feedback and critiques from the wider community. In particular, given that I have done significant work towards my research vision but still have 1.5 years to tie things together, the timing of this DS is ideal for me to communicate with senior researchers and fellow students about the direction of my dissertation work. I am quite excited about the potential exposure of my work and also hoping to gain insight about unrealized directions, design and study considerations, and new opportunities that would ensure a meaningful contribution to UbiComp and clinical community.

Biographical Sketch

I am pursuing my Ph.D. in Information Science at Cornell University. I am a member of People-Aware computing group and supervised by Tanzeem Choudhury[2]. My other committee member includes Prof. Geri Gay[3] and Deborah Estrin[4]. I am expecting to complete my Ph.D. by the end of 2016.

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