Modeling Digital Health for the Future : Reference Model & Meta-Language

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Problem: Technological change outpaces our ability to fully conduct research on a specific technology before its impact fades in the open marketplace. Further, we are stuck in a perpetual publication *déjà vu* of "technology feature X in digital intervention Y for patient population Z", without a reference for understanding if we have been there before.

Current Work: *Agile Science* (Hekler et al. 2016), and just-in-time adaptive and personalized *microinterventions* (Nahum-Shani et al. 2018, Spruijt-Meitz & Nilsen 2014, Yardley et al. 2016) are new ways of capturing the iterative, quasi-realtime and fine-grained nature of precision digital health. Frameworks supporting these methods are needed.

The Gap: Health 3.0 digital interventions lack models, frameworks, and languages for expressing technology constructs and their effectiveness in human behavior change (HBC). While several families of HBC theories exist, few connect to technology in more than an ad hoc way other than HBC Support Systems theory (Oinas-Kukkonen 2013).

Approach: I propose a *reference model* & *event-based meta-language* for Digital Health Interventions (DHIs). The idea is to provide a vocabulary for describing DHIs to escape *déjà vu* and black-box descriptions. Such constructs will enable multidisciplinary research and invariant expressions of effectiveness in the face of new technology.

Incomplete History of DHI Tech Evolution

2000 — Diversification of Computing
Wide availability of PDAs & QWERTY phones, SMS messaging, gaming platforms, and 3G cellular networks
eHealth apps evolve from robocall and clinical staff reminders to SMS

2005 — Smartphones & Social Media
Facebook debuts '04 and then the iPhone in '07. Twitter, Instagram, Android, Galaxy and more follow
mHealth arrives at scale, going from feature phones to smartphones

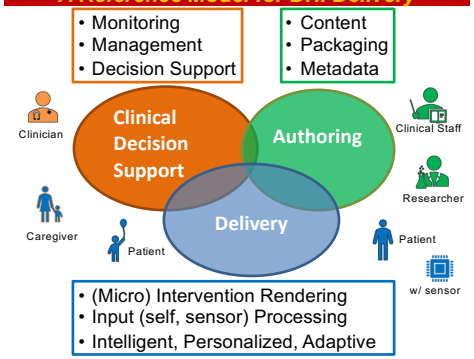
2010 — Rise of IoT & Cloud Computing
4G & Voice Services arrive, wearables & SmartHome, and transition to *X*aaS cloud offerings on Azure, AWS, & GCP
mHealth 2.0 arrives via rich input from smartphones, homes & wearables

2015 — Big Data & AI Explode
Confluence and maturity of prior innovations, struggles with explosion of data, security/privacy forefront
mHealth evolves to 3.0 with AI & BD applications; emphasis on personal, adaptive health and new methods

2020 — The Internet of Everything
What's next? 5G, IoE, expansion of voice and home delivery platforms
mHealth evolves to…10.0? How do we advance core science and keep pace?

This trendline overlays the rapid rate of tech change with personalized healthcare delivery. We need ways to step back from details and describe commonalities of how such platforms impact Digital Health Interventions.

A Reference Model for DHI Delivery



Why another Reference Model? Detailed presentations of DH technology are at a deeper specificity than required for multidisciplinary research. We need to identify common features.

This high-level model identifies 3 major systems in a DHI platform; each has user-facing aspects.

The *Delivery* system is the most important. It is responsible for *rendering (micro)interventions* across multiple platforms (left), accepting input from sensors and self-reporting apps, and performing the AI-adaptive and personalized computation to determine *when, how,* and exactly *what* to deliver for the microintervention.

The model does not include EHR systems, IoT, AI, networks, or other specific technologies that may be integrated or interfaced within an instance of a DH technology platform.

Meta-Language for MicroIntervention Events

Fine-grained (micro)interventions consist of sequences of technology and human interactions composed over time to achieve target outcomes. We are unaware of any attempt to describe such interactions so we may express and reason about such sequences. Below is a sketch:

Let $\boldsymbol{L}=\{E, O, S^O, S^E, R\}$ be a language where $\boldsymbol{E}=\langle e_1, e_2, \ldots, e_n\rangle$ is a sequence of events, $\boldsymbol{E^C}$ a subsequence of E filtered by condition C, $\boldsymbol{O}=\{o_1, o_2, \ldots, o_n\}$ a typed set of objects $\boldsymbol{S^O}=\{s^O{}_1, s^O{}_2, \ldots, s^O{}_k\}$ a set of object states, $\boldsymbol{S^E}=\{s^e{}_1, s^e{}_2, \ldots, s^e{}_m\}$ is a set of event states, and $\boldsymbol{R}=\{r1, r2, \ldots, rj\}$ a set of Relations s.t. $r(E^C, S^O, S^E) :\rightarrow \langle E^C, S^O, S^E\rangle$. E_i captures events, external or initiated by some O_i. O_i is an object of interest (people, devices) in a domain. S^X define state models for events and objects (transitions are in R). R maps event sequences based on object end event states to new events and transitions of new states and objects.

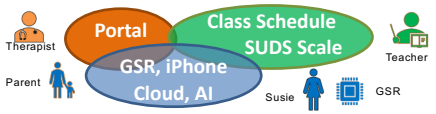
Research Questions

Our research questions :1) *How do we compare feature effectiveness across DHIs?, 2) How do we anticipate feature effectiveness in new DHI design2, and 3) How do we make cost-effective decisions about platforms for a new DHI?*
A reference model and language will transform the field by providing a common vocabulary for describing DHIs, impacting their design, development, and evaluation, and anticipating future technological innovation impacts on DHIs.

Example Scenario

Susie is a pre-teen under treatment for anxiety using CBT. A galvanic skin response (GSR) sensor is connected to her iPhone. During a test, elevated arousal detected by the GSR triggers a notification on the iPhone to practice relaxation techniques such as measured breathing. The phone transmits the condition to the cloud where AI personalized algorithms determine to notify a nearby caregiver (teacher) to passively observe Susie and tells the app to follow-up with Susie using its diary feature during lunch. At episode conclusion care-provider/givers are aware and track Susie's progress through the CDS portal.

Reference Model Instance:



Meta-Language Description:

Susie's GSR transmits data at 3Hz to the iPhone, which also generates social media notifications (Instagram, text, Snapchat, etc.) at 2x/sec. $\boldsymbol{E}$ is $\langle i_1, t_1, g_1, g_2, t_2, g_3, t_3, g_4, s_1, g_5, s_2, g_6, t_5\rangle$. $\boldsymbol{E^C}$ is $\langle g_1, g_2, g_3, g_4, g_5, g_6\rangle$ for the GSR. The relevant objects are Susie, the iPhone, and the GSR, with respective states measured by the GSR, connectivity, and active monitoring. A further subsequence on E^C, $E^{C'}=\langle g_4, g_5, g_6\rangle$, identifies a second of above threshold readings, changing Susie's state to *anxious*, triggering the response cycle (which could also be defined).