International Workshop on New Computationally-Enabled Theoretical Models to Support Health Behavior Change and Maintenance

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The global burden of disease is tightly related to conditions that are preventable and treatable through promoting changes in key human behaviors. As more regions of the world have increasing percentage of older adults in the total population, chronic disease and mental illness will become the major public health challenges nationally and globally. Reactionary "sickcare" systems that fail to prevent disease have become financially unsustainable. It is a global imperative that we move to a preemptive model that advances health "up front." Population-scale health and wellness at a sustainable cost can only be supported by successful promotion of behavioral changes including improving diet, increasing physical activity, promoting hand washing and safe sex, decreasing smoking, and preventing alcohol abuse. The proposed workshop focuses on developing new paradigms for understanding health behavior change and maintenance that 1) reflect the unprecedented advances in mobile health technologies, ubiquitous data and innovative analyses, and 2) access the heretofore unimagined avenues for intervention that can help us to understand, predict and change human behavior.

Intellectual Merit: The leading causes of mortality and morbidity across the globe can be linked to human behavior and behavioral risk factors. These factors are also linked to chronic disease and mental illness, which are becoming major public health and fiscal challenges nationally and globally. Current theories of behavior change and maintenance, however, provide an inadequate foundation on which to develop technologies to support public health. Interactive, mobile, personal, and adaptive technologies may permit the creation of a novel class of health interventions. New theories of behavior and behavior change and maintenance are therefore needed that explain dynamic, social behavior and that may support the exploitation of real-time, dynamic, longitudinal, and personal data acquired using new sensor technologies to create dynamic feedback systems that motivate and sustain behavior change. This workshop will identify major challenges and opportunities that could inspire a paradigm shift in behavioral theory. The workshop will also help build the transdisciplinary community necessary to successfully develop new computationally-based or computationally-enabled theories of behavior change and maintenance.

Broader Impact: Reactive, "sick-care" health systems can no longer economically support the care of the aging population in the US and around the world. New, prescriptive and dynamic theories of behavior change and maintenance must be developed that can be used to motivate the creation of cost-sustainable technologies that support health and wellness. The proposed workshop will bring together international leaders in medicine and public health, behavior, engineering, systems science, game design, and a host of other relevant disciplines. The goal of the meeting will be to encourage the experts to collectively take the first steps towards developing a new paradigm in behavior change theory.

Key Words: Population health, theories of human health behavior, real-time data, predictive modeling, persuasive computing, data mining

Project description

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Background

The global burden of disease is tightly related to conditions that are preventable and treatable through promoting changes in key human behaviors. According to the WHO, the top two causes of death in middle- and high-income countries are (1) ischemic heart disease, and (2) stroke and other cerebrovascular diseases[1]. In the US, heart disease alone contributed to over half a million deaths in 2009[2]. These numbers are similar in Europe. In fact, a prospective study by Andersen and Chu[3] notes that cardiovascular disease accounts for nearly 30% of all deaths worldwide, and the percentage in low- and middle-income countries is similar to the global average. In low-income countries, the top cause of death is lower respiratory disease spread from person to person, while the 3rd and 4th top causes of disease are HIV Aids and ischemic heart disease, respectively. *The bulk of these leading causes of death can be linked back to behavioral risk factors.*

For example, diet, physical activity, and sleep are tightly related to obesity, which in turn is related to a host of diseases. In fact, diseases related to obesity are responsible for perhaps the highest burden of morbidity across the globe, including heart disease, cerebrovascular disease, stroke, and diabetes mellitus. The cost of obesity-related morbidity and mortality is increasing. It is estimated that in 2008, overweight and obesity contributed to 113.9 billion dollars in increased medical costs in the US[4]. The prevalence of obesity continues to be unacceptably high in both adults [5] and children [6] in the United States and worldwide [7-9]. Smoking is another behavior that contributes to the risk of many of the leading causes of mortality and morbidity [10]. While rates of tobacco use have plateaued in the US, these rates continue to increase in many parts of the world[11]. Mental illness presents another important context for behavioral interventions. Mental illness accounts for the largest proportion of disability in developed countries [12], and in the US and Canada, it accounts for 25% of all life years lost to disability and premature mortality[13]. Stress management has been shown to effectively reduce symptoms of depression and anxiety, as well as reduce risk of suicide [14-16]. While an effective HIV vaccine continues to elude us, the most effective means to confront the continuing HIV epidemic is to reduce behavioral risk [17]. Finally, the top cause of disease in low-income countries remains the spread of disease from person to person that could be reduced through behavior change.

As more regions of the world have increasing percentage of older adults in the total population, chronic disease and mental illness will become the major public health challenges nationally and globally. Reactionary "sickcare" systems that fail to prevent disease have become financially unsustainable. It is a global imperative that we move to a preemptive model that advances health "up front." Population-scale health and wellness at a sustainable cost can only be supported by successful promotion of behavioral changes including improving diet, increasing physical activity, promoting hand washing and safe sex, decreasing smoking, and preventing

alcohol abuse [10, 18]. Existing behavioral interventions are inadequate, due to concerns about both behavioral and economic sustainability. Technology-supported behavioral interventions offer a new strategy to explore, and because these interventions may be cost-effective at population scale, they may be *necessary* to effectively address persistent and growing public health issues globally.

Behavior change and maintenance (BC&M) is critical to the important mission of advancing global health at a viable cost. BC&M theories model the interaction between the individual, the environment, decisions, knowledge and attitudes, past behavior, and current behavior. Strong models provide guidance for design of effective interventions that motivate desirable health-related behavior for individuals or societies. Existing models may be weak in this regard; they are not prescriptive and do not take advantage of available ubiquitous continuous data that could be tapped to build real-time tailored models of individuals' behavior in context. Many current theories provide only relatively high-level, and some might argue common-sense, guidelines to intervention designers. Despite the extensive effort that has gone into developing and using existing theories, successful promotion and maintenance of change in key health-related human behaviors has proven difficult.

Current models of BC&M do not anticipate and provide guidance on how to exploit new computationally-enabled behavioral and contextual measurement, visualization, tailoring, and dynamic interaction with information[19].

There are four major limitations in the most popular/studied scientific models of behavior change.

- Limitation #1: These models are based on relatively slow information exchange and behavioral change. They model (or assume) behavior change at the scale of days, weeks, months, or years, not seconds, and they do not model rapid, dynamic, fluctuation of behavior according to multiple inputs and stimulus responses over time.
- Limitation #2: These models are based on limited conceptualizations of delivery of information. They often model (or assume) communication between an expert and layperson, with infrequent contact, delivered via verbal or printed communication, often in clinical settings, or through large-scale public health efforts. They do not model fast, interactive health communication taking place between individuals and all members of their personal and professional networks, where messages are shared in a variety of media and with complex, possibly overlapping, sets of people.
- Limitation #3: These models do not take into account the amount of data that can now be collected on an individual's behavior and environment, or the fact that much data related to behavior and decision making can be collected in real-time. Current models provide no guidance on how streaming data that can be instantly analyzed could be used to present timely, tailored, and context-sensitive feedback in real time, and they do not provide insight on how data on behavior can be used to instantly mold health communications or interventions that adapt to individual or environmental changes, or even interventions that quickly change the environment itself.
- Limitation #4: Although several of these models may not focus solely on individual behavior, they often fail to acknowledge the full influence of other contextual influences and constraints (e.g., economic influence, choice architectures, and dynamic social interaction). Current models also provide little guidance on understanding the relationships between health decision making across different health tasks, such as management of diet, screen time, physical activity, medication adherence, etc. The models fail to provide a holistic approach to support a variety of simultaneous health BC&M changes.

Due to these limitations, current scientific models of behavior change may provide inadequate guidance when designing new technology-enabled systems designed to support sustainable, cost-effective health behavior change and maintenance across the human lifespan and healthspan.

The proposed workshop is inspired by the idea that new technologies in data collection, aggregation, sharing and communication reveal a clear need for technology-informed behavior theory, measurement and analytics. New models of BC&M will, in turn, pave the way for the development of systems that improve health.

Opportunities: Ubiquitous computing and BC&M

Computers can support BC&M in new ways by computationally measuring and modeling behavior, affective states, and the environments in which these behaviors occur, in real time. Computational systems may operate at three levels simultaneously to support behavior change: the personal level, the environmental level, and the societal level.

The Personal Level

Data collection modalities including sensors from mobile and ubiquitous computing now enable real-time sensor fusion/pattern recognition to infer behavior/states. These systems can also measure internal and external environmental conditions that influence personal behaviors. Opportunities for ubiquitous, tailored feedback increase as individuals integrate "screen-time" into their everyday life in short and long bursts, day and night. These changes in how people are using electronic devices have come about with the proliferation of computationally-powerful and always-networked phones, tablets, desktop computers, car computers, gaming systems, and e-readers. New theories of BC&M aimed at modification of a particular individual's behavior might guide the development of cost-effective and sustainable health interventions. These computational systems could: 1) operate using data streams and strategies for data utilization *only* possible with computing (e.g., sensor- and computer- based behavior/state/environment measurement and modeling, real-time adaptive feedback) and 2) exploit new modes of information exchange (layperson to layperson, layperson to expert, frequent (minute-by-minute) contact, automated or computer-assisted communication, game design theory, etc.).

The Environmental Level

Behavioral economists have identified the importance of environment (i.e., the "choice architecture") as well as individual and environmental incentives on BC&M. Computational systems that are embedded within a person's environment – the home, workplace, transportation vehicles, community establishments – may enable new ways to measure and model relationships between personal decision-making and environmental situations. New theories linking computationally-inferred understanding of individual behavior and decision making with environmental influences may drive the development of user interface systems that provide support for individual behavior change via automatic manipulation of environmental contexts.

The Societal Level

Although the impact of mass media health communication has been extensively studied, behavior change theories are typically based on one-way models of communication. Media consumption at the societal level is increasingly becoming an interactive experience. Data can be aggregated and viewed instantly from not just one's immediate environment, but from the entire community or society. Visualization tools allow "zooming in" to an individual scale and "zooming out" to see aggregate patterns and, possibly, real-time changes in those patterns. This data aggregation, with the potential for targeted individual feedback in real-time to all of

the individuals in massive groups of people, may create new technology-facilitated opportunities for measuring and motivating health behaviors at the societal scale.

New Behavioral Models to Drive Innovation

New models are needed that can guide the creation of computer systems that dynamically deliver information in real-time to support BC&M at the personal, environmental, and societal levels. Novel systems science paradigms, such as agent-based and dynamic systems modeling, can be utilized along with real-time data streams to model the complex, dynamic processes that most certainly underlie BC&M. Emerging theories from human-computer interaction and game design on the properties that make compelling and sustainable interactive experiences may help interventionists create sustainable, longitudinal systems. Electronic tools that pinpoint conditions (environmental, societal, social, personal, and biological) that precede behavioral change may be used with new theories to support health. Utilizing new theories that provide insight into how to take into account multiple real-time intervention points and continuous data collection to promote behavior change, may stimulate the creation of more effective and cost-effective health promotion, disease prevention, and delivery of care interventions.

Discussion among a transdisciplinary group researchers from different cultures and immersed in diverse health promotion, disease prevention or health care systems (with different constraints, incentives, etc.) may spark creative ideas that would not emerge otherwise.

Advantages of International Collaboration

US and European health preventive health and health care delivery systems have different cost and quality drivers, regulatory challenges, and end-user expectations[20]. Tools for supporting next-generation health care, such as electronic medical record systems, are also in different stages of development and integration. Health care delivery is a massive enterprise, and the complexity of the system and any potential change to "business as usual" in any particular country can hinder discussions about disruptive change.

This international workshop is designed specifically to encourage discussion that transcends the constraints of any specific health or medical system or cultural expectations related to health care. Moreover, the workshop is structured to encourage idea generation between researchers who have diverse experience in health research, and who have access to a variety of sources of individual-level data, population data, electronic medical records, and prototype health behavior change measurement systems. An international collaboration will foster necessary discussions on how culture, environment, and technology-driven forms of human interaction might impact key health behaviors, and how these influences can be modeled using new technologies. We hope to encourage a greater openness among US researchers to consider the study and development of "game changing" behavioral theories that drive development of systems that work at the personal, environmental, and societal level to support health, even if wide scale deployment of the systems may not seem viable in the US at this time due to the economic/business constraints created by the peculiarities of the US model. Finally, this workshop aims to encourage conversations about differences in research methodologies and expected outcomes necessary to lead to translation of research into practice.

Desired outcomes and deliverables

The major outcome from the proposed workshop will be a publishable white paper from a transdisciplinary group of experts that reviews the state of the field in terms of technology-assisted BC&M and identifies new challenges and opportunities. The group will identify areas where breakthroughs in computational techniques will support or require new mechanisms and theories supporting BC&M. The goal of the paper will be to

describe fundamental scientific and engineering barriers or gaps in the state of knowledge that must be resolved in order to drive bold changes in healthcare delivery in the next 10-20 years. A secondary desired outcome will be to spark ideas for future research collaborations among the workshop participants that start to address the gaps and barriers.

Scientific Questions/Challenges

The workshop and resulting white paper will be organized to address the following scientific questions and challenges, which can be loosely categorized into questions about behavior theory, measurement of behavior, and computational persuasive interfaces.

1) Extending behavior theory

A fundamental question to be explored in the workshop is how to develop and evaluate new theories of BC&M that can inform the development of effective, computationally-enabled health and wellness systems. Workshop participants will identify subfields that may not have been considered during the development of existing theories – fields such as computational sensing, human-computer interaction, game design/interaction, and mobile/ubiquitous computing. Promising ideas may be drawn from animal learning theory, marketing theory, (social) network analysis, behavioral economics, neuroscience, lifespan and developmental psychology, education, environmental scientists and systems science. Participants will then be asked to identify research challenges and gaps in knowledge.

Among the questions that may be considered are,

- Can models be developed that can account for short-term and long-term behavior change?
- Can behavior change be modeled as a transition system, acknowledging that behaviors and states can change rapidly, and health-related activity and health interventions may change (or need to change) accordingly? How can models capture the dynamic nature of real-life behavior and the dynamic influence of relationships, information and environments, and provide a framework that drives delivery of dynamic health information?
- Would models that acknowledge complex temporal influences on behavior that span weeks, months, or even years, provide insight into the design of health systems that support change in the moment?
- Can models of change account for simultaneous change along multiple health dimensions and the complex relationships between them?
- What is the nature of timing of measurement and information delivery on the effectiveness of feedback delivered by new dynamic systems, and how might a technical system maximize engagement and impact by manipulating the timing of information delivery?
- What type of behaviors, emotions, cognitions, context, environments and systems need to be measured to enable behavior change at the personal, environmental, and societal levels? We know a great deal about behavior measurement in non-mobile sensing. How much of what we know is valid in ubiquitous sensing? What type of measurement, timing and method for feedback will maximize health outcomes in various settings?

2) Exploring "holistic" measurement of behavior

Research to date on sensing activity, behavior, or affective states may have suffered from a tendency for engineers to use the sensing tools they are most familiar with (or have access to) rather than the combination of multi-modal sensors that may best accomplish a measurement task. Similarly, researchers in the health

domains tend to study measurement of particular behaviors and behavioral determinants that are assumed to be related to particular diseases or health states out of context from a person's entire emotional, cognitive, social, behavioral or contextual environment or life phase.

Among the questions that may be considered are,

- What are the scientific and technical barriers to creating and validating systems that accomplish sensing in a more holistic way, where multi-modal sensor fusion is used to continuously recognize a variety of behaviors and behavioral determinants that impact health?
- How does the field move from recognition of short-term, common behaviors (posture, ambulation, stressful event, etc.) to recognition of long-term patterns and trends that may need to be identified to support behavior change interventions (in a meeting, going to work, preparing for a trip, feeling stressed, etc.)?
- What are the relationships between personal sensing and sensing using computing systems in the environment, or computing systems used by entire societies?
- How can success in fields such as speech recognition, based in large part on acquisition of massive datasets, be repeated in fields related to recognition of specific health-related behaviors?
- How are imperfect activity recognition systems to be used in practice? To achieve good performance, will the end-user need to participate in training the system and "fixing" it when it breaks, and are new computational interactive learning models required to support this?
- What are appropriate statistical models for representation of uncertainty and aggregation of uncertainty over a person's long-term behavior of days, weeks, or months, and can these models be used by algorithms to support real-time behavioral feedback?

3) Creating and evaluating computational persuasive interfaces and systems

New theories on behavior change that model dynamic change and computational systems that can measure personal behavior, the environment, and societal behavior or trends should support creation of new systems that actively motivate behavior change. Workshop participants will consider how the theory will lead to practical systems, and the barriers that must be overcome when both creating prototypes and proving efficacy to enable population-scale adoption.

Among the questions that may be considered are,

- How might high-frequency human-computer interaction be used to support longitudinal engagement with a wellness system?
- Are some types of incentives (financial, game rewards, social feedback, etc.) orders of magnitude more effective than others in supporting engagement?
- What are the methodologies that should be used to evaluate computer-assisted behavior change systems using new BC&M models? Are there metrics the field should expect to see in publications that will enable incremental progress and major breakthroughs?
- How should systems designed to work for years be evaluated if they depend on technology that may change at a much more rapid pace?
- How can open systems be encouraged, shared, and maintained?
- How should behavioral, social, and computer scientists and engineers structure their scientific inquiries to support development of sound theories that use technology but without too much dependence on any particular implementation of the technology?

- What are the implications for experimental design and statistical methods for evaluating time series systems with real-time automated behavioral measurement and an intensive human-algorithmic feedback loop in the system?

In all three areas, workshop participants will be encouraged to think about implications of questions at the personal, environmental, and societal scales. Their mandate will be to identify high-risk but high-payoff research trajectories.

Format

We propose to facilitate a 1.5 day, 30 person workshop. Invitees will consist of a mix of experts in behavior change theory, health and wellness systems, behavior measurement and measurement technology, and various types of "persuasive" interventions. Participants will be included from academia, industry, and government, with half of the participants from the US and the remainder from Europe. The workshop will be kept small to facilitate discussion. The schedule will be set by participants during the 1.5 months prior to the workshop. Participants will agree to provide perspectives before, during, and after the workshop according to the following schedule:

June 1	Prompts (probing questions to solicit ideas on workshop topics) sent to workshop participants
June 23	Prompt responses due (2-3 pages of material and 1-2 recommended paper citations); Responses distributed to all workshop participants
July	Second round of prompts
August 30	Participant topic suggestions and short talk suggestions due. Begin an iterative procedure facilitated online to identify topics to discuss in the workshop (a similar procedure to "unconference" topic identification) – this will be used to identify who gives short talks on which topics to provoke discussion at the workshop
September 15	Workshop schedule distributed
Oct 16-17, 2012	Workshop!!
November	Organizers circulate a draft outline for the white paper; Writing teams contribute/edit content
Deceomber-February	Final editing/review of the white paper

Invitees

We will invite approximately 15 participants from the US and 15 participants from the EU, including the organizers. US participants will be covered by the NSF unless they are government representatives. EU participants will be covered with assistance from the European Commission. Our goal is to achieve wide diversity in topic area.

We note a recent workshop in a somewhat related area entitled: "Workshop on Patient Empowerment: A Transdisciplinary Informatics-based Approach," chaired by Leslie Lenert M.D., M.S., and held November 30 – December 2, 2011, in Park City, Utah, USA. This workshop aimed to explore current barriers in creating intelligent applications that empower patients. **The workshop that we are proposing here will be 1) The first transdisciplinary international workshop of its kind to explore technology and health behavior change, and 2) The first to address the need to develop new theories of behavior change based in the clear need for technology-informed behavior theory, measurement and analytics.**

Logistics

The invitation-only workshop will be held in Brussels because of its central location and central function in the European Union. Travel for US participants that are not US Government Employees will covered from the proposal budget. The organizers will lead with a collaborative presentation laying out the vision and feasibility of developing a new paradigm in BC&M that employs new technologies for data collection, aggregation, analysis and feedback. This introduction will be based on their work in the field of mobile health, health psychology, and computing for health promotion and behavioral change, as well as the discussion by participants prior to the meeting. Arrangements are being made with a suitable hotel for workshop venue, in discussion with Loukianos Gatzoulis, PhD, Scientific officer at the European Commission. The workshop is planned for October 16-17, 2012.

Preliminary Agenda, to be adjusted based on input from the participants

Day 1	
8:30 – 9:00	Overview and Introductions
9:00 – 10:00	Background talk: Challenges and Opportunities (Collaboratively assembled by four organizers)
10:00 – 10:15	*Coffee Break*
10:15 – 12:30	Background "speed talks" on provocative ideas (topics determined in March)
12:30 – 13:30	*Lunch*
13:30 – 16:00	Breakout Groups 1 (topics/groups/goals determined in September)
16:00 – 16:15	*Coffee Break*
16:15 – 18:15	Breakout Groups 2 (topics/groups/goals determined in September)
19:30 –	Work/Play Dinner at local restaurant
Day 2	
8:30 – 10:00	Summary of 1st day & discussion
10:00 – 10:15	*Coffee Break*
10:15 – 12:30	Breakout Groups 3 (topics/groups/goals determined in September)
12:30 – 13:30	*Lunch*
13:30 - 15:00	Most important problems and path forward speed talks from groups
15:00 – 15:15	*Coffee Break*
15:15 – 17:00	General discussion, finalization of writing teams
17:00	Conclusion & Farewell

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