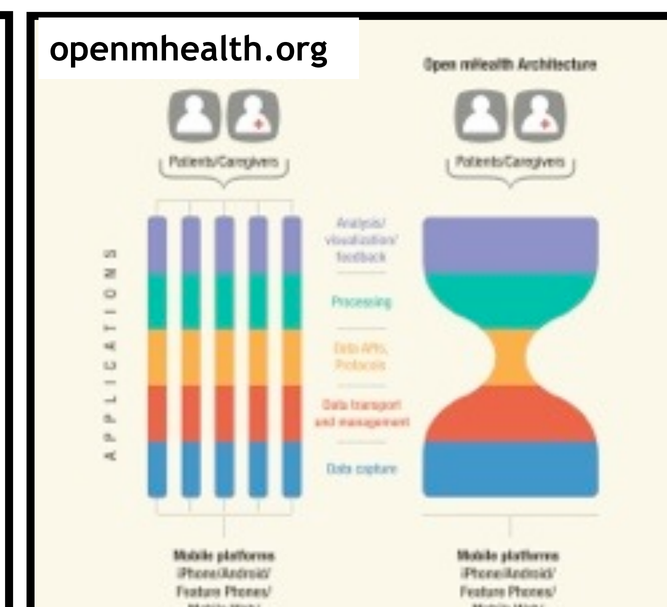
# Embedding mobile computing and research in everyday life

Deborah Estrin
Professor, Cornell Tech, New York City
destrin@cs.cornell.edu
work done in collaborators with collaborators from
UCLA, openmhealth.org, iSTC, ...

Enabled by >6 x $10^9$ mobile phone users, increasingly with: GPS, imagers, touch screens, Internet, app stores

Motivated by 6 x $10^9$ people on planet earth, their health needs, and economic realities



**from embedded to mobile to participatory sensing**

**mhealth: 'personal evidence', n=me**

**whats next?**
*personal data APIs, mobile personal informatics, NEW YORK CITY!*

**an end-to-end argument for driving systems research with authentic applications**

# Lessons from the field of embedded sensing 2002-2010

**Early themes: many simple measurements**
small platforms
autonomous operation

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**Midterm themes: multi-modal measurements**
varied platforms
human-assisted operation

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**Early themes: many simple measurements**
small platforms
autonomous operation

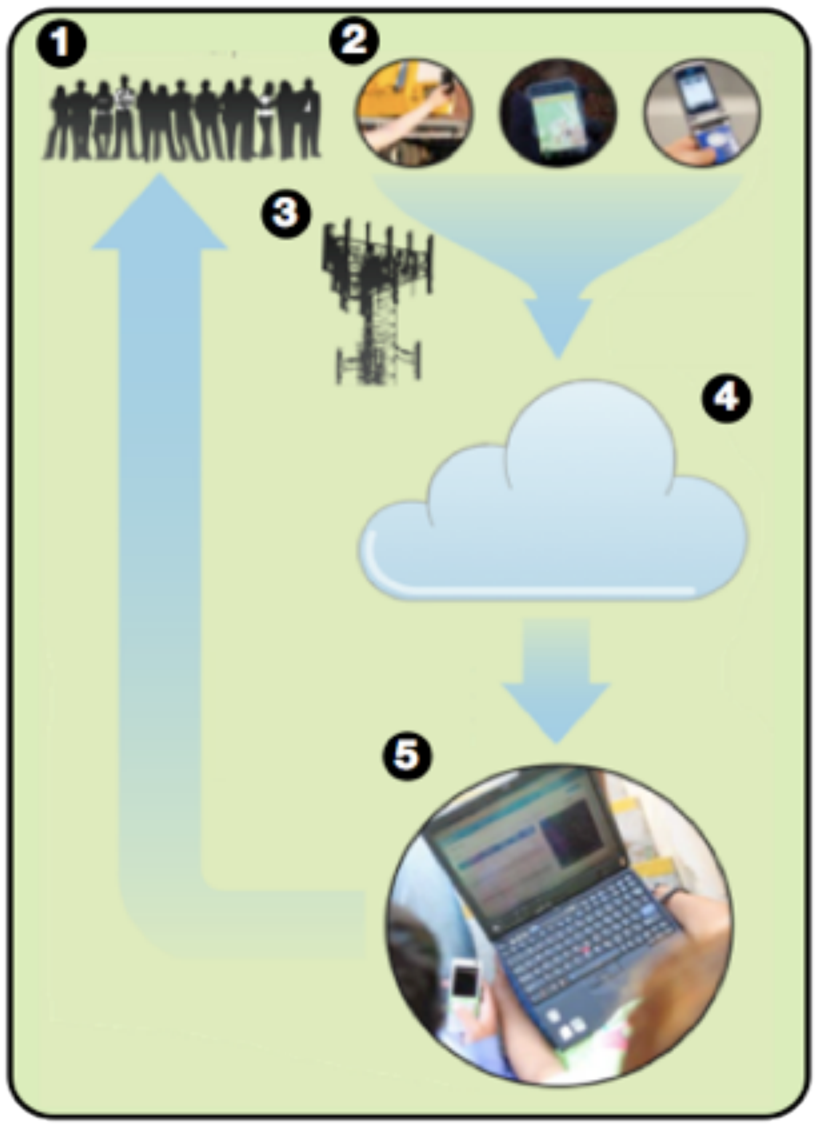
**Midterm themes: multi-modal measurements**
varied platforms
human-assisted operation

**Eventual themes: model-based measurement**
mobile platforms
assistive systems, infovis

# **Participatory Sensing** (starting ~2006)

individuals and communities using personal mobile devices and web services to systematically explore and document their lives

(builds on methodologies of experience sampling [Csik85] and photovoice [Wang95])




**Real time**
(always on)

**Real place**
(always carried)

**Real context**
(historical, environmental, spatial, social)

**Real applications**
(environment, education, community, health)


**w/ Mark Hansen (Statistics/DMA), Jeff Burke (REMAP/TFT)**

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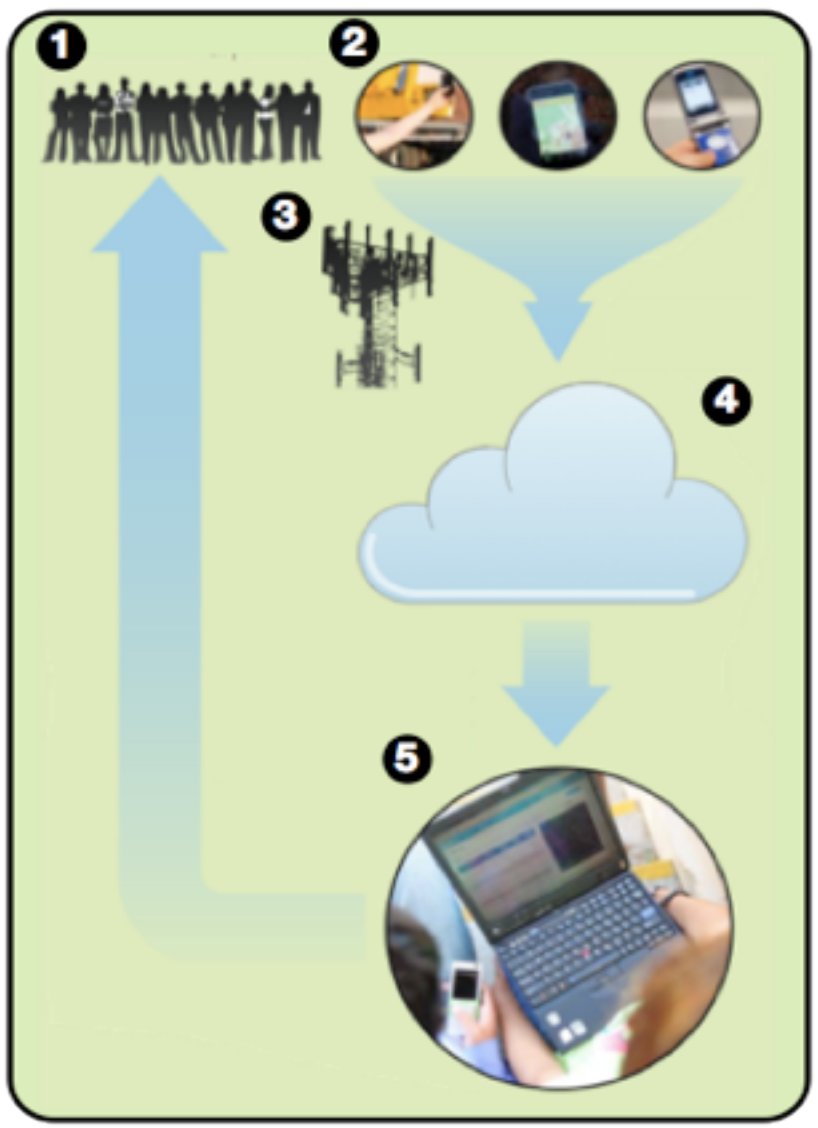


**Real time**
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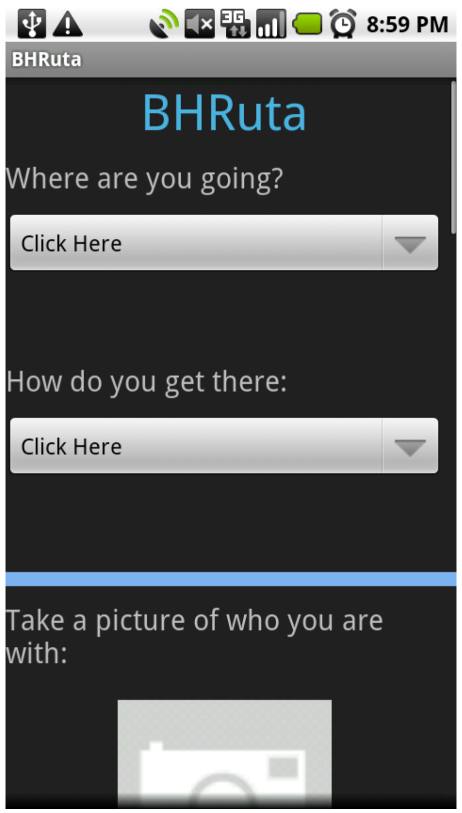
**Real context**
(historical, environmental, spatial, social)

**Real applications**
(environment, education, community, health)

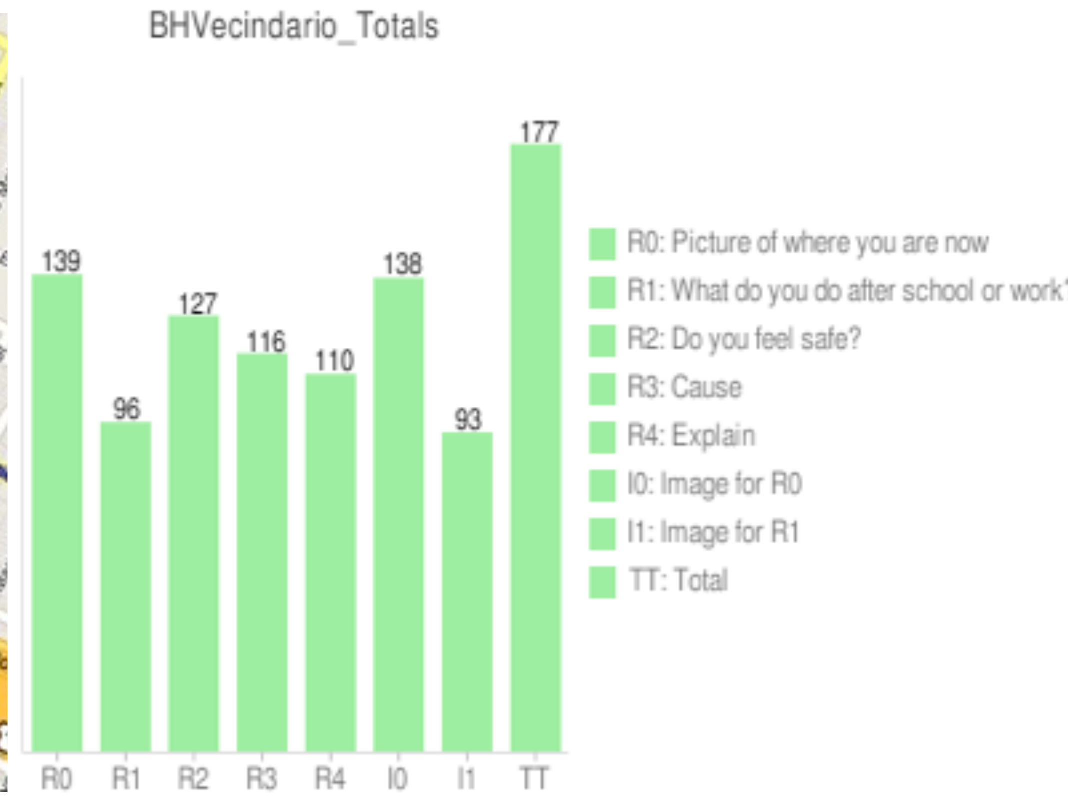
**Chose applications that scaled *down*... as well as *up*:** *i.e.*, utility at small *n so real use can guide iterative cycles of innovation*

**w/ Mark Hansen (Statistics/DMA), Jeff Burke (REMAP/TFT)**

# Assessing environmental factors: Community data gathering (Boyle Heights, 2010)








| | | | | | |
|---|---|---|---|---|---|
| 20100415 A0000022036677 | raiders | 2010-04-22 22:49:17.310000-07:00 | upldat: 2010-04-22 22:49:29.580879-07:00 | 34.06251 | -118.19812 |

Where are you going? Errands


Place you stopped. What are you doing:
Other | groceries

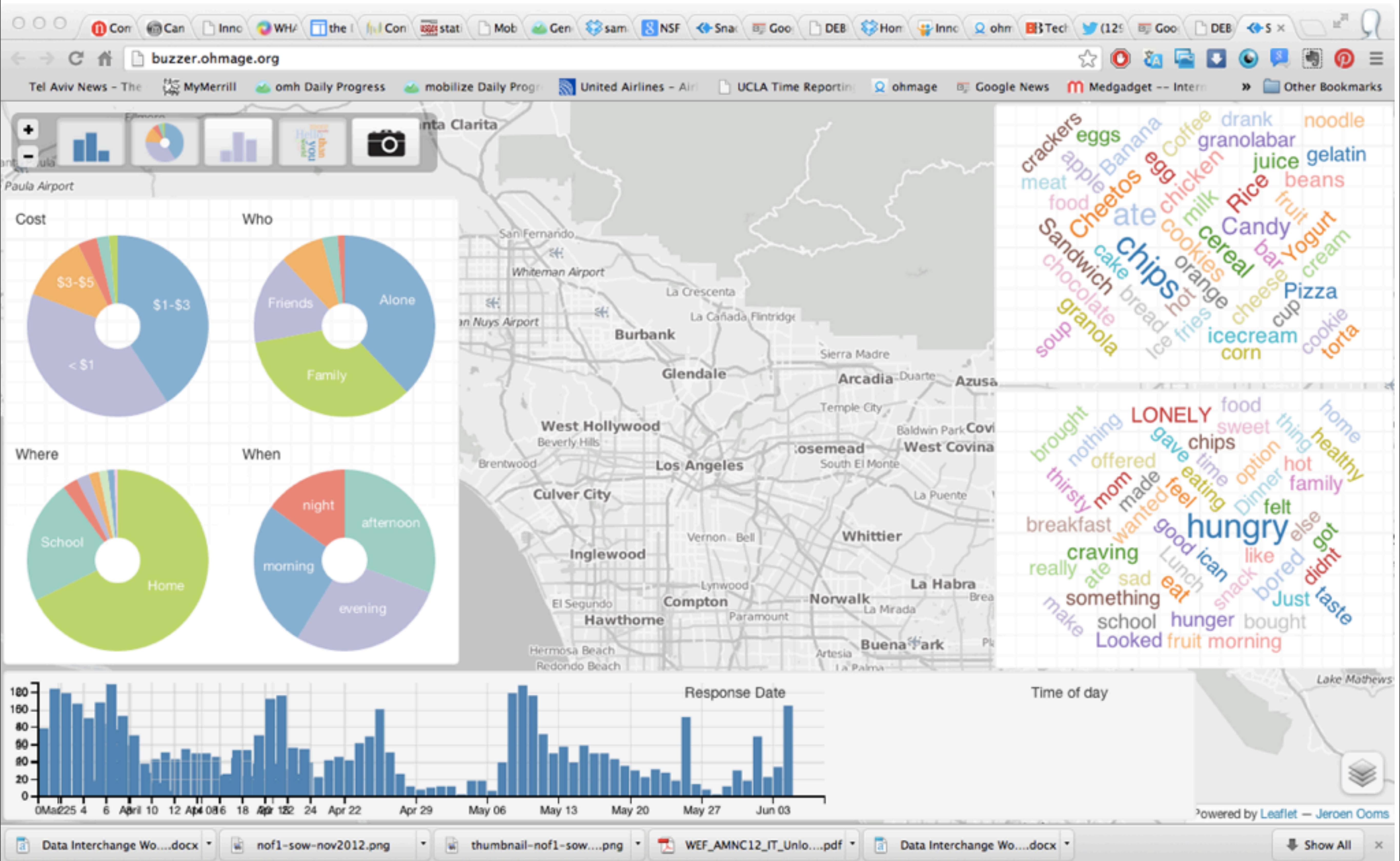
What represents your neighborhood:
street name


How do you get there? Walk
What where you ate along the way:
Street vendor

What did you eat along the way:
Other | tacos

Acker, Samanta, Belany et al

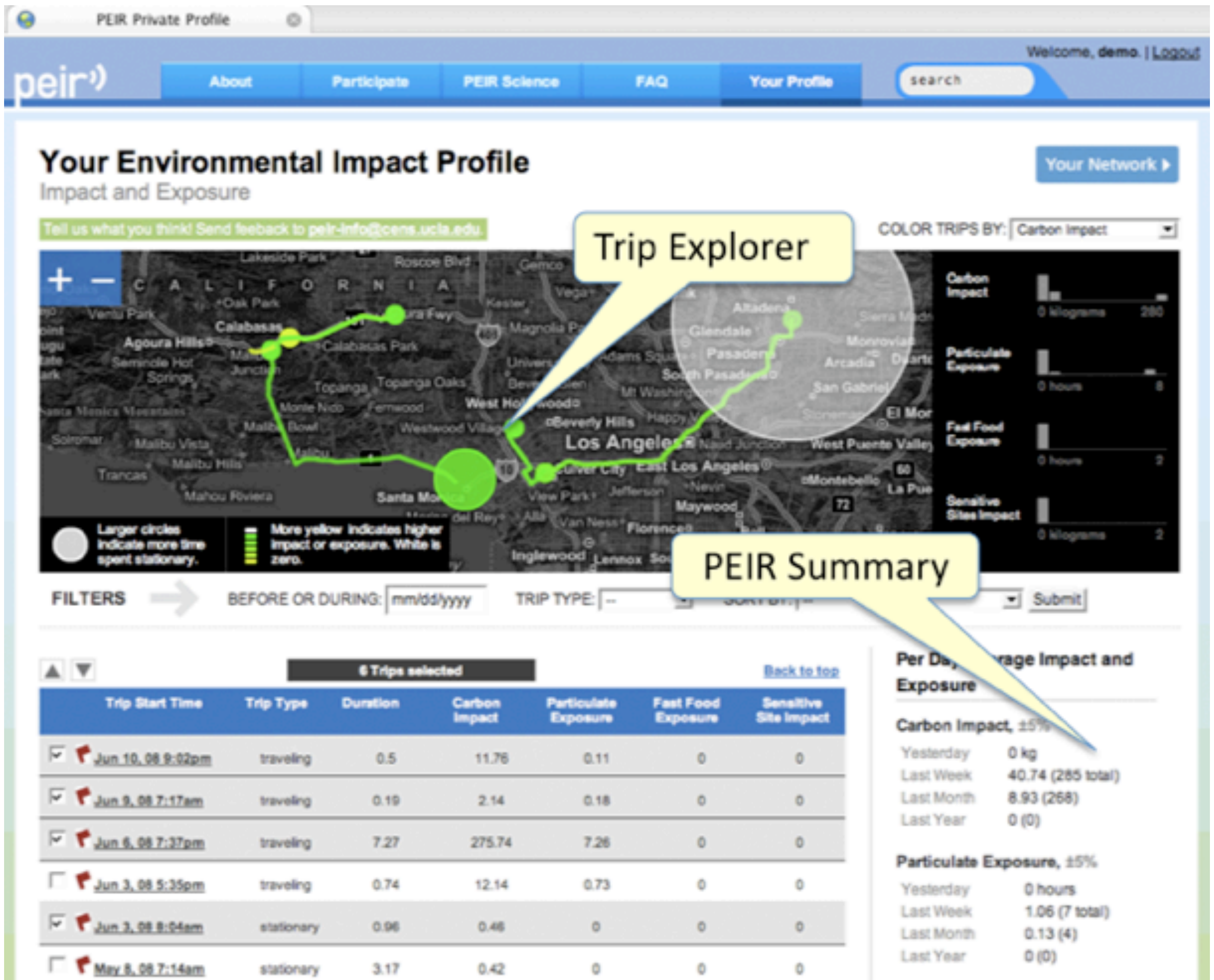
# *Snackboard* dashboard to >3000 entries about snacking collected by high school students in 2012 (J. Ooms)



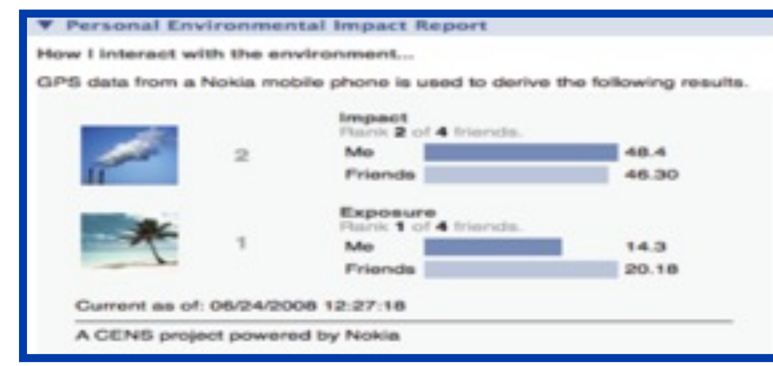

w/ Jeroen Ooms, Mark Hansen, Hongsuda T.

# Telling traces: PEIR (2007-08)

model-based estimation using continuous location-activity-time series




**Individual time-location traces** used to automatically estimate daily personal carbon impact and air particulate exposure




PEIR Facebook Application

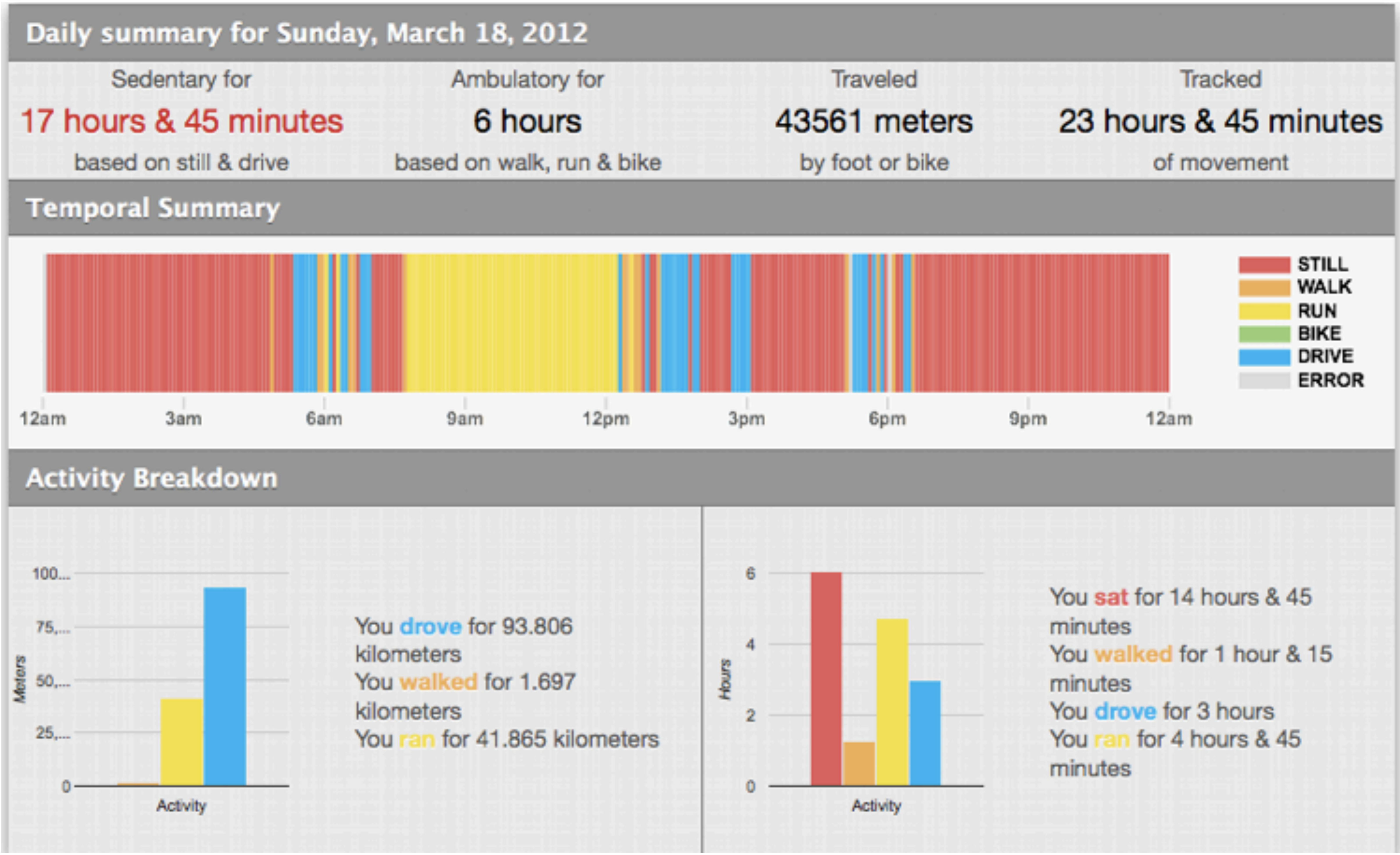
http://peir.cens.ucla.edu

Wired NEXTFEST,

Chicago 2008

w/ Mark Hansen (Statistics/DMA), Jeff Burke (REMAP/TFT); Funded by Nokia

# *Pivot to focus on mobile health (mhealth) ....and personal n=me evidence*




**UI: E. Wang**

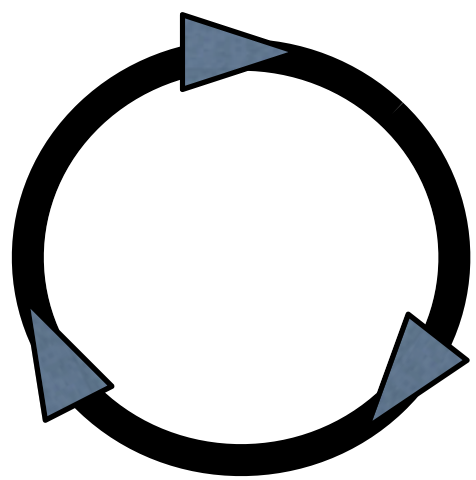
# The promise of mobile Health (mHealth)

***transform previously unmeasured behaviors and practices into personalized, evidence-based, and evidence-producing care***

Photo: Marshall Astor, WWW

*symptoms, side-effects, outcome measures, actions, activities, exposures..*

*capture/record activity, mobility, self-reports, tool-use, "digital exhaust"*


*visualize, summarize, highlight; inform, advise, persuade*

*store, analyze, classify, fuse, mashup, filter, aggregate data*

# Why chronic disease management?

- 3 lifestyle behaviors (poor diet, lack of exercise, smoking) cause 1/3rd of US deaths; 50% Americans have 1 or more chronic diseases; age of onset getting younger.

- Over the next 20 years, Non Communicable Diseases will cost worldwide
  > $ 30 trillion; mental health > $16.1 trillion (WEF, 2011)

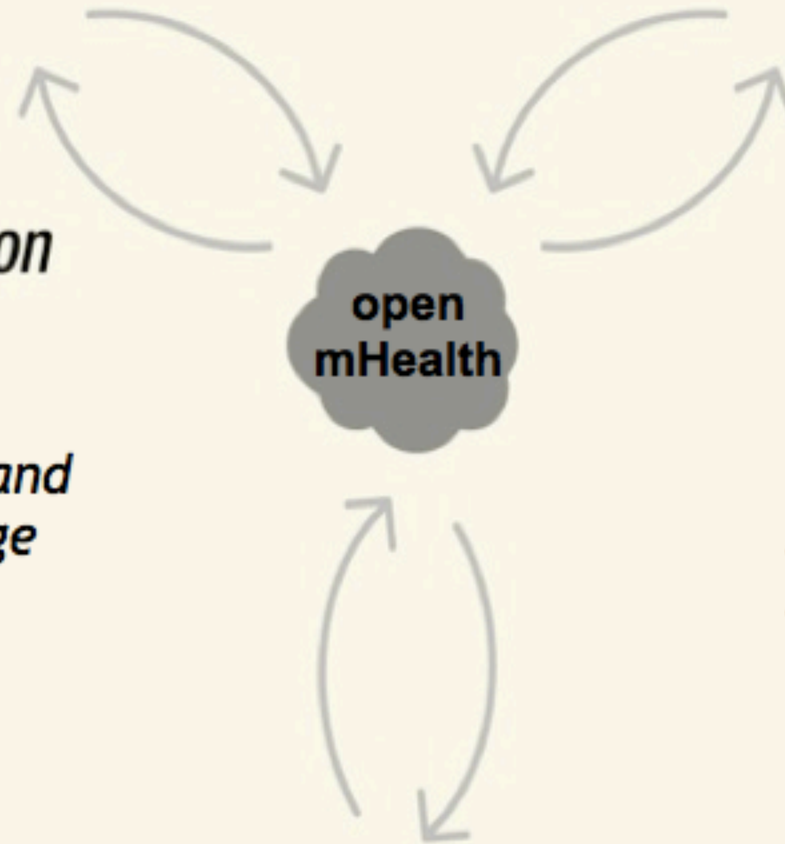
- Equip individuals, families w/tools for measurement, management, understanding outside clinical setting

# mHealth derived data serves 3 essential workflows

**Participant self-care**

*How is this new medication working for me?*

*patient apps: personal-evidence and clinically-informed tools to engage and support healthy behaviors*




**Clinical care**

*How is the patient responding to new care plan?*

*'relevant-time' clinical dashboards: summarizing and correlating symptoms, side effects, meds, and health behaviors*

*mhealth-enabled n-of-1 studies: systematic, individualized studies of treatment alternatives*

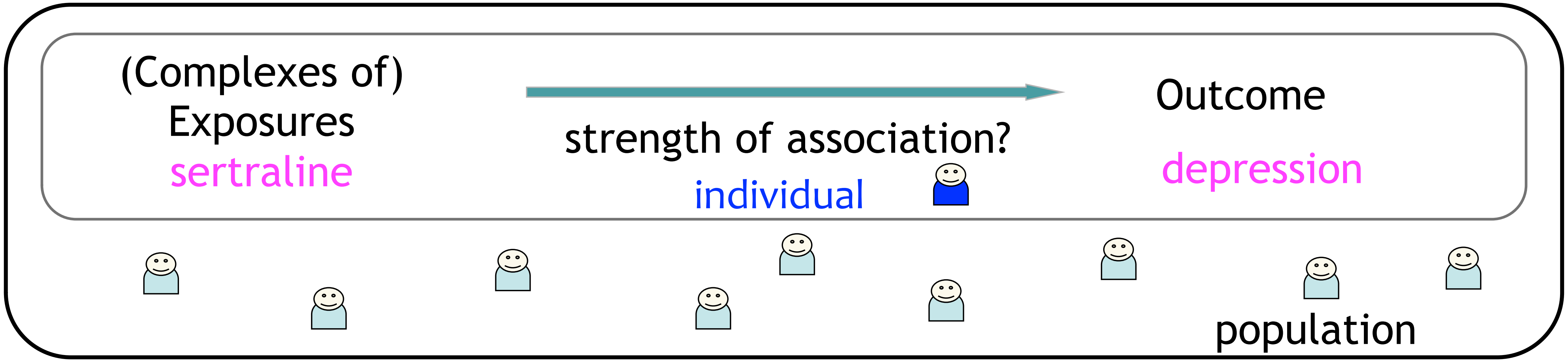
**Research evidence**

*What works best in different contexts?*

*mHealth evidence-base: which mHealth techniques are effective, and for whom*

**w/ Ida Sim, Open mHealth**

# Transformative methodological tool: recasting 'evidence'




Sim, Kravitz

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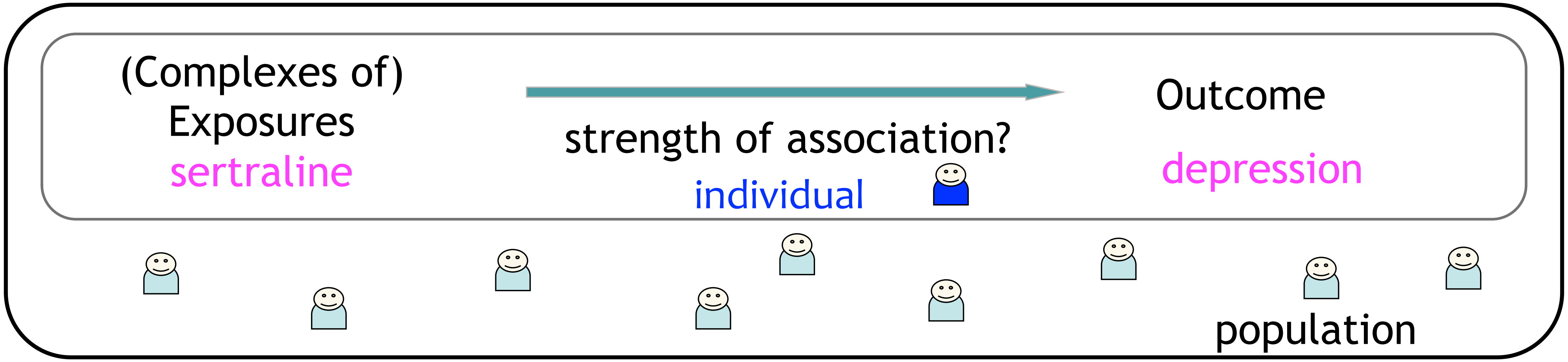
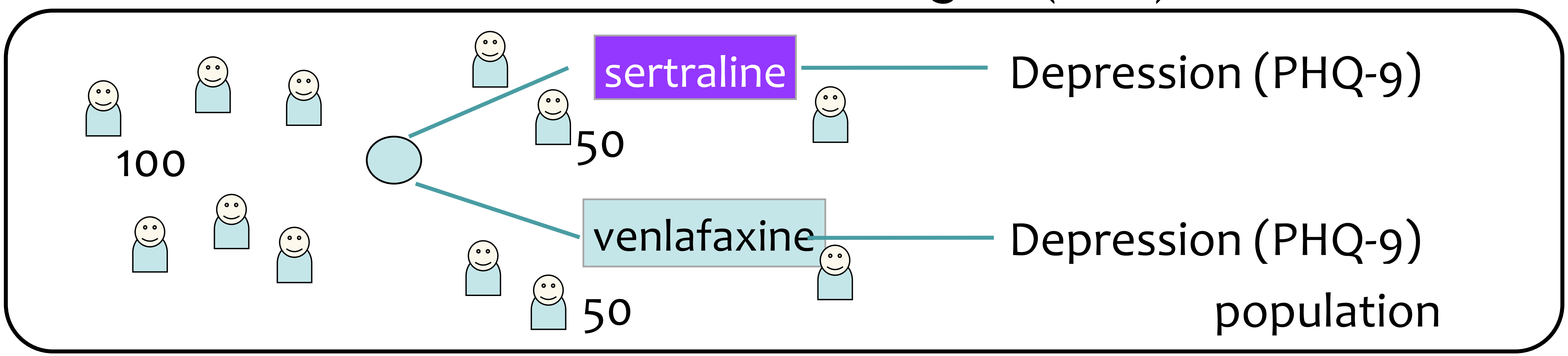



‘does it work on average?’ (RCT)



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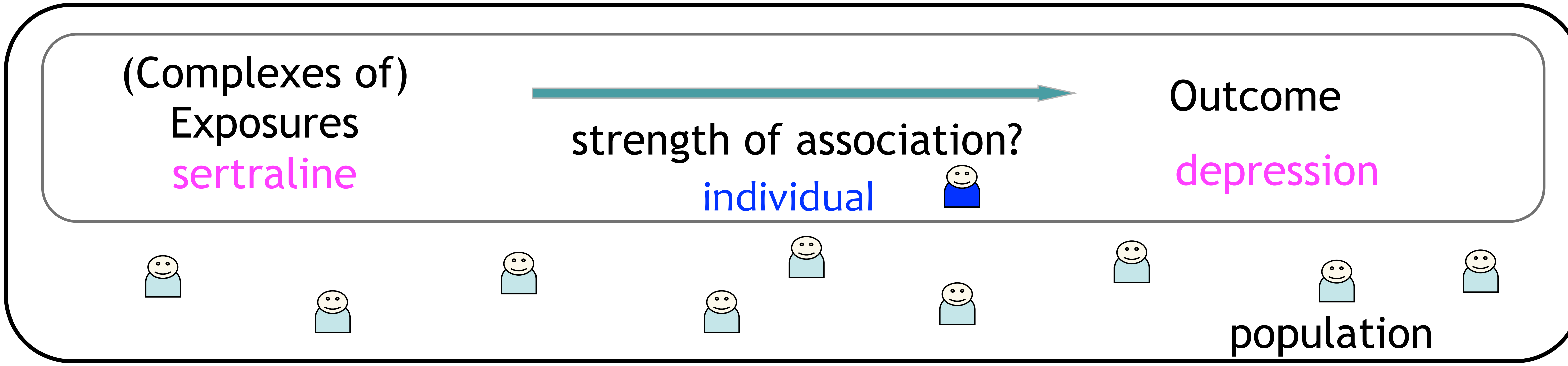


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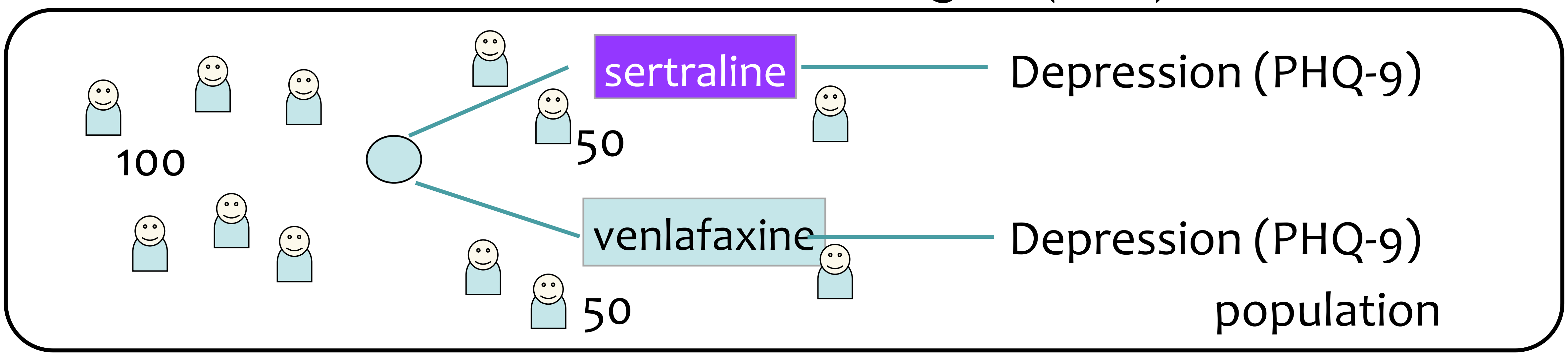
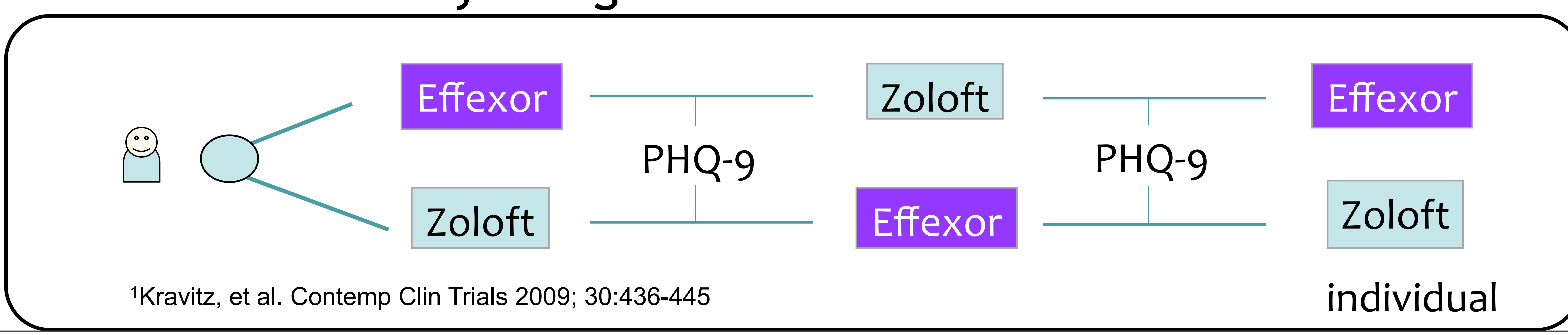


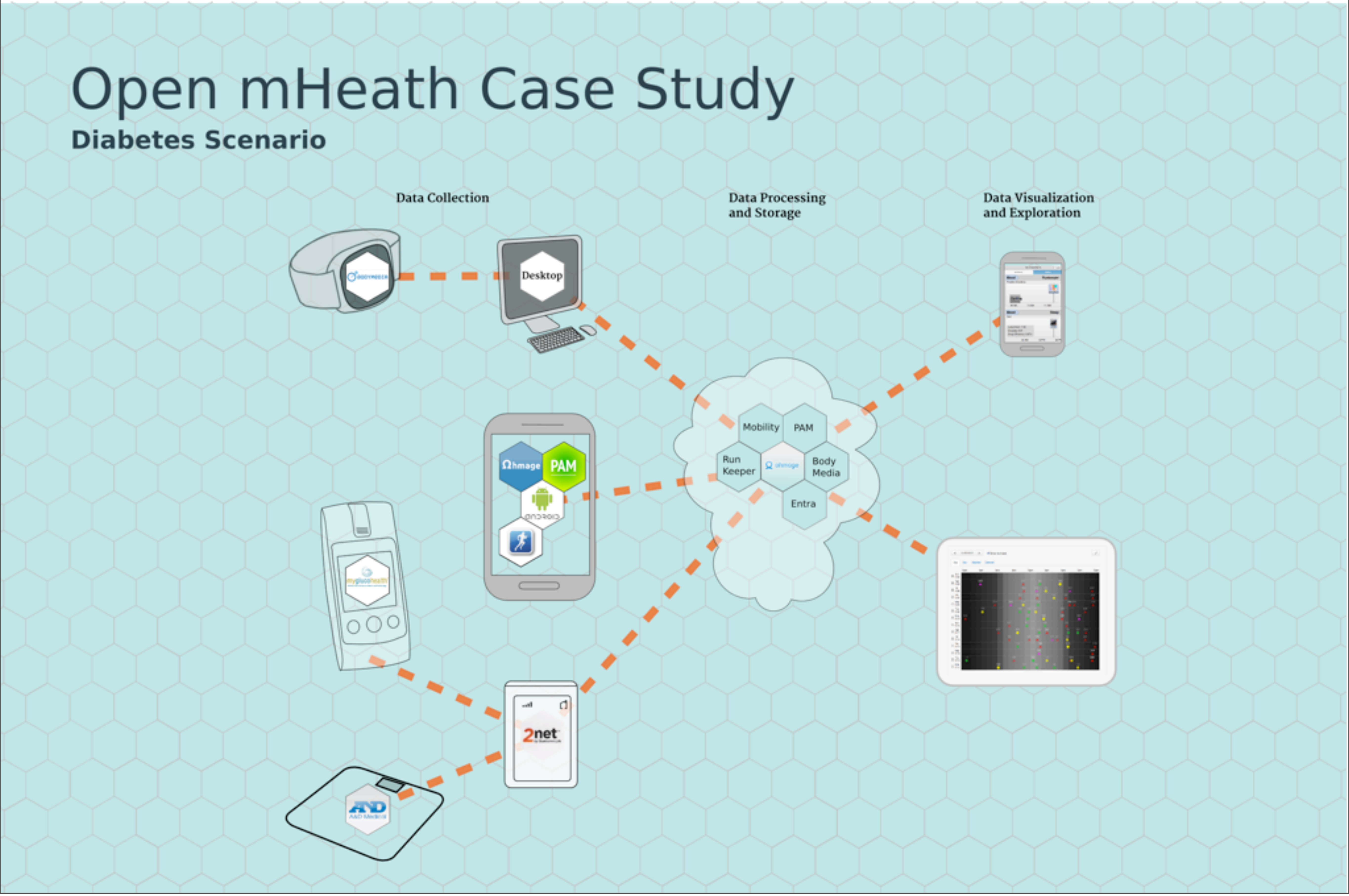

## N-of-1 study design: 'does it work for Mr. Jones?'



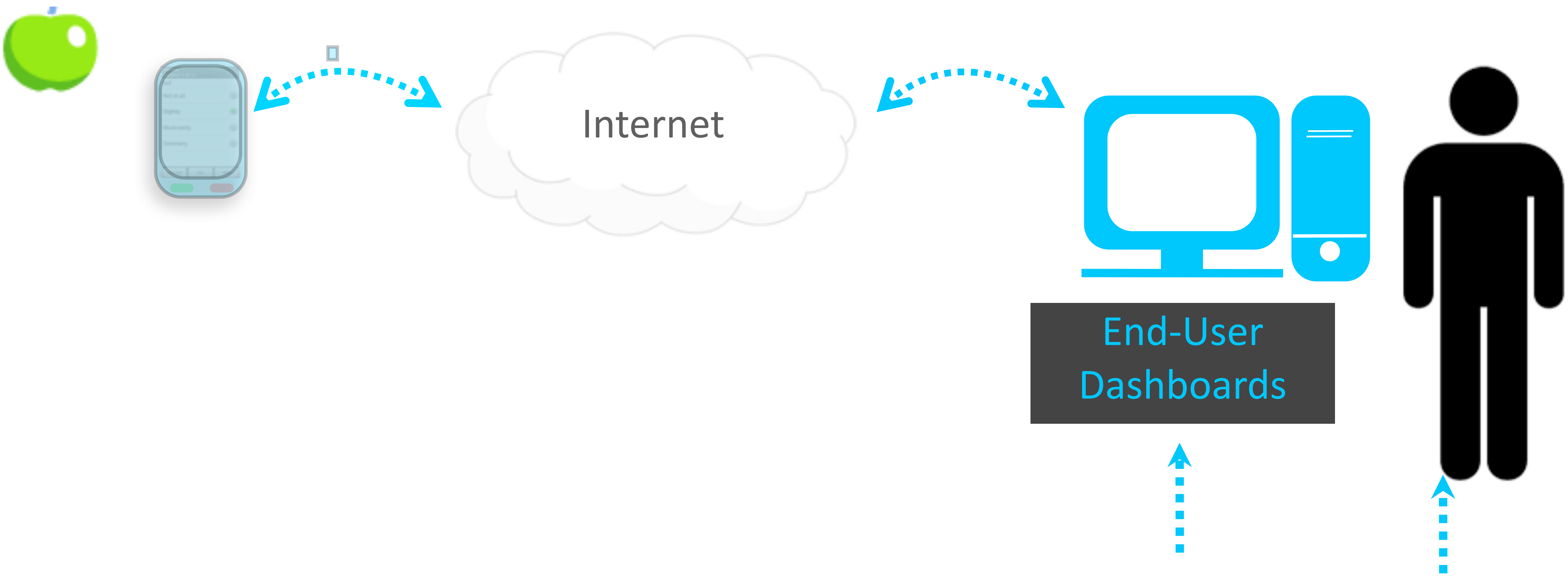

[1]Kravitz, et al. Contemp Clin Trials 2009; 30:436-445

Sim, Kravitz

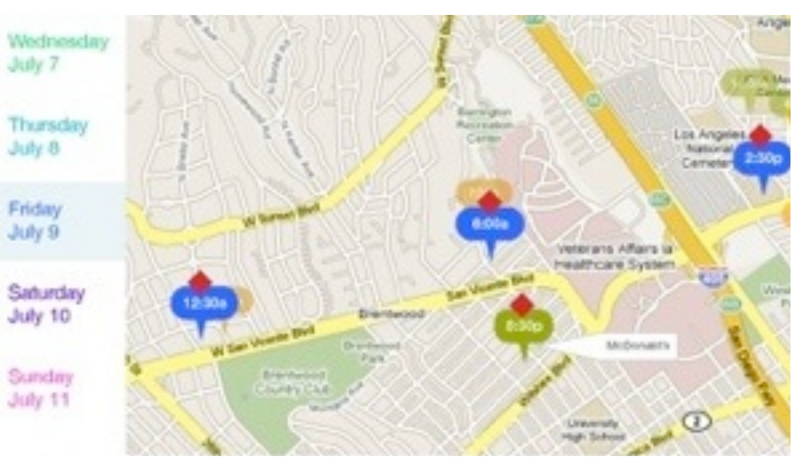
# Open mHealth co-innovation use case: Diabetes



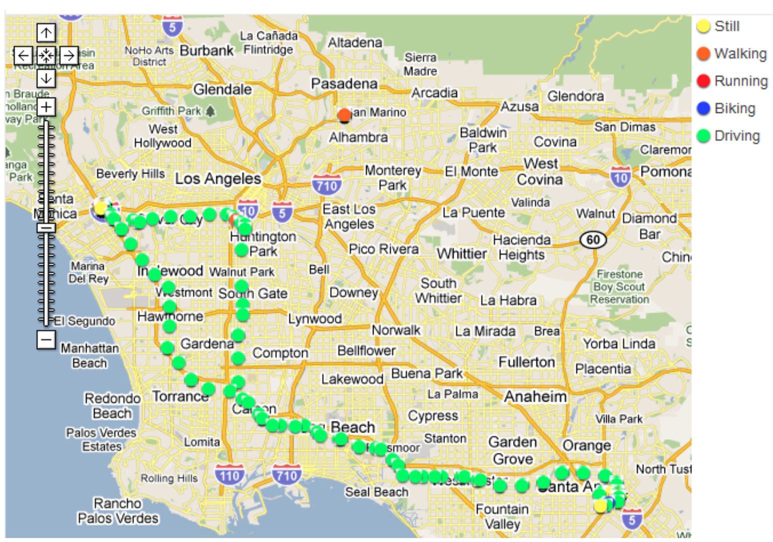
# Not just a mobile app: data analysis, sensemaking, as critical and more challenging



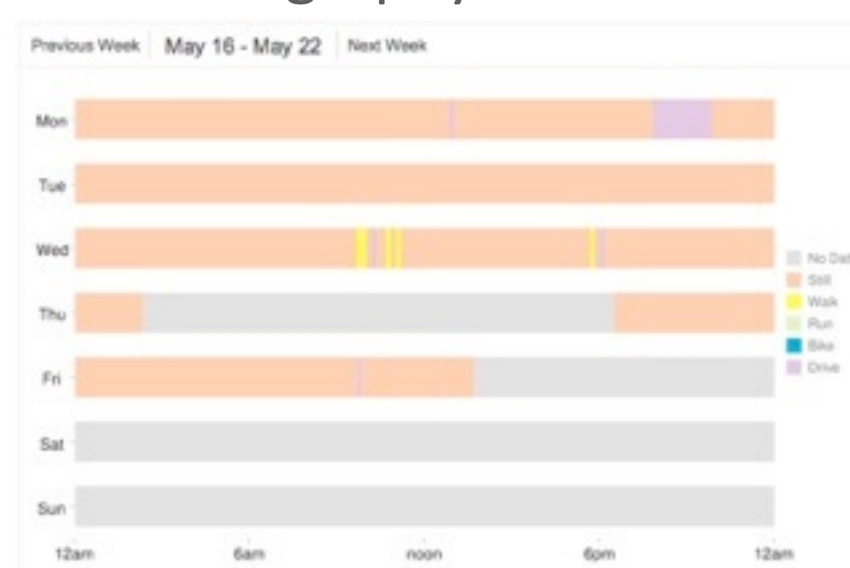

Correlations in time and space




Actigraphy over space

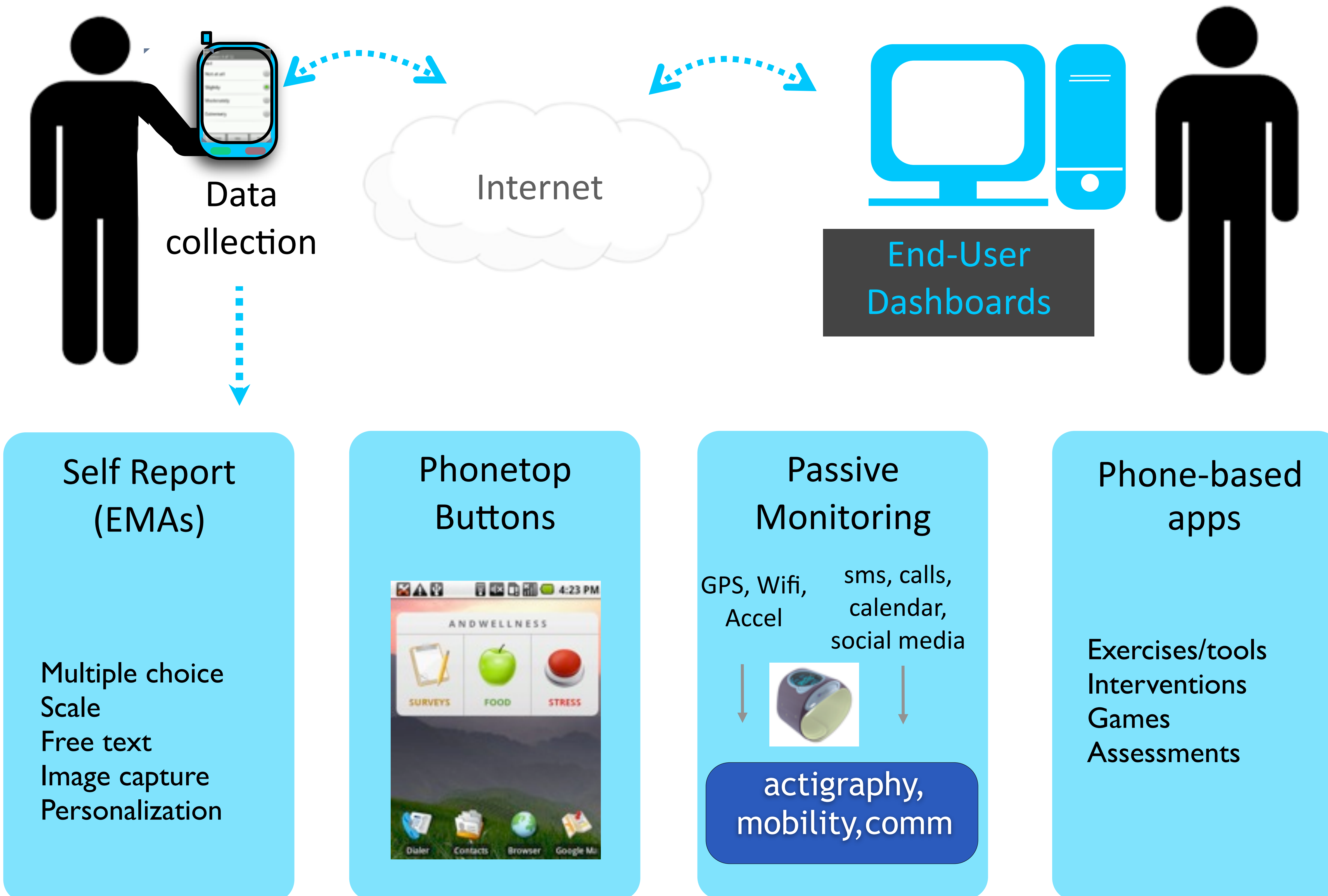



Actigraphy over time




**Ramanathan, Selsky, et al**

# Many features apply across applications

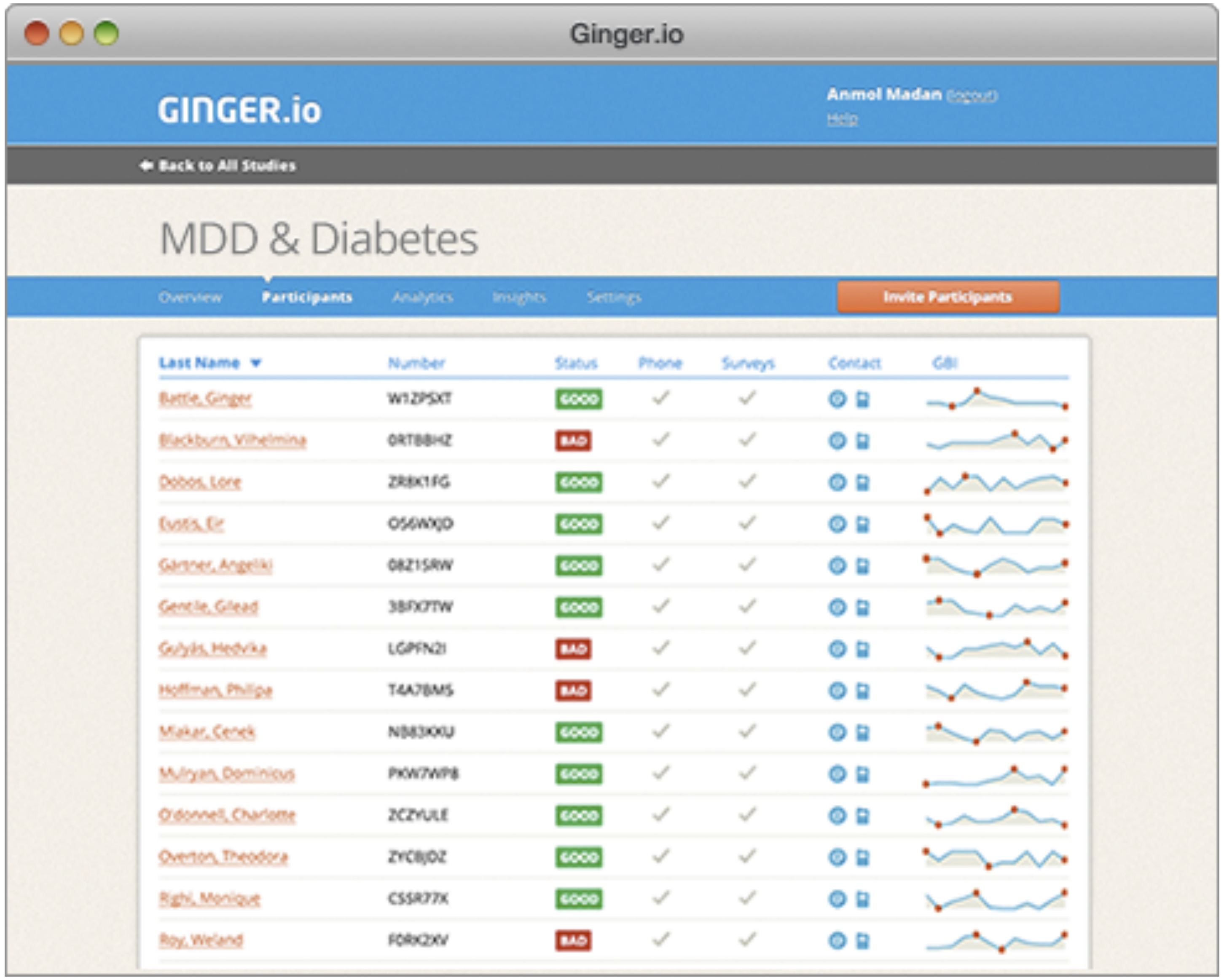



Ramanathan, Selsky, et al

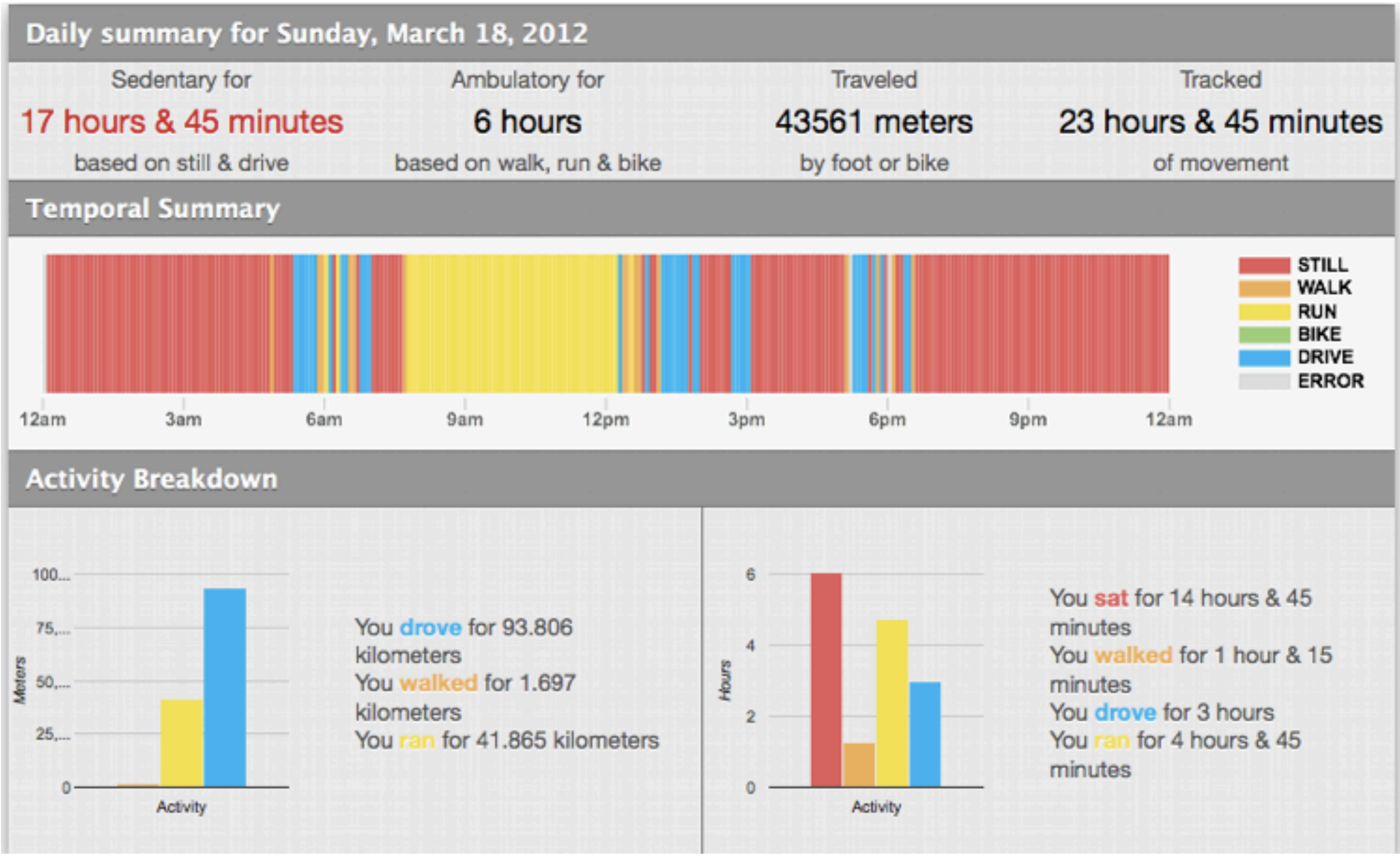
# “Real Sensor” streams



# http://ginger.io/the-platform/

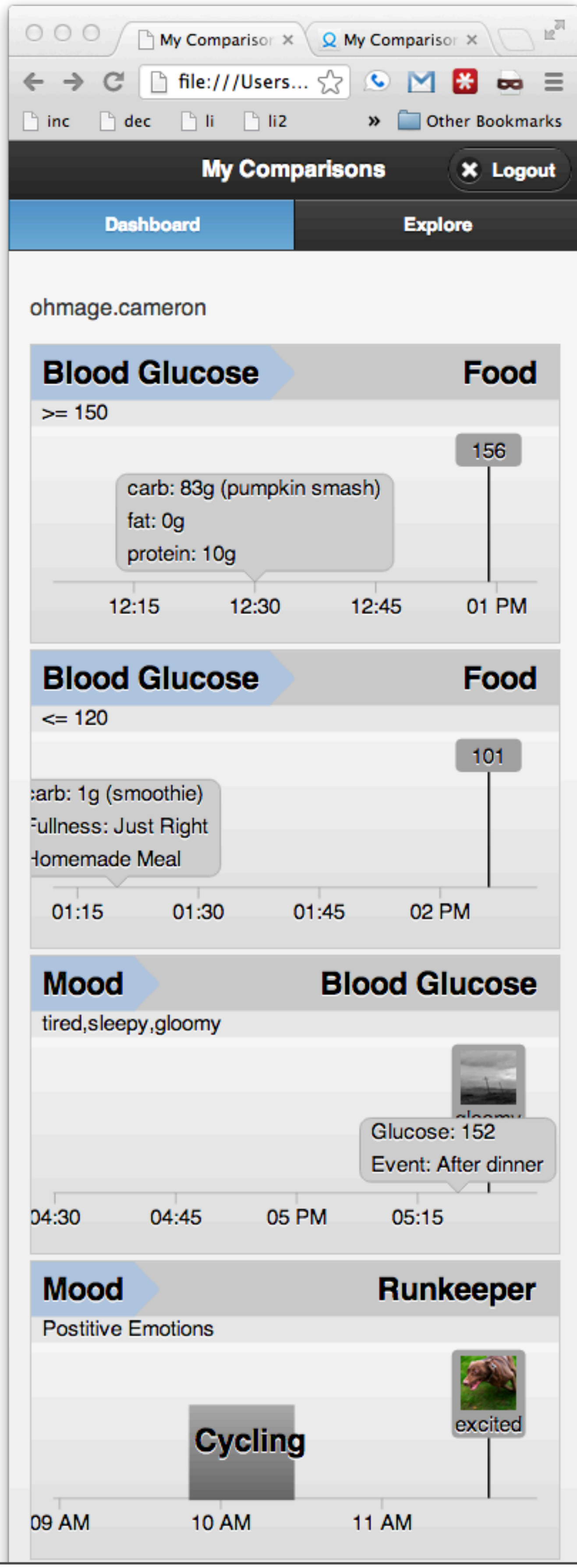
# http://ohmage.org
# continuous activity, location traces and prompted self-report

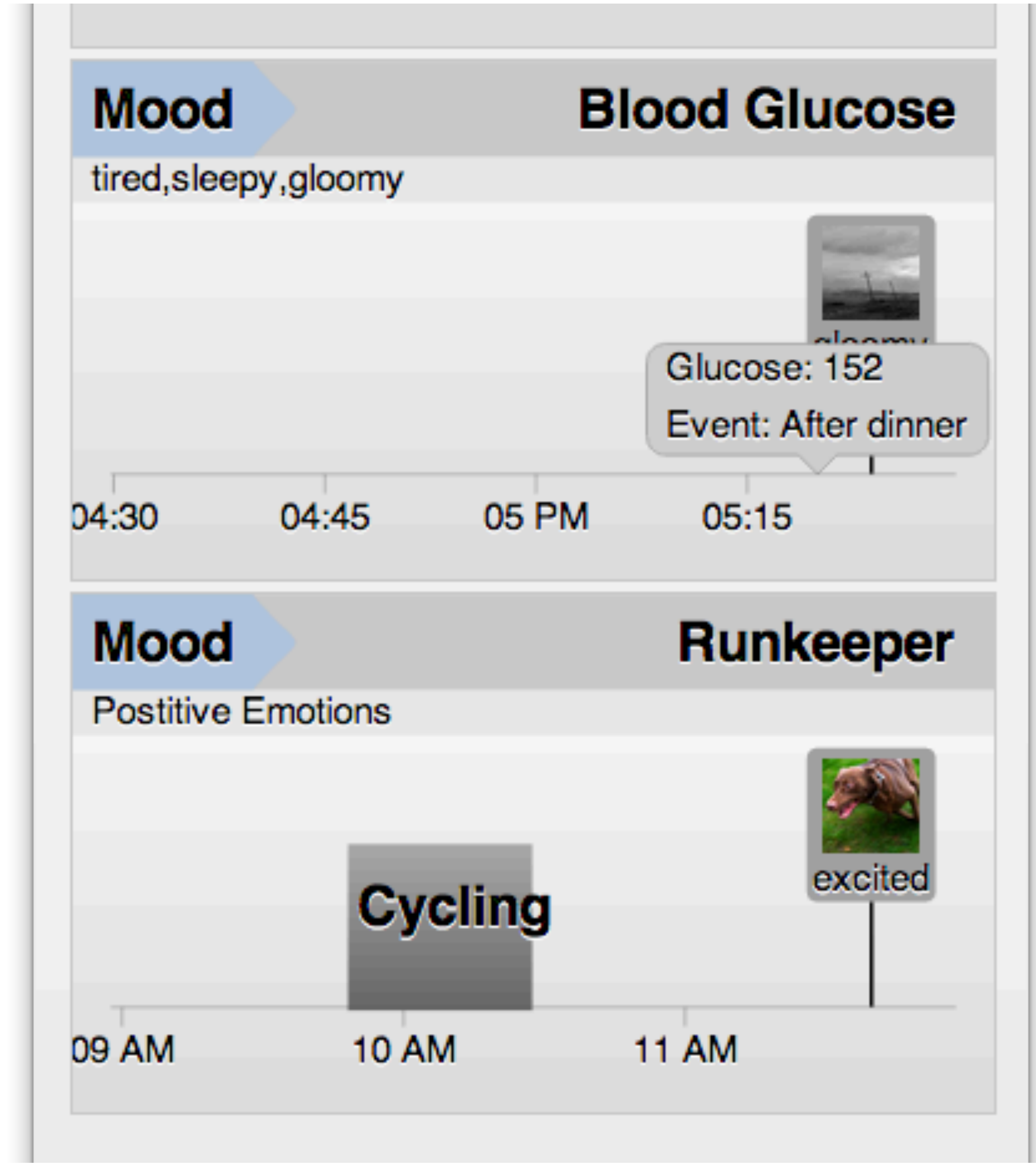



UI: E. Wang

# Photographic Affect Meter: PAM (Pollak et al)

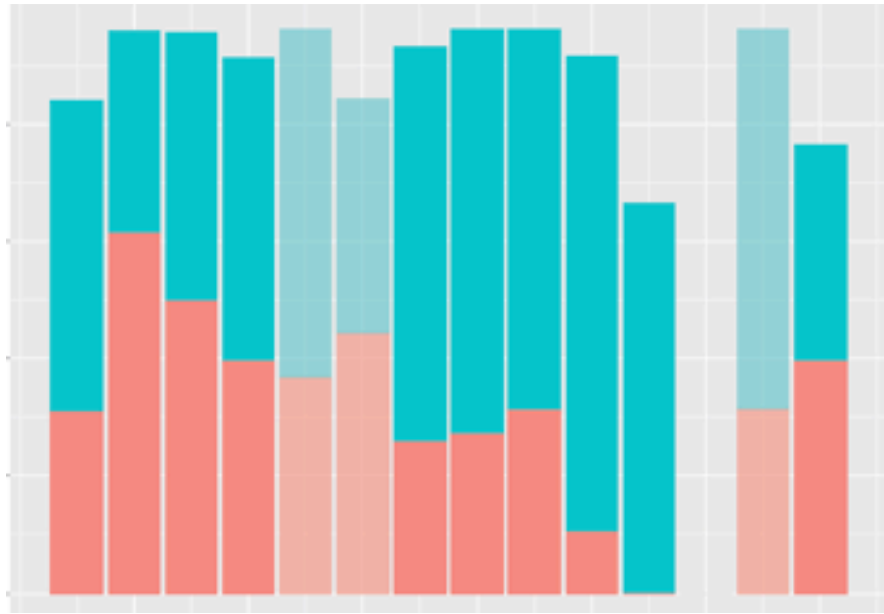
# My comparisons feedback screen



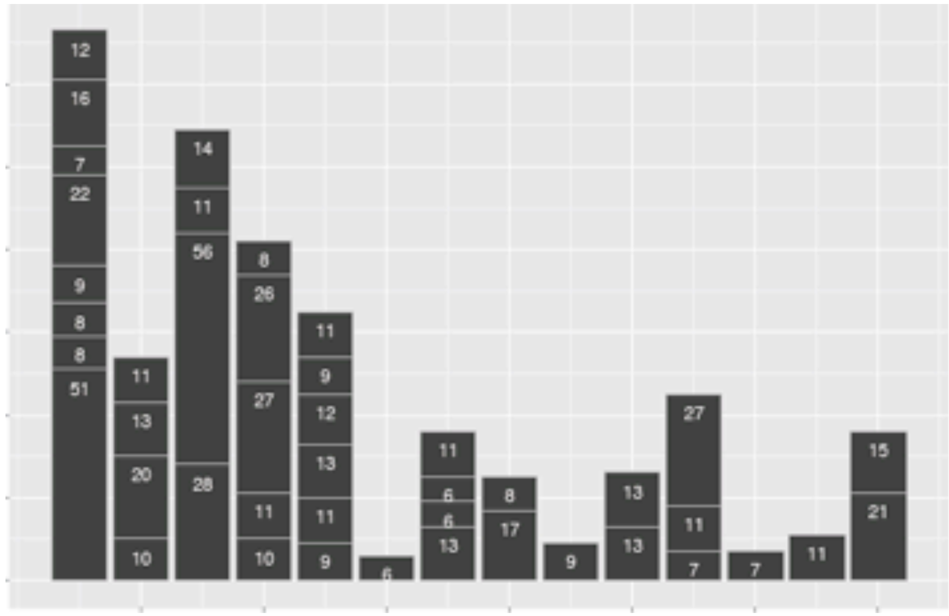



# Next steps: transforming passive information into behavioral biomarkers for chronic diseases


Hours at home per day



Walking periods > 6 min per day



**Personalized, rapid, indicators of health improvement, relapse, side-effects, symptoms using: mobility logging and digital traces (vocabulary, games, spending)**

# Deriving behavioral biomarkers...from app and sensor streams

**behavioral biomarker/indicator**

- in-person variance/patterns of fatigue, pain, depression, insomnia, cognitive function...

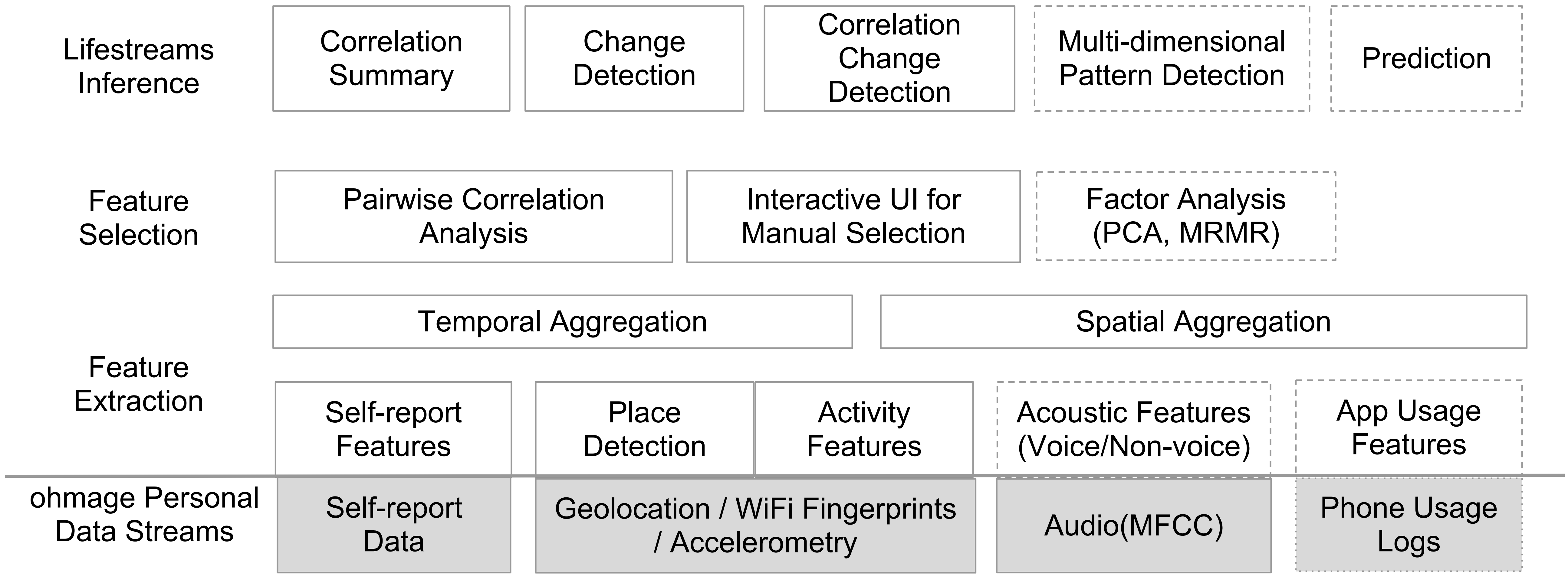
**summarization**

- ambulatory/sedentary cumulative and durations,walking speed
- sleep times,social interactions
- time spent before leaving house, hours spent at home

**state classification**

- sedentary/ambulatory
- at home/work
- using apps
- communicating

# Lifestreams: Modular Data Analysis Software Stack

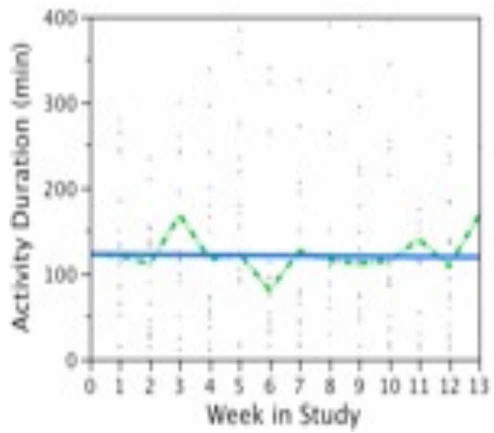



**Hsieh, Tangmunarunkit, Ramanathan, et al**

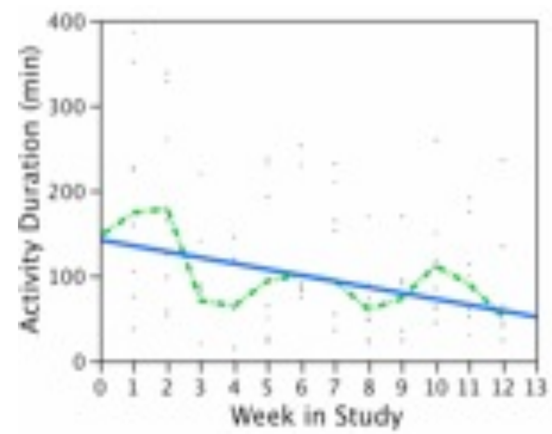
# Behavioral Biomarkers can drive tailored infographics, informational incentives, feedback, game mechanics

**ubifit participants who...**

**had the garden**

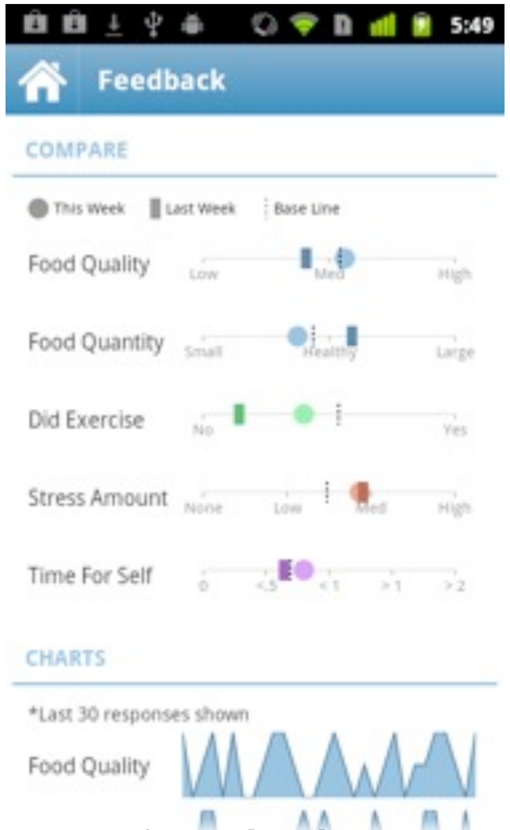


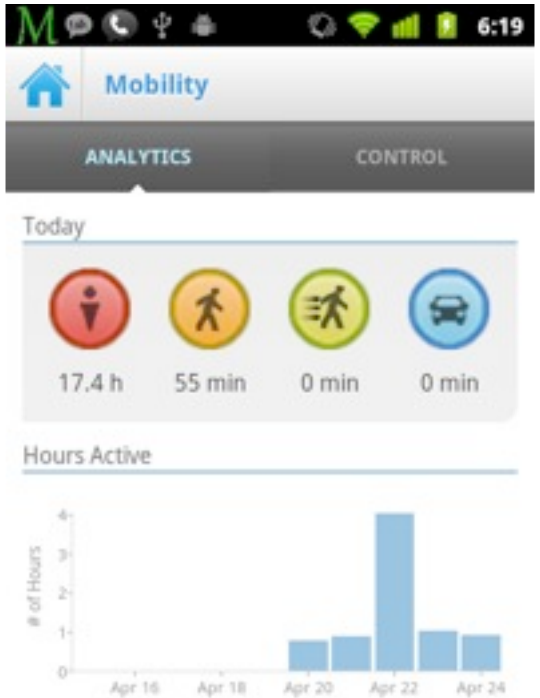

**did NOT have the garden**



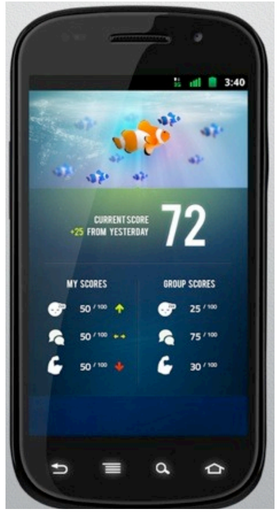


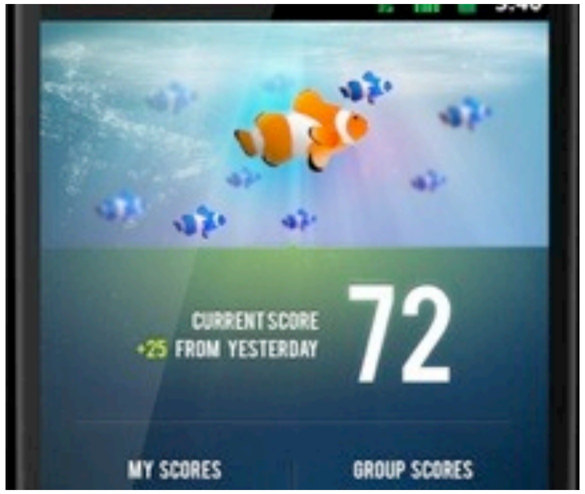
ubifit
(S. Consolvo et al, UW/Intel)




NIH funded new-moms study in progress
(Ramanathan, Ketcham, Estrin...)






Mobile Ambient Wellbeing Display
(T. Choudhury, Cornell)

# Data reduction, selective sharing, privacy

**usability and privacy served by sharing only extracted data features**

***TMI (too much information) filter***

**New privacy models emerging for raw data**

http://www.weforum.org/issues/rethinking-personal-data

http://personal.com

http://wethedata.org

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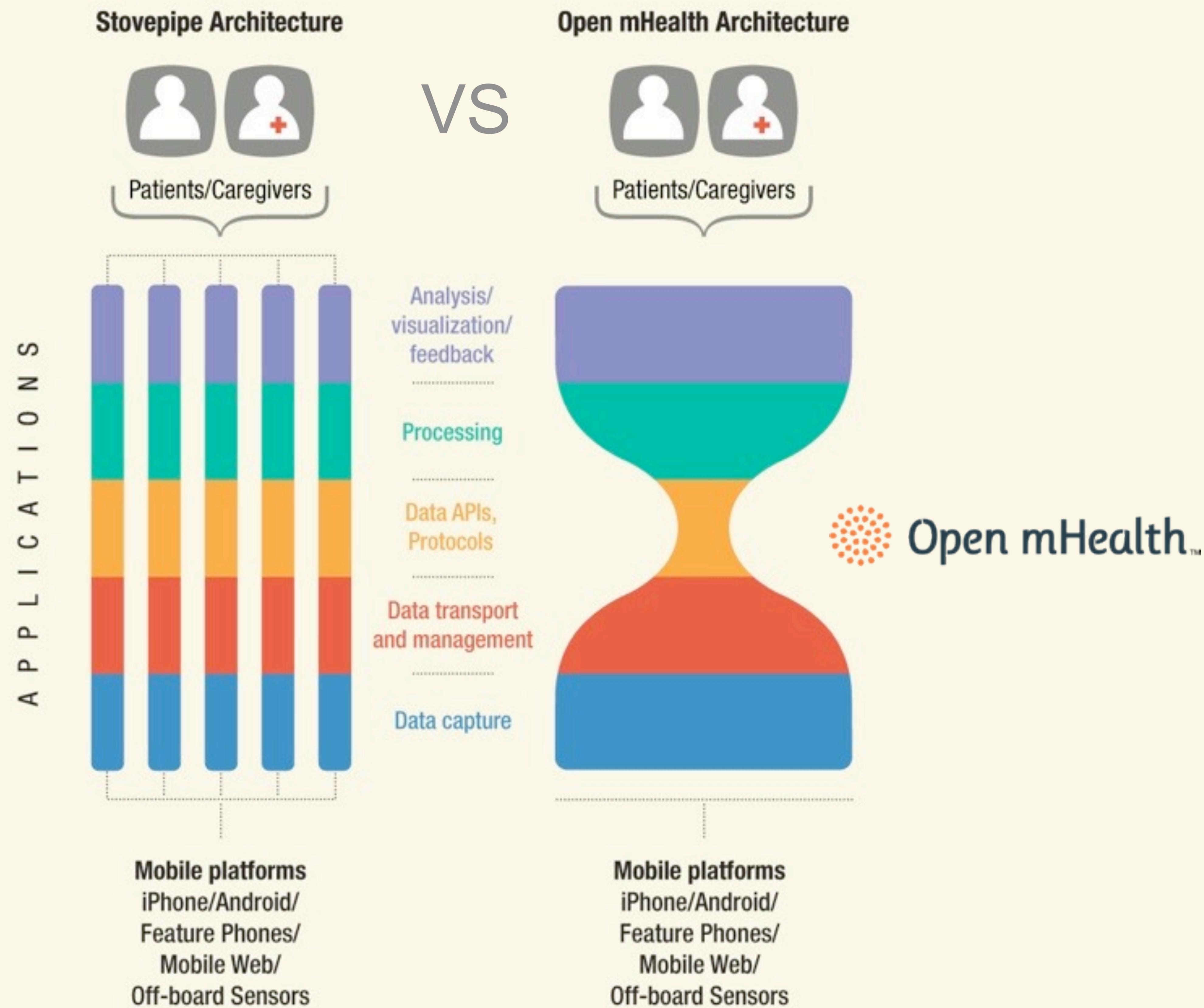
# Third IT pillar of personalized, precision, medicine

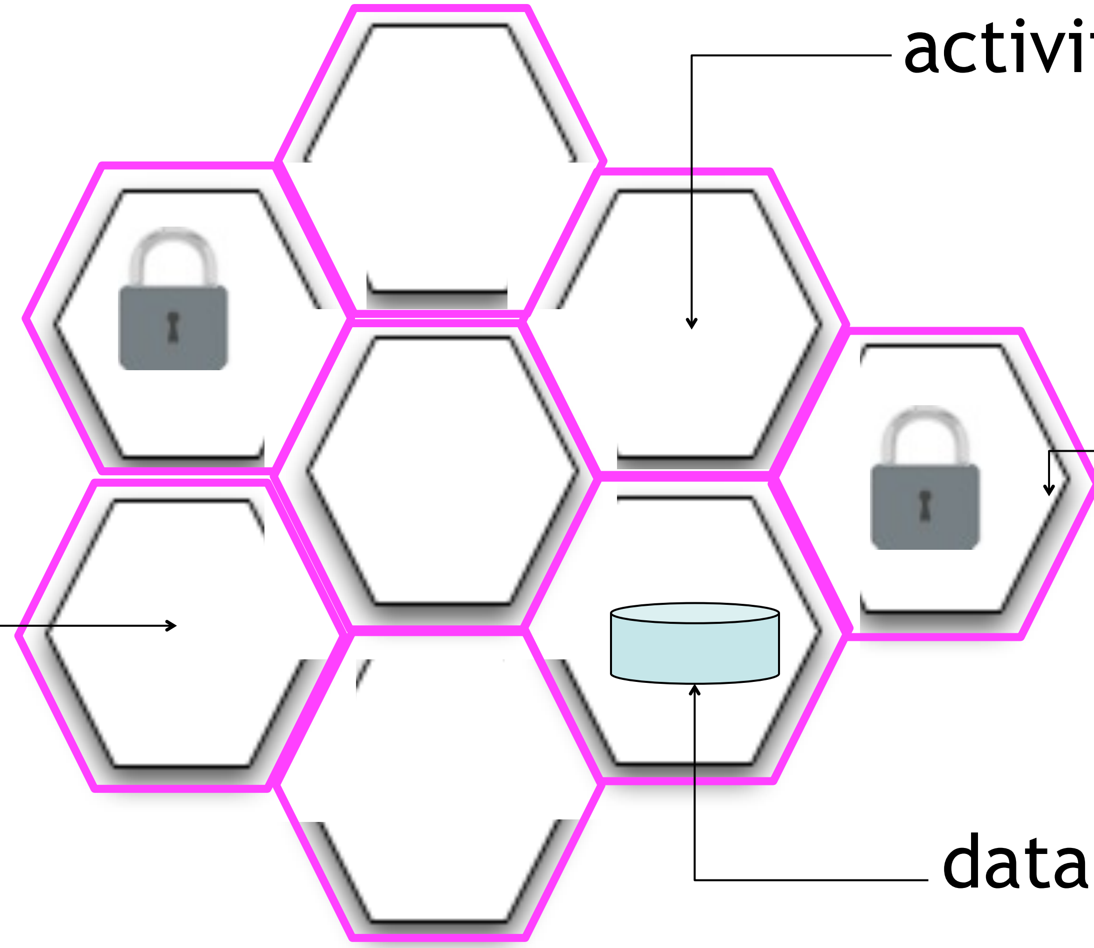
"Big data" (EHRs, Web mining) **+** Omics **+** "small data" (mHealth, digital traces)

# Open architecture and community

so mHealth solutions can integrate best available apps and techniques



# open architecture for mobile health



activity classification

graphing significant changes in mobility

proprietary component with omh API

data storage (e.g., PHR)

a small set of common principles/practices by which these modules are described and interface to one another

Estrin, Sim. *Science* 2010; 330:759-760
Chen, et al. *JMIR* 2012; 2012;14(4):e112.

# Open mHealth light-handed approach to semantics

**Foster broad ecosystem of software components that can process or visualize a single payload ID**

- competition, different algorithms, new approaches ...
- after all ... this is all ‘new stuff’...processes and products will be iterating rapidly as we learn

**Enable a data standard process that supports rapid evolution**

- fits the desired and unavoidable dynamics of a *learning healthcare* ecosystem

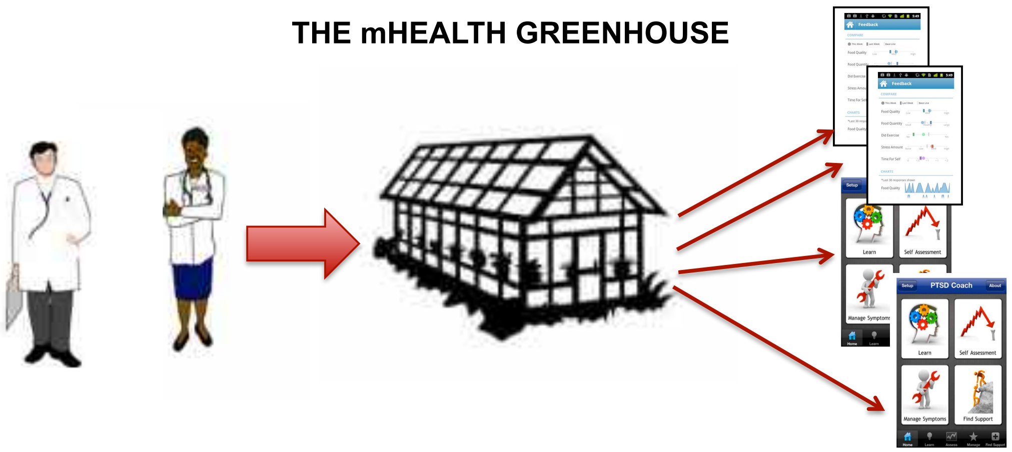
**Data payload defined by Schema ID, version, lightweight schema**

- utilize payload IDs to represent existing standards as well
- accommodate both existing software and existing standards

# Whats next ...

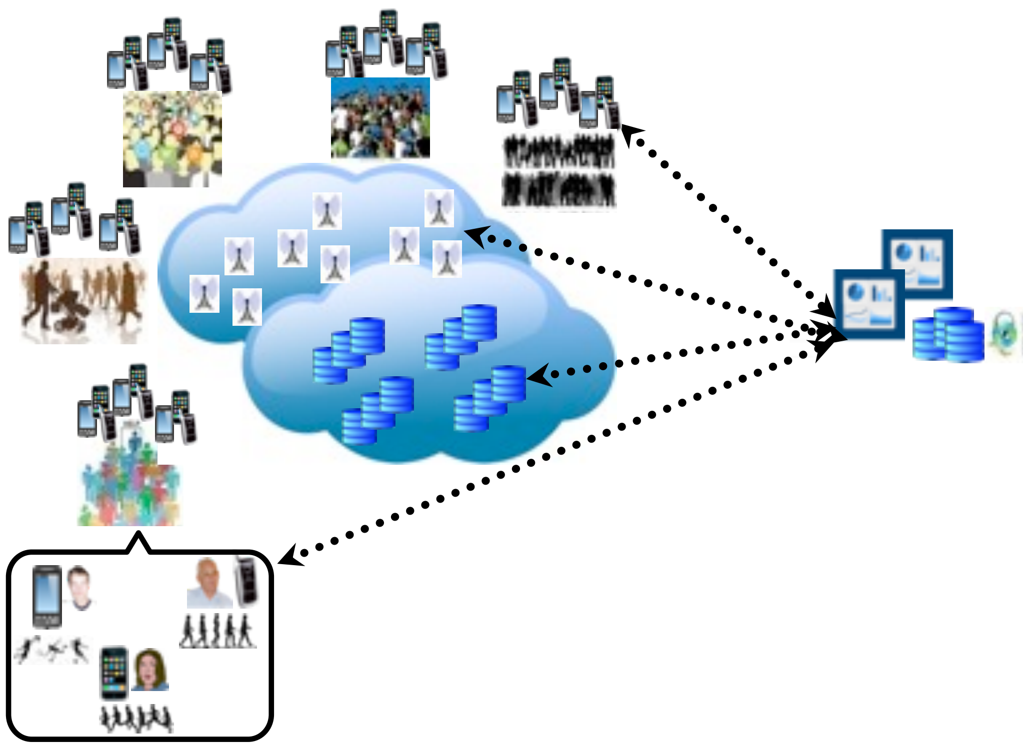
## mHealth Greenhouse

- collaborate with innovative clinicians to develop new ways to address patient care by leveraging mobile data: behavioral biomarkers
- tools to support patients' disease-management
- support rapid, iterative prototyping and piloting




## mpire: mobile personal informatics research and experimentation

- Open up programmatic access to individuals to obtain their personal digital traces from mobile, search, social, e-commerce, games, apps
- Personal Data APIs to foster personal services/apps
- Testbed in NYC with access to 1000's of mobile subscribers for experiments with privacy and detailed analytics



# End to end arguments in systems-*research* design:
## *a case for including authentic applications in experimental systems research*

**Original argument [Saltzer, Reed, Clark, 1981]**

- "...functions placed at low levels of a system may be redundant or of little value when compared with the cost of providing them at that low level."
- "The argument appeals to application requirements, and provides a rationale for moving function upward in a layered system, closer the application that uses the function."

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### Implications for systems-research/innovation

- authentic applications needed as part of systems research exploration to keep functional and performance requirements on a purposeful track
- need to build...**and use**...

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### More general lessons from systems

- architecture, modularity, well-defined interfaces, analytics are critical
- enable rapid, iterative, automated, learning and sharing across applications, institutions, markets
- importance of shared robust open infrastructure

# Acknowledgments: Collaborators and Sponsors


**Collaborators**

Technology Collaborators :
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Graduate students: Faisal Alquaddoomi, Hossein Falaki, Brent Flagstaff, Andy Hsieh, Jinha Khang, Donnie Kim, Min Mun, Sasank Reddy, Vids Samanta

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