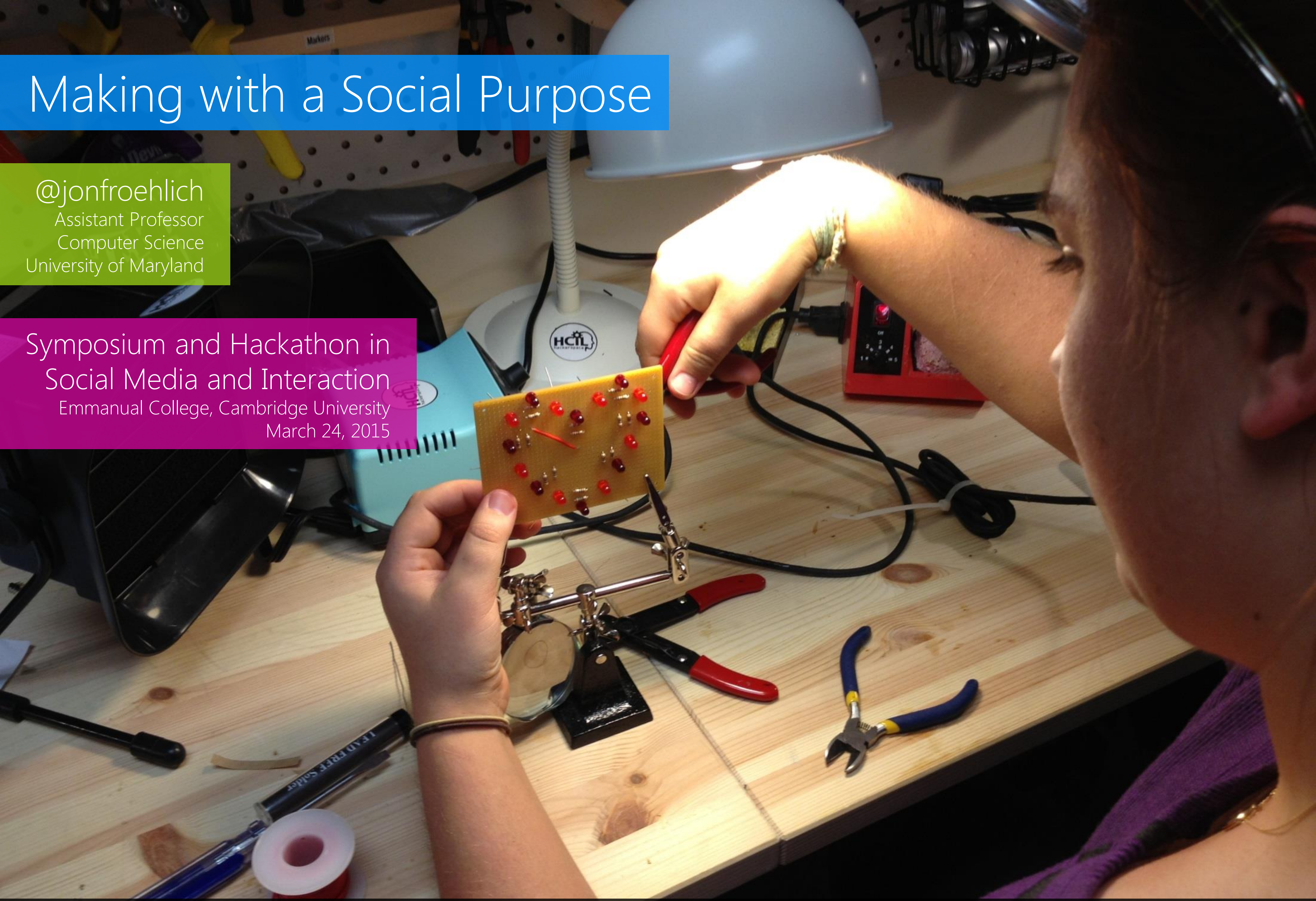
Making with a Social Purpose

@jonfroehlich
Assistant Professor
Computer Science
University of Maryland

Symposium and Hackathon in Social Media and Interaction
Emmanual College, Cambridge University
March 24, 2015



Human Computer Interaction Laboratory
COMPUTER SCIENCE UNIVERSITY OF MARYLAND
makeability lab
UNIVERSITY OF MARYLAND

My Group

Started in 2012


makeability lab
A lablet within the HCIL

HCIL

Human-Computer Interaction Lab


HCIL Begins
1983
Ben Shneiderman
Founding Director
The human information processor from The Psychology of Human Computer Interaction
Lab in Comp. & Space Sciences Bldg pre-1988
NOOBIE 1986 (A. DRUIN'S MASTER'S THESIS AT MIT)
Ben Shneiderman Trading Card
PROF. AZRIEL ROSENFELD (1931-2004)

Ben Shneiderman

Circa 1983

Ben Shneiderman

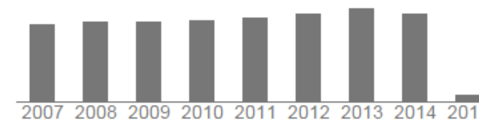
Follow

Professor of Computer Science, University of Maryland
human-computer interaction, information visualization, social media
Verified email at cs.umd.edu - Homepage

Title 1–20	Cited by	Year
Designing the user interface-strategies for effective human-computer interaction B Shneiderman Pearson Education India	10442	1986
Readings in information visualization: using vision to think Morgan Kaufmann	3894	1999
The eyes have it: A task by data type taxonomy for information visualizations B Shneiderman Visual Languages, 1996. Proceedings., IEEE Symposium on, 336-343	3052	1996
Designing the user interface: strategies for effective human-computer interaction B Shneiderman Addison-Wesley	2113	1992
1.1 direct manipulation: a step beyond programming languages B Shneiderman Sparks of innovation in human-computer interaction 17, 1993	2044	1993
Tree-maps: A space-filling approach to the visualization of hierarchical information structures B Johnson, B Shneiderman Visualization, 1991. Visualization'91, Proceedings., IEEE Conference on, 284-291	1430	1991
Tree visualization with tree-maps: 2-d space-filling approach B Shneiderman ACM Transactions on graphics (TOG) 11 (1), 92-99	1395	1992
Software psychology B Shneiderman Winthrop	1218	1980
Visual information seeking: tight coupling of dynamic query filters with starfield displays C Ahlberg, B Shneiderman	1154	1994

Google Scholar

Citation indices	All	Since 2010
Citations	61318	20393
h-index	98	65
i10-index	396	221



Co-authors View all...

Catherine Plaisant

Phillip B Gibbons


LeahFindlater
JenGolbeck
BenShneiderman
BenBederson
JonFroehlich
AnneRose
MichelleMazurek
CatherinePlaisant
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NicholasDiakopoulos
JennyPreece
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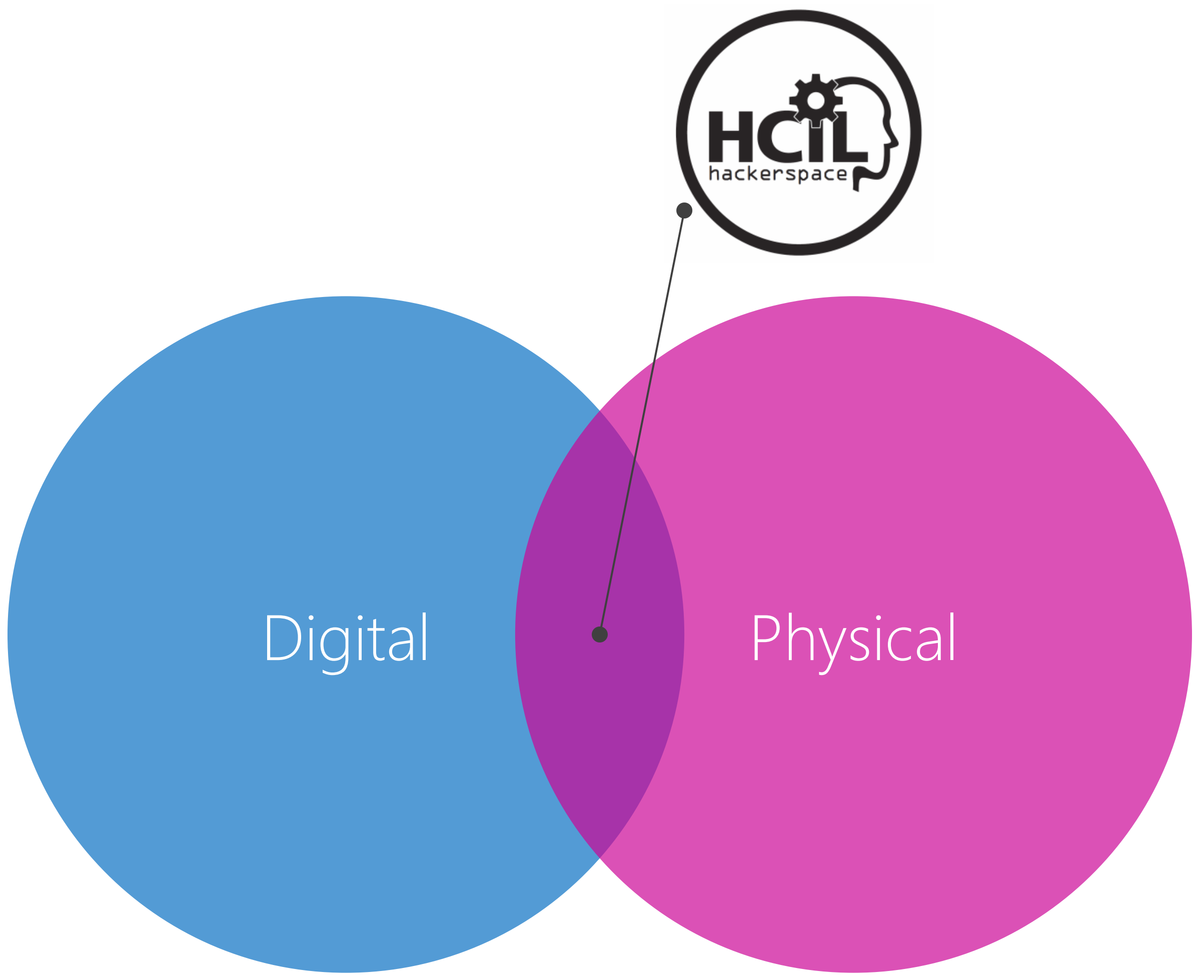
computer science
ischool
english & journalism
hcil
education
psychology
AllisonDruin
MonaLeighGuha
TammyClegg
JuneAhn
EvanGolub
TimClausner
KentNorman
IraChinoy


Main Lab
From Front

Main Lab

From Back


HCIL Usability Lab
With Two-Way Mirror

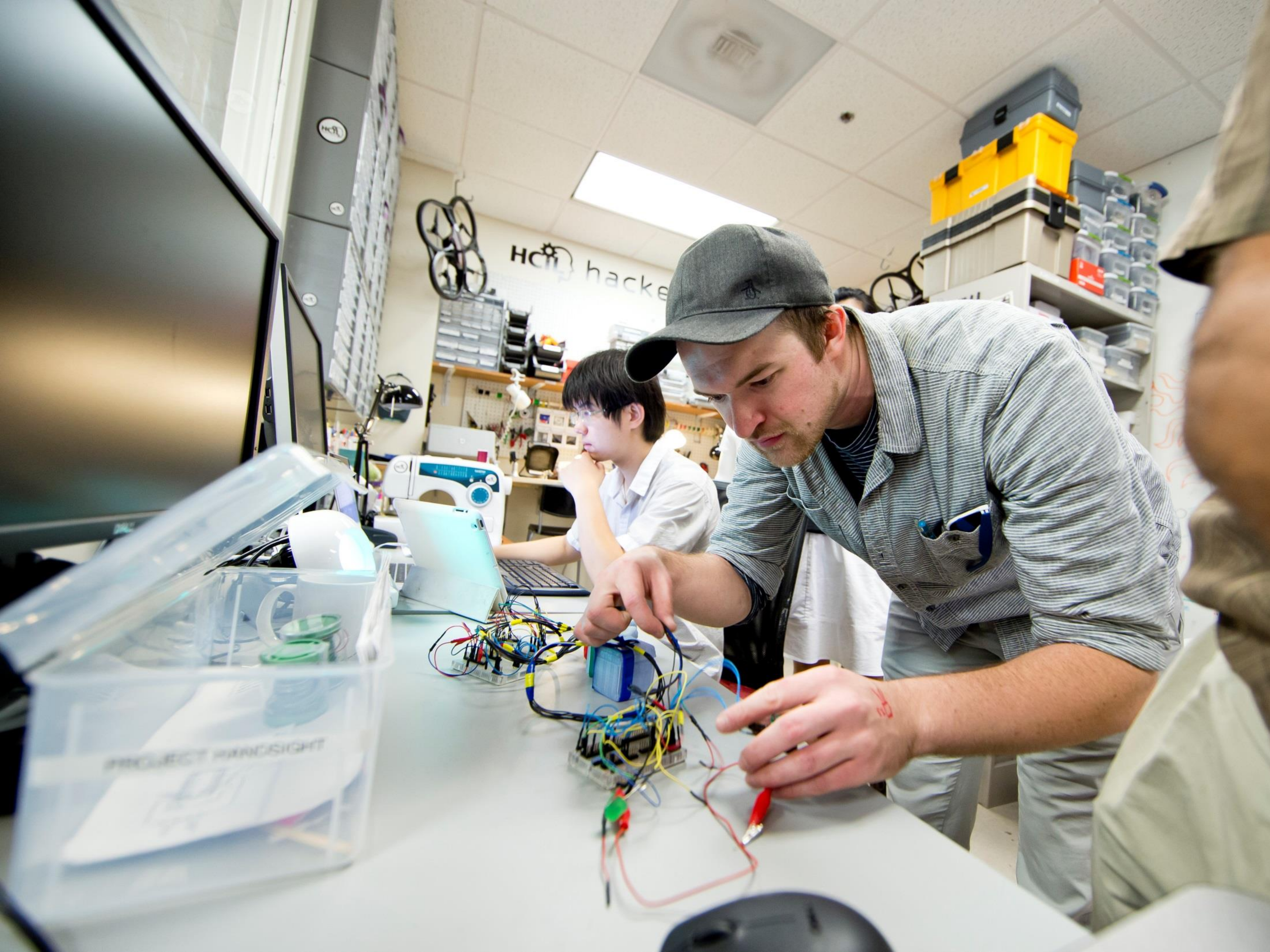

HCIL
hackerspace
Digital
Physical

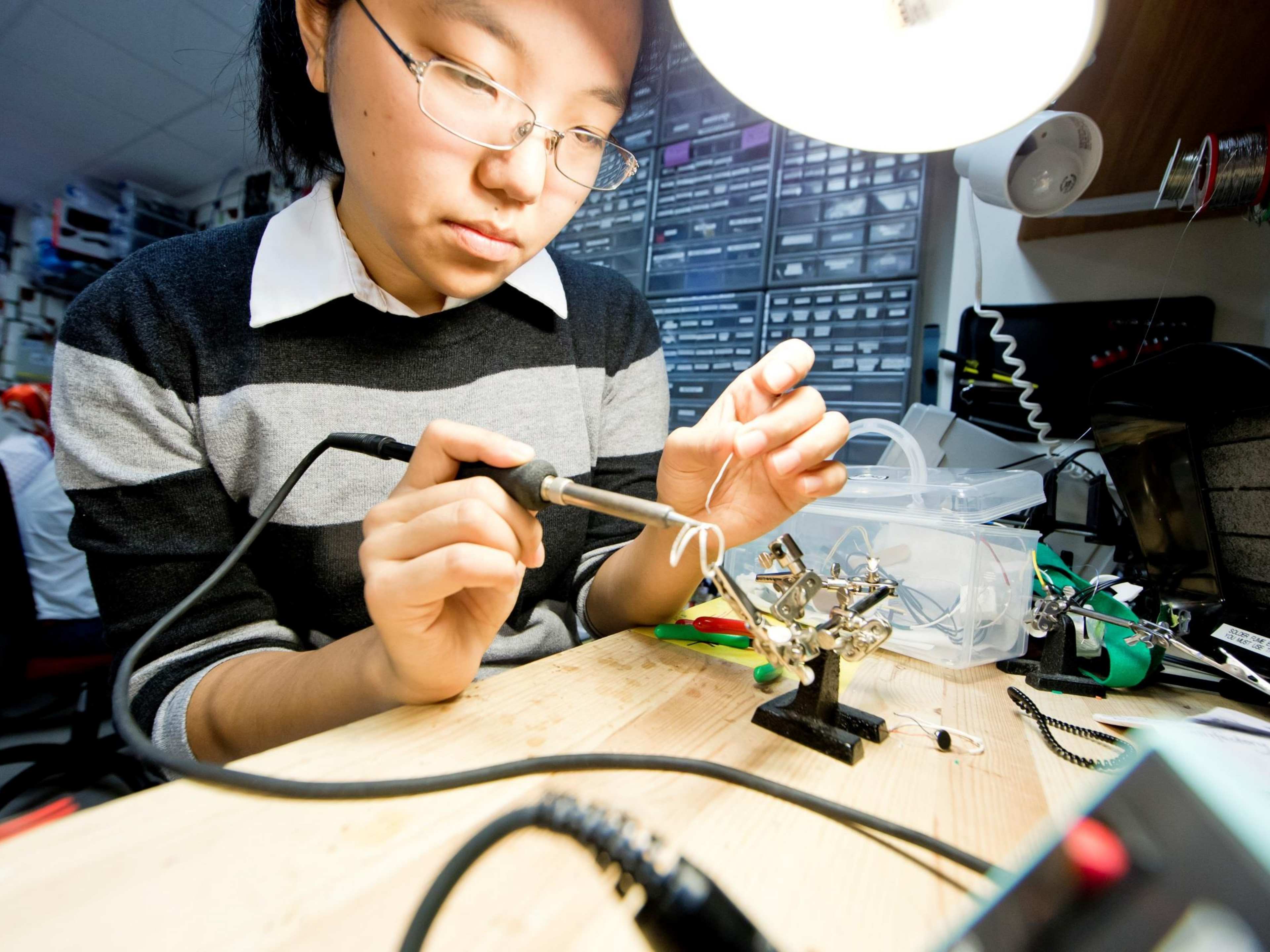
HCIL Hackerspace

Front Entrance


HCIL hackerspace
HACKER SPACE
Schedule
DELL


rspace
HCIL
HACKER
SPACE
DELL


HCIL




TEXTILES, CRAFTS, AND CLAY – OH MY


Crayola
MARKERS


HCIL hackerspace
Lung
Small Intestine


HR
90 BPM
PACE
7:44

"Joy is a well-made object, equaled only to the joy of making it."

-a Canadian Native American tribe saying, as quoted by Mark Fraunfelder (author, co-founder of BoingBoing , & editor of MAKE Magazine)

Preamble

This class is about making, being creative, taking risks. We will make to learn and learn to make. We will use materials to help us think and to push our own boundaries of what interactive computing is and could be. I taught this class once before: http://cmsc838f-f12.wikispaces.com. It was, by most accounts, a success (I think!). I learned a lot. The class learned a lot. Most importantly, along the way, we had *fun* together, we *made* interesting things, and we *helped* each other (peer learning ftw).

As another indicator of success, the aforementioned Fall2012 class generated one MS thesis topic, one PhD thesis topic, and two publications (with more to come!). In addition, the instructables posted for the final project have garnered over 74,265 views and have been favorited 317 times (as of Jan, 2014) including HandSight (9,330 views, 58 favorites), indoor/outdoor tracker (33,642 views, 88 favorites), x-track music visualizer (7,150 views, 63 favorites), and the HCIL Hackerspace interactive living wall (22,613 views, 98 favorites). I hope for a similar diversity of compelling ideas and successes this year!

I will state up front: in this class, I do not have all the answers (note: I never do but particularly not in this class). I am learning with you. I am pushing myself to learn new things. You should too. So, it's likely that we'll experience some failures along the way. A mini-project might fail. My lectures might fail. But that's OK. Failures can often lead to accidental innovation and they most certainly help you learn. If you don't fail sometimes, you're not trying hard enough. :)

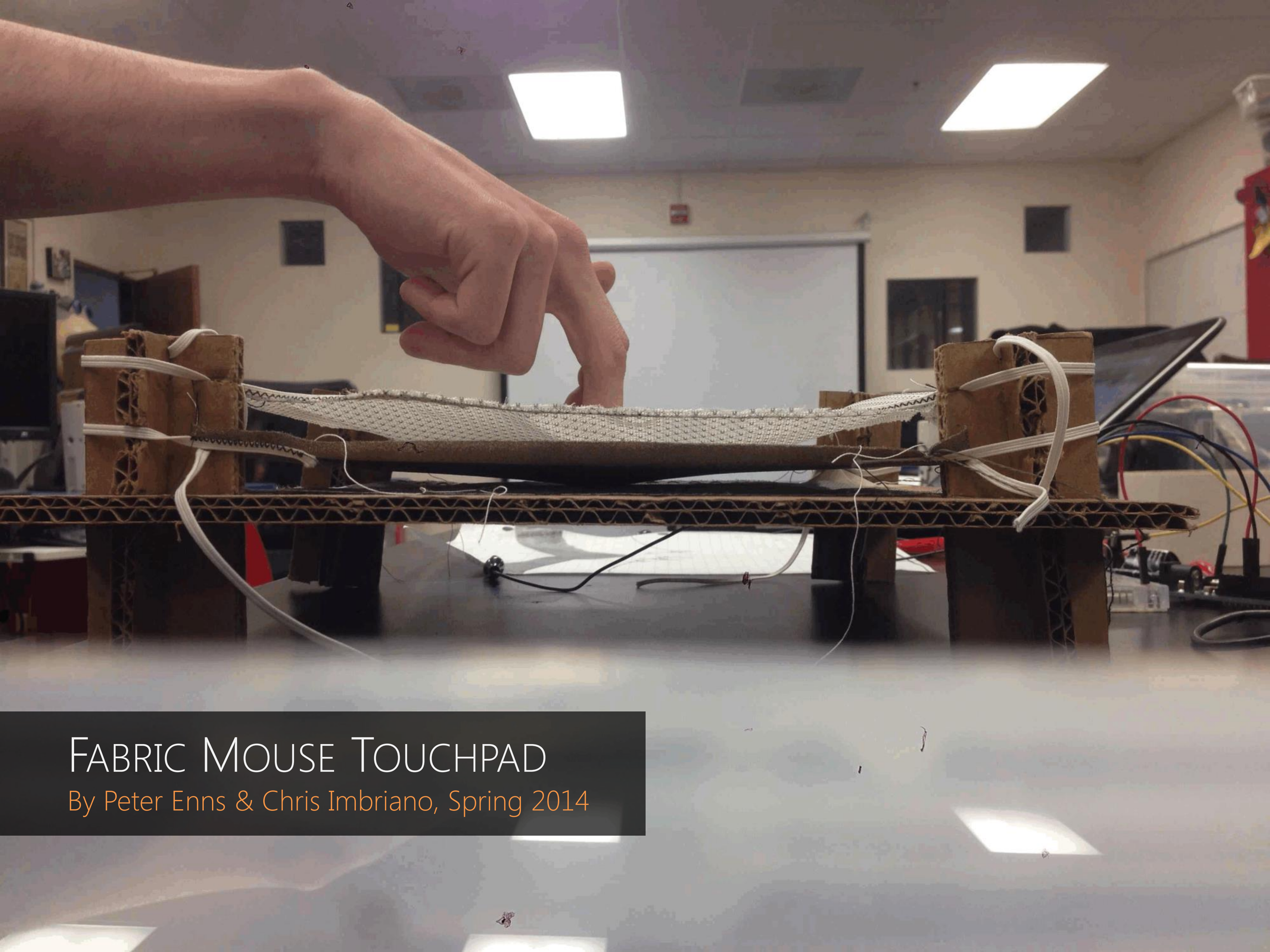
Course Pages
- Home
- Schedule
- Resources
- HCIL Hackerspace

Individual Assignments
- IA01 Background Survey - 1/29
- IA02 Arduino Graph - 2/13
- IA03 Partner Eval for MPA01 - 3/10
- IA04 Partner Eval for MPA02 - 4/02
- IA05 Partner Eval for MPA03 - 4/21

Mini-Project Assignments
- MPA01 Input Inventions - 3/3
- MPA02 High-Low Tech - 3/26
- MPA03 Kinects & Motors - 4/16

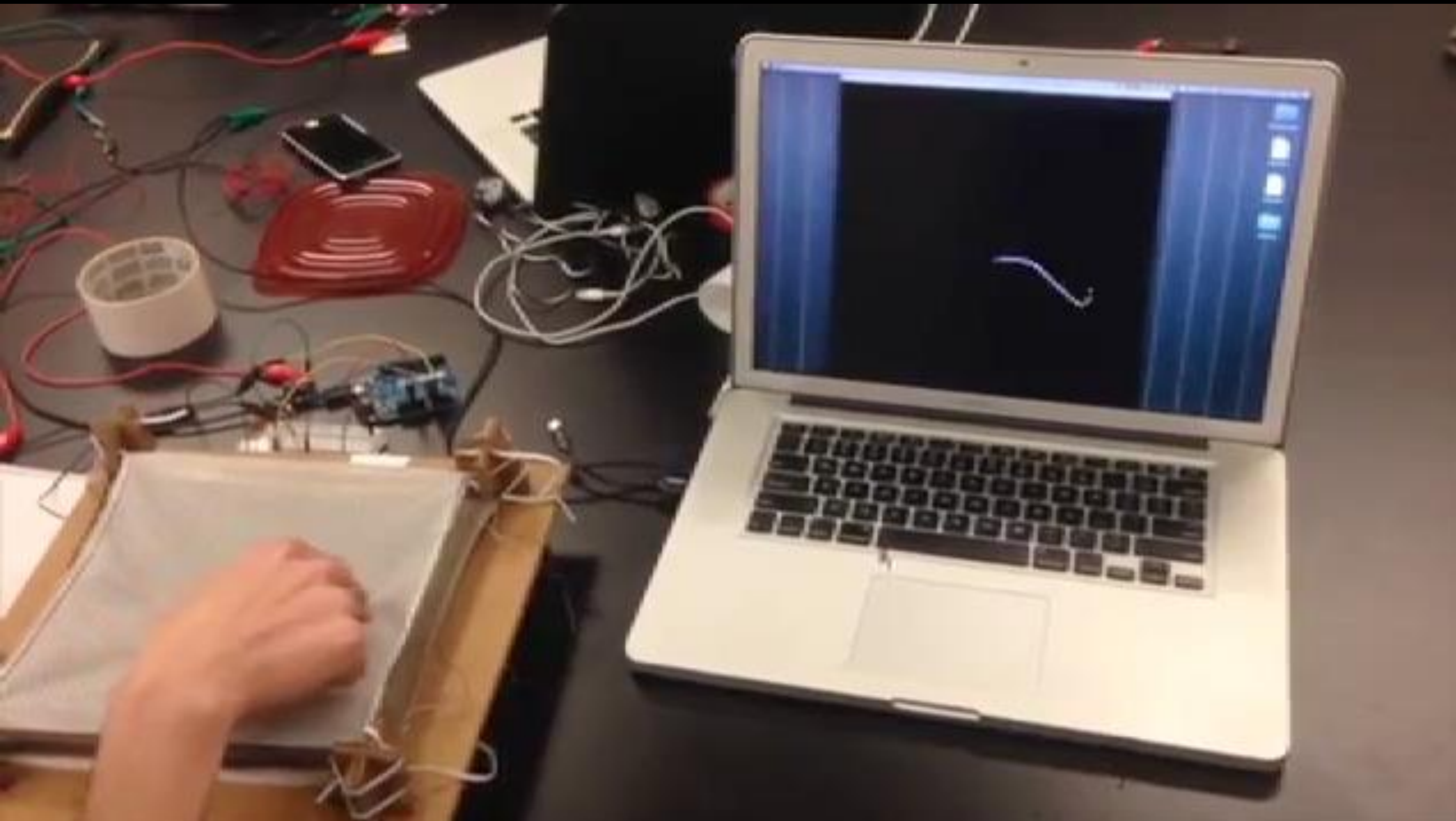
Semester Project Assignments
- SPA01 Project Pitch
- SPA02 Project Presentation
- SPA03 Project Instructable
- SPA04 Project Video
- SPA05 Project Artifact

Reading Assignments
- RA01 Tangible Bits - 1/29
- RA02 Arduino Intro - 2/3
- RA03 Electricity Intro - 2/13
- RA04 Switches (p 39-59) - 2/19
- RA05 Input Technology - 2/26
- RA05 Sensor-Based Input - 2/26
- RA06 Prototyping 3/5



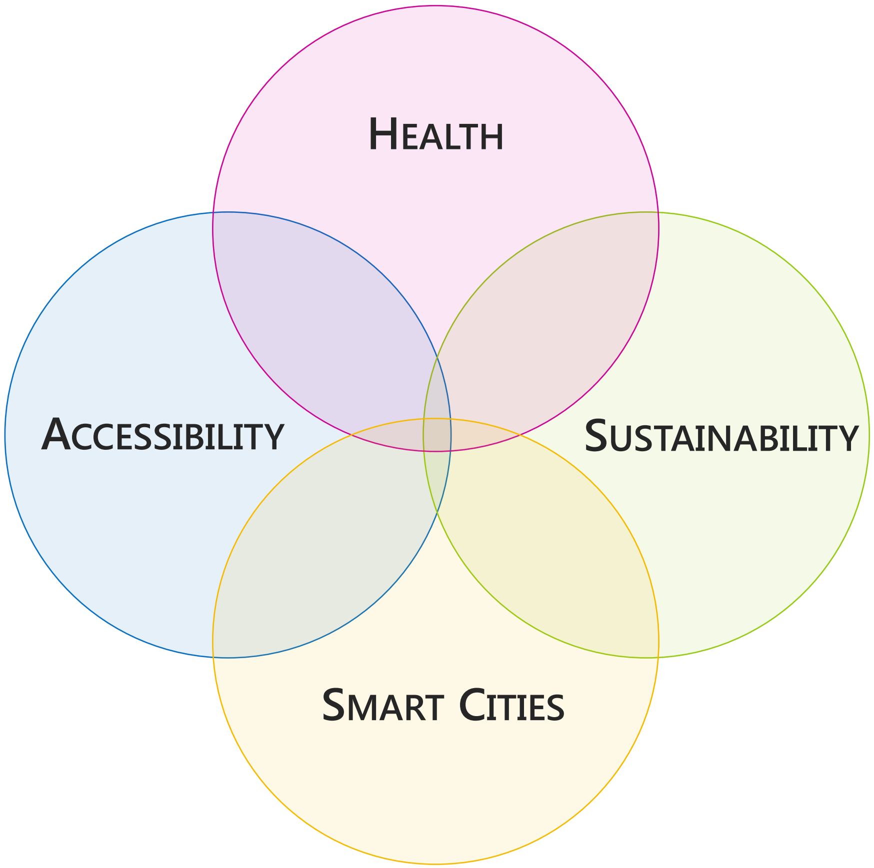
Fabric Mouse Touchpad

By Peter Enns & Chris Imbriano, Spring 2014

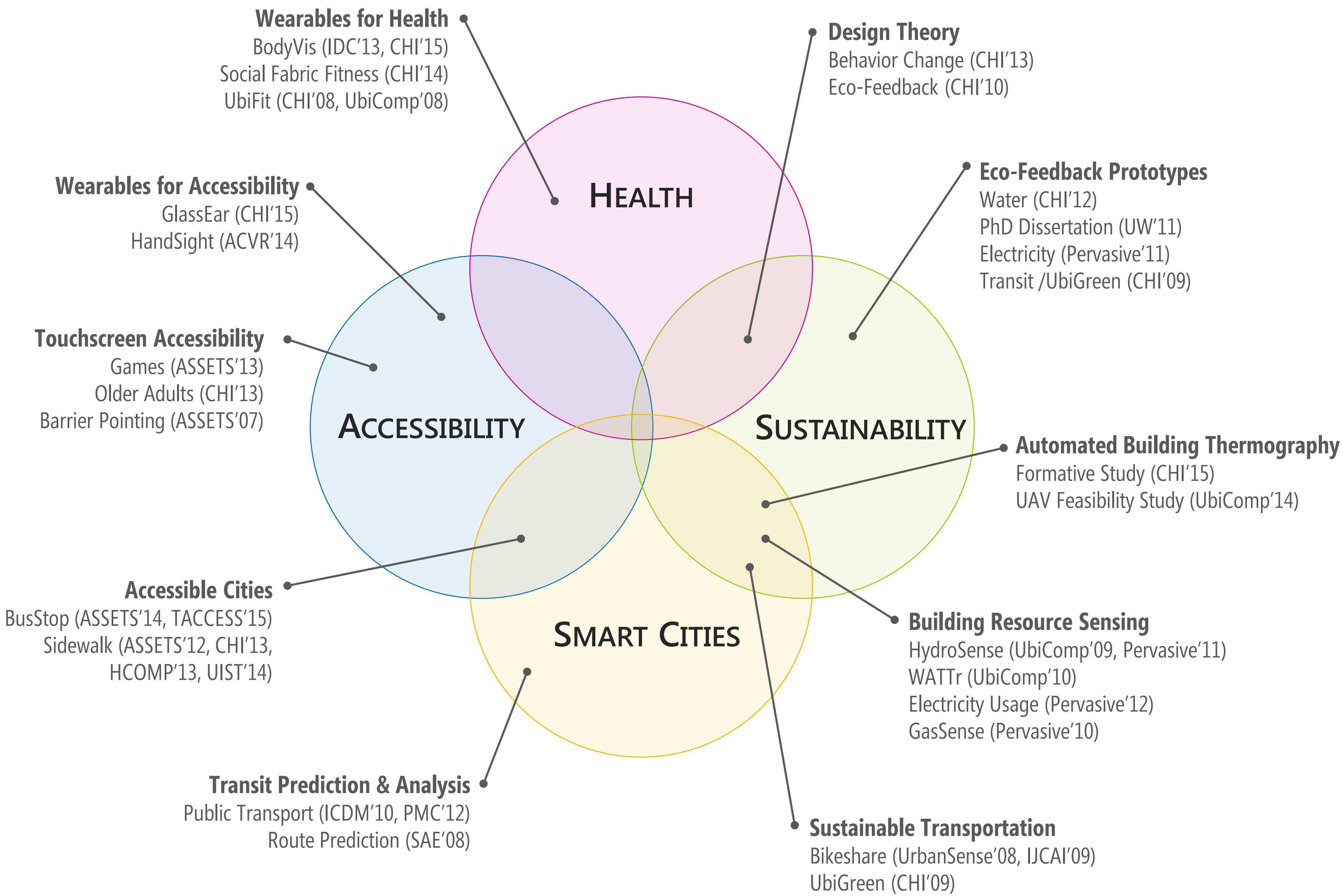



MUSICAL SPAGHETTI MADNESS
By Richard Johnson, Spring 2014

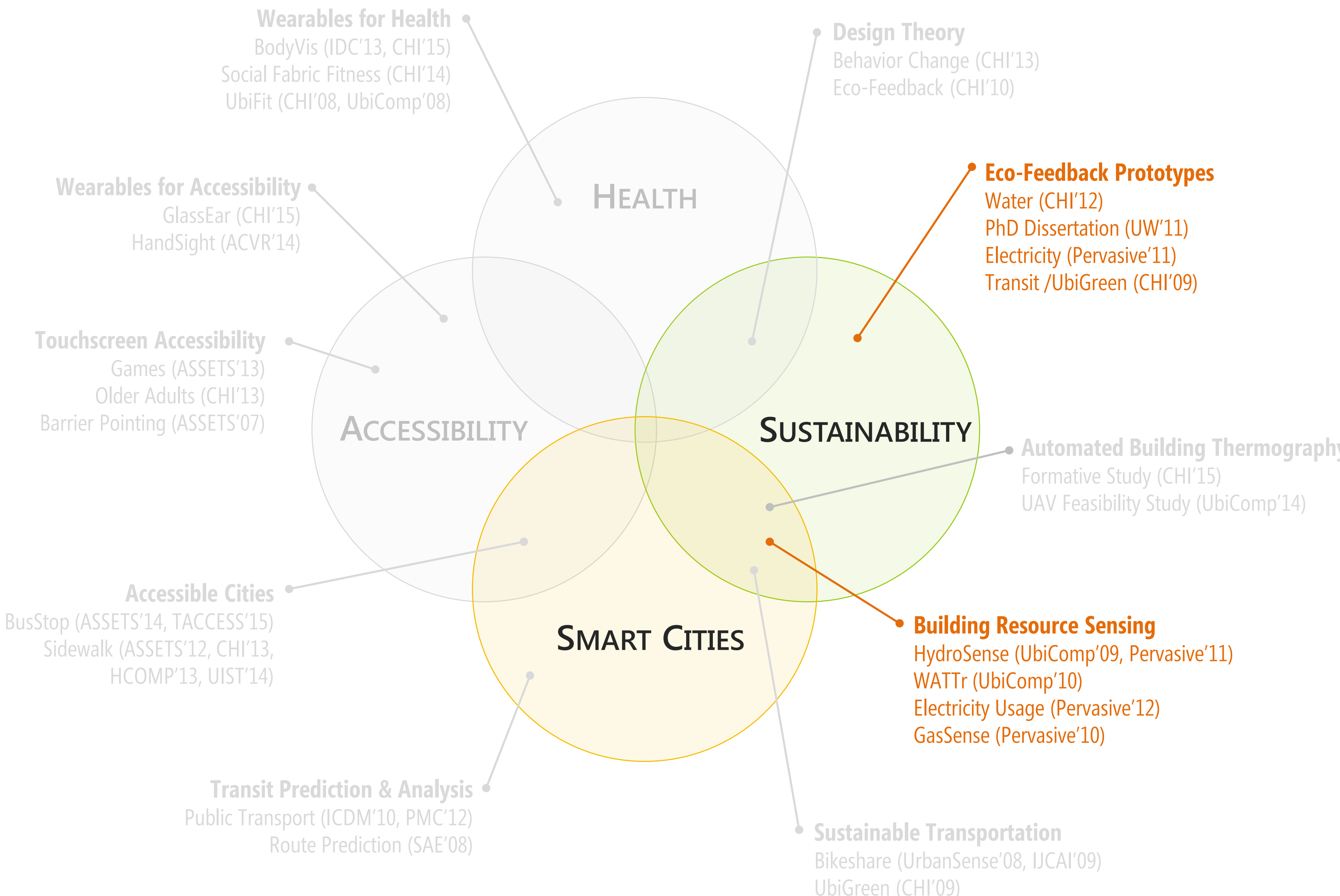
My Research



My Research


Wearables for Health
BodyVis (IDC'13, CHI'15)
Social Fabric Fitness (CHI'14)
UbiFit (CHI'08, UbiComp'08)
Design Theory
Behavior Change (CHI'13)
Eco-Feedback (CHI'10)
Wearables for Accessibility
GlassEar (CHI'15)
HandSight (ACVR'14)
Eco-Feedback Prototypes
Water (CHI'12)
PhD Dissertation (UW'11)
Electricity (Pervasive'11)
Transit /UbiGreen (CHI'09)
Health
Touchscreen Accessibility
Games (ASSETS'13)
Older Adults (CHI'13)
Barrier Pointing (ASSETS'07)
Accessibility
Sustainability
Automated Building Thermography
Formative Study (CHI'15)
UAV Feasibility Study (UbiComp'14)
Accessible Cities
BusStop (ASSETS'14, TACCESS'15)
Sidewalk (ASSETS'12, CHI'13,
HCOMP'13, UIST'14)
Smart Cities
Building Resource Sensing
HydroSense (UbiComp'09, Pervasive'11)
WATTr (UbiComp'10)
Electricity Usage (Pervasive'12)
GasSense (Pervasive'10)
Transit Prediction & Analysis
Public Transport (ICDM'10, PMC'12)
Route Prediction (SAE'08)
Sustainable Transportation
Bikeshare (UrbanSense'08, IJCAI'09)
UbiGreen (CHI'09)

My Research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Route Prediction (SAE'08)
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Bikeshare (UrbanSense'08, IJCAI'09)
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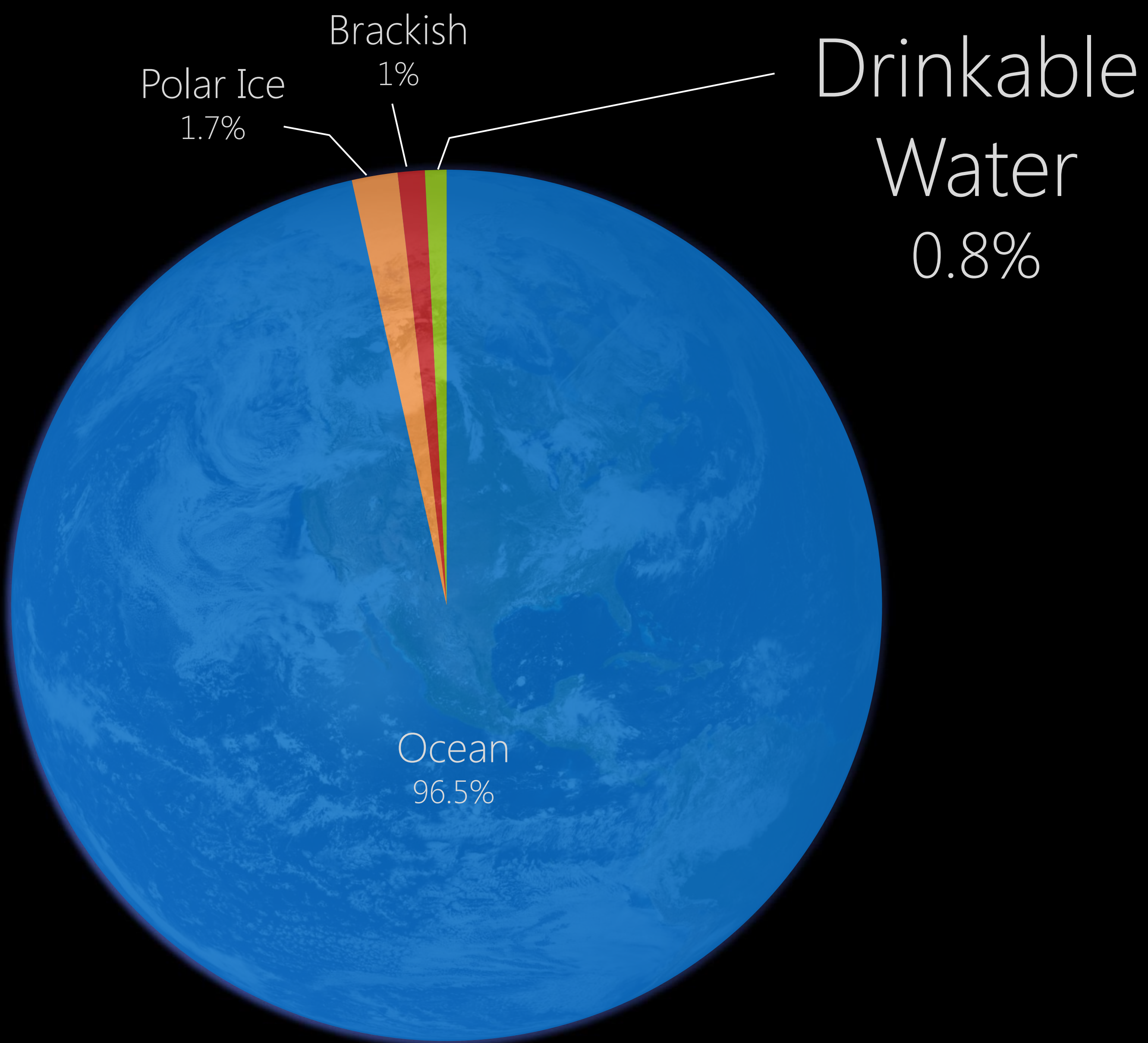
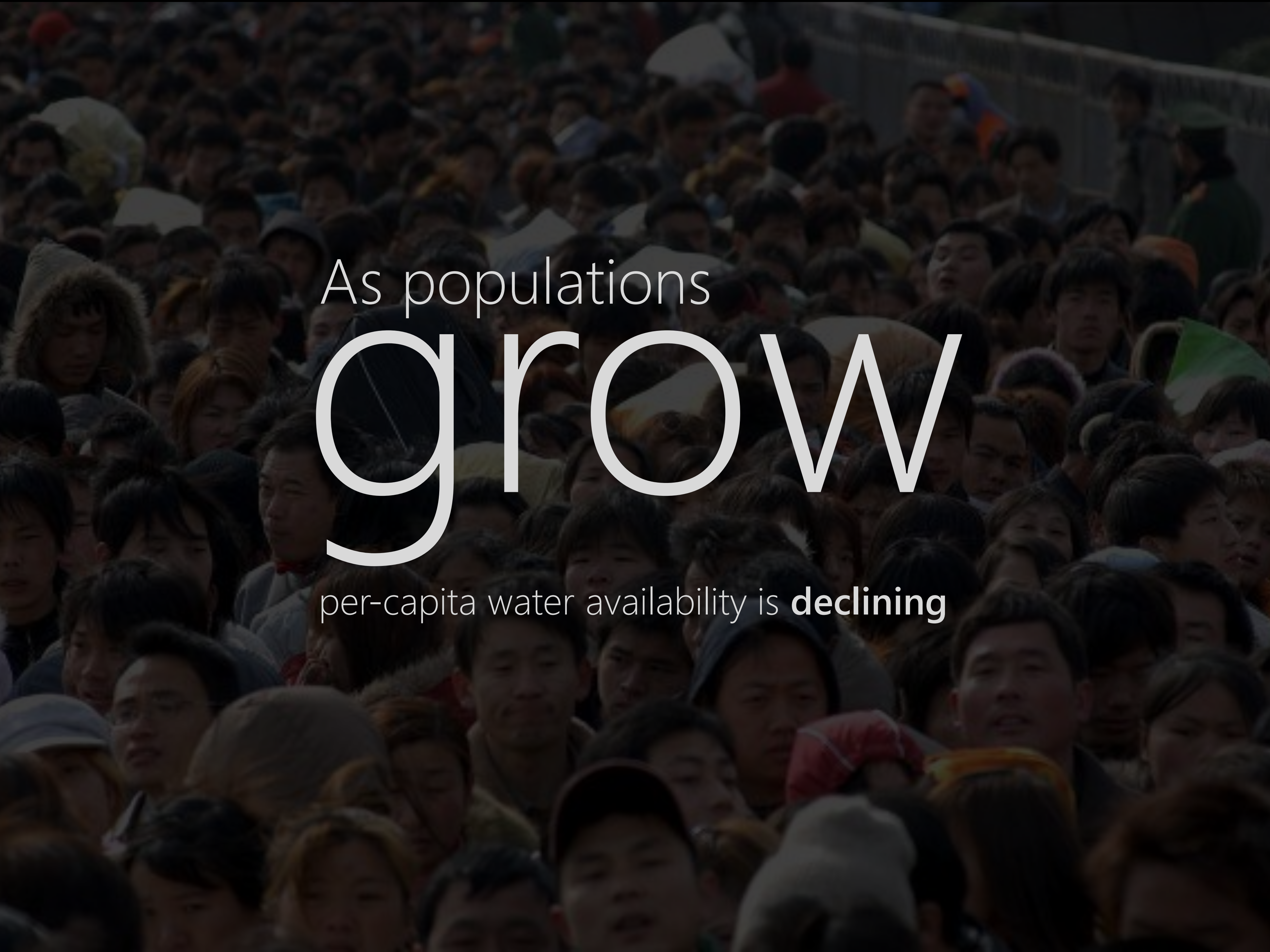
two-thirds

of the earth’s surface is covered by water



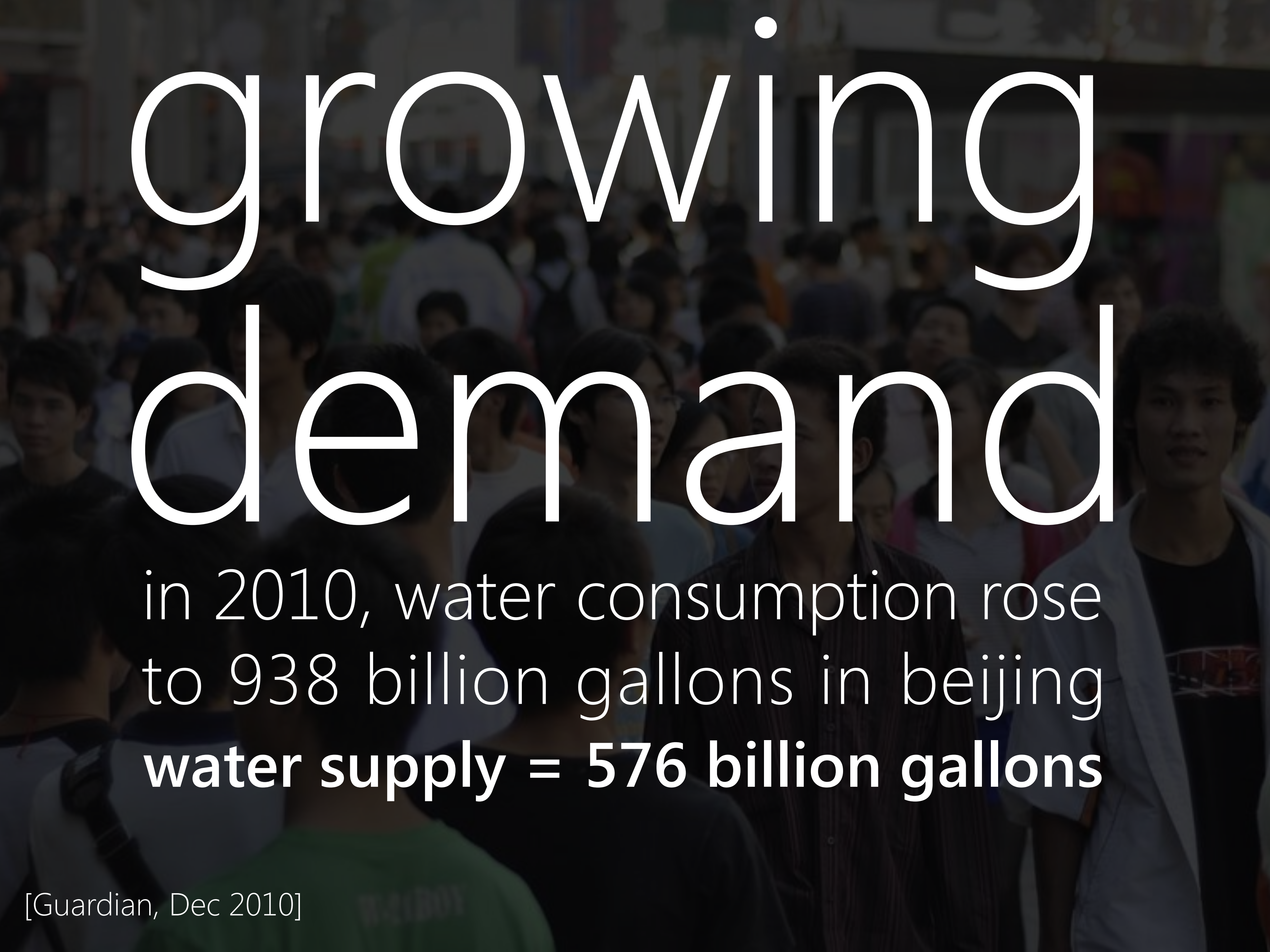
[Glennon, *Unquenchable: America's water crisis and what to do about it*, 2009; Gleick, *World Policy Journal*, 2009]


As populations
grow
per-capita water availability is **declining**


water availability disproportionately felt in
urban environments
[Barlow, 2007]

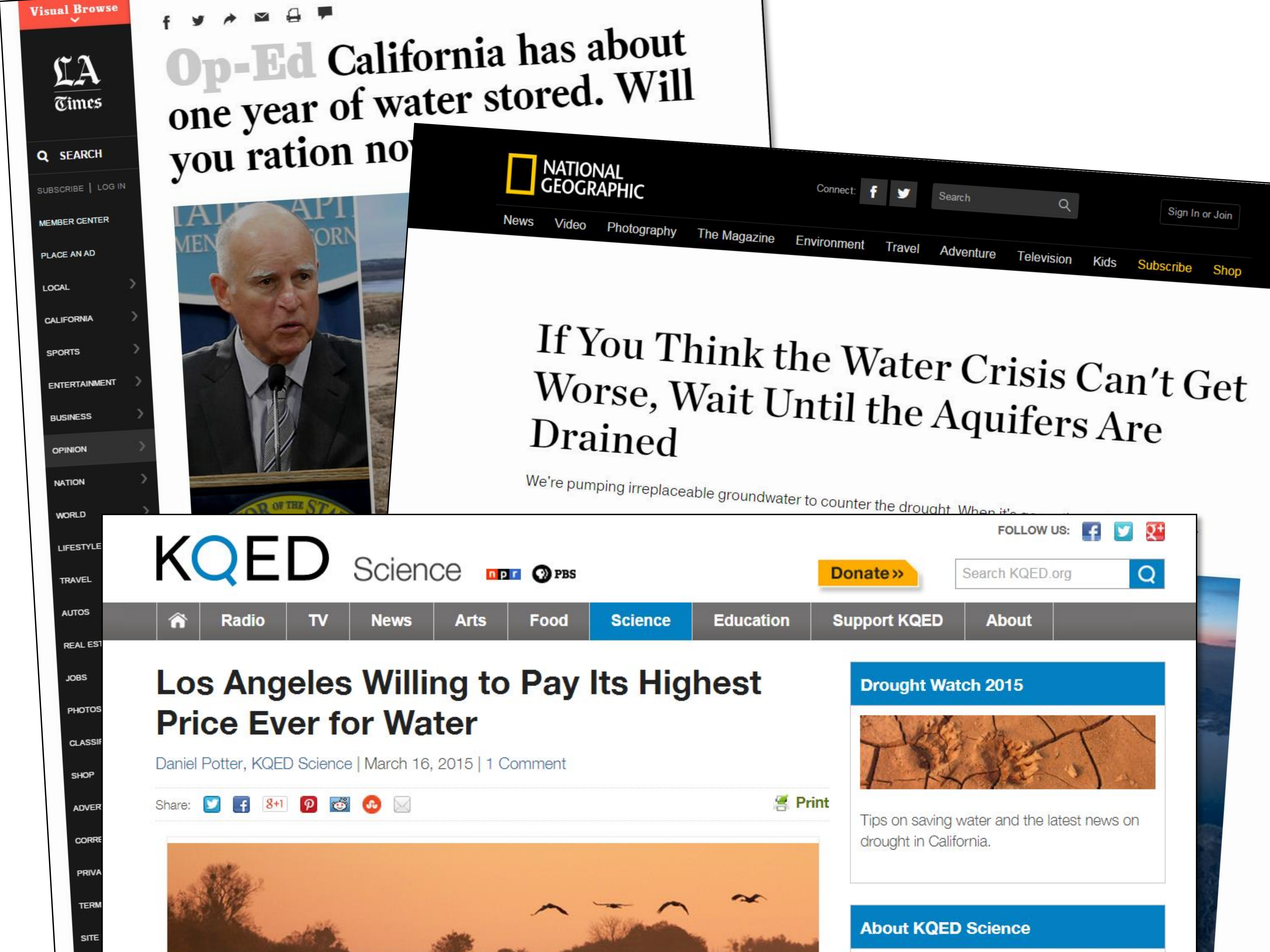
This places an enormous strain on drinkable water supplies

[Inman and Jeffery, 2006; Gleick *et al.*, 2008 Vairavmoorthy, 2006]


growing
demand
in 2010, water consumption rose
to 938 billion gallons in beijing
water supply = 576 billion gallons
[Guardian, Dec 2010]


"china melting snow to meet
freshwater demand"
[Guardian, Dec 2010]


barcelona, spain
importing water by ship for $35m a month
[Bloomberg News, Feb 2009]



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Op-Ed California has about one year of water stored. Will you ration no
NATIONAL GEOGRAPHIC
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Los Angeles Willing to Pay Its Highest Price Ever for Water
Daniel Potter, KQED Science | March 16, 2015 | 1 Comment
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Drought Watch 2015
Tips on saving water and the latest news on drought in California.
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new sources of water
more costly to extract

Shifting Focus

from finding new supplies to **using existing supplies** more **efficiently**

eco-feedback

sensing and visualizing behavior to reduce environmental impact

toyota prius

toyota prius

The Washington Post

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For Hybrid Drivers, Every Trip Is a Race for Fuel Efficiency

By Michael S. Rosenwald
Washington Post Staff Writer
Monday, May 26, 2008

Katie Sebastian accuses her friend Evan Hirsche of getting better mileage than she does because he lives in Bethesda and has flatter everyday trips than she encounters in hilly Takoma Park. She suspects the Hirsche family of taking frequent long drives out of town, which also helps them.

"They claim they haven't been out of town in a while," she said, "but I know they have."

Hirsche retorts: "It is well known that Katie is a lead-footer."

Their friendly rivalry stems from the Prius effect. Both drive a Prius, the Toyota hybrid with an elaborate dashboard monitor that constantly informs drivers how many miles per gallon they are getting and whether the engine is running on battery or gasoline power. That can change driving in startling ways, making drivers conscious of their driving habits, then adjusting them ...

Evan Hirsche averages 43 mpg with his Prius, while Katie Sebastian, shown with her son, Cole, averages 41 mpg. The drivers have friendly rivalry over their mpg scores, fueled by the Prius hybrid's real-time mileage readings. (By Kevin Clark -- The Washington Post)

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100 mpg? For 'hypermilers,' that sounds about right

Updated 6/27/2008 2:06 PM | Comments 446 | Recommend 103 | E-mail | Save | Print | Reprints & Permissions | RSS

By Chris Woodyard, USA TODAY

GILBERT, Ariz. — After a 29-mile jaunt from his Phoenix office to his home here, Louis Hudgin proclaimed his gas mileage "pitiful."

He averaged just 88.3 miles per gallon.

MAXIMIZING MPG: What experts think of hypermiler techniques
TELL US: How do you squeeze the most miles out of every gallon?
ACROSS THE USA: Drivers slow down as costs accelerate

Most drivers would take a victory lap if they managed to squeeze that kind of mileage out of increasingly precious gasoline. Even on this, a bad day, Hudgin coaxed 28 mpg more out of his 2000 Honda Insight hybrid than its federal highway mpg rating.

Hudgin's disappointment — he usually averages about 100 mpg this time of year — stems from his pride in being no ordinary driver.

He's a hypermiler, part of a loose-knit legion of commuters who've made racking up seemingly unattainable mpg an art. And a sport.

Hypermilers practice such unorthodox techniques as coasting for blocks with their car's engine turned off, driving far below speed limits on the freeway, pumping up tire pressure far beyond car and tire makers' recommendations ...

By Michael Chow for USA TODAY

... in of Gilbert, Ariz., squeezes as much ... can get from his 2000 Honda Insight.

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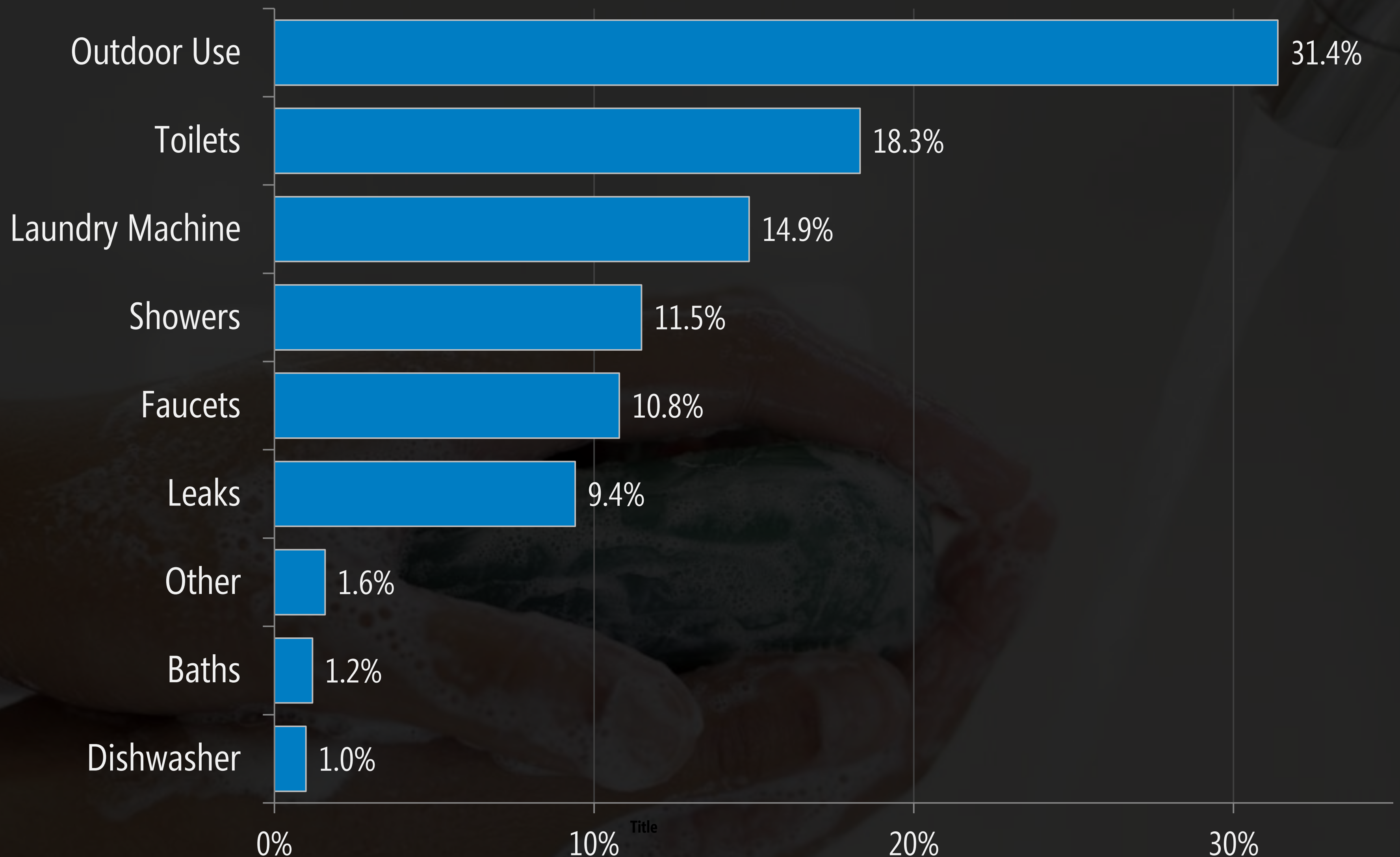
THE DISCUSSION

GAS AT A PREMIUM

toyota prius
Consumption
Energy
60.5 MPG
204 miles
Reset
power-aware cord
cord light pulsates & varies in intensity based on power draw
Gustafsson and Gyllenswärd, CHI2005]
jetsam
visualization allows pedestrians to view amount and type of garbage at-a-glance
[Paulos and Jenkins, CHI2005]
microsoft hohm
Energy Charts
Electricity Usage
the energy detective
Real-Time Use
$ 0.40 per Hour
2.480 kilowatts
TED
DENON
wattson
control4 dashboard
Menu
Thursday, January 6
My Home Now
Price Per kWh
$0.00
0.1 kW
My Cost Per Hour
$0.01
5:30 pm
78°
62°
So Far Today 0.6 kWh
Control4
google powermeter
Google PowerMeter
heat sink
[Arroyo et al., CHI2005]


what
are the most water consuming activities in the average North American home?

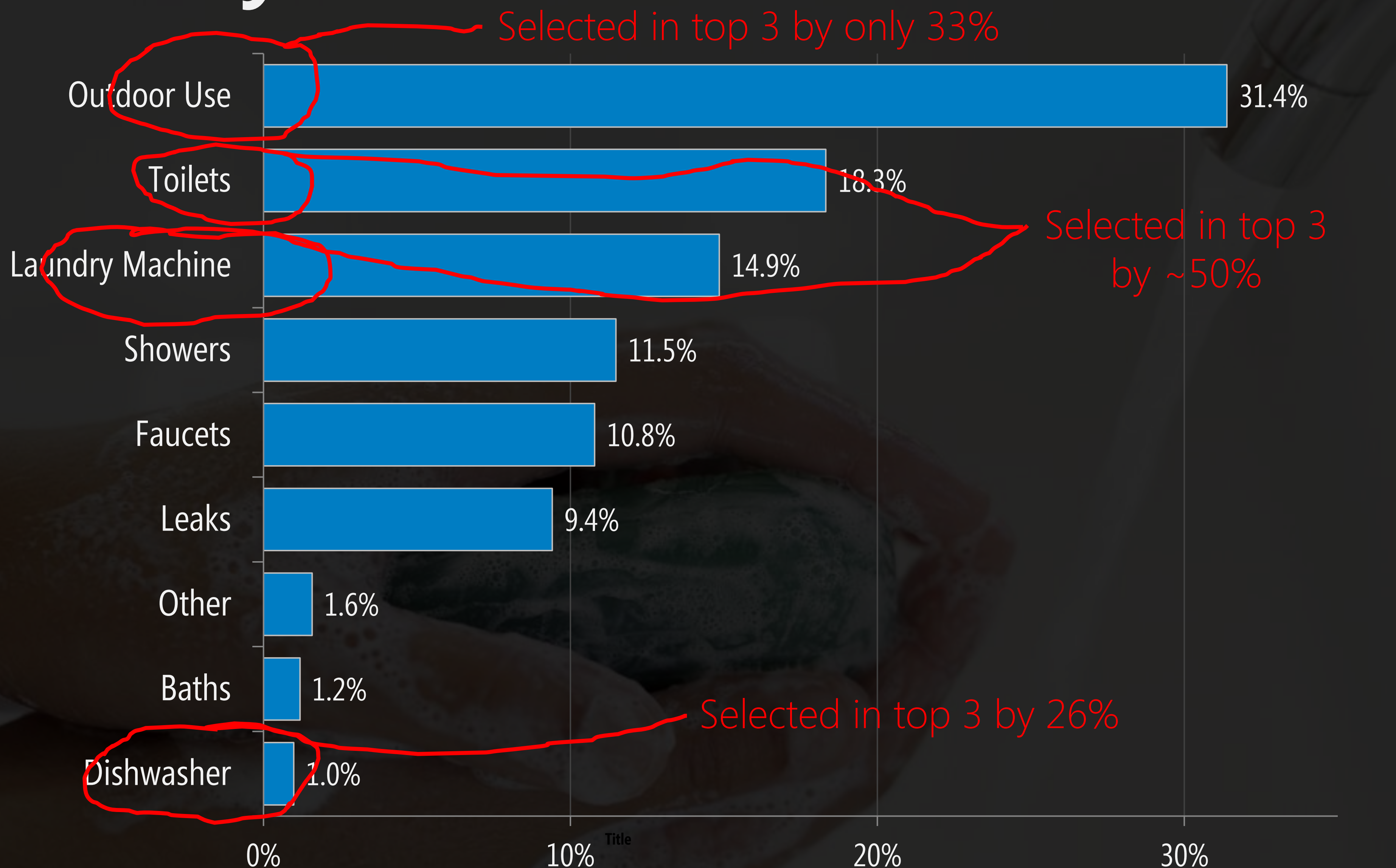
top water usage activities



[Vickers, Handbook of Water Use and Conservation, 2001]

We asked **656 people** the same thing

survey results



[Vickers, Handbook of Water Use and Conservation, 2001]

Why **don't** we know this?

water feedback

Municipal Services Statement

City of Tempe
P.O. Box 29617
Phoenix, AZ 85038-9617
480-350-8361
480-350-8400 (TDD)

0000127520000000010068700154711 8

Account Number:	100687-00154711
Utility Amount Due:	127.52
Voluntary Donation:	1.00
Total + Voluntary Donation:	128.52
Date Due:	1/8/2007

Enter Amount Paid:

Make checks payable to the City of Tempe.

LINDER HOLLINQUEST
7450 S KENWOOD DR
TEMPE AZ 85283-4921

Mark if address change requested on reverse side

PLEASE FOLD BEFORE TEARING

Return the top portion of this statement with your payment.

Keep the bottom portion of this statement for your records.

See reverse side for important information.

Account Number: 100687-00154711
Current meter reading: 16507
Billing period: 12/2006
Previous meter reading: 16305
Service Address: 7450 S KENWOOD LN
Meter read date: 11/20/2006
Gallons delivered: 20,200
Days of service: 27

Account Activity

Date	Description	Amount
	Payments Received Thank You	100.00
12/12	Water Quality Fee	0.13
12/12	Tempe City Tax	0.61
12/12	State Tax	2.15
12/12	Sewer Service Charge	7.28
12/12	Water Consumption	20.11
12/12	Water Service Charge	13.99
12/12	1% Delinquent Fee	0.40
12/12	Sewer Charge	11.48
12/12	Residential Refuse	17.41

Date Due: 1/8/2007
The due date on this bill applies ONLY to current charges.
VISA Mastercard, Amex & Discover payments accepted, call 480-350-8361

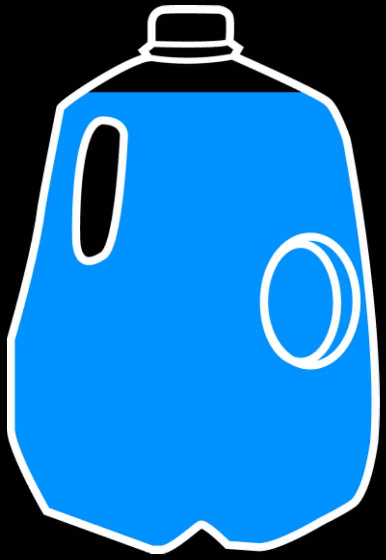
Previous Balance	- Payments	- Credits	= Past Due Balance	+ Delinquency Fees	+ New Charges	+ Other Debits	= Utility Amount Due	+ Voluntary Donation	= Total Including Voluntary Donation
153.96	100.00	0.00	53.96	0.40	73.56	0.00	127.52	1.00	128.52

Year to Date Voluntary Donation Thank You: 0.00

Help to Others voluntary donation program makes it easier to help neighbors in need. Help to Others supports essential human service programs for children, families and seniors. If you do not wish to contribute to this program, simply pay only the "Utility Amount Due."

water feedback

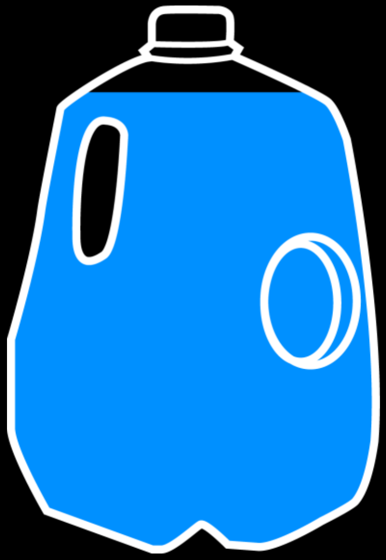
10,230
gallons



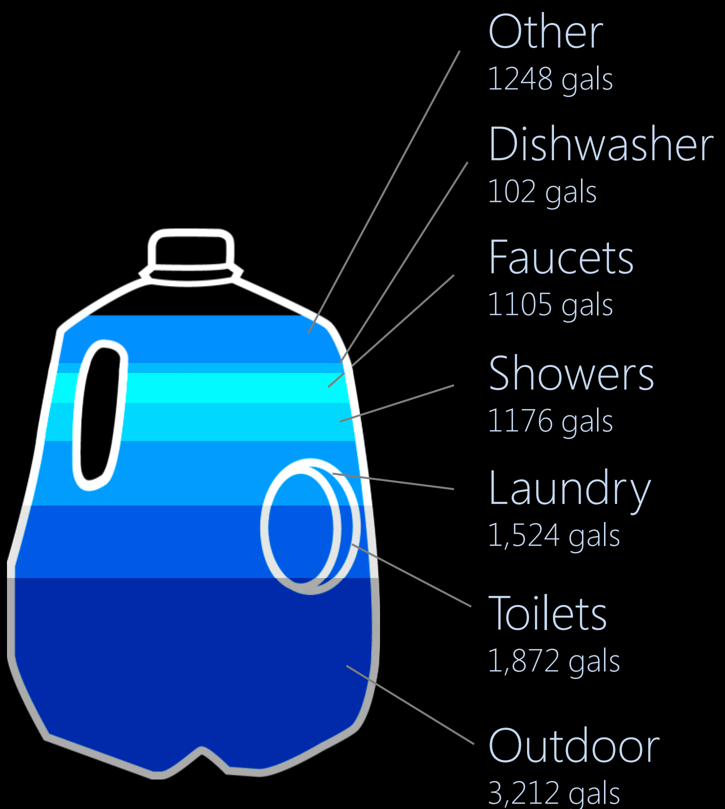
SAFEWAY
SAVE MORE AT SAFEWAY
GROCERY
SFWY PRTZLE STICK 1.50 B
RegPrice 1.79 CardSav .29
BLKBERY PRES
SFY CANOLA OIL
CEREAL PNT BUTTER
CHILI SAUCE SWT
CHF-B PIZZA
LK GRLC SCE
REFRIG/FROZEN
LUC CHEESE
RegPrice 6.79 CardSav
SPINACH ARTICHOKE
RegPrice 3.79 CardSav
3S CRWN VEG RSTD
RegPrice 3.79 CardSav
2@2.50 SFWY SEL MEDALL FC
RegPrice 7.58 CardSav
MARGARINE
#SFY BENEHIST TAB
BAKED GOODS
LD COSMIC BROWNIES 1.29 B
OROWEAT RYE 3.14 B
CUSTARD PIE 9IN 4.99 B
RegPrice 5.99 CardSav 1.00
CHOC CREAM PIE 4.99 B
RegPrice 5.99 CardSav 1.00
**** TAX 6.76 BAL 144.25
VF MC XXXXXXXXX 144.25
CHANGE .00
TOTAL SAVINGS 16.97
NUMBER OF ITEMS = 35
SAFEWAY
SAVE MORE AT SAFEWAY
Month: April 2006
Total Food Units: 1527
Total Price: $642
[Kempton & Layne, Energy Policy, 1994]

10,230

gallons

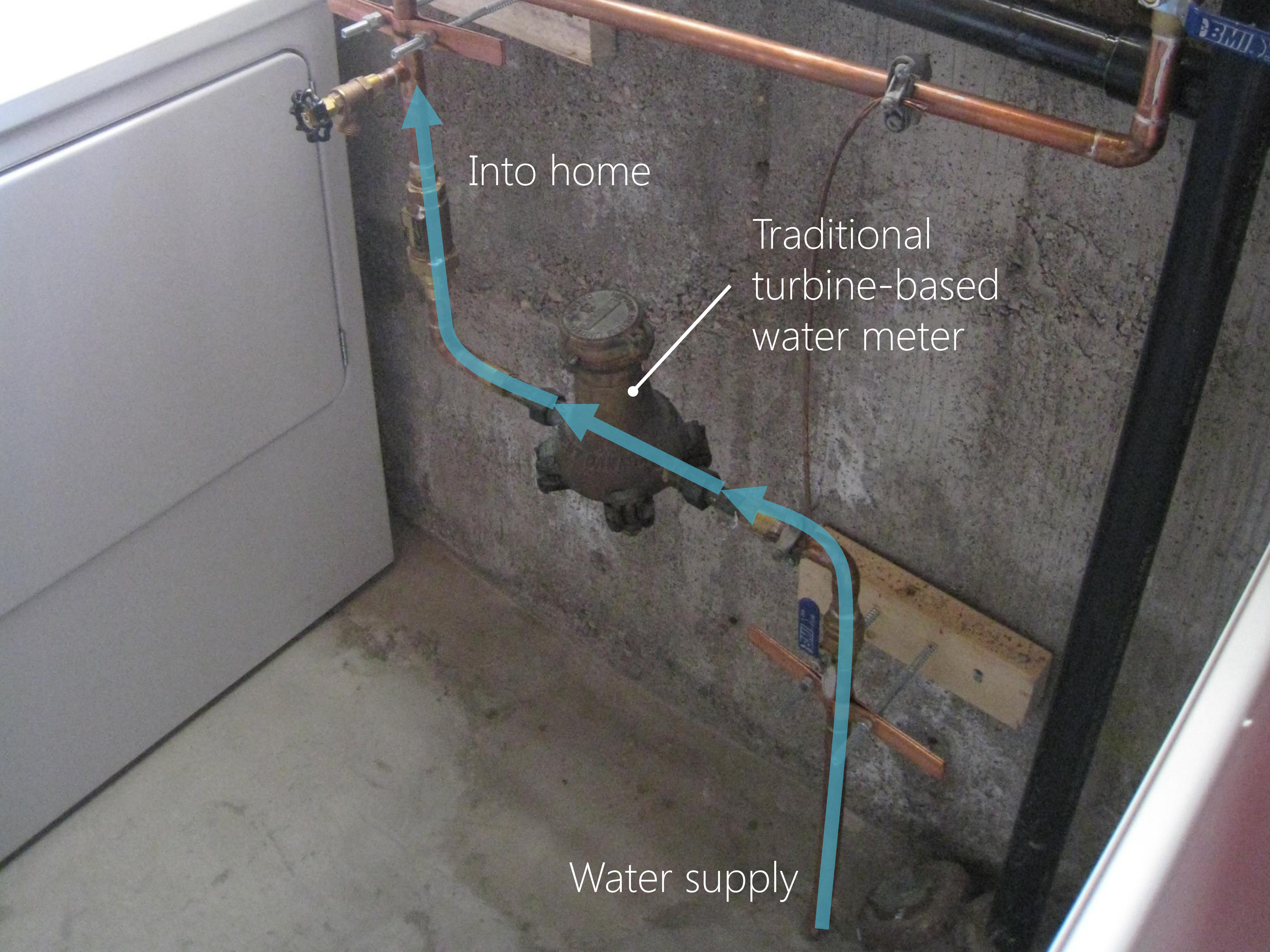


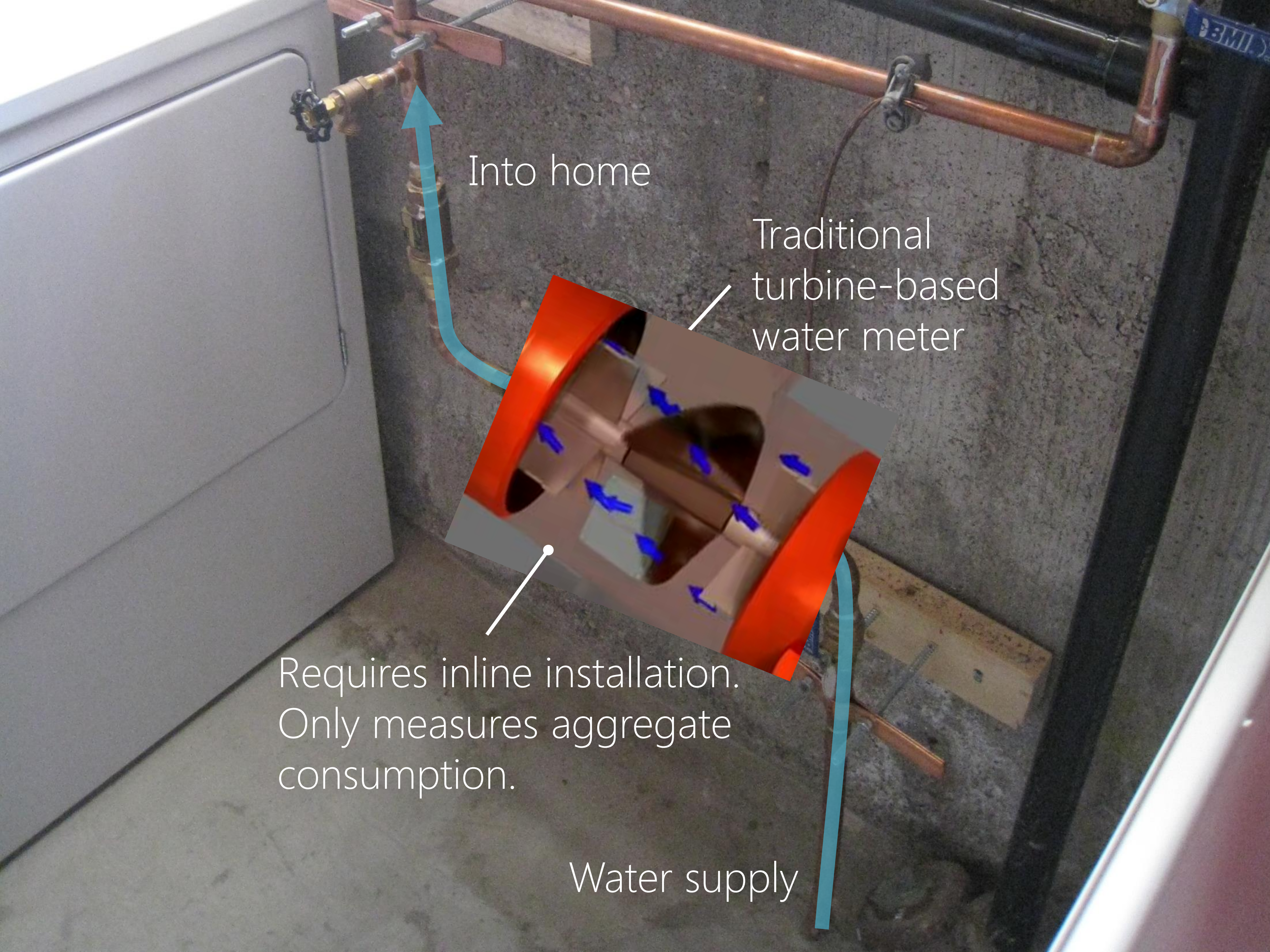
10,230 gallons



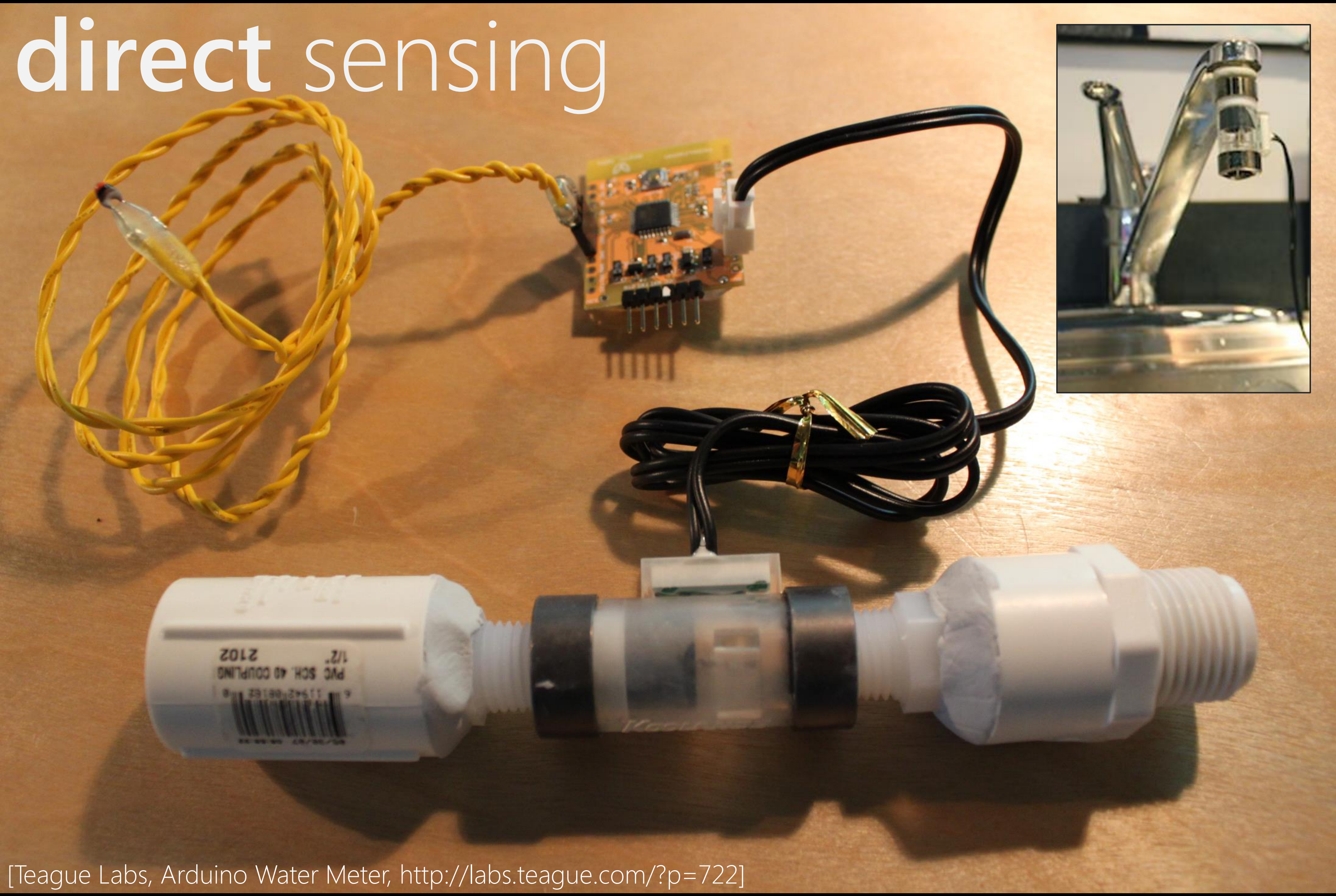
10,230 gallons

How could we measure this "disaggregated" level of consumption?


Into home
Traditional turbine-based water meter
Water supply


Into home
Traditional turbine-based water meter
Requires inline installation. Only measures aggregate consumption.
Water supply

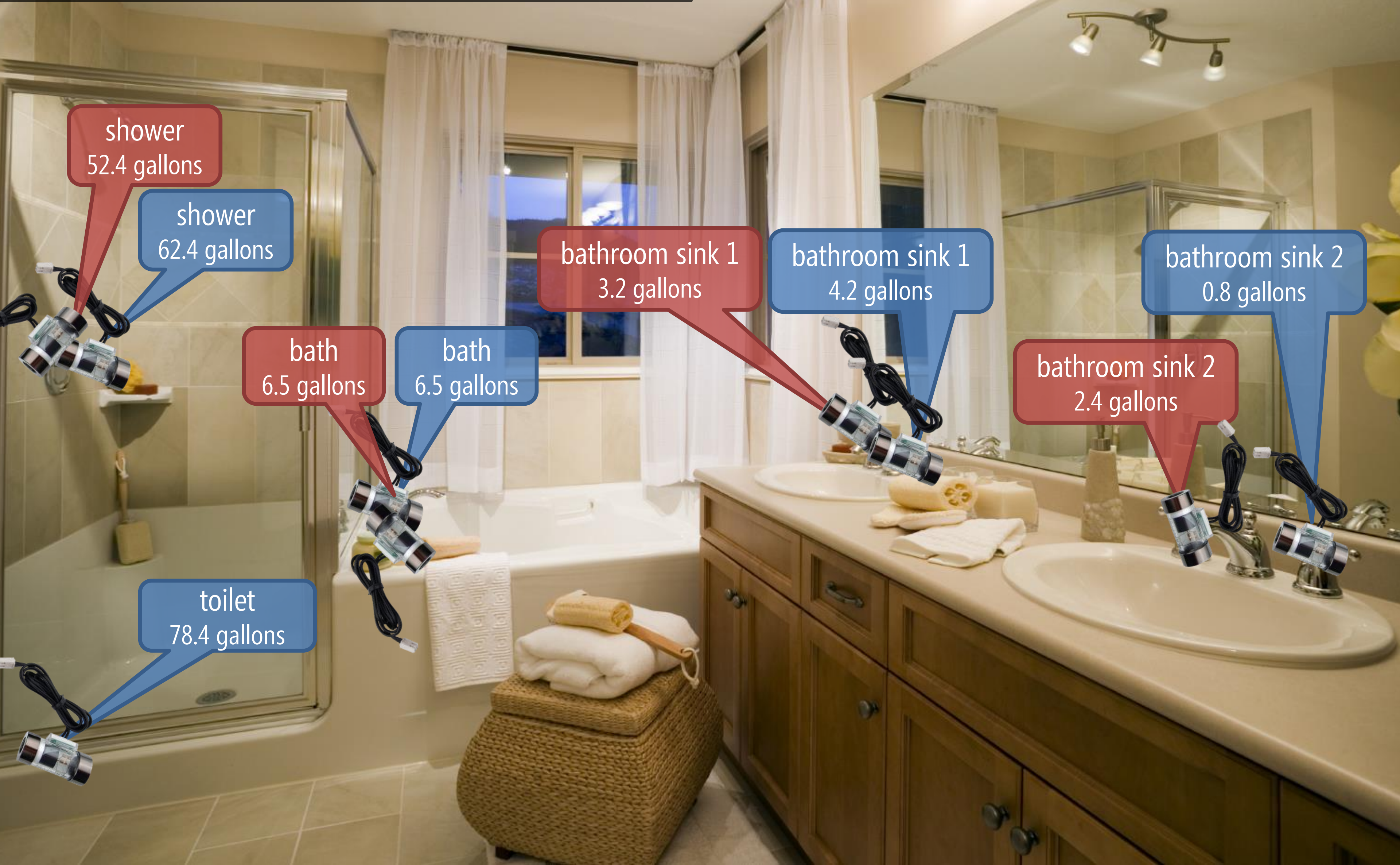
direct sensing

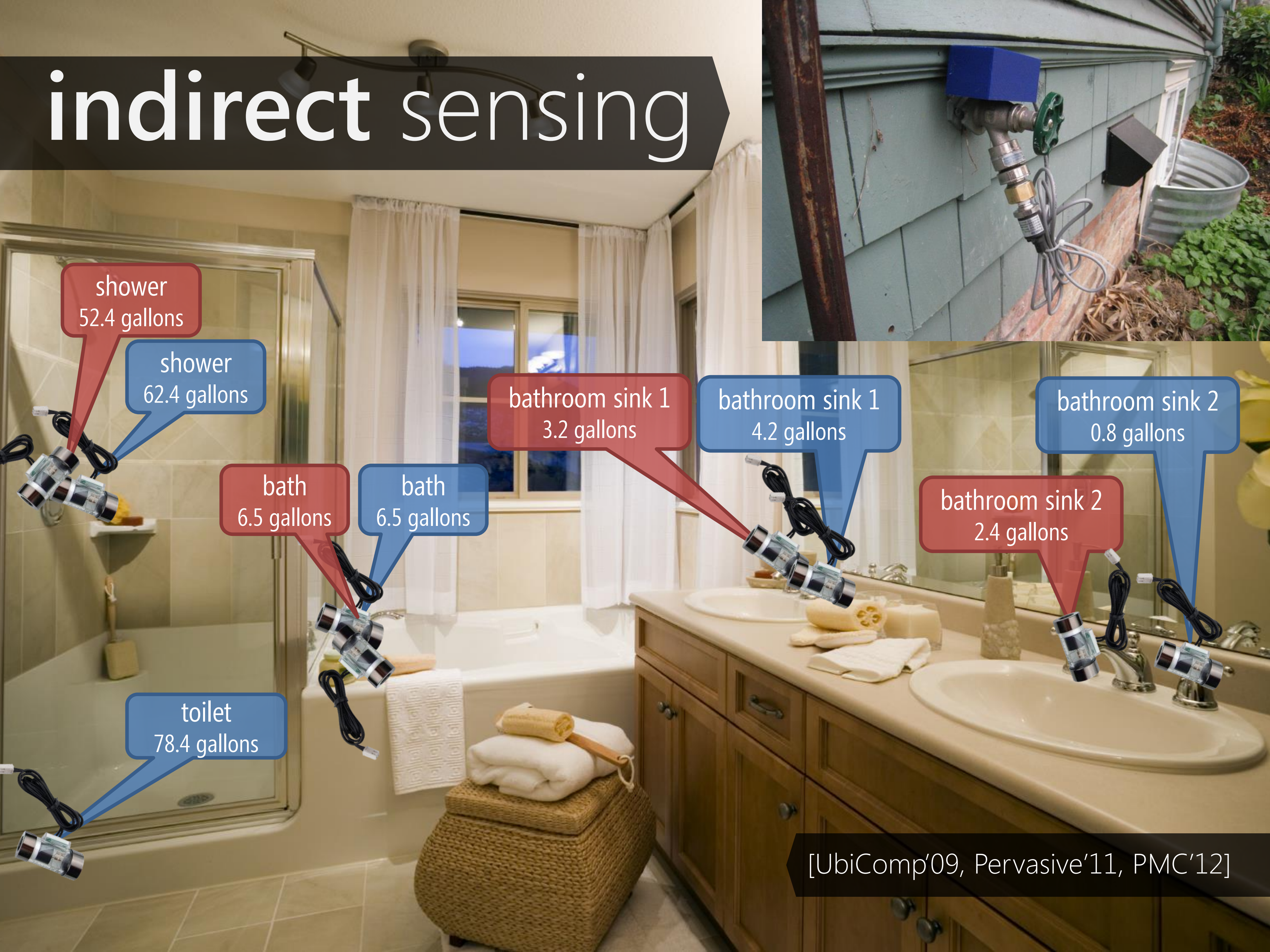


[Teague Labs, Arduino Water Meter, http://labs.teague.com/?p=722]

direct sensing

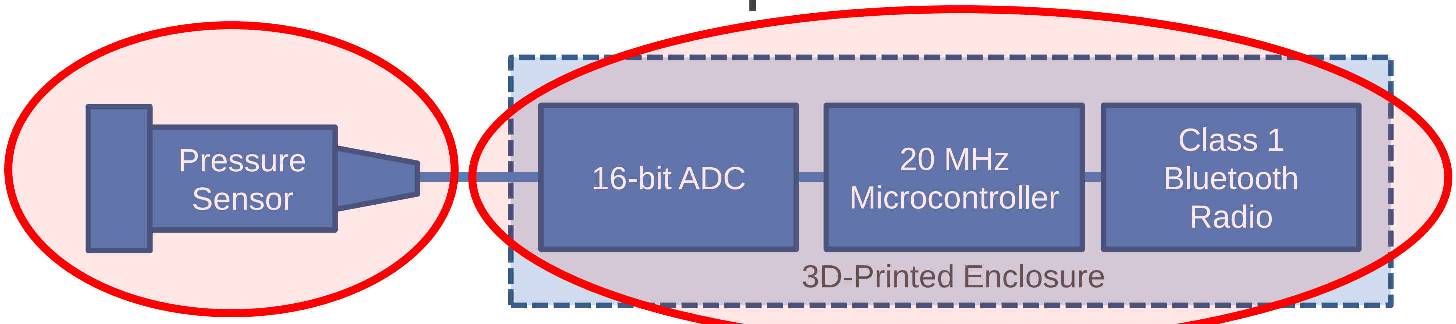
direct sensing

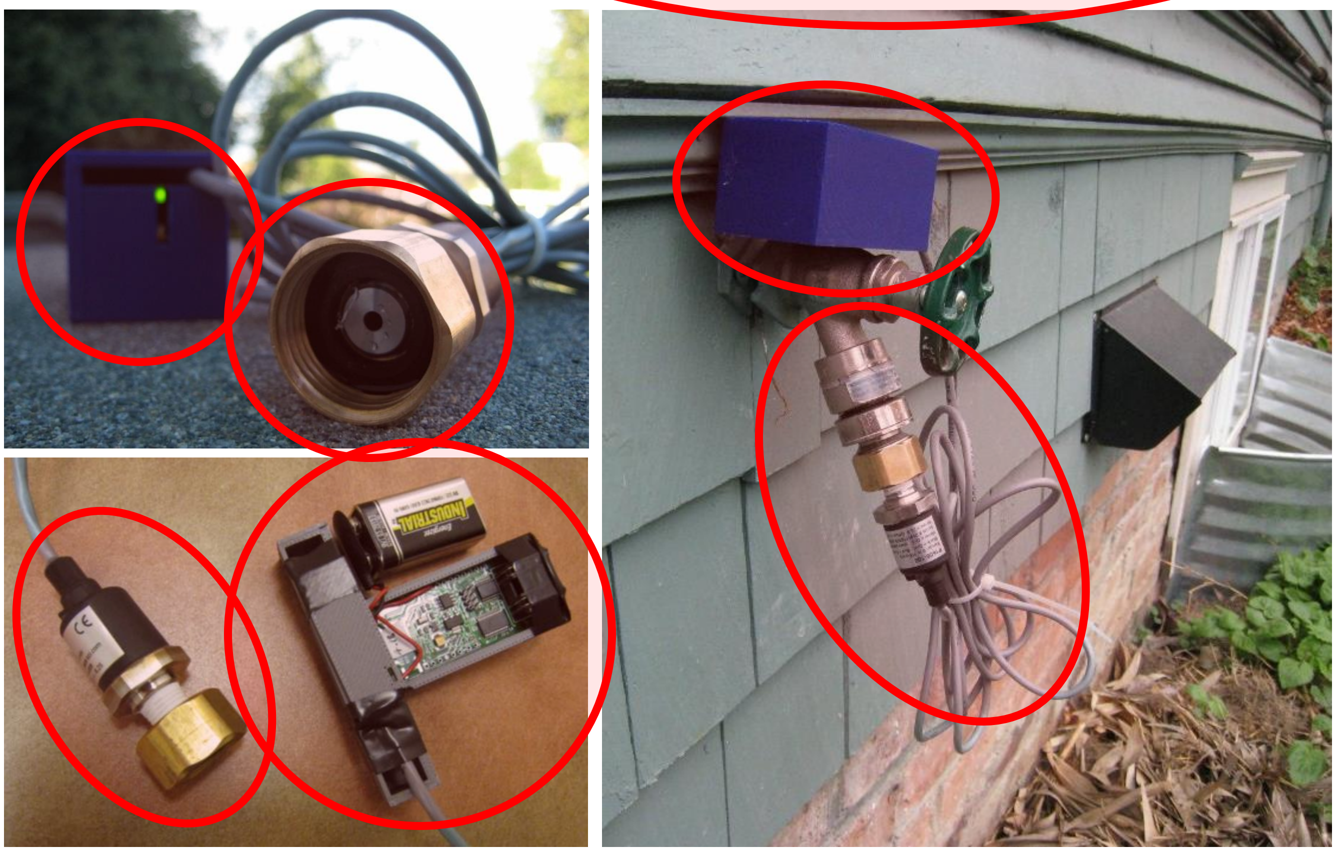



indirect sensing
shower
52.4 gallons
shower
62.4 gallons
bath
6.5 gallons
bath
6.5 gallons
bathroom sink 1
3.2 gallons
bathroom sink 1
4.2 gallons
bathroom sink 2
0.8 gallons
bathroom sink 2
2.4 gallons
toilet
78.4 gallons
[UbiComp'09, Pervasive'11, PMC'12]


indirect sensing
shower
bathroom sink 1
bathroom sink 2
2.4 gallons
HydroSense attempts to infer fixture-level usage for the entire home from a **single** point.
[UbiComp'09, Pervasive'11, PMC'12]

hydrosense implementation

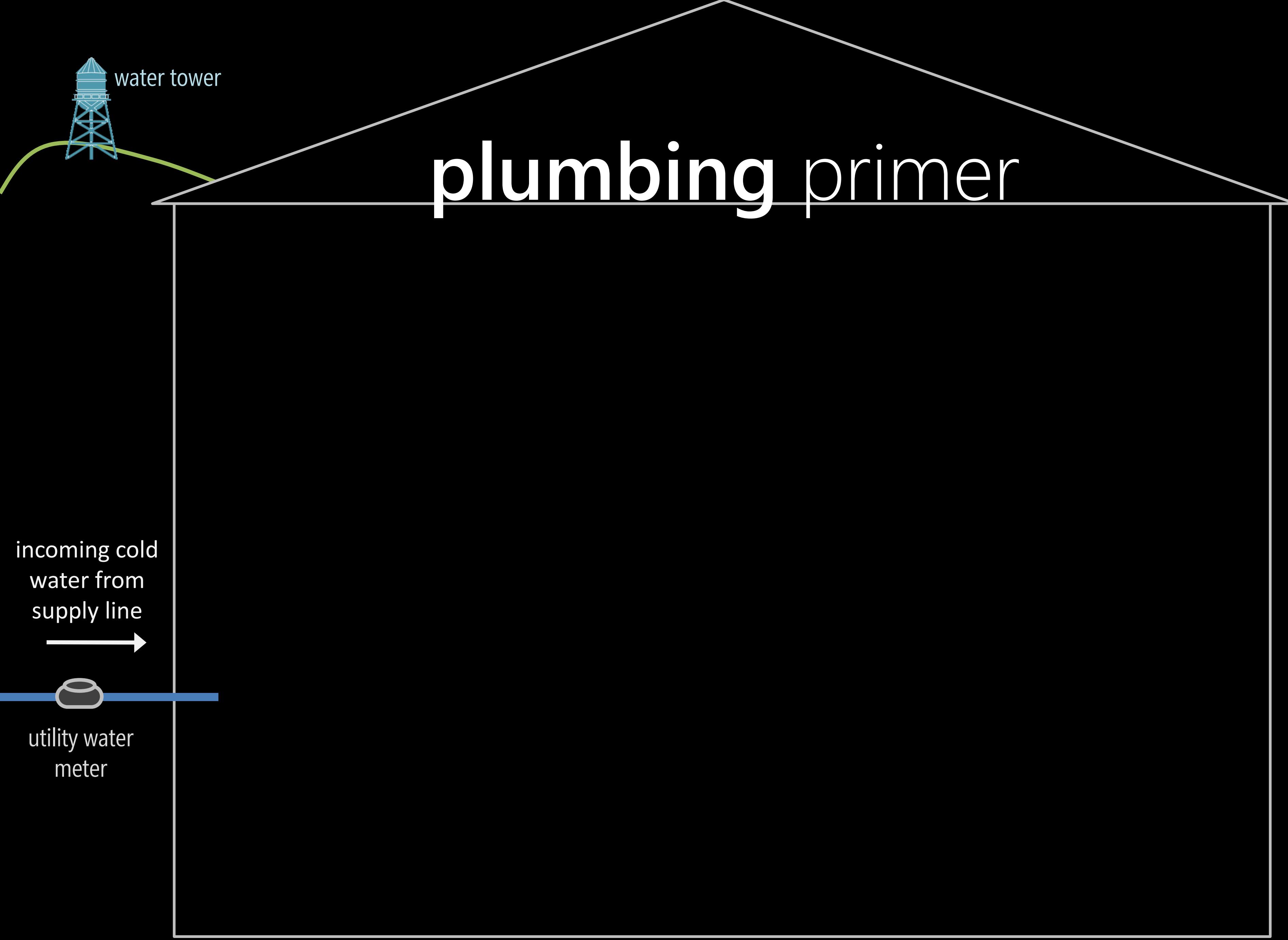




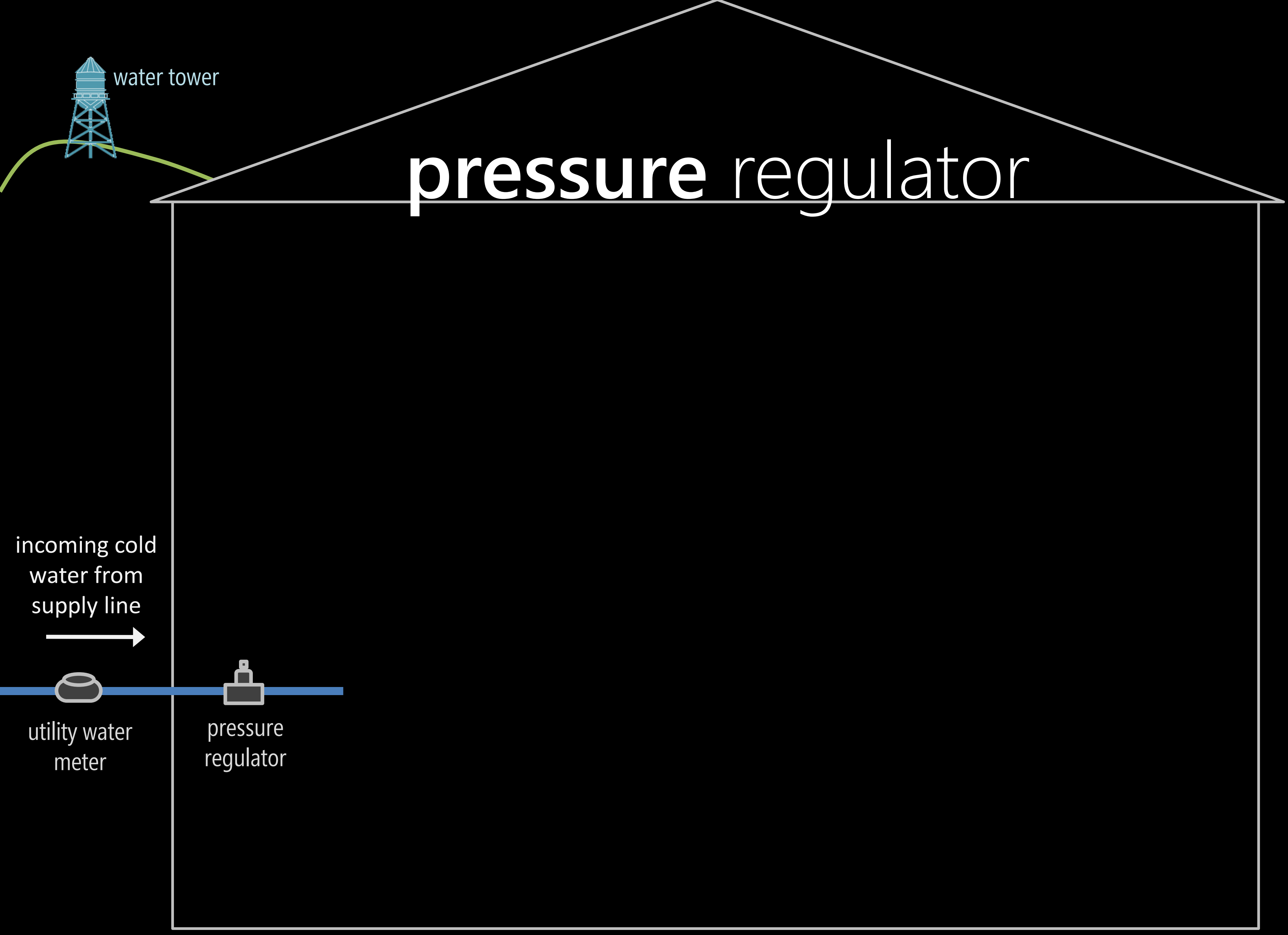
brief plumbing primer

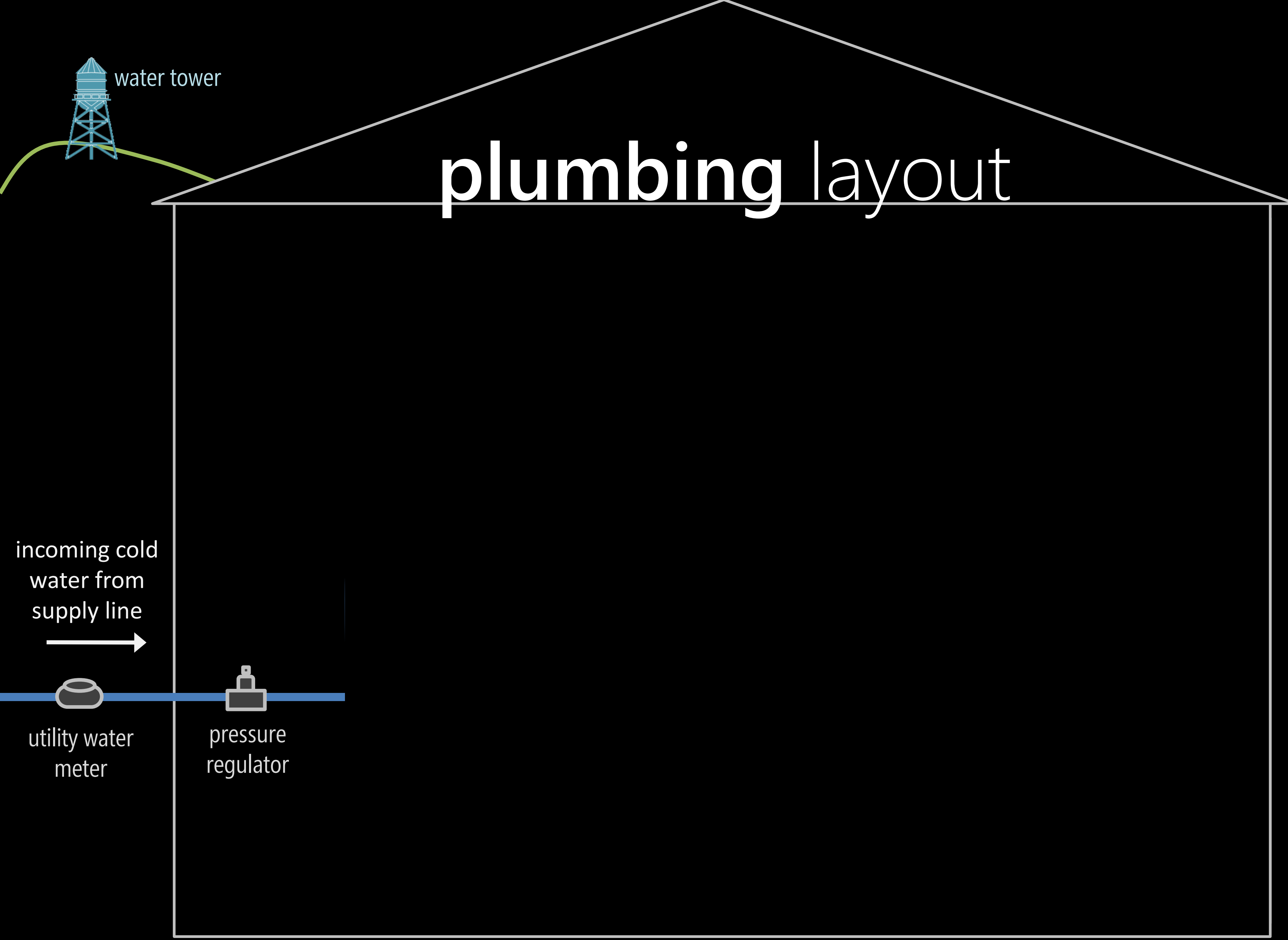
plumbing primer

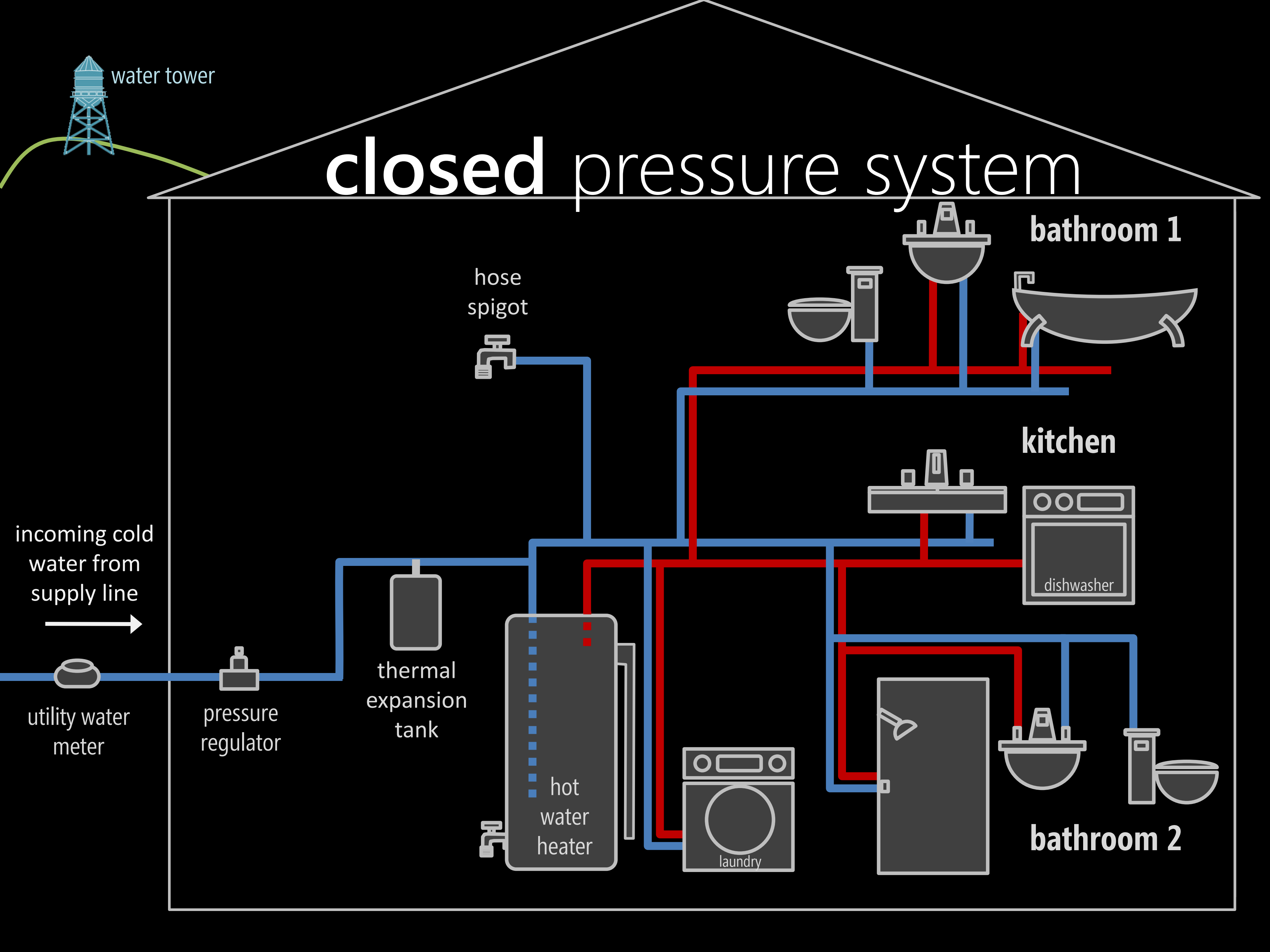
plumbing primer

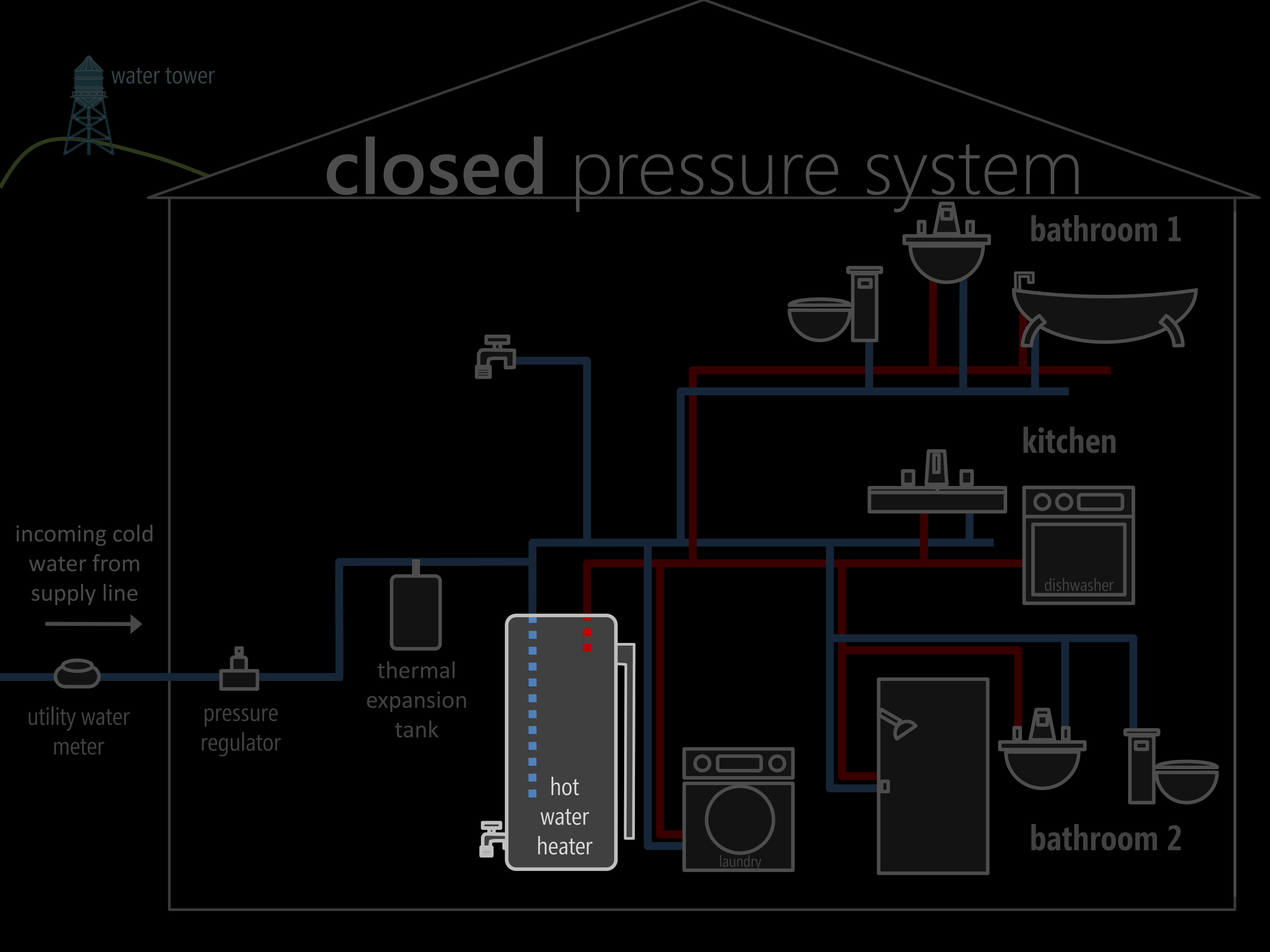


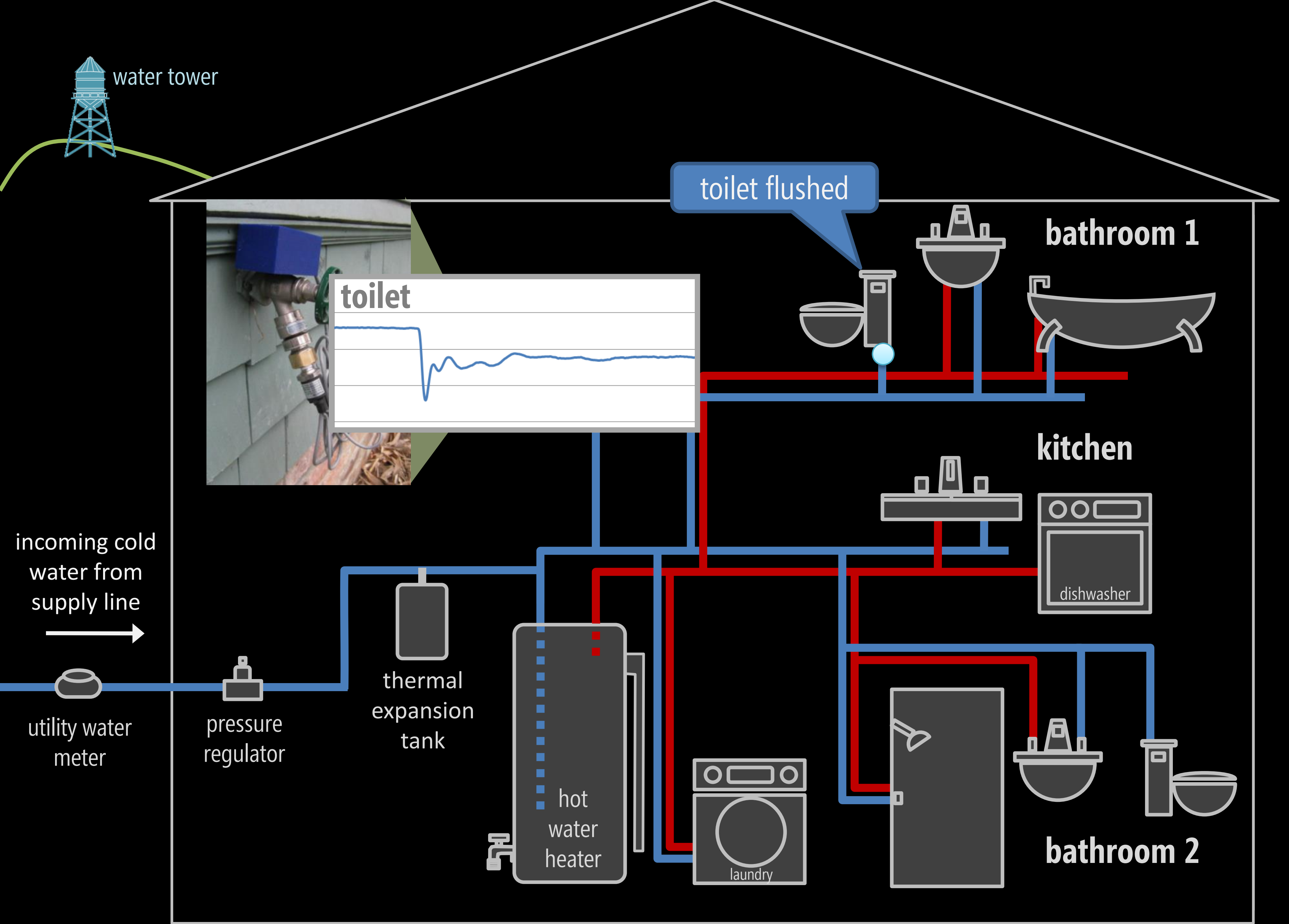
pressure regulator

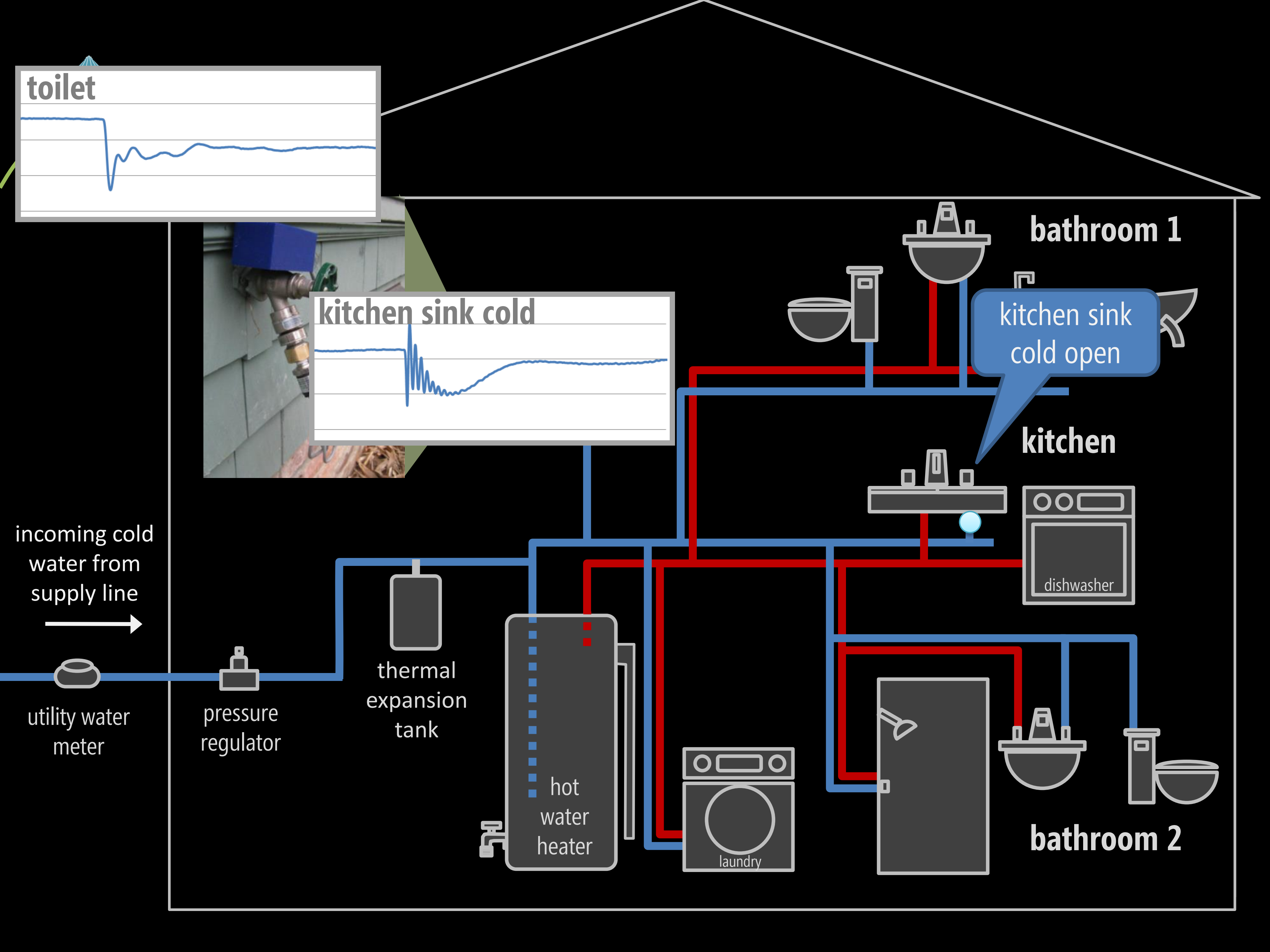



plumbing layout
water tower
incoming cold water from supply line
utility water meter
pressure regulator

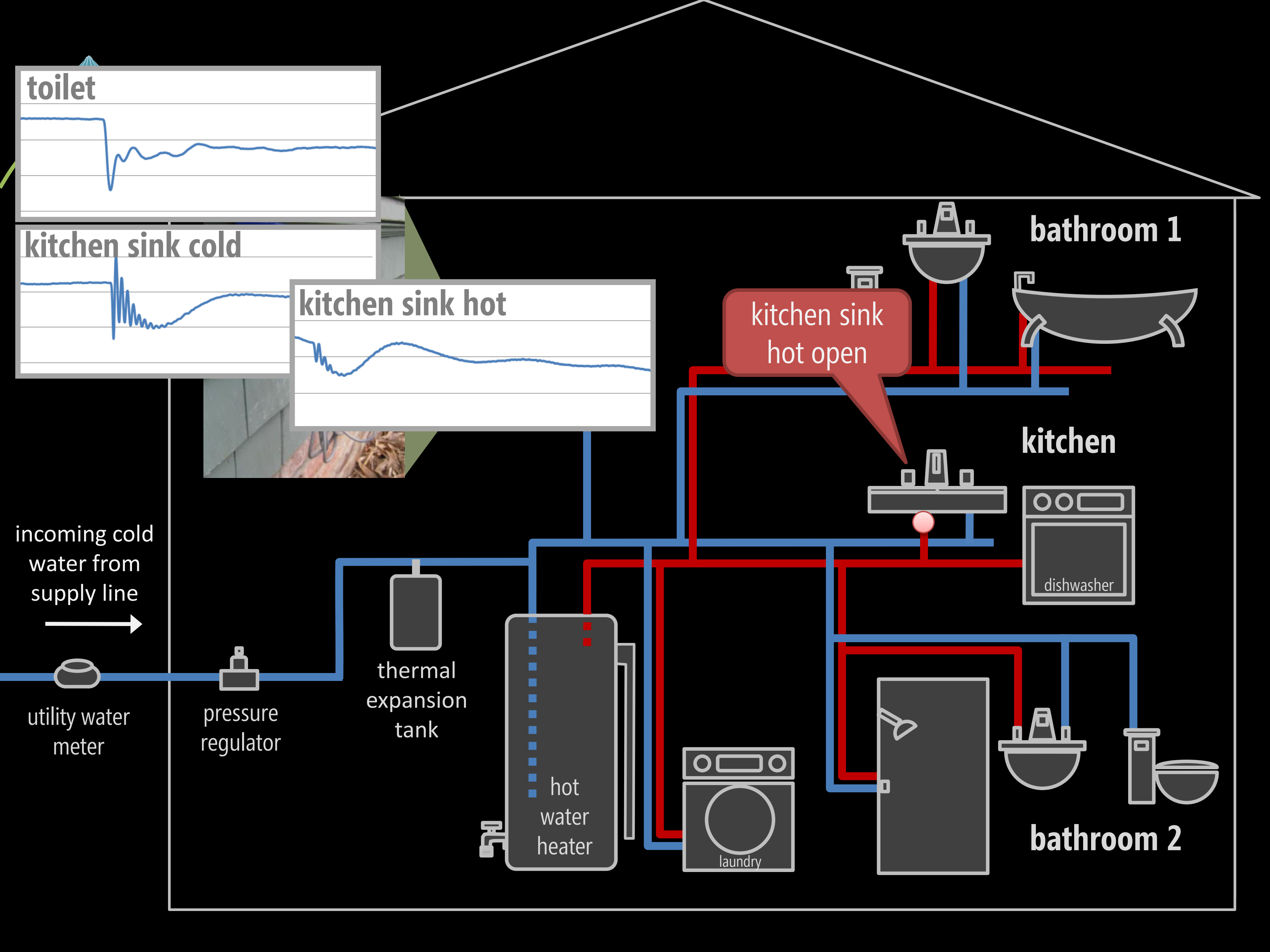

closed pressure system
water tower
bathroom 1
hose
spigot
kitchen
incoming cold
water from
supply line
dishwasher
thermal
expansion
tank
utility water
meter
pressure
regulator
hot
water
heater
laundry
bathroom 2

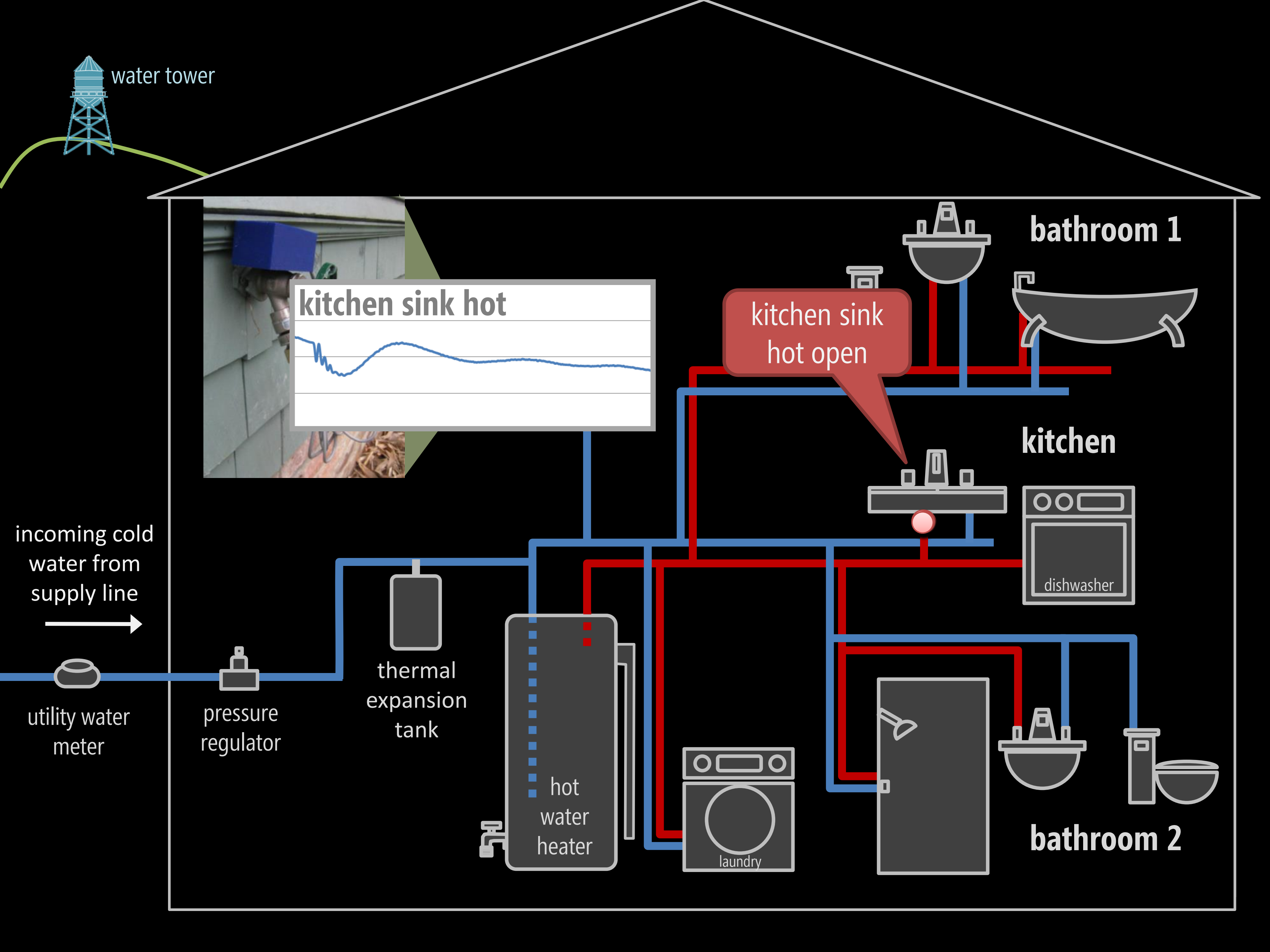

water tower
closed pressure system
bathroom 1
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2

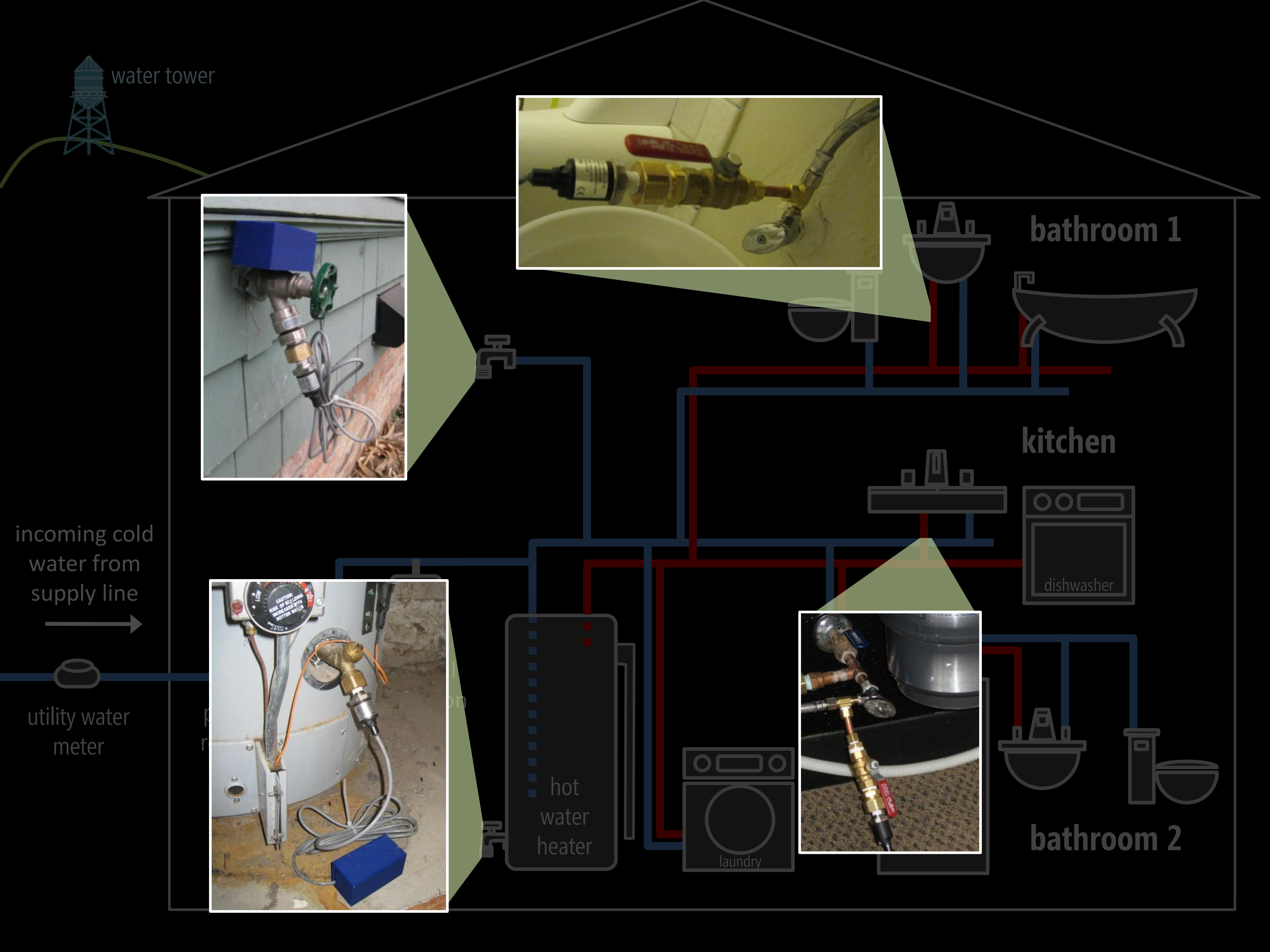

water tower
toilet flushed
bathroom 1
toilet
kitchen
incoming cold water from supply line
dishwasher
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2



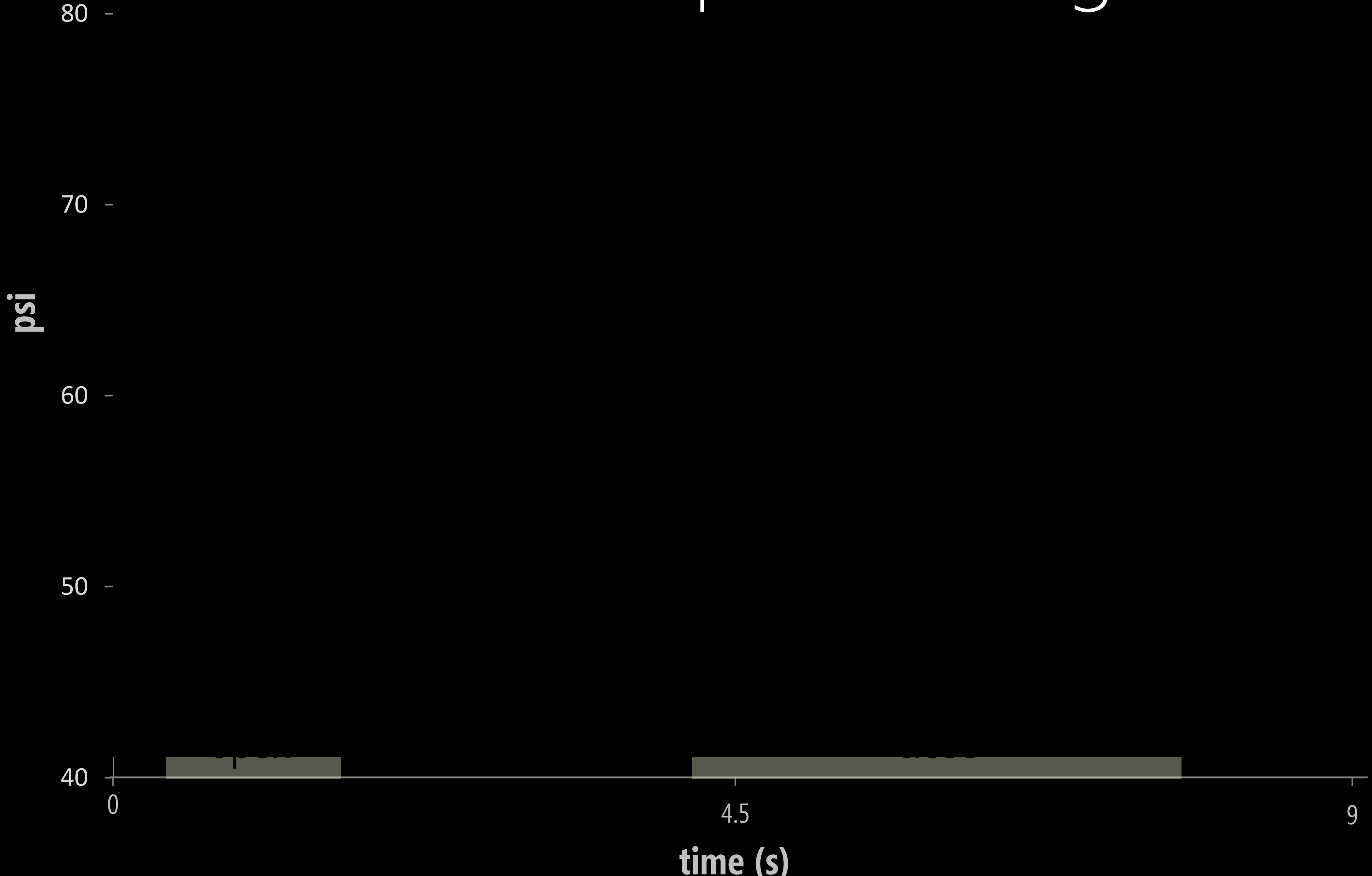
toilet
kitchen sink cold
bathroom 1
kitchen sink cold open
kitchen
dishwasher
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2


toilet
kitchen sink cold
kitchen sink hot
kitchen sink
hot open
bathroom 1
kitchen
dishwasher
incoming cold
water from
supply line
utility water
meter
pressure
regulator
thermal
expansion
tank
hot
water
heater
laundry
bathroom 2

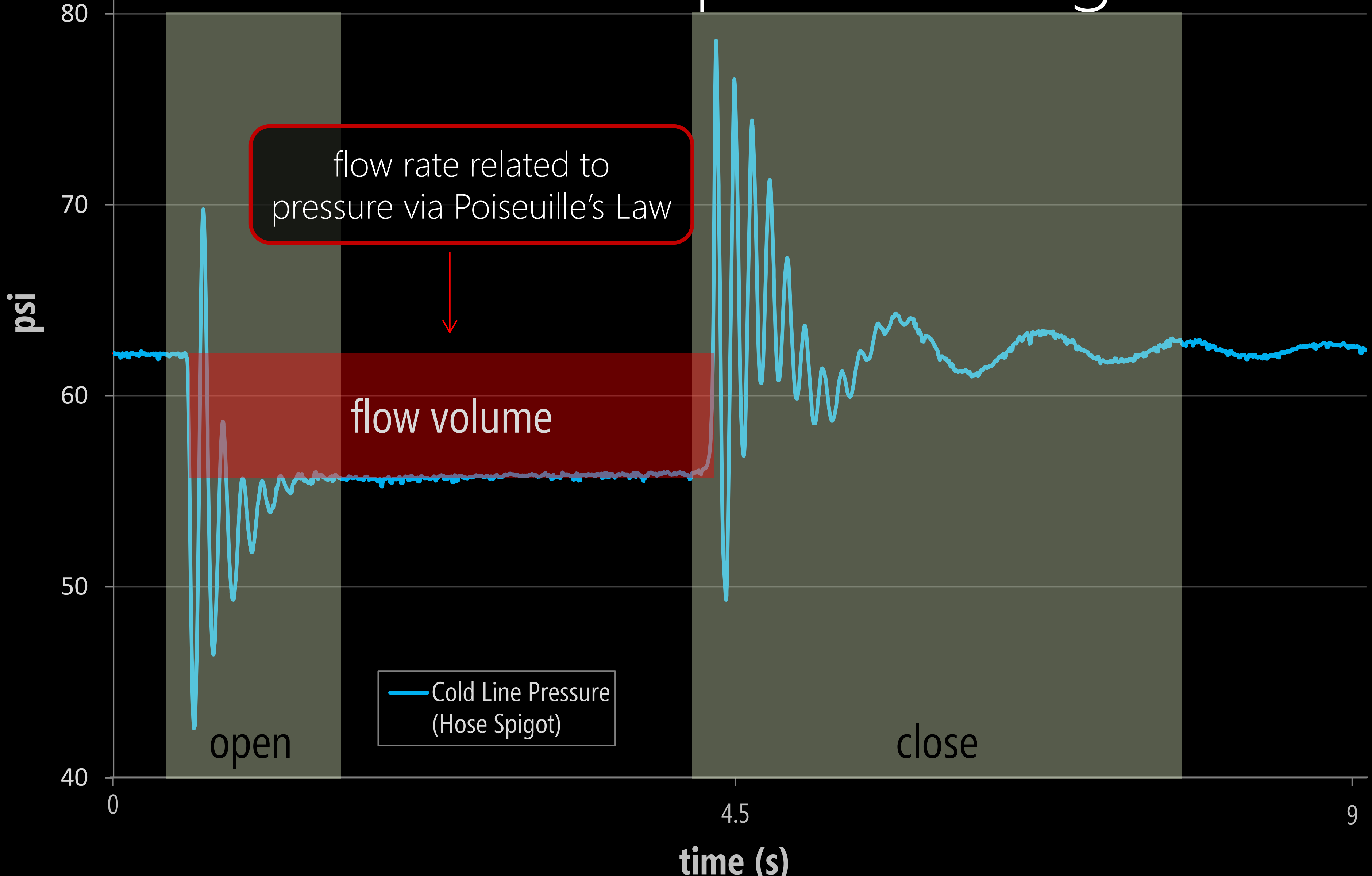

water tower
bathroom 1
kitchen sink hot
kitchen sink
hot open
kitchen
incoming cold
water from
supply line
dishwasher
thermal
expansion
tank
utility water
meter
pressure
regulator
hot
water
heater
laundry
bathroom 2

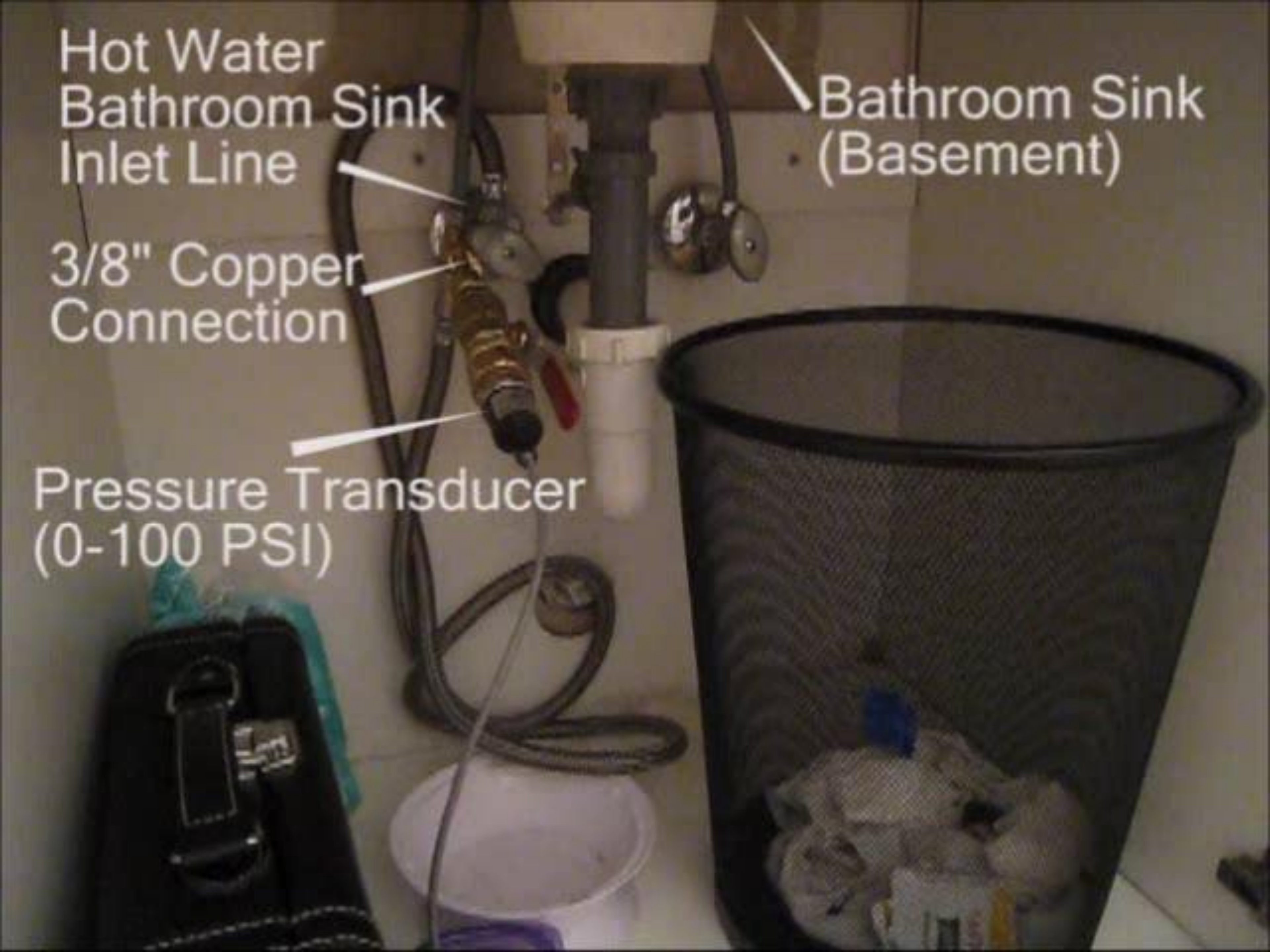

water tower
bathroom 1
kitchen
dishwasher
incoming cold water from supply line
utility water meter
hot water heater
laundry
bathroom 2

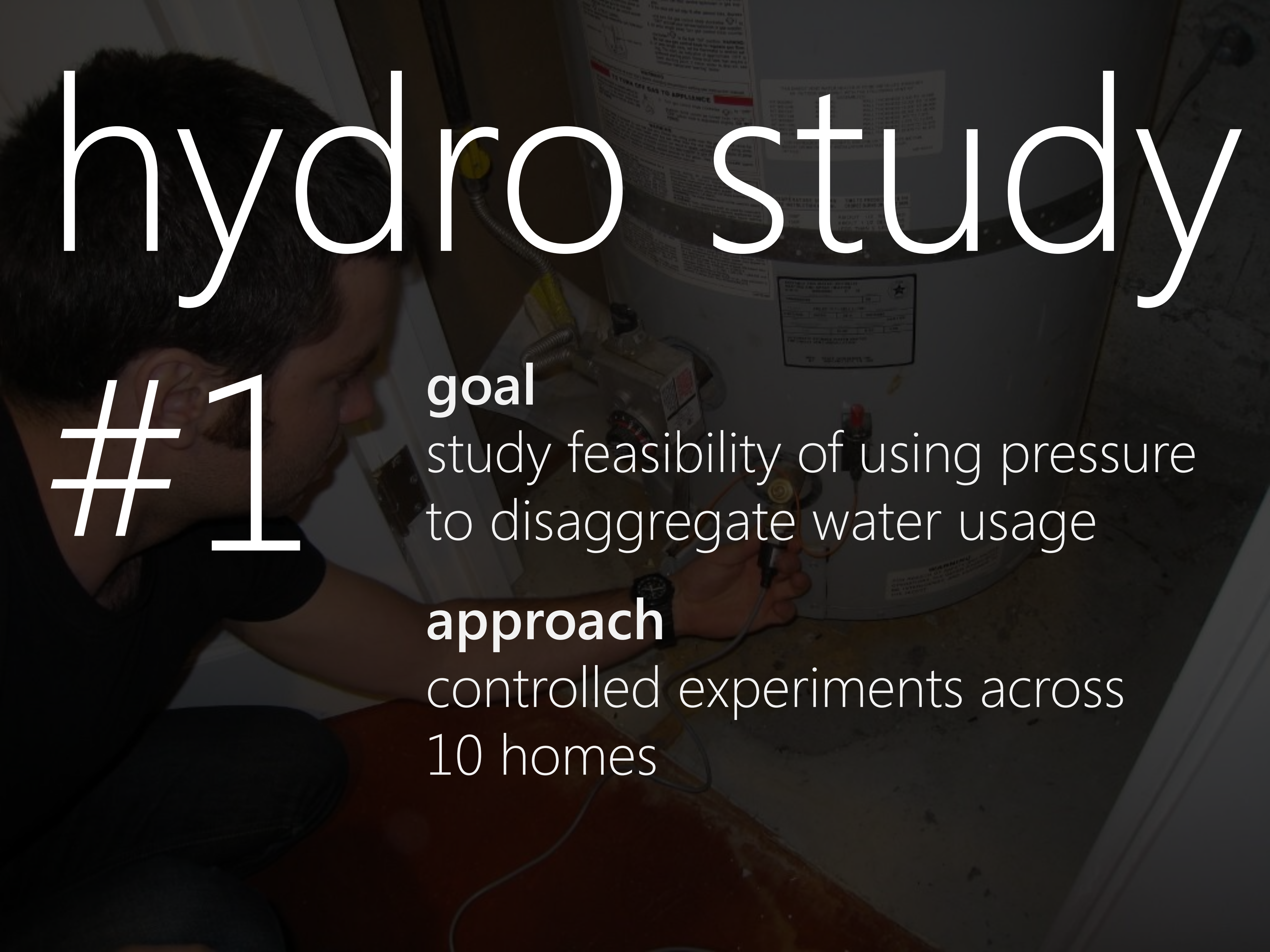
bathroom sink pressure signal



bathroom sink pressure signal




Hot Water
Bathroom Sink
Inlet Line
Bathroom Sink
(Basement)
3/8" Copper
Connection
Pressure Transducer
(0-100 PSI)



hydro study

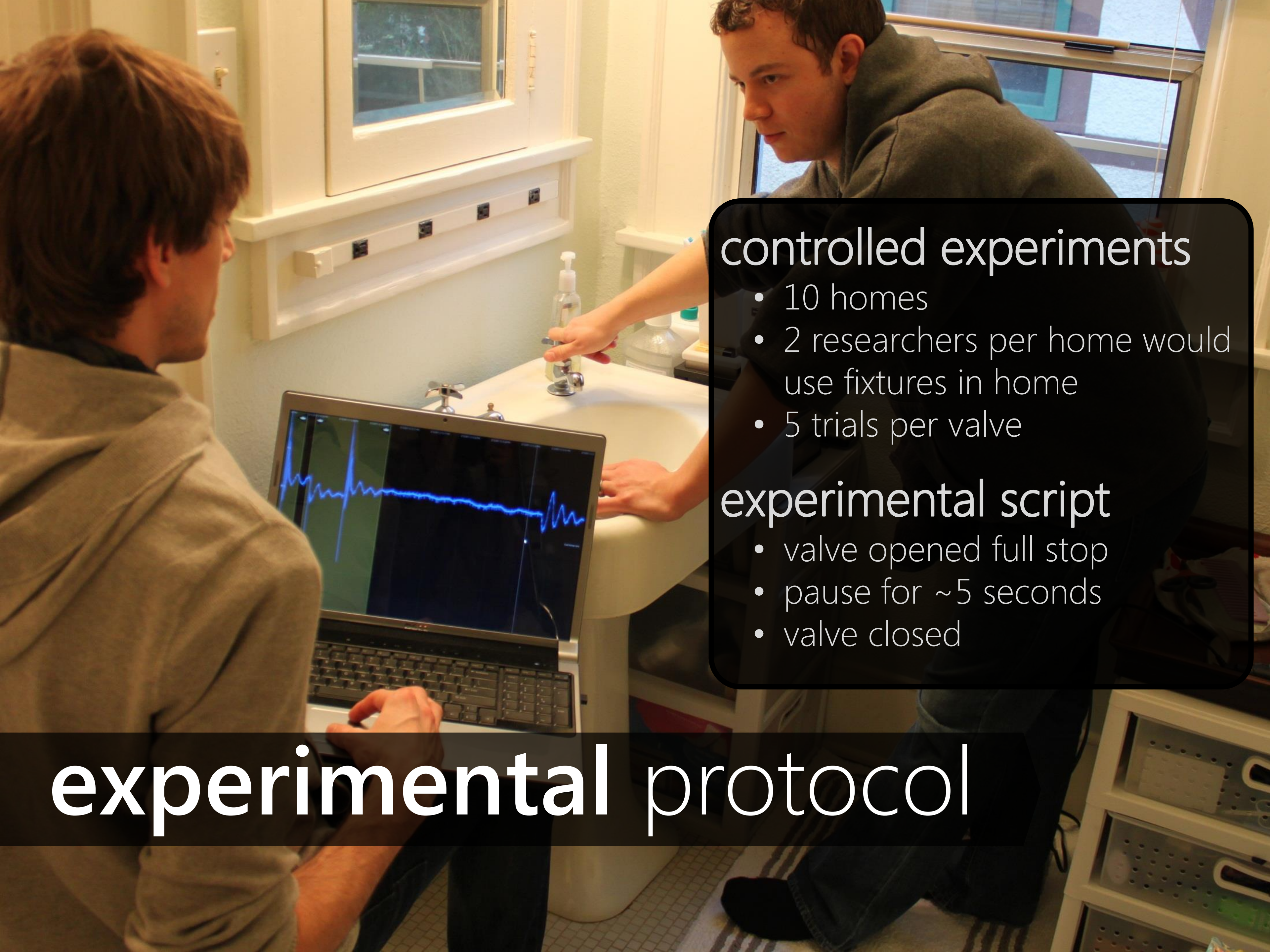
#1

goal

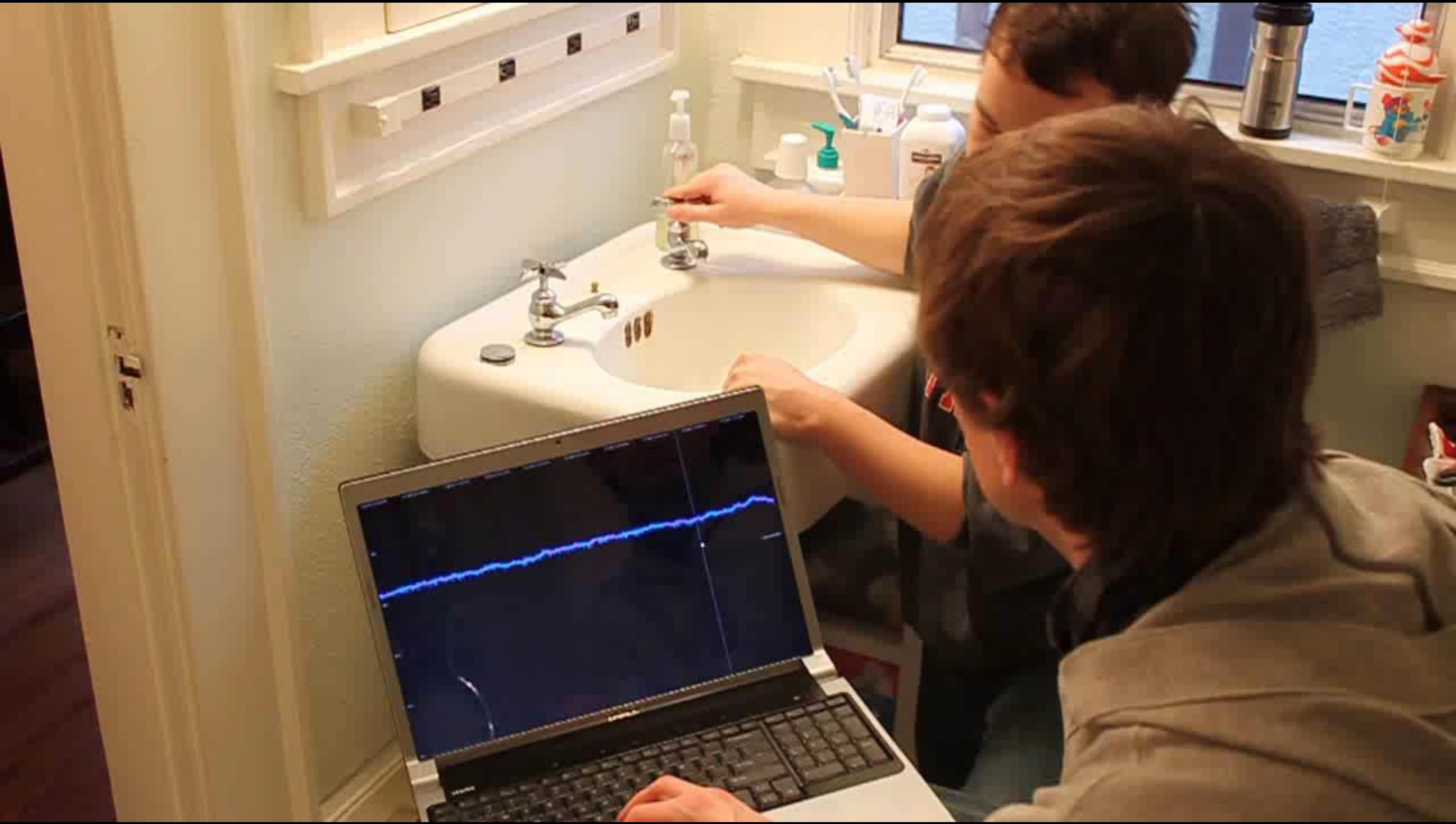
study feasibility of using pressure to disaggregate water usage

approach

controlled experiments across 10 homes

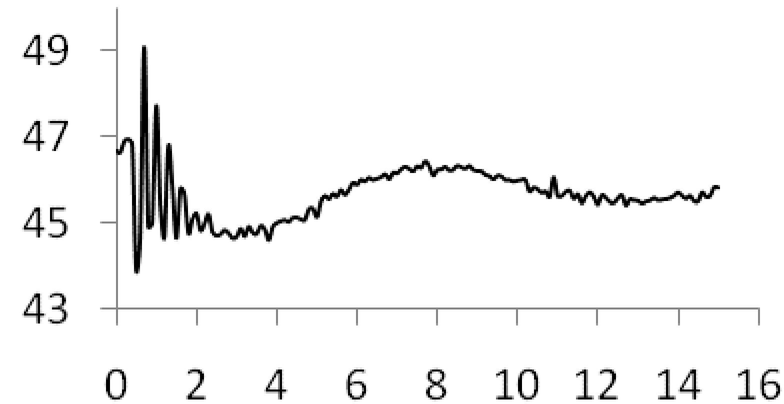

controlled experiments
10 homes
2 researchers per home would use fixtures in home
5 trials per valve
experimental script
valve opened full stop
pause for ~5 seconds
valve closed
experimental protocol

controlled data collection

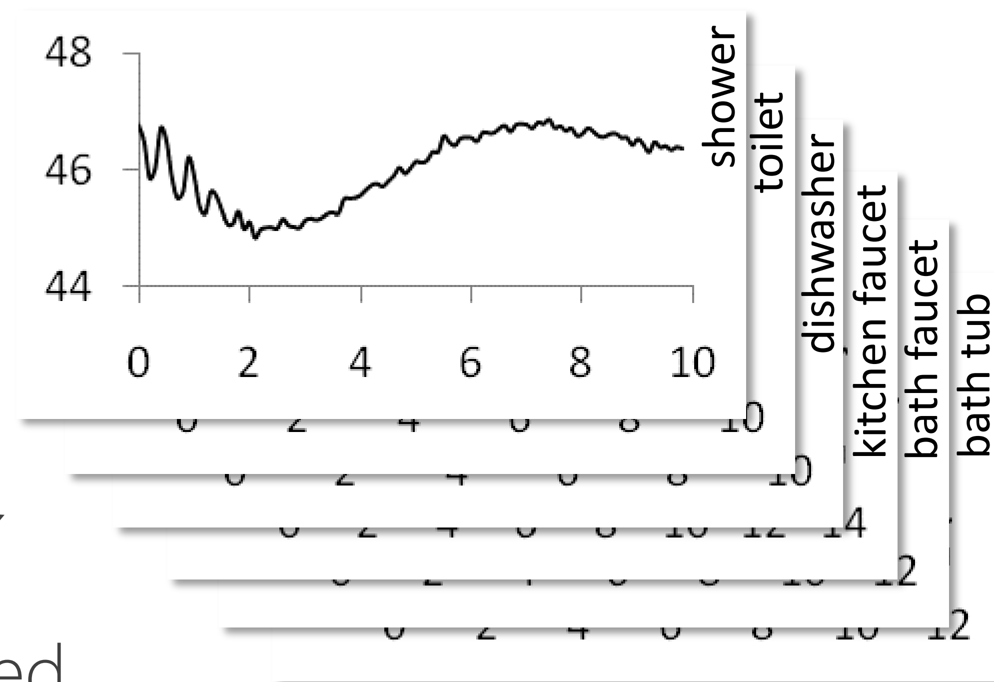


fixture classification

unclassified open event



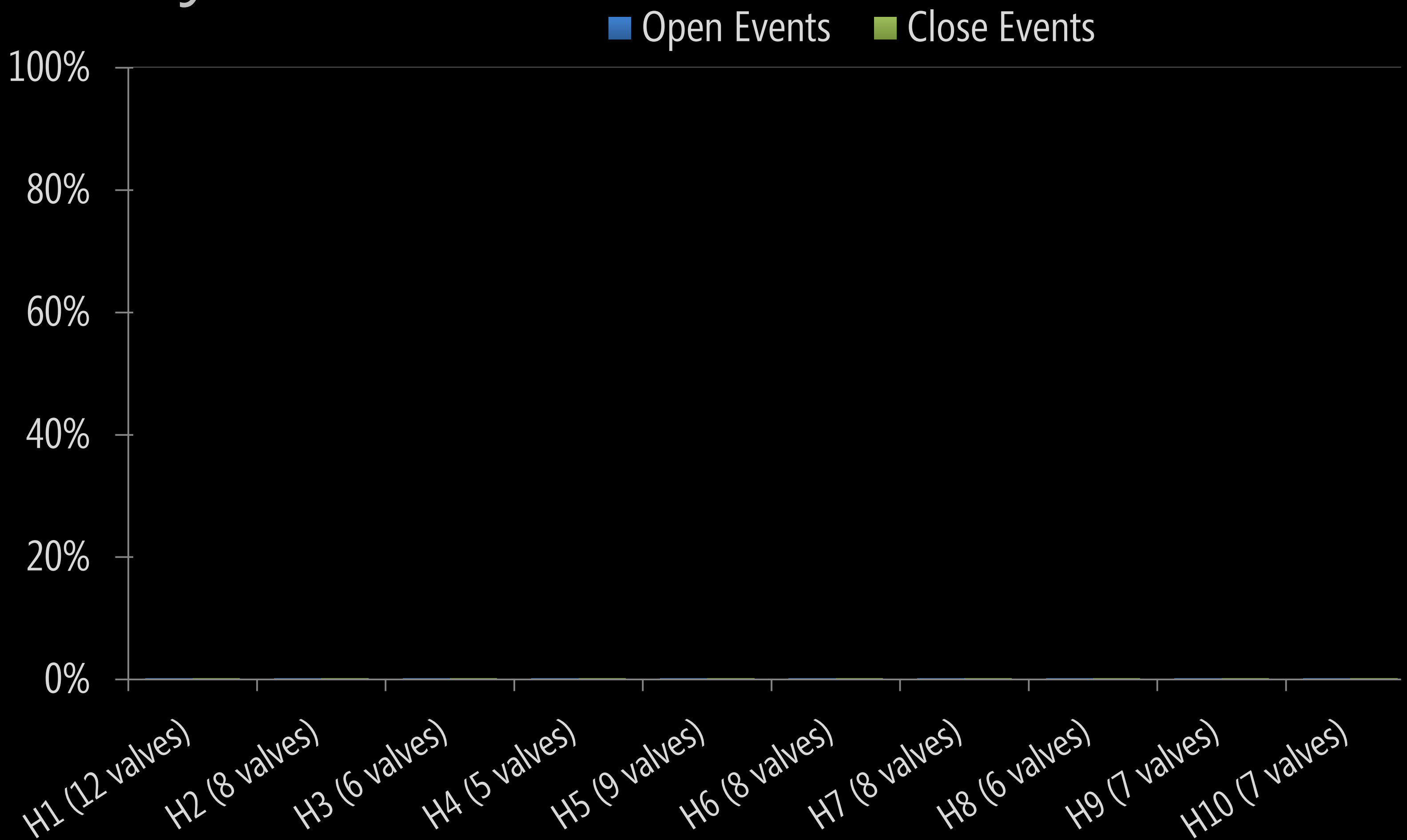
open event library



compare via matched filtering across multiple signal transformations

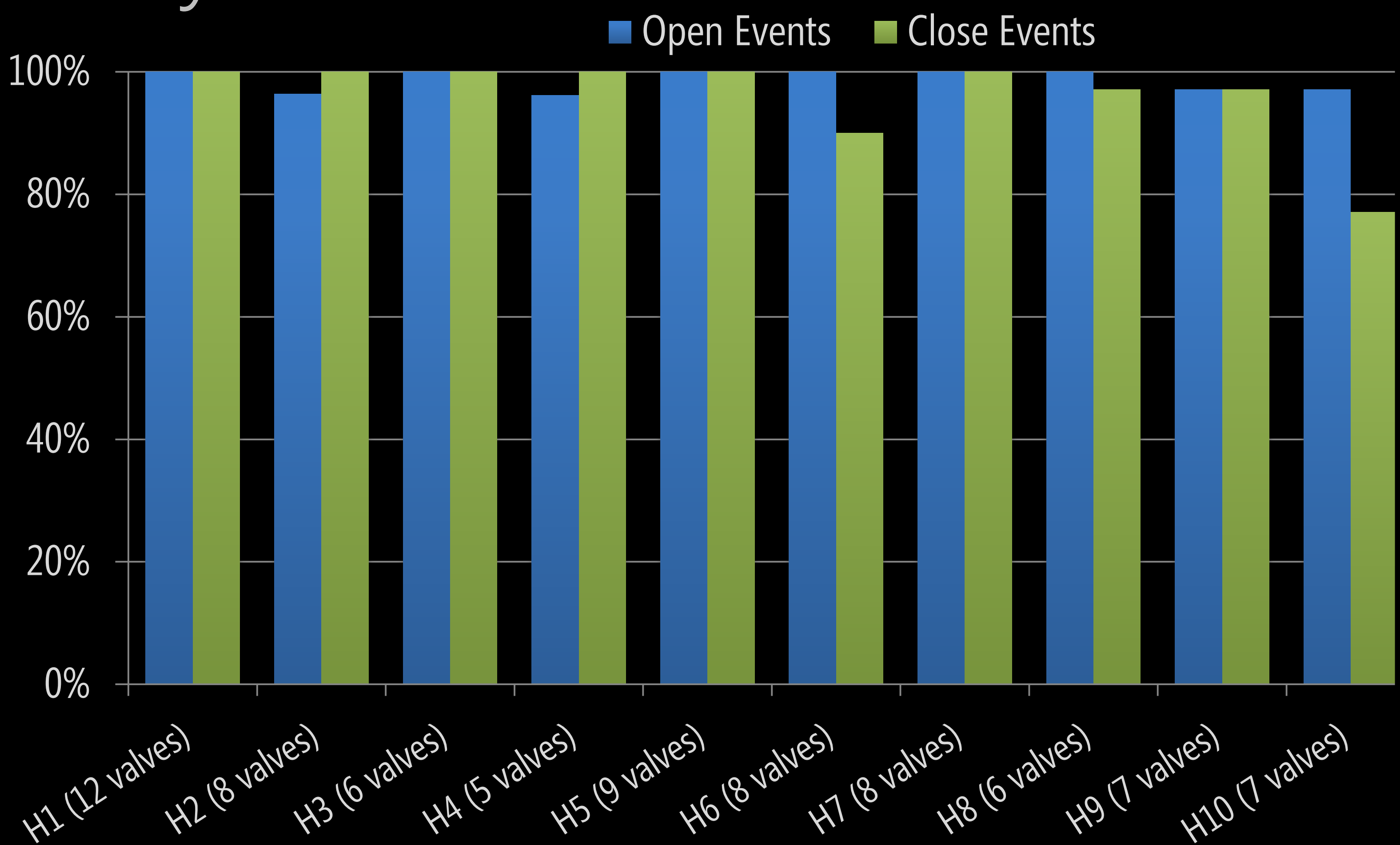
How **accurately** does HydroSense work?

fixture classification results
by home



10-fold cross validation

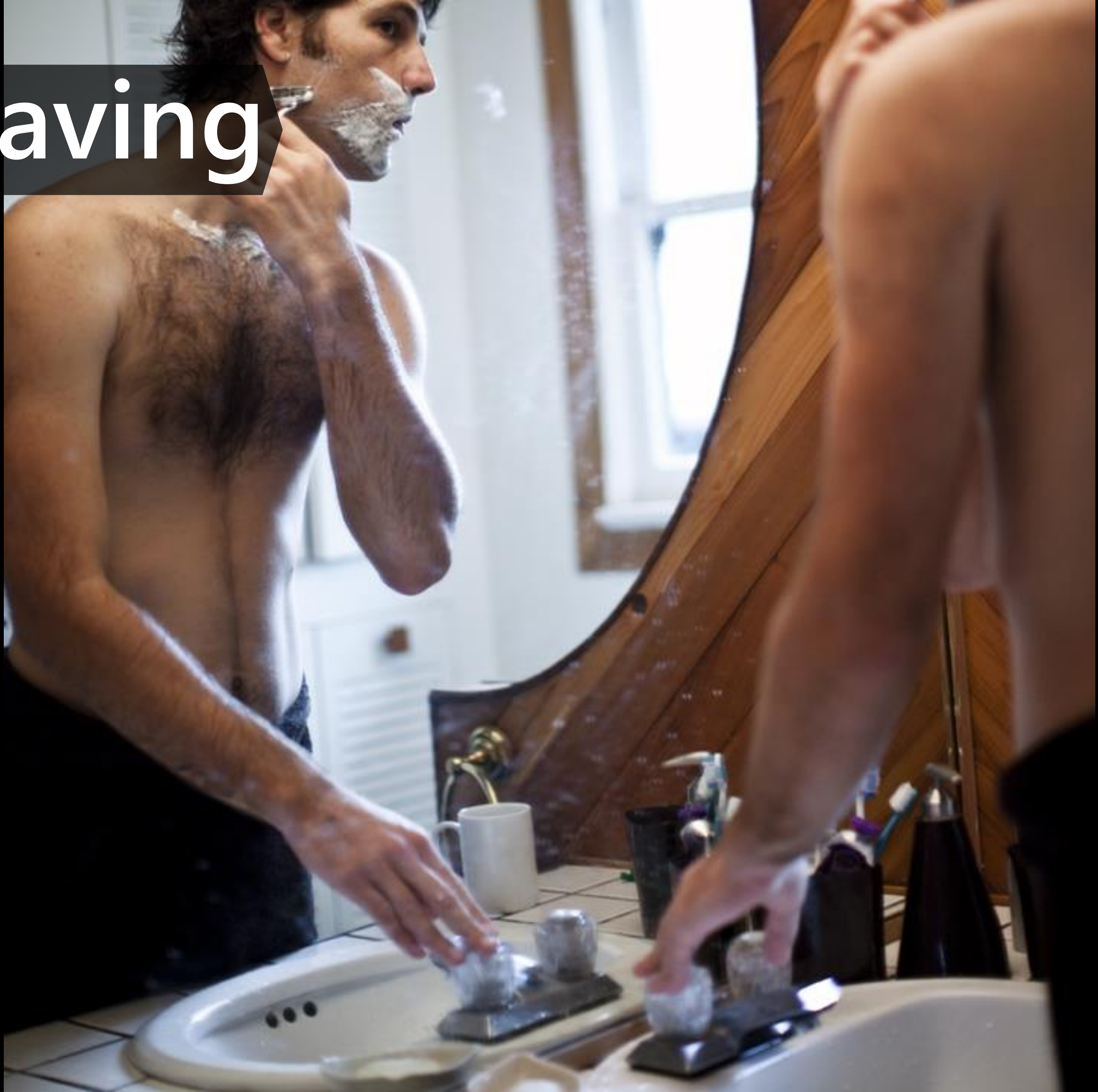
fixture classification results
by home



10-fold cross validation

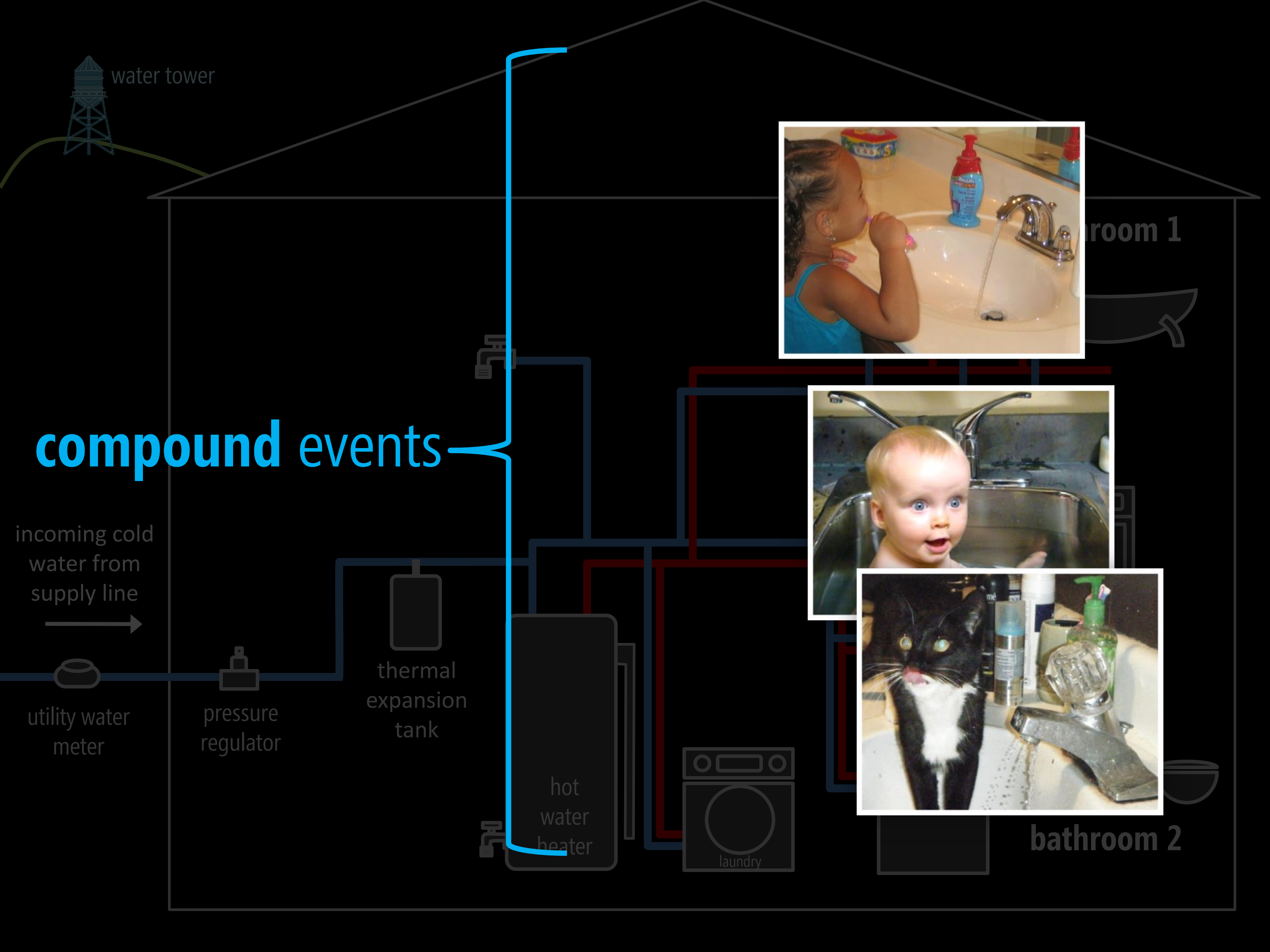
brushing teeth

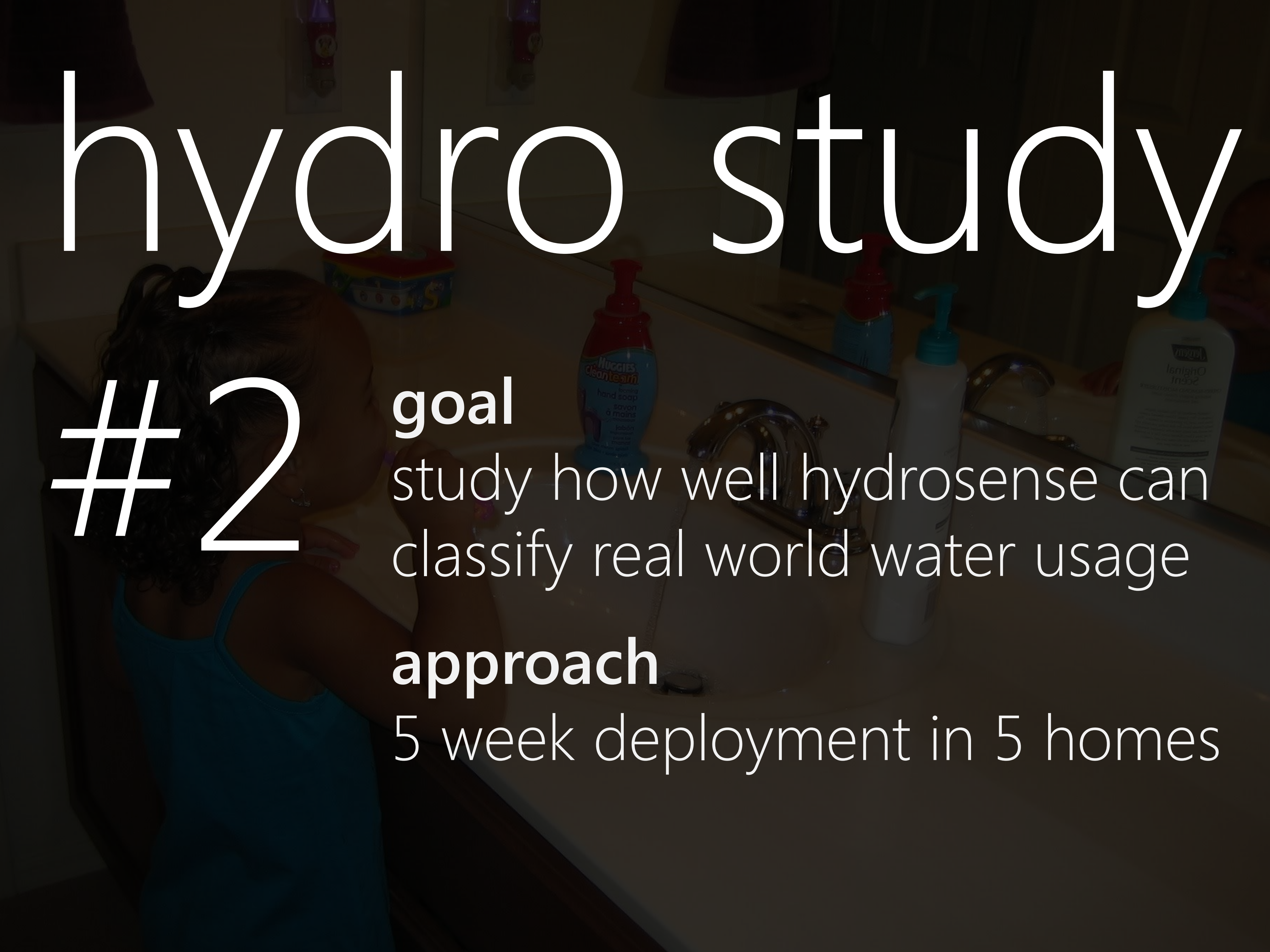
shaving




bathing

paw washing


water tower
compound events
incoming cold
water from
supply line
utility water
meter
pressure
regulator
thermal
expansion
tank
hot
water
heater
laundry
bathroom 2



hydro study

#2

goal

study how well hydrosense can classify real world water usage

approach

5 week deployment in 5 homes

in the first study, pressure waves were **manually** annotated with “ground truth labels” describing:

- the fixture used
- the water temperature

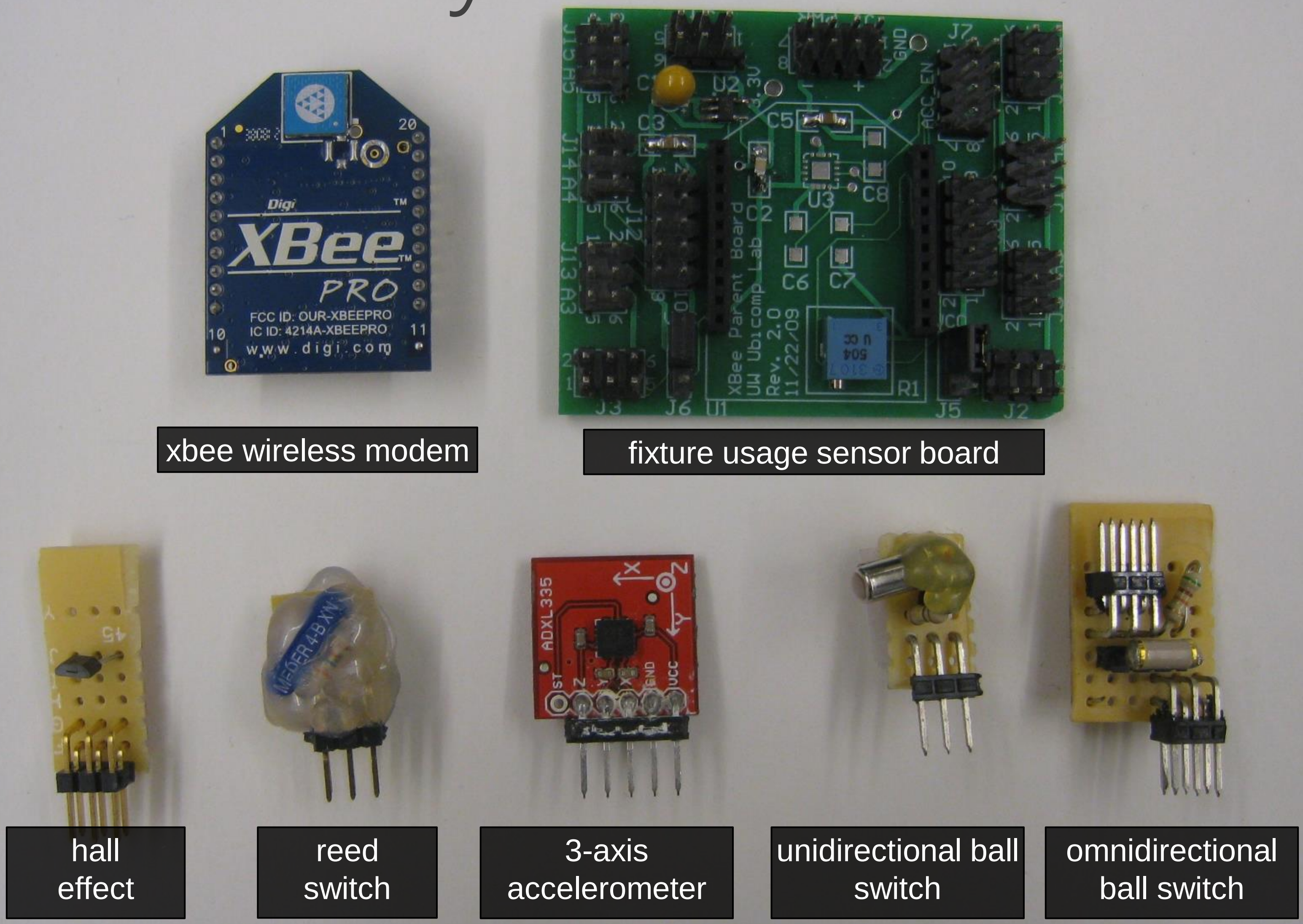

I'm about to flush the toilet!
Awesome! Marked it. Thanks Mr. Johnson

how

can we record **real-world** water usage?

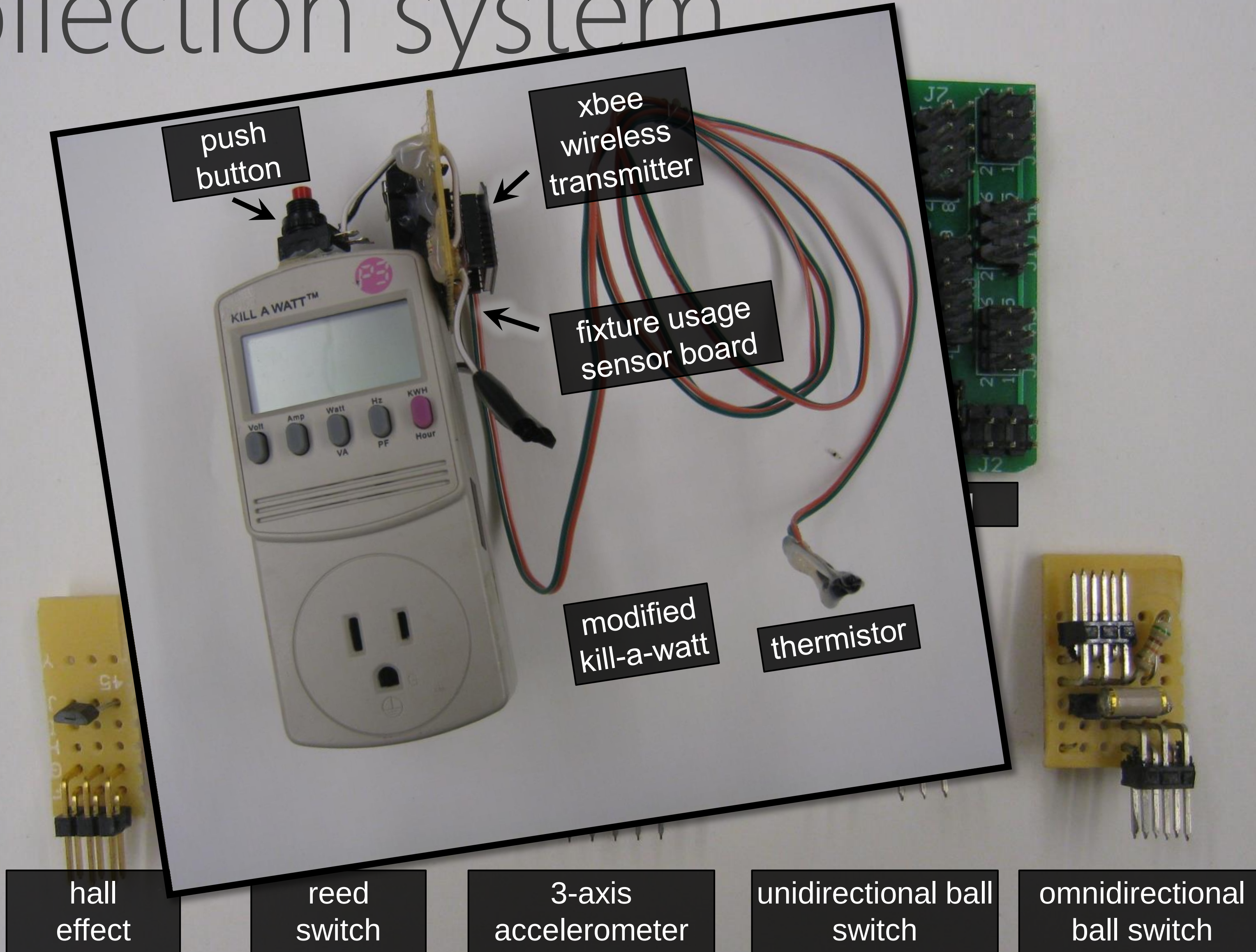
many failed solutions

custom ground truth data collection system




accelerometer
Accelerometer
& Ball Switch
Taped on

custom ground truth data collection system



deployment sites

residents	2	2	4	2	2
size	3000 sqft	750 sqft	1200 sqft	700 sqft	750 sqft
floors	3	2	2	3rd flr	6th flr
fixtures	17	8	13	8	8
valves	28	13	21	13	13

In total, we instrumented almost 90 individual water valves


H
C

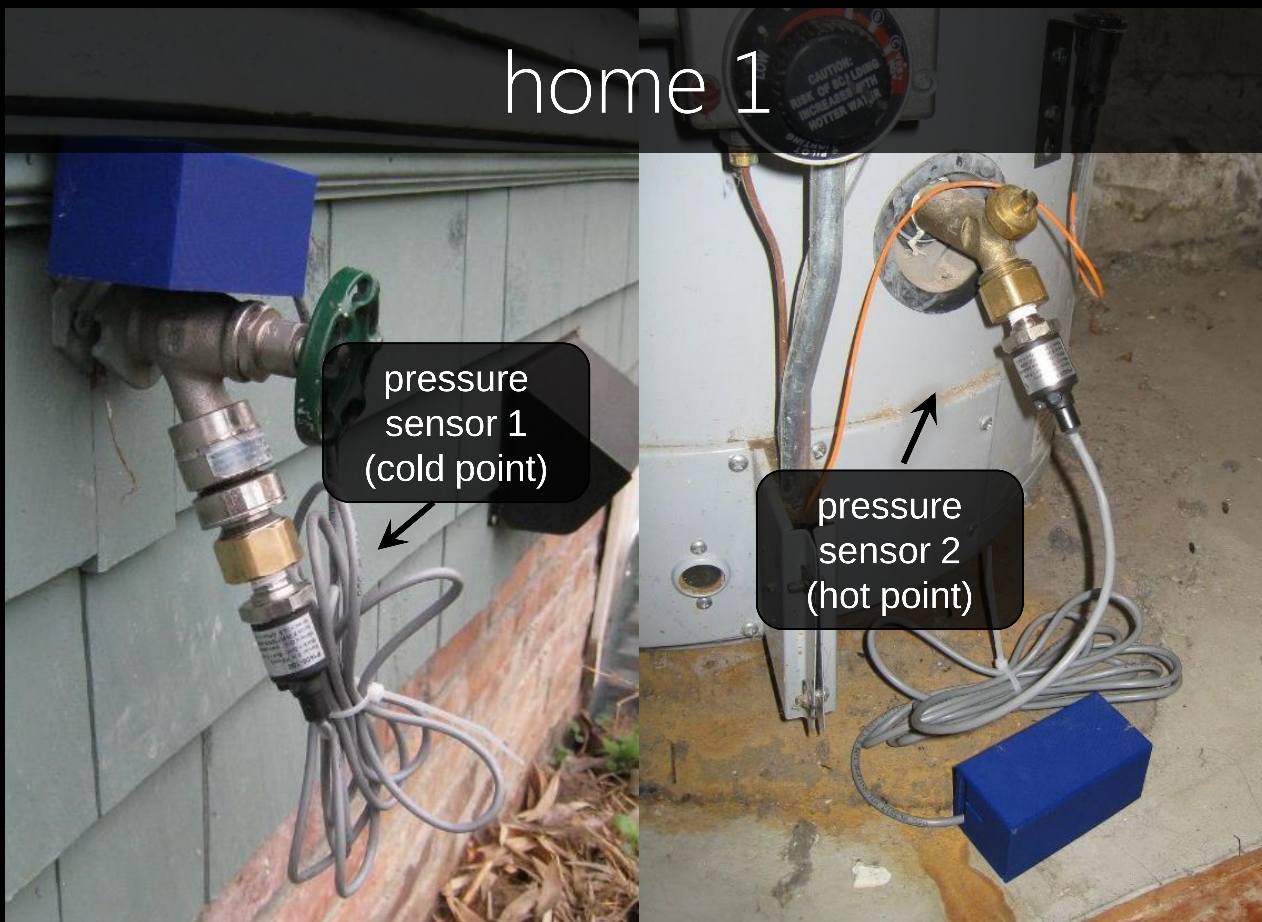

DELL


HOT
COLD

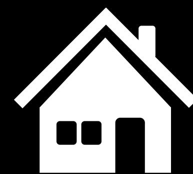
PB32
XBee
XTRA RINSE
SET
PULL KNOB TO START-PUSH TO STOP
COTTONS
REGULAR
PERMANENT PRESS
KNITS
PERMANENT
PRESS
DELICATES
LIGHT SOIL
MEDIUM
HEAVY
POWER WASH
30 MIN
AUTO SOAK
vy Duty Super Capacity
= RINSE
= EXTRA RINSE
= SPIN


KitchenAid Superba
ICE
CHILLED WATER

two pressure sensors per home



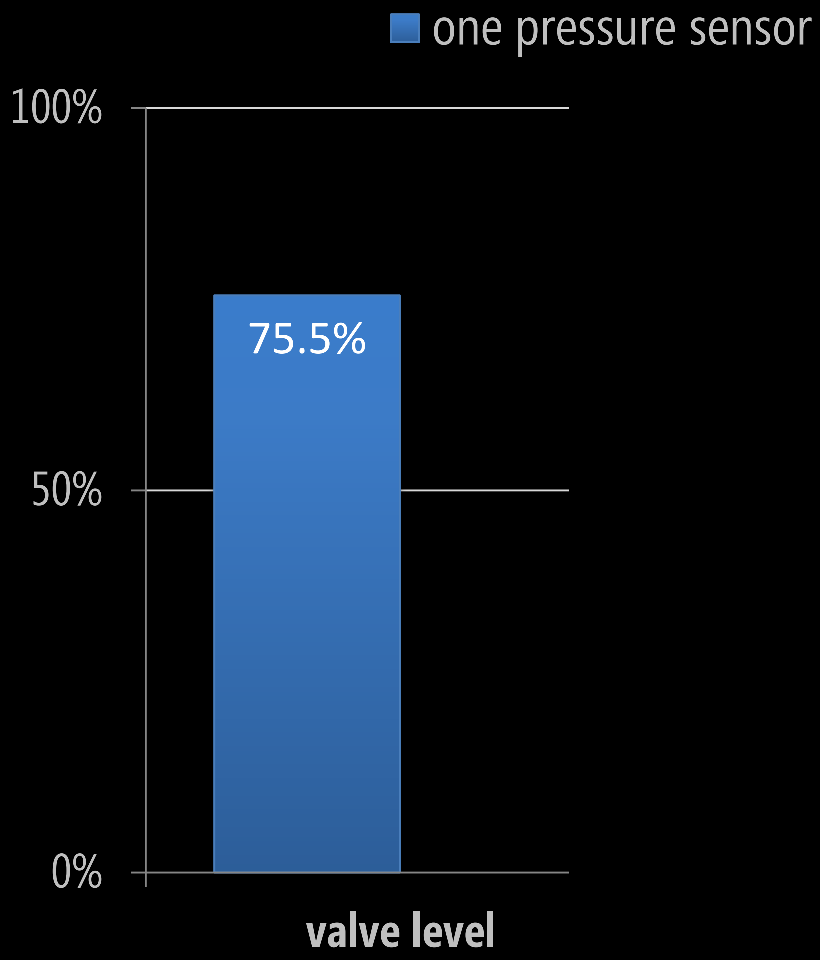
5-week dataset

						totals
days	33	33	30	27	33	156
events	2374	3075	4754	2499	2578	14,960
events/day	71.9	93.2	158.5	92.6	78.1	95.9

How **accurately** does HydroSense work on real-world water usage activities?

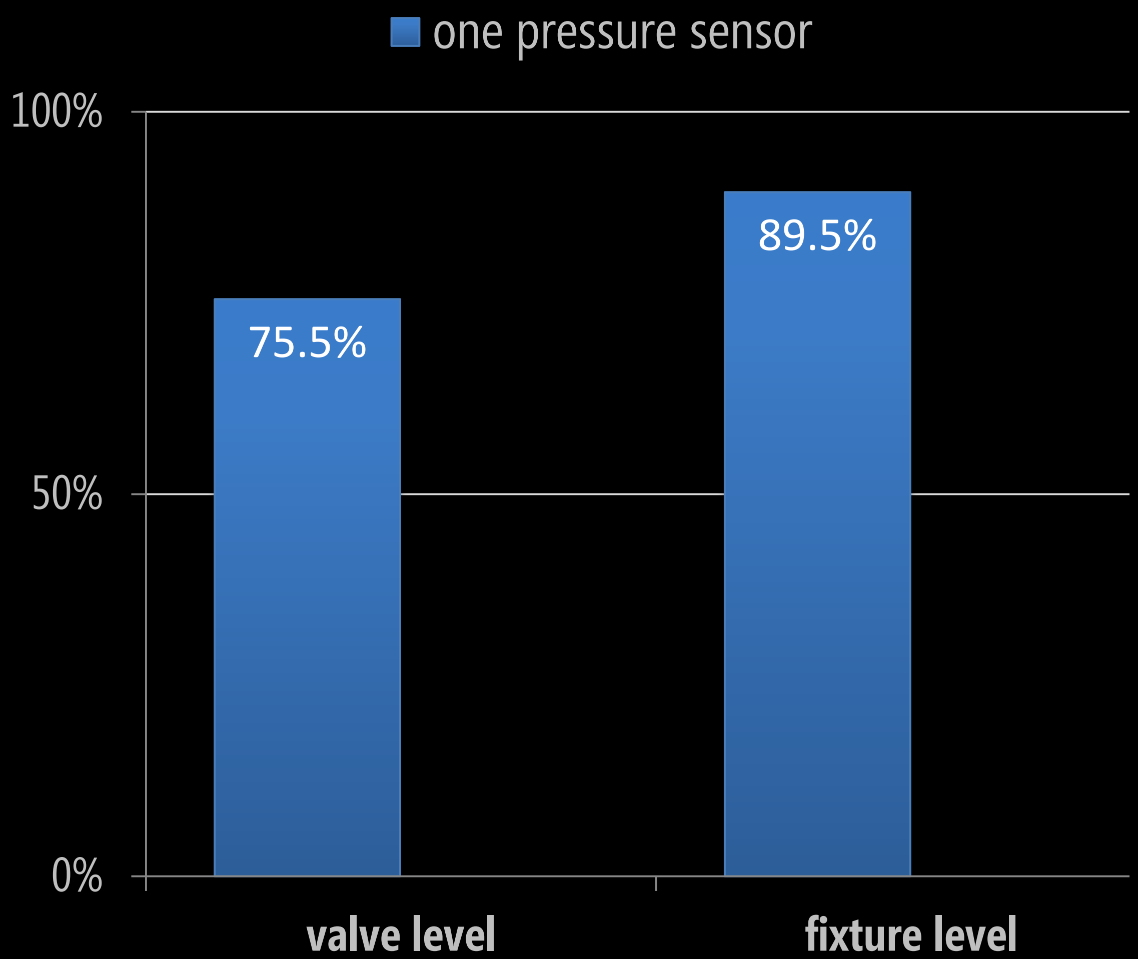
hydrosense classification results

real-world water usage data



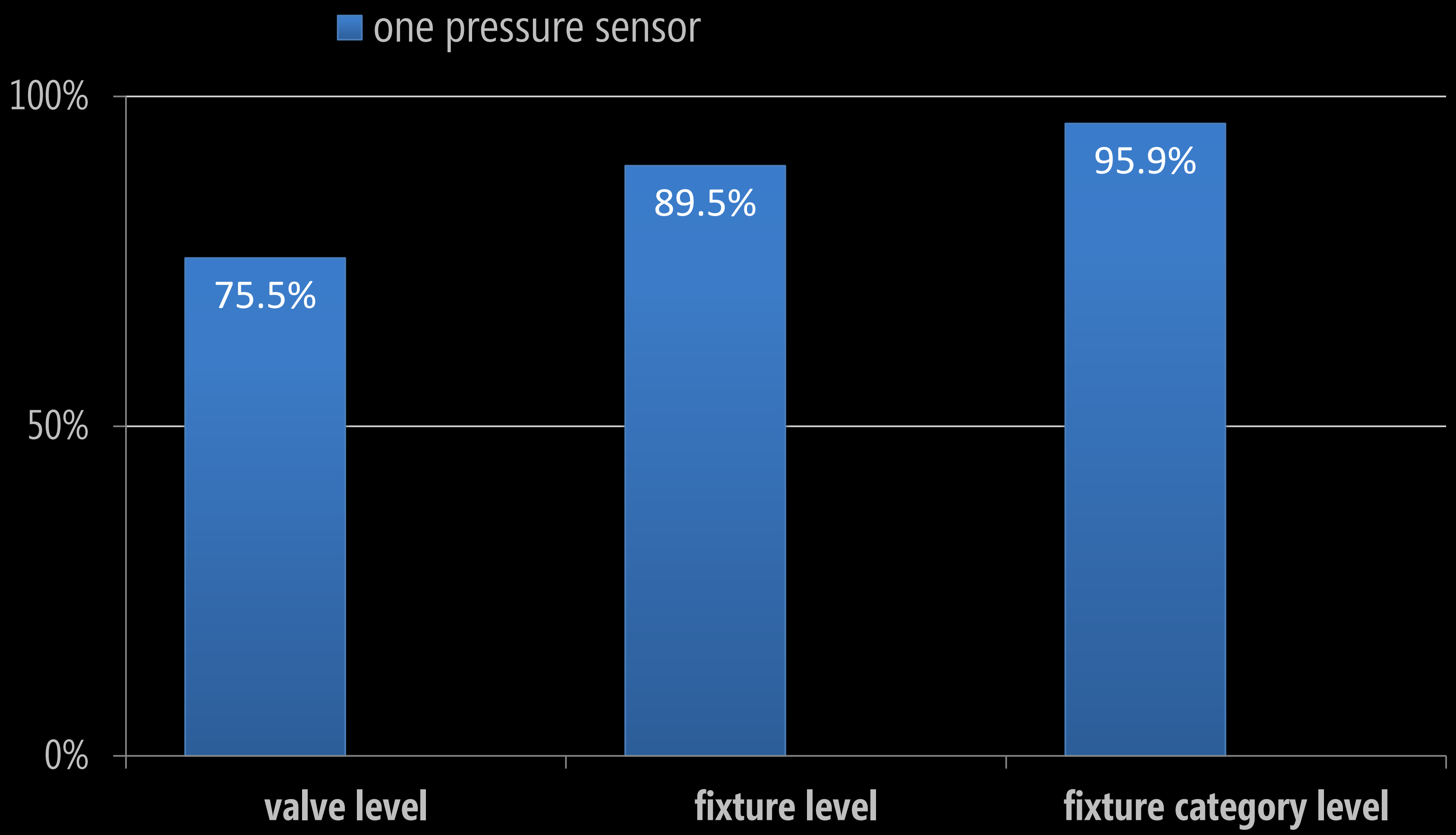
hydrosense classification results

real-world water usage data



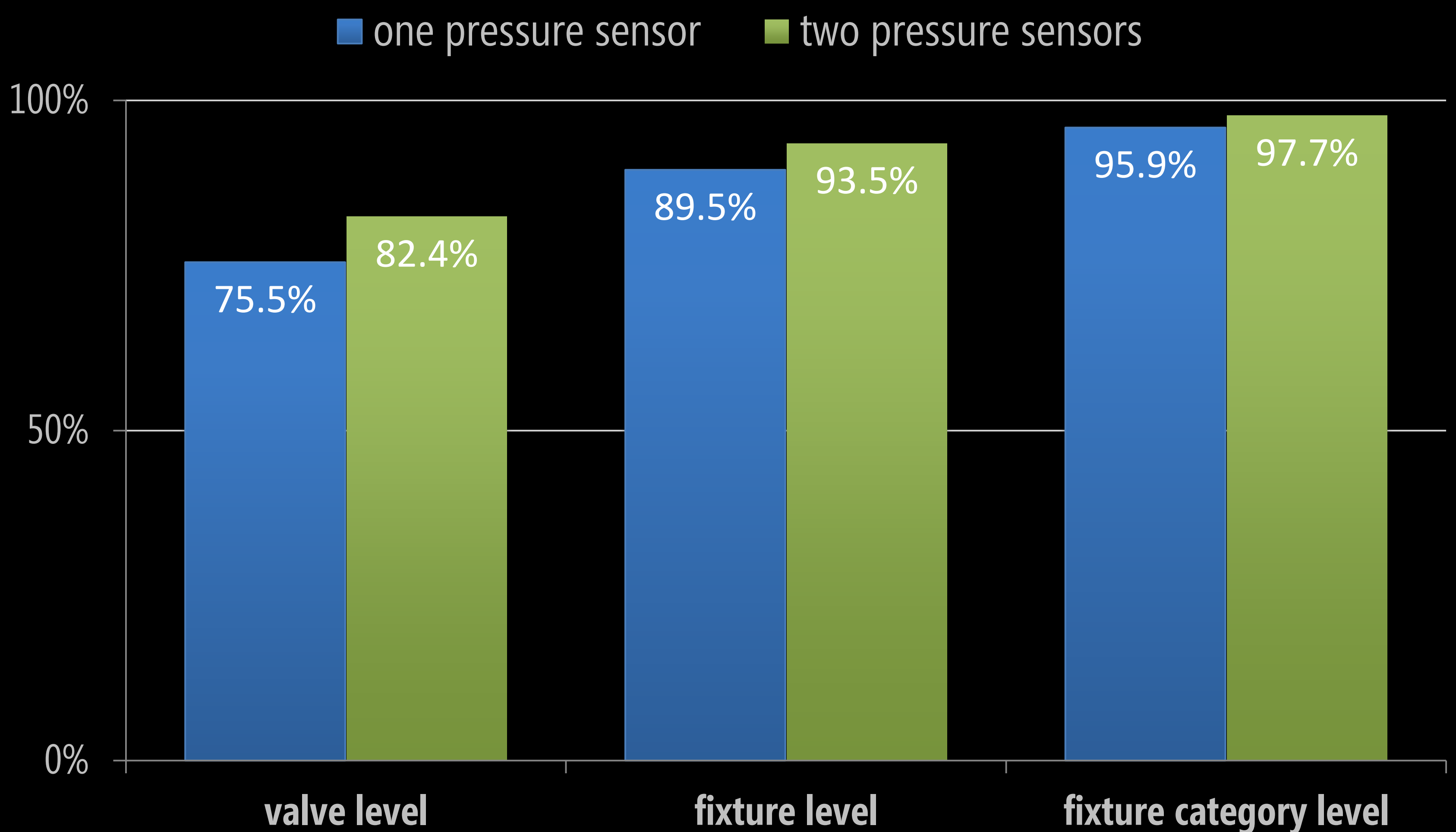
hydrosense classification results

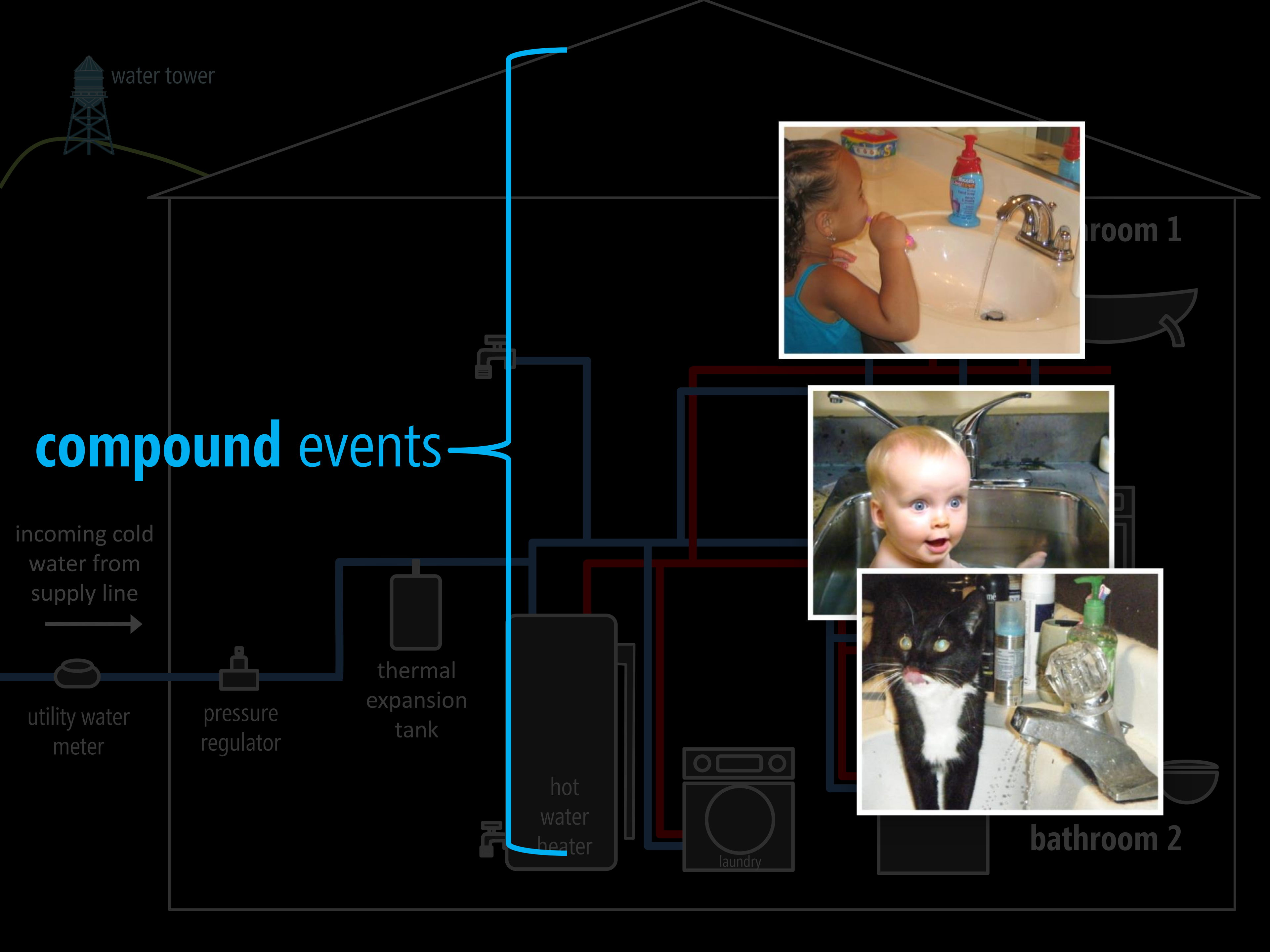
real-world water usage data



hydrosense classification results

real-world water usage data




water tower
compound events
incoming cold water from supply line
utility water meter
pressure regulator
thermal expansion tank
hot water heater
laundry
bathroom 2

22%

of all water events were compound

41.8%

of all bathroom sink events were compound

Technology **patented and licensed** to Belkin Inc.

ECHO WATER

Belkin Echo Water technology identifies waste and leaks indoors and out, all from under the kitchen sink.

LIVES UNDER YOUR KITCHEN SINK. SEES ALL YOUR WATER USE.

Belkin Echo Water is a simple, single sensor that can be installed by anyone under a kitchen sink. Simply turn off the cold water line, attach the Echo sensor and plug it into the spare power outlet next to your waste disposal. Once installed, Echo water senses vibrations that occur throughout your plumbing system every time you use water. Belkin Echo's advanced machine learning-based algorithms analyze these vibrations and accurately identify every fixture in your home—from shower to toilet to irrigation—and log when each is used, for how long, and accurately calculate how much water each consumes. This information helps you use water more efficiently, and can even identify leaks and other potential problems - before they become serious. It's an ideal solution for homeowners, residential building managers, and vacation homes. Echo Water is moving into large-scale pilots in 2013, and should be more generally available in the United States during 2014.

Also explored **disaggregated energy** and **gas sensing**

SMART ENER

Disaggregated End-Use Energy Sens for the Smart Grid

This article surveys existing and emerging disaggregation techniques for energy-consumption data and highlights signal features that might be used to sense disaggregated data in an easily installed and cost-effective manner.

Jon Froehlich, Eric Larson, Sidhant Gupta, and Gabe Cohn
University of Washington

Matthew S. Reynolds
Duke University

Shwetak N. Patel
University of Washington

Imagine an energy feedback system that displays not only total power consumption and cost, but also suggests specific cost-effective measures to improve energy efficiency. Such a system could report, for example, "Based on your energy consumption patterns, you could save US$360 per year by upgrading to a more efficient refrigerator, which would pay for itself after 21 months." The challenge in this scenario is how to sense end uses of energy to provide feedback at the individual device or appliance level. Emerging smart meters promise a tighter temporal coupling between energy usage and feedback (down to 15-minute sampling intervals). However, the focus still is on aggregate consumption, making it difficult for consumers to ascertain which devices or appliances are responsible for their energy usage. Disaggregated end-use energy data promises to transform the way residents, utilities, and policy makers think about and understand how energy is consumed in the home.

Our research team and many others worldwide are working toward a new generation of electricity, water, and natural gas measurement systems that are low cost, easy to install, and

GasSense: Appliance-Level, Single-Point Sensing of Gas Activity in the Home

Gabe Cohn[1], Sidhant Gupta[2], Jon Froehlich[2], Eric Larson[1], Shwetak N. Patel[1,2]

[1]Electrical Engineering, [2]Computer Science & Engineering
UbiComp Lab, DUB Group, University of Washington
Seattle, WA, 98195
{gabecohn, sidhant, jfroehli, eclarson, shwetak } @ uw.edu

Abstract. This paper presents GasSense, a low-cost, single-point sensing solution for automatically identifying gas use down to its source (e.g., water heater, furnace, fireplace). This work adds a complementary sensing solution to the growing body of work in infrastructure-mediated sensing. GasSense analyzes the acoustic response of a home's government mandated gas regulator, which provides the unique capability of sensing both the individual appliance at which gas is currently being consumed as well as an estimate of the amount of gas flow. Our approach provides a number of appealing features including the ability to be easily and safely installed without the need of a professional. We deployed our solution in nine different homes and initial results show that GasSense has an average accuracy of 95.2% in identifying individual appliance usage.

Keywords: Ubiquitous Computing, Sustainability, Sensing, Gas

1 Introduction and Motivation

Natural gas is the most widely consumed energy source in American homes [19]. It is used for furnaces, water heaters, stoves, fireplaces and, in some cases, clothes dryers. In the US, natural gas prices have quadrupled over the past decade due to growing demand and limited pipeline capacity [3]. As a result, government agencies and gas utilities have scrambled to implement conservation programs to reduce demand and better help customers manage energy costs (e.g., [7, 17]). Although recent work in the UbiComp and Pervasive research communities has focused on sensing electricity and water usage in the home [10, 12, 15, 16, 18], little attention has been directed towards sensing natural or propane gas usage. Unlike electricity and water usage, which are often the result of direct human actions such as watching TV, doing laundry, or taking a shower, gas usage is dominated by automated systems like the furnace or hot water heater. This disconnect between activity and consumption leads to a lack of consumer understanding about how gas is used in the home and, in particular, which appliances are most responsible for this usage [14]. Most people simply have no means of judging their household gas consumption other than a monthly bill, which, even then, does not provide itemized details about *what* accounts for this consumption.

eco-feedback

sensing and visualizing behavior to reduce environmental impact


Water Usage Eco-Feedback
Daily average consumption by fixture for the month of May
69.3 gallons
Weekly consumption pattern for the month of May
average consumption for this day of the week
average daily consumption
M T W T F S S

Two sets of designs:

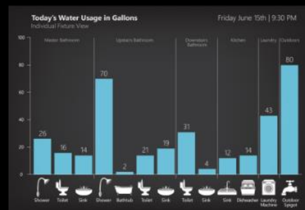
1 **Design Dimensions**
Isolate eco-feedback design dimensions in the context of water usage

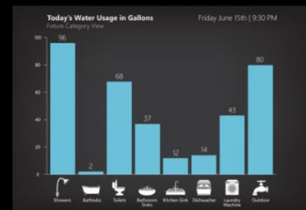
2 **Design Probes**
Meant to elicit reactions about how displays would fit within a household and investigate issues such as privacy, competition, family dynamics.

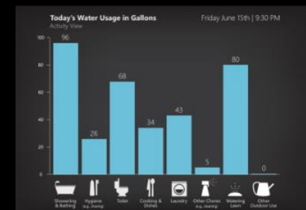
DESIGN SET 1: ISOLATING DESIGN DIMENSIONS

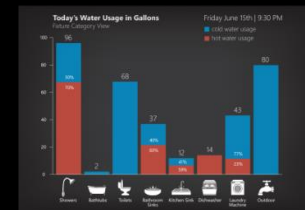
Design Dimensions Explored

Data Granularity

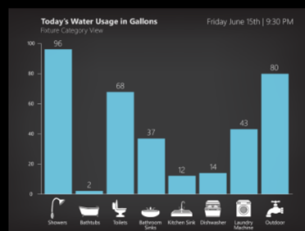

Individual Fixture

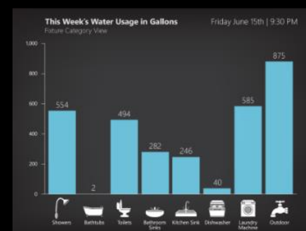

Fixture Category

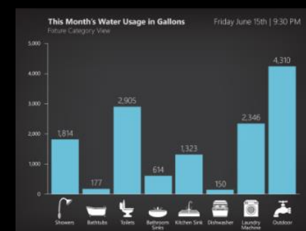

Activity


Hot and Cold

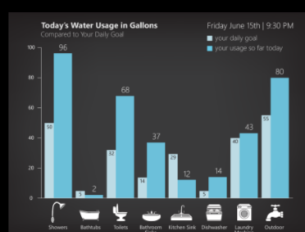
Time Granularity

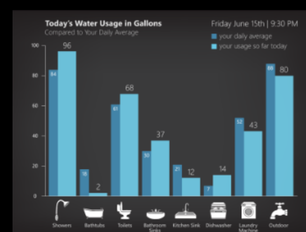

So Far Today

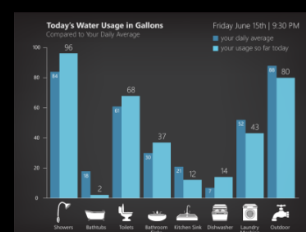

So Far This Week

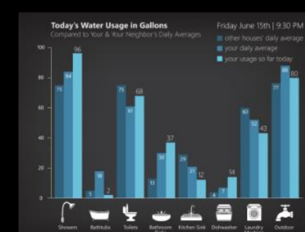

So Far This Month

Comparison

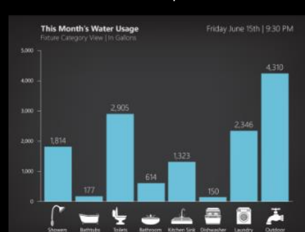

Self Comparison


To Others

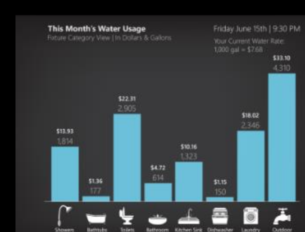

To A Goal

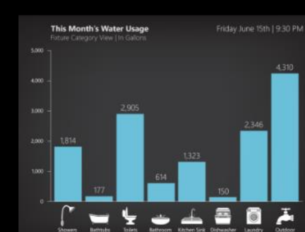

Social/Self

Measurement Unit


In Gallons

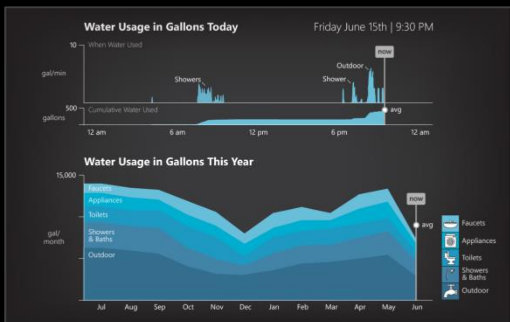

In Dollars


Dollars / Gallons


Including Sewage

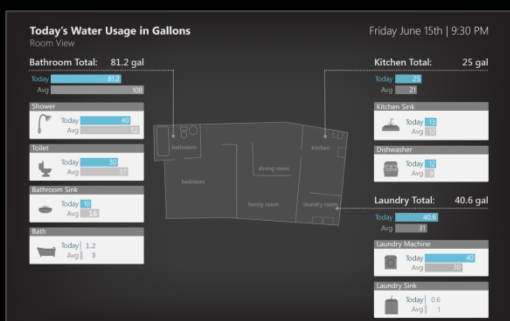
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

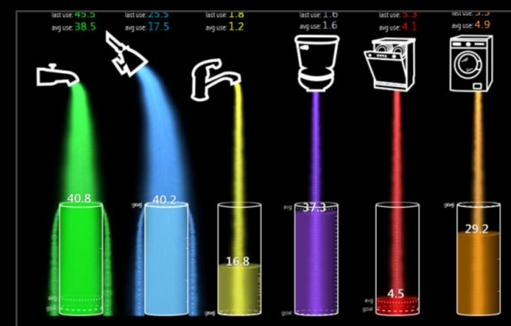


Time-Series

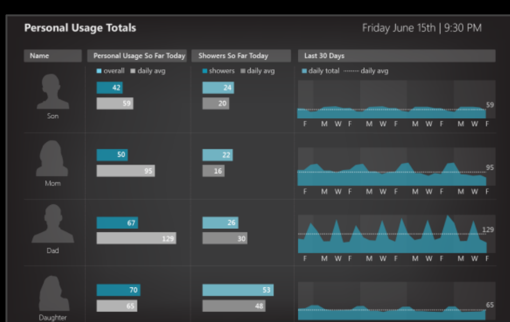
Aquatic Eco-system



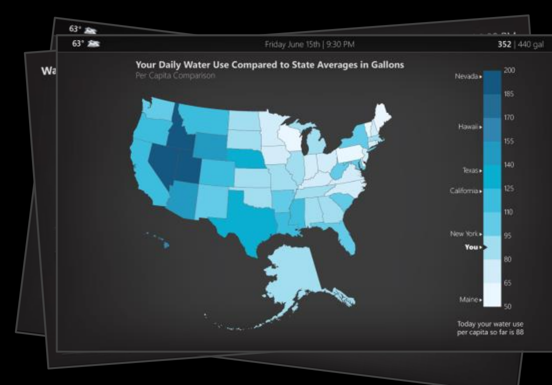
Spatial



Rainflow



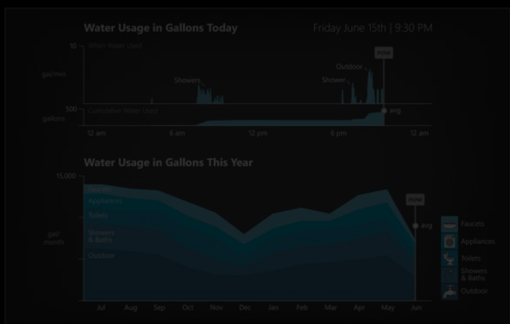
Per-Occupant



Other

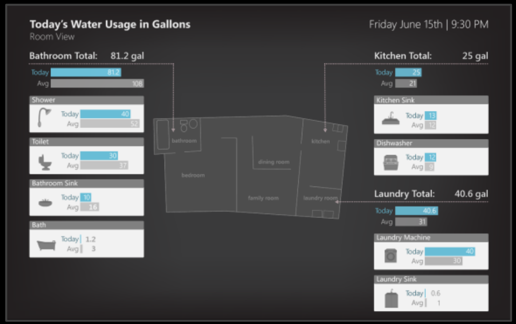
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

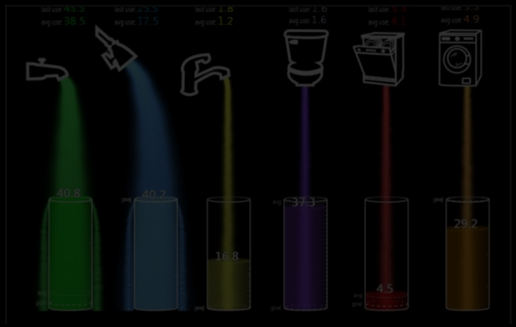


Time-Series

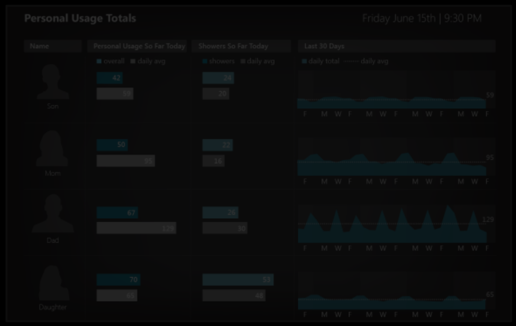
Aquatic Eco-system



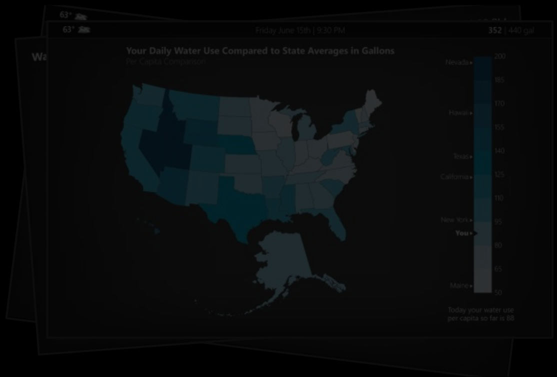
Spatial



Rainflow



Per-Occupant



Other

Spatial View

Today's Water Usage in Gallons

Room View

Friday June 15th | 9:30 PM

Bathroom Total: 81.2 gal

Today	81.2
Avg	108

Shower

Today	40
Avg	52

Toilet

Today	30
Avg	37

Bathroom Sink

Today	10
Avg	16

Bath

Today	1.2
Avg	3

Kitchen Total: 25 gal

Today	25
Avg	21

Kitchen Sink

Today	13
Avg	12

Dishwasher

Today	12
Avg	9

Laundry Total: 40.6 gal

Today	40.6
Avg	31

Laundry Machine

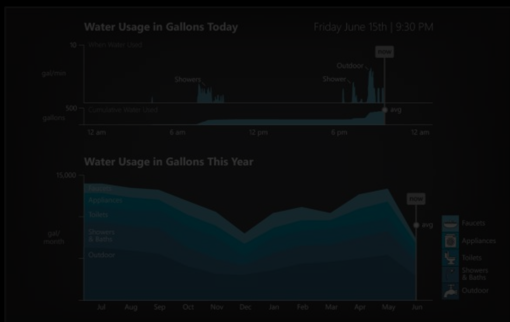
Today	40
Avg	30

Laundry Sink

Today	0.6
Avg	1

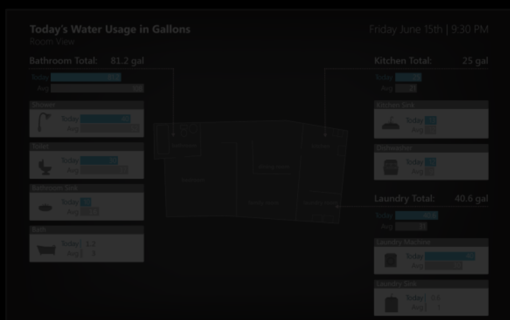
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

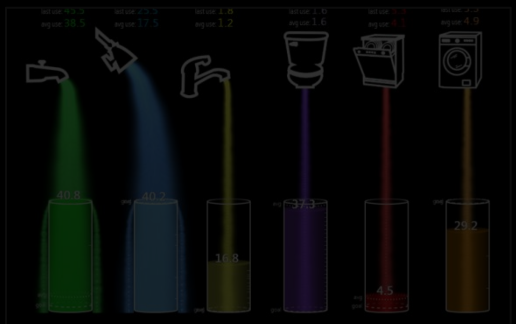


Time-Series

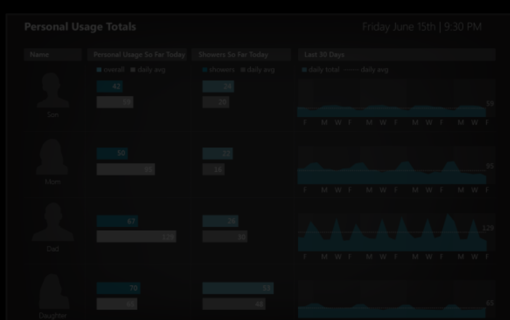
Aquatic Eco-system



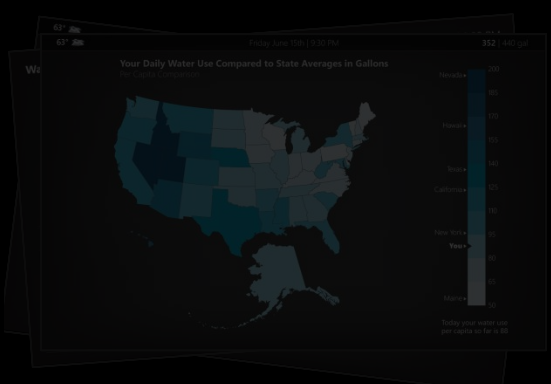
Spatial



Rainflow



Per-Occupant



Other

Aquatic Ecosystem Design Influences

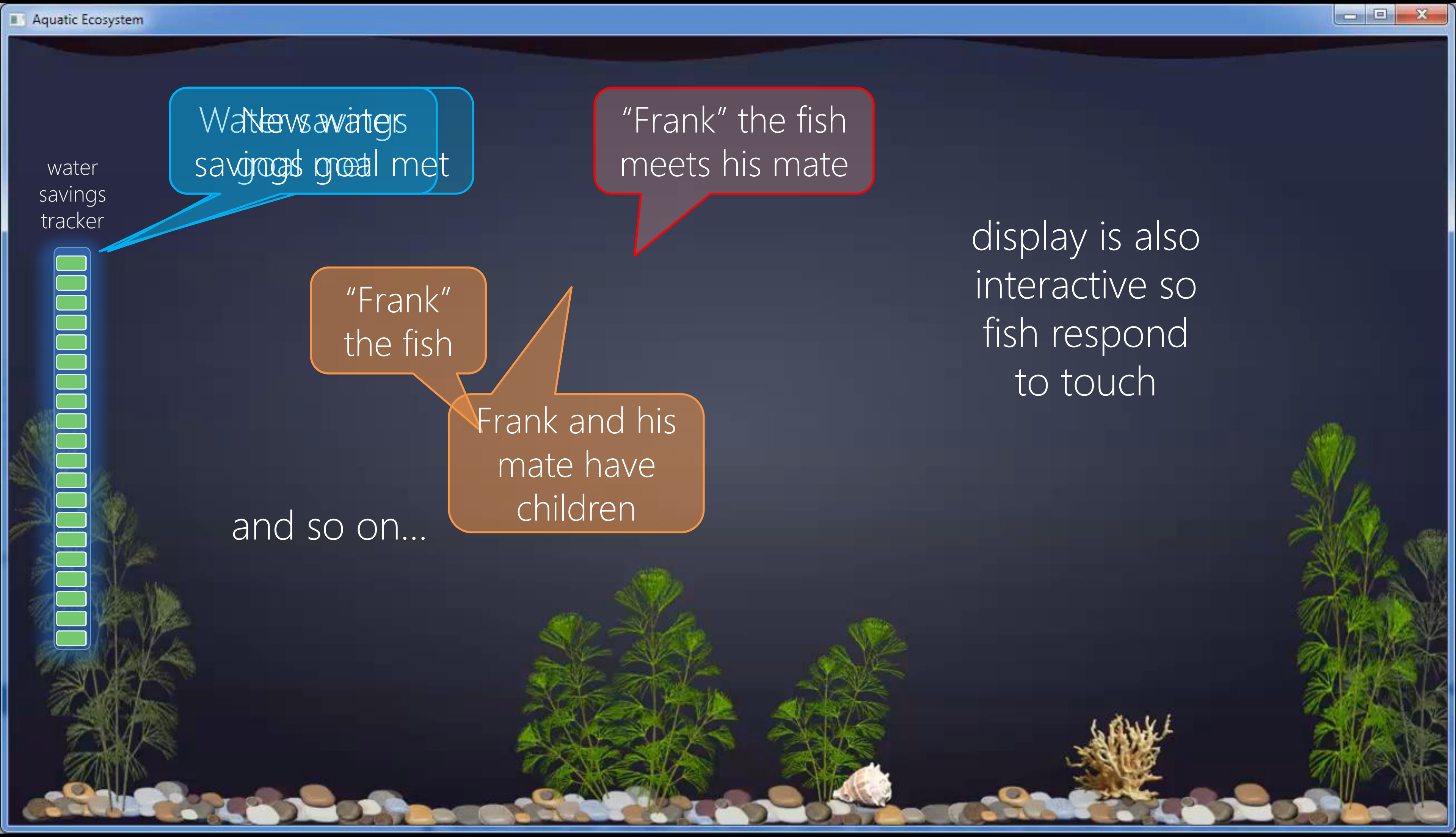
ubifit

Consolvo *et al.*, CHI2008
Consolvo *et al.*, UbiComp2008

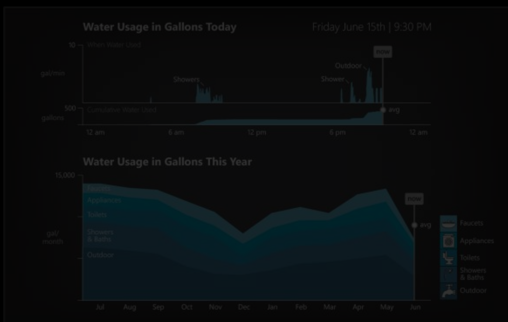
ubigreen

Froehlich *et al.*, CHI 2009

Aquatic Ecosystem View

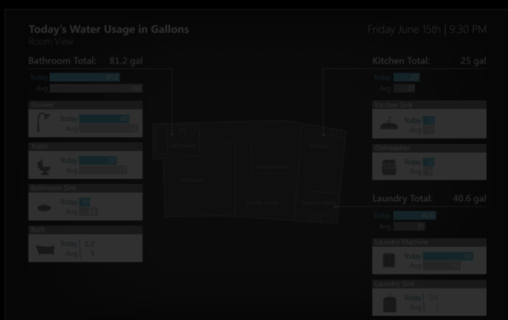


Design Probes Explored

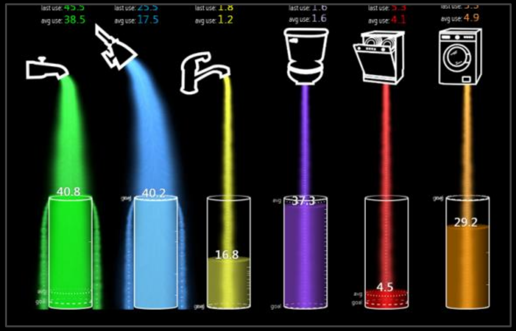


Time-Series

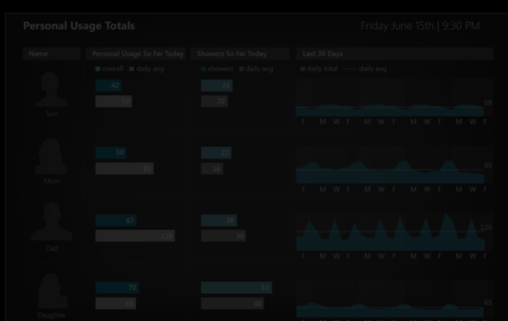
Aquatic Eco-system



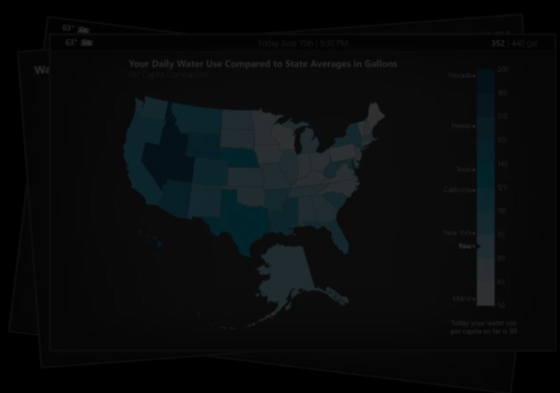
Spatial



Rainflow

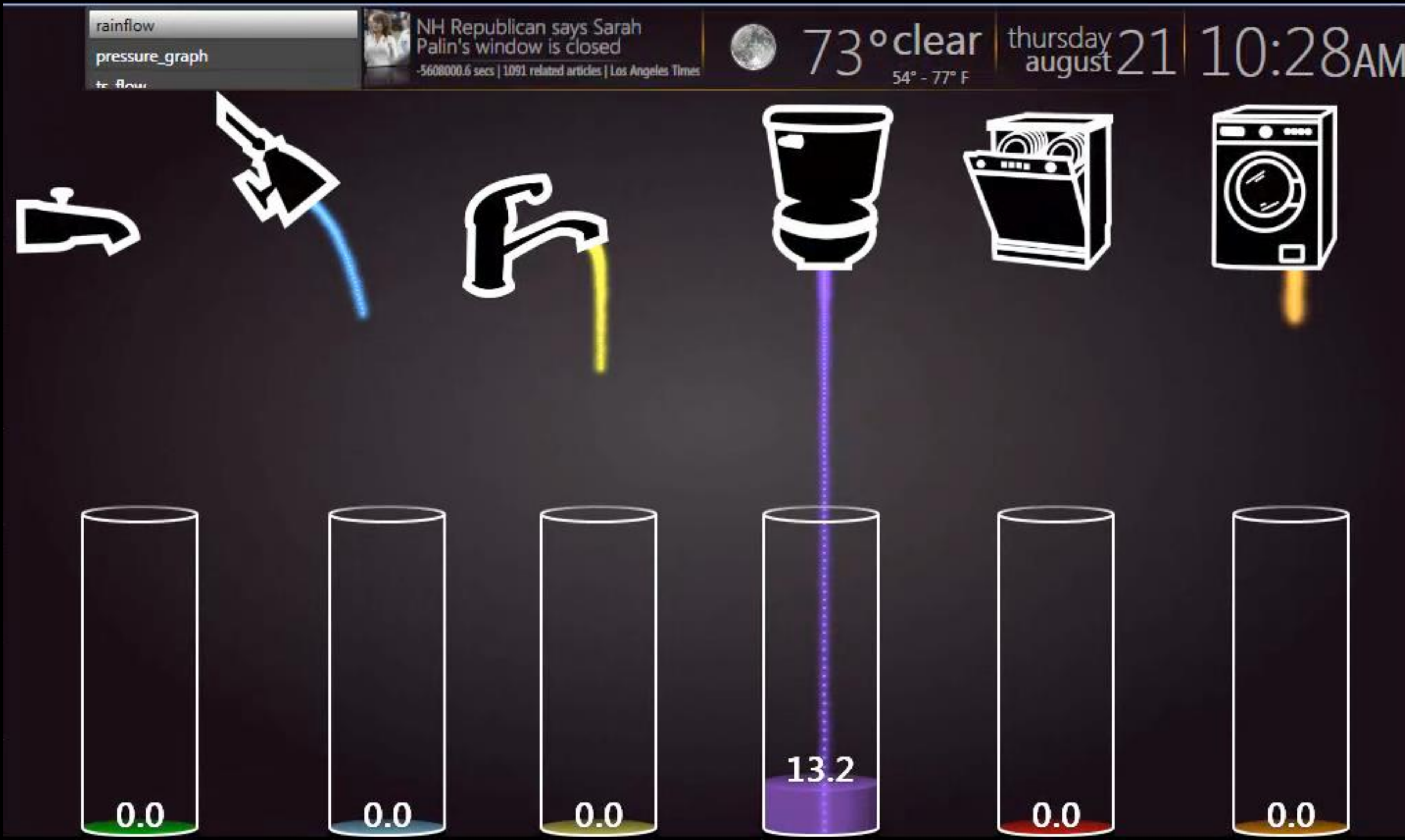


Per-Occupant



Other

Rainflow View



Source: Froehlich *et al., CHI'12*

The Design and Evaluation of Prototype Eco-Feedback Displays for Fixture-Level Water Usage Data

Jon Froehlich[1,7], Leah Findlater[6,8], Marilyn Ostergren[6], Solai Ramanathan[3], Josh Peterson[5], Inness Wragg[4], Eric Larson[2], Fabia Fu[3], Mazhengmin Bai[3], Shwetak N. Patel[1,2], James A. Landay[1]

Computer Science and Engineering[1], Electrical Engineering[2], Pre-Engineering[3], Interaction Design[4], DxArts[5], Information School[6]
University of Washington, Seattle
{ostergrn, eclarson, shwetak, landay}@uw.edu

Computer Science[7]
College of Information Studies[8]
University of Maryland, College Park
{jonf, leahkf}@umd.edu

ABSTRACT
Few means currently exist for home occupants to learn about their water consumption: *e.g.,* where water use occurs, whether such use is excessive and what steps can be taken to conserve. Emerging water sensing systems, however, can provide detailed usage data at the level of individual water fixtures (*i.e., disaggregated* usage data). In this paper, we perform formative evaluations of two sets of novel eco-feedback displays that take advantage of this disaggregated data. The first display set isolates and examines specific elements of an eco-feedback design space such as *data* and *time granularity*. Displays in the second set act as *design probes* to elicit reactions about competition, privacy, and integration into domestic space. The displays were evaluated via an online survey of 651 North American respondents and in-home, semi-structured interviews with 10 families (20 adults). Our findings are relevant not only to the design of future water eco-feedback systems but also for other types of consumption (*e.g.,* electricity and gas).

Author Keywords
Eco-feedback, water, sustainability, iterative design

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI).

INTRODUCTION
Cities across the world are facing an escalating demand for potable water due to growing populations, higher population densities and warmer climates [12,13]. As new sources of water become more environmentally and economically costly to extract, water suppliers and

Figure 1: In our in-home interviews, participants selected preferred locations in their home to place our prototype water usage display.

Eco-feedback has been offered as one strategy to encourage conservation and help build the connection between home activities and resource use (see [4,6,9] for a review). However, most past work has focused on energy, with water-based eco-feedback largely limited to sensing and feedback at the *point-of-consumption* and to simple ambient and/or LED-based displays [2,19,21,22,30]. Although this type of feedback can potentially reduce usage at the installed fixture [30], it is limited in its ability to convey broader patterns of use or to compare across fixtures. These systems have also disproportionately focused on faucet and shower usage, which account for only 22% of water use in the average North American home [29].

In this paper, we explore a range of eco-feedback designs enabled by *disaggregated* (*i.e.,* fixture-level) water usage data. Our work is inspired by emerging technologies that can sense water usage at *individual fixtures* with only one

Sensing and Feedback of Everyday Activities
to Promote Environmental Behaviors

Jon E. Froehlich

A dissertation
submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington

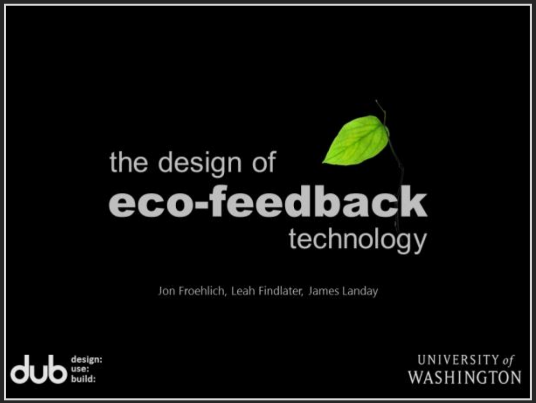
2011

Program Authorized to Offer Degree:
Department of Computer Science and Engineering

Jon Froehlich, **Sensing and Feedback of Everyday Activities to Promote Environmental Behaviors**, *PhD Dissertation 2011*

Other Talks on Eco-Feedback Visualization

If you want to learn more about the visualization side of my work, check out the following on slideshare:



http://goo.gl/3ldFUu

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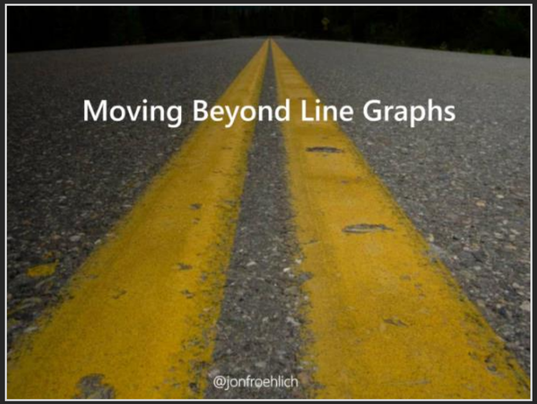
http://goo.gl/ijrgxK



http://goo.gl/aV3B3F

http://goo.gl/vpwNIY

Environmental Behavior Sensing and Feedback Work

Sensing Focus

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Feedback Focus

- Froehlich, J. (2015) Gamifying Green: Gamification and Environmental Sustainability. *The Gameful World*
- Froehlich, J., Findlater, L., Ostergren, M., Ramanathan, S., Peterson, J., Wragg, I., Larson, E., Fu, F., Bai, M., Patel, S., & Landay, J. (2012) The Design and Evaluation of Prototype Eco-Feedback Displays for Fixture-Level Water Usage Data. *Proceedings of CHI 2012*, 2367-2376.
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- Froehlich, J. (2009) Promoting Energy Efficient Behaviors in the Home through Feedback: The Role of Human-Computer Interaction. *HCIC2009 Winter Workshop*

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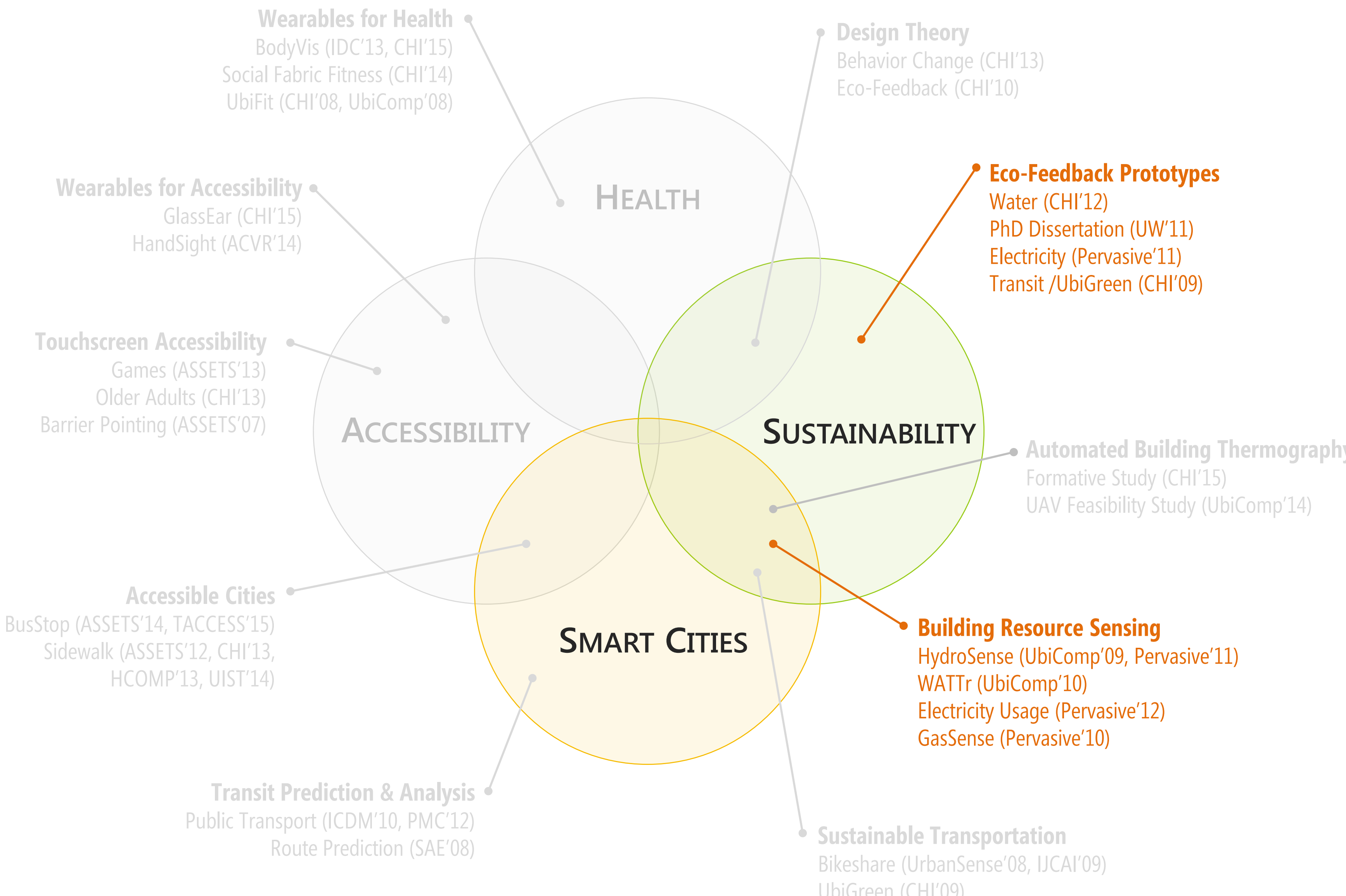
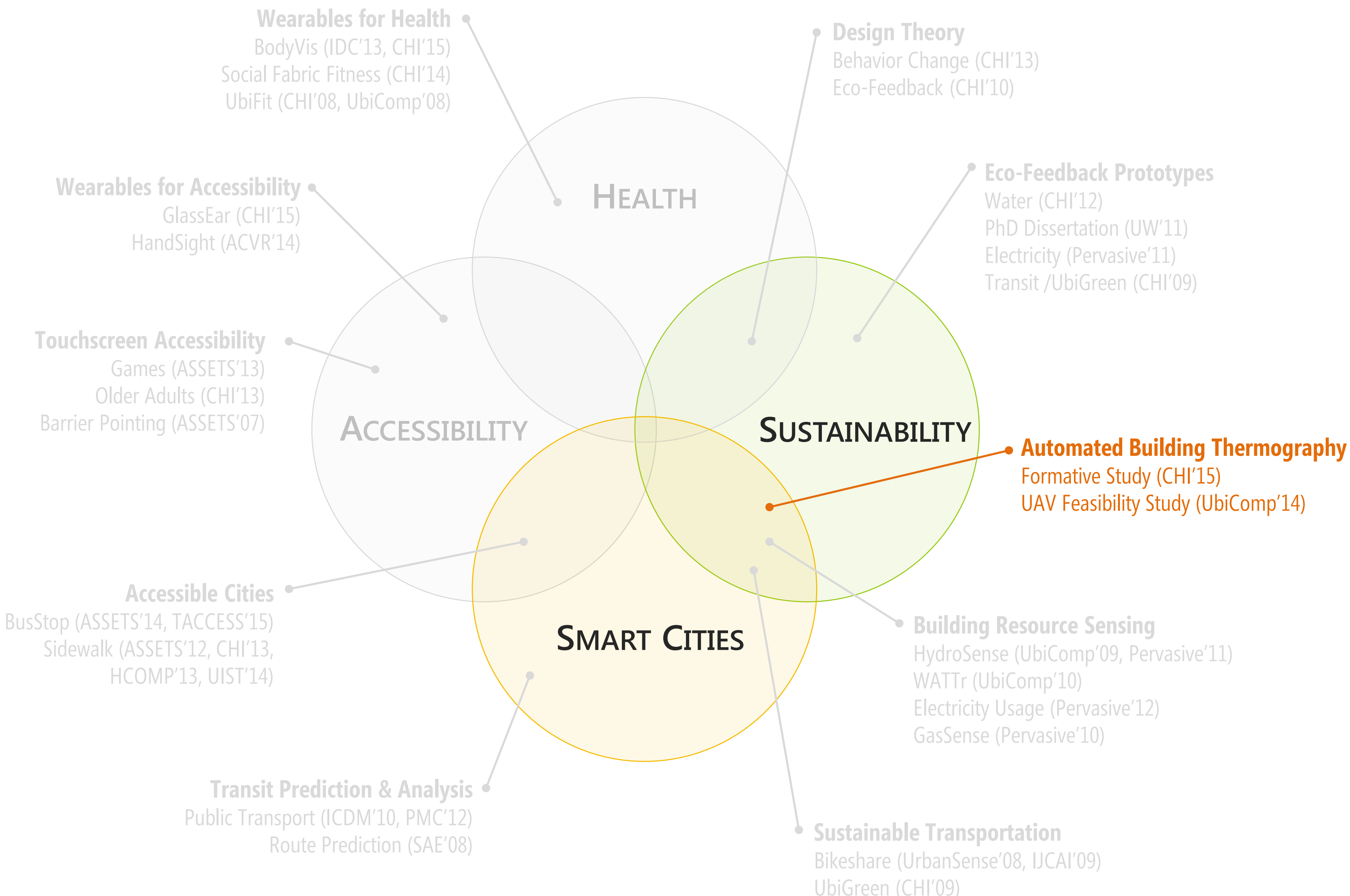
- Froehlich, J. (2011) Sensing and Feedback of Everyday Activities to Promote Environmental Behaviors. University of Washington Doctoral Dissertation 2011
- Froehlich, J., Everitt, K., Fogarty, J., & Landay, J. (2009) Sensing Opportunities for Personalized Feedback Technology to Reduce Consumption. *CHI2009 Workshop: Defining the Role of HCI in the Challenges of Sustainability*
- Froehlich, J., Dillahunt, T., Klasnja, P., Mankoff, J., Consolvo, S., Harrison, B., & Landay, J. (2009) UbiGreen: investigating a mobile tool for tracking and supporting green transportation habits.*Proceedings of CHI 2009*, 1043-1052.

My Research


Wearables for Health
BodyVis (IDC'13, CHI'15)
Social Fabric Fitness (CHI'14)
UbiFit (CHI'08, UbiComp'08)
Design Theory
Behavior Change (CHI'13)
Eco-Feedback (CHI'10)
Health
Eco-Feedback Prototypes
Water (CHI'12)
PhD Dissertation (UW'11)
Electricity (Pervasive'11)
Transit /UbiGreen (CHI'09)
Wearables for Accessibility
GlassEar (CHI'15)
HandSight (ACVR'14)
Touchscreen Accessibility
Games (ASSETS'13)
Older Adults (CHI'13)
Barrier Pointing (ASSETS'07)
Accessibility
Sustainability
Automated Building Thermography
Formative Study (CHI'15)
UAV Feasibility Study (UbiComp'14)
Accessible Cities
BusStop (ASSETS'14, TACCESS'15)
Sidewalk (ASSETS'12, CHI'13,
HCOMP'13, UIST'14)
Smart Cities
Building Resource Sensing
HydroSense (UbiComp'09, Pervasive'11)
WATTr (UbiComp'10)
Electricity Usage (Pervasive'12)
GasSense (Pervasive'10)
Transit Prediction & Analysis
Public Transport (ICDM'10, PMC'12)
Route Prediction (SAE'08)
Sustainable Transportation
Bikeshare (UrbanSense'08, IJCAI'09)
UbiGreen (CHI'09)

My Research



Wearables for Health
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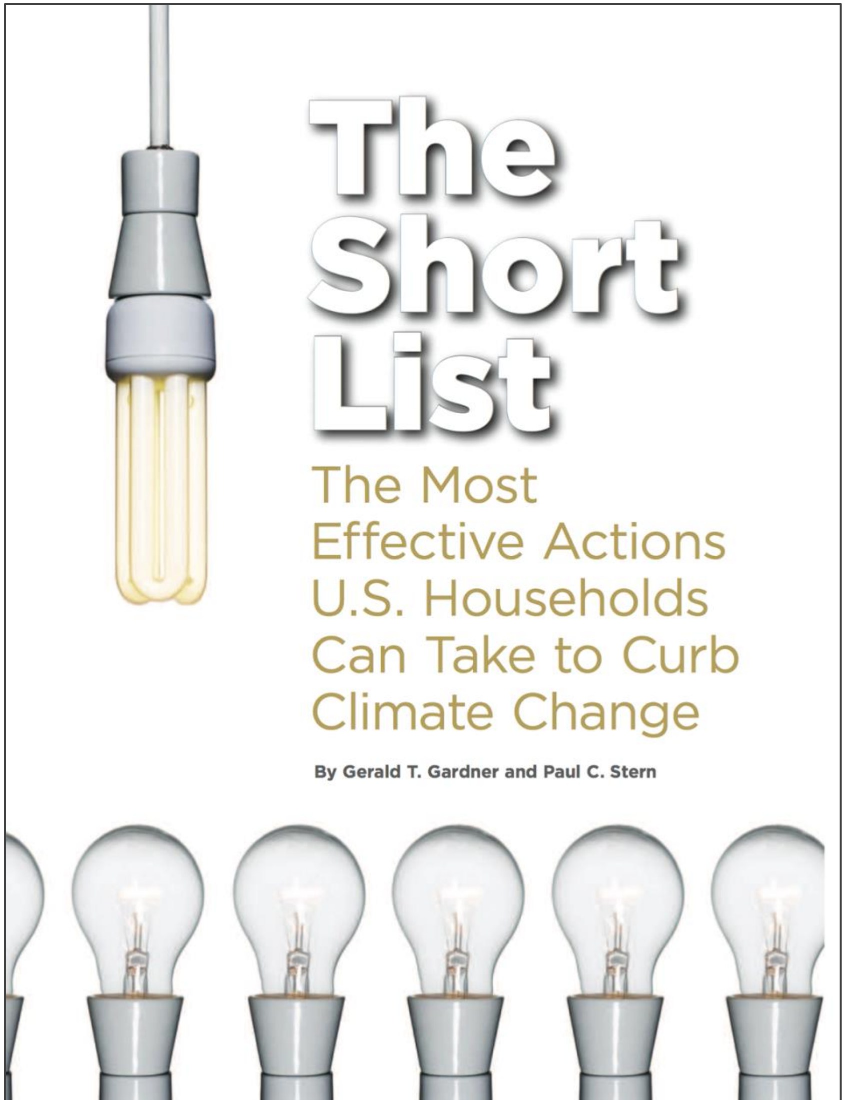
ENCOURAGING EFFECTIVE SUSTAINABLE ACTION



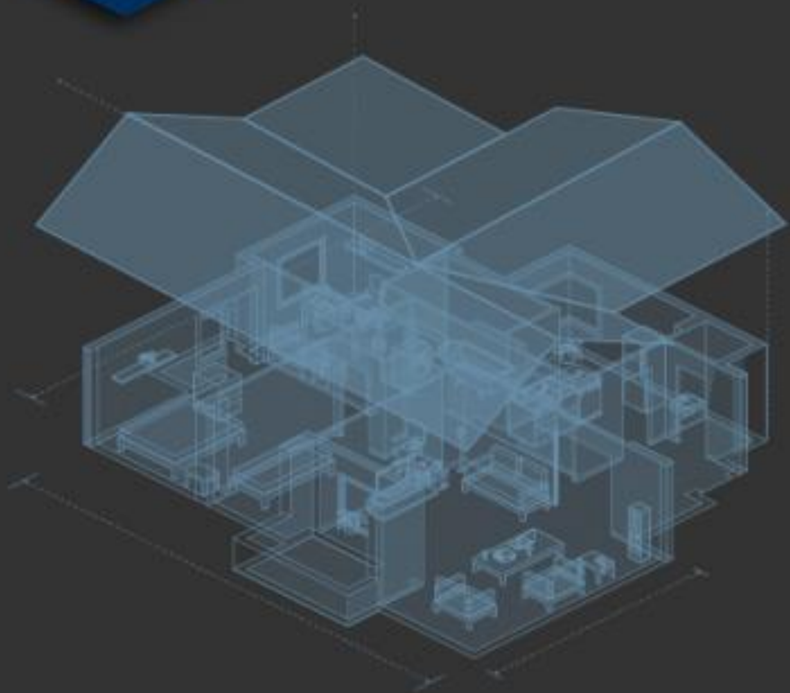
1. CURTAILMENT BEHAVIORS
Involve forming new routines to reduce environmental impact (*e.g.,* taking a shorter shower, biking to work)

2. EFFICIENCY BEHAVIORS
One-time actions that provide a lasting impact such as replacing windows with energy-efficient counterparts or reinsulating your home

[Source: Gardner & Stern, Environment: Science and Policy for Sustainable Development, 2008]

Energy Saver 101: Home Energy Audits

Take the first step to improving your home's energy efficiency: get a home energy audit.



What is a home energy audit?

A home energy audit helps you pinpoint where your house is losing energy and **what you can do to save money**. A home energy auditor will also assess health and safety issues that might exist in your home.

The audit involves two parts: the **home assessment** and **analysis** using computer software.

DID YOU KNOW?

You could **save 5 to 30 percent** on your energy bill by making efficiency upgrades identified in your home energy audit.

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Home » Thermographic Inspections

Thermographic Inspections

June 25, 2012 - 3:27pm

WHAT DOES THIS MEAN FOR ME?

- You can save 5%-30% on your energy bill by making upgrades following a home energy assessment.
- A professional energy auditor may conduct a thermographic inspection to detect where your

Energy auditors may use thermography -- or infrared scanning -- to detect thermal defects and air leakage in building envelopes.

HOW THERMOGRAPHIC INSPECTIONS WORK

Thermography measures surface temperatures by using infrared video and still cameras. These tools see light that is in the heat spectrum. Images on the video or film record the temperature variations of the building's skin, ranging from white for warm regions to black for cooler areas. The resulting images help the auditor determine whether insulation is needed. They also serve

RELATED ARTICLES

Professional Home Energy Audits

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Home Energy Audits Can Help You Keep That New Year's Resolution

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Thermal Cameras

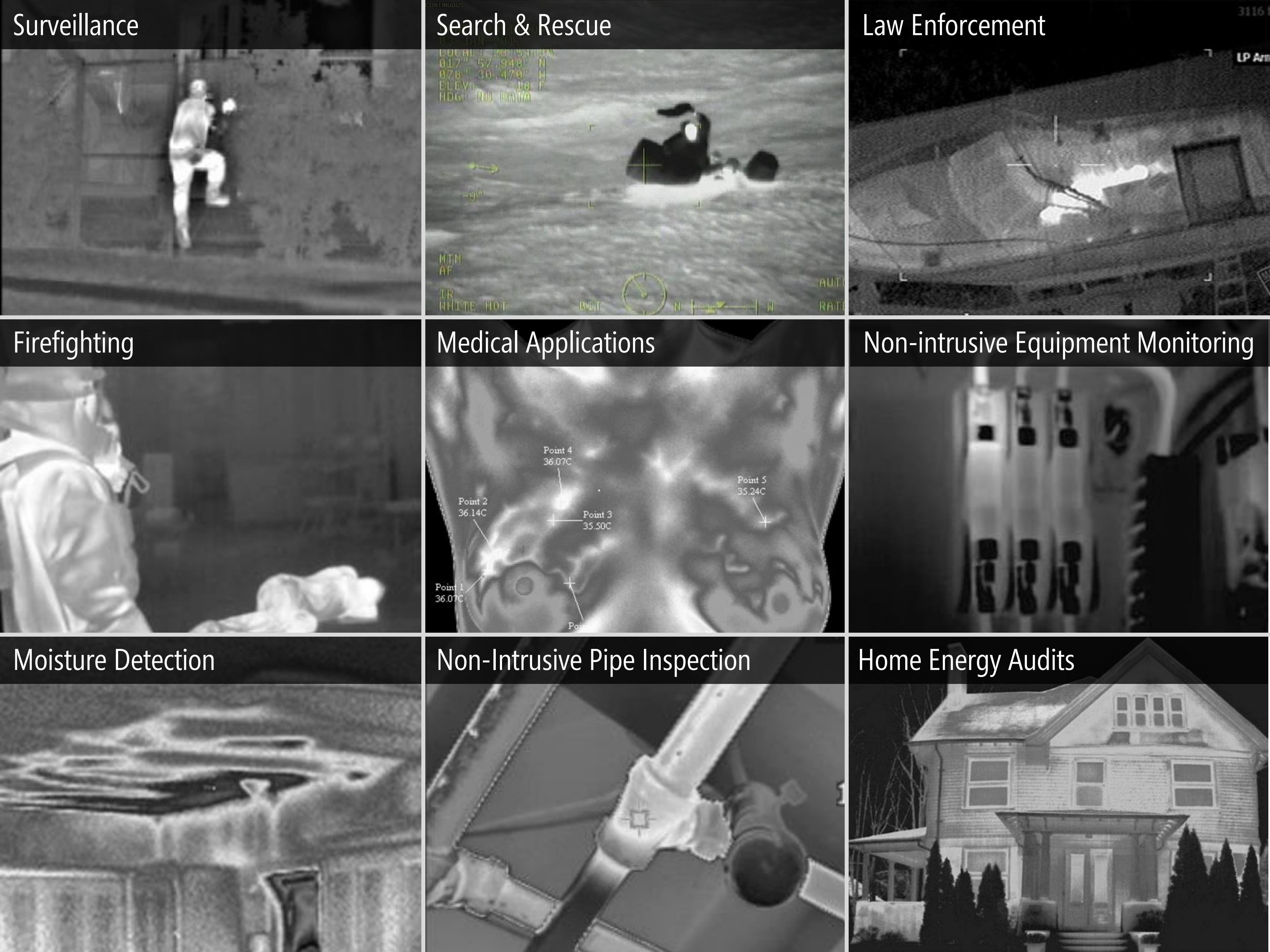
Thermal cameras (or infrared cameras) **detect electromagnetic radiation** with lower frequencies than visible light (*i.e.,* infrared frequencies)

All objects above absolute zero emit infrared radiation, so **thermal cameras can ‘see’ in the dark** without external illumination.

The amount of radiation emitted by an object increases with temperature, **so thermal cameras can** also measure heat.

There must be a **minimum 10° C temperature differential** between a building's interior and exterior to properly detect thermal leakage. Here, the 2nd floor appears to be leaking hot air perhaps **due to poor insulation**.

Lots of Emerging Thermal Camera Applications


Surveillance
Search & Rescue
Law Enforcement
Firefighting
Medical Applications
Point 4
36.07C
Point 2
36.14C
Point 3
35.50C
Point 5
35.24C
Point 1
36.07C
Non-intrusive Equipment Monitoring
Moisture Detection
Non-Intrusive Pipe Inspection
Home Energy Audits


Surveillance
Search & Rescue
Law Enforcement
Firefighting
Medical Applications
Point 4
36.07C
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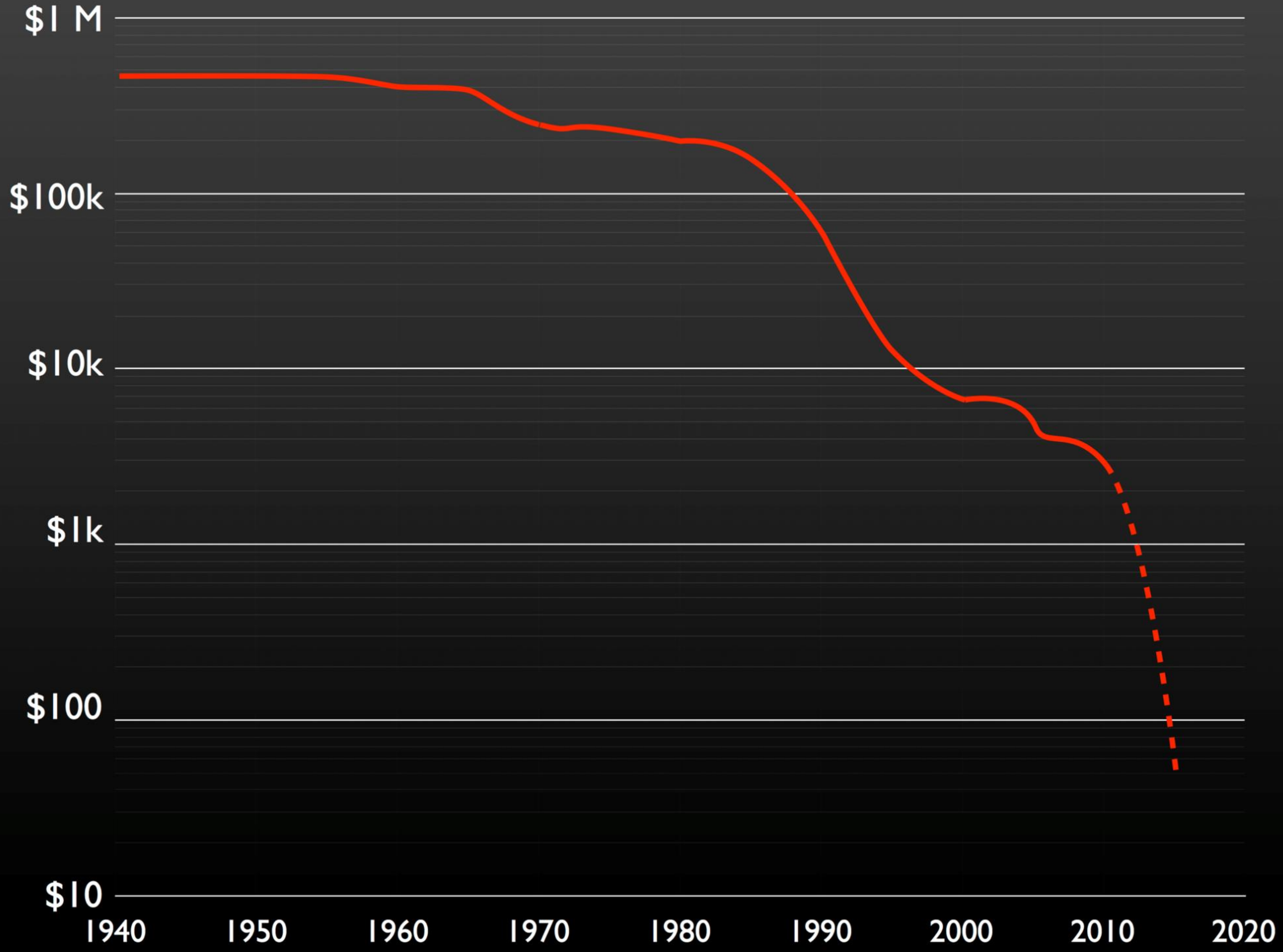
36.14C
Point 3
35.50C
Point 5
35.24C
Point 1
36.07C
Non-intrusive Equipment Monitoring
Moisture Detection
Non-Intrusive Pipe Inspection
Home Energy Audits

Cost of Infrared Sensing Technology



Source: Larson *et al.*, CHI2011, http://www.slideshare.net/ericcooperlarson/heatwave-chi2011

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Kits
LCDs +
Programmers +
Prototyping +
Raspberry Pi
Retail +
Robotics +
Sensors +
Swag
Tools +
Wearables +
Widgets
Wireless +
Retired +

HOME / PRODUCT CATEGORIES / KITS / FLIR DEV KIT

FLiR Dev Kit

KIT-13233 ROHS✔

★★★★☆ 5

Description: The FLiR Dev Kit includes a breakout as well as a Lepton® longwave infrared (LWIR) imager. With this kit you will be able to be able to bring FLiR's thermal imaging reliability and power to your Arduino, Raspberry Pi, or any ARM based development tool all in an easy to access breadboard friendly package. All you need to do to get this kit set up, simply attach the Lepton® imager module into the provided breakout, connect the headers, and you will be seeing in full darkness in no time!

The Lepton® LWIR module included in each FLiR Dev Kit packs a resolution of 80 x 60 pixels into a camera body that is smaller than a dime and captures infrared radiation input in its nominal response wavelength band (from 8 to 14 microns) and outputs a uniform thermal image. Meanwhile, each breakout board in these kits provides the socket for the Lepton®, power supply's, 25Mhz Crystal Oscillator, 100 mil header for use in a breadboard or wiring to any host system. A few things to consider about this kit: the breakout board will accept a 3-5V input and regulate it to what the Lepton® wants, to read an image from the lepton module all you need is an SPI port, and to configure the camera settings you also need an I^2C port, although this is not required.

Note: This kit comes in two separate parts and will need to be assembled once received. The Lepton® module is extremely sensitive to electrostatic discharge (ESD). When inserting it into the breakout board be sure to use proper personal grounding, such as a grounding wrist strap, to prevent damage the module.

Includes:

- 1x FLiR Lepton® - Thermal Imaging Module
- 1x FLiR Lepton® - Breakout Board

Features:

$349.95

ADD TO CART

1	quantity
	38 in stock
$349.95	1+ units

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4. Tag @FLIRONE on Instagram or @FLIR_ONE on Twitter
SAMPLE POST
We're out here #skateboarding red hot with the @FLIRONE #FLIRONEcontest

Research/Design Provocation

What if **everyone had a thermal camera** built into their smartphones?

Could ordinary people become **amateur thermographers** (*i.e.,* citizen scientists) contributing thermal data about built infrastructure in their cities?


13.9
1.8
Energy audits and
thermographic surveying
are time and labor intensive

How can we **automate** thermographic assessments?

1. Data collection
2. Model generation
3. Analysis
4. Report generation

How can we **automate** thermographic assessments?

What might this **automation enable**? For example, more frequent scanning may enable new types of temporal analyses.

Could we **automate** the thermographic inspection process using **robotics**?

Towards Automated Thermal Profiling of Buildings at Scale Using Unmanned Aerial Vehicles and 3D-Reconstruction

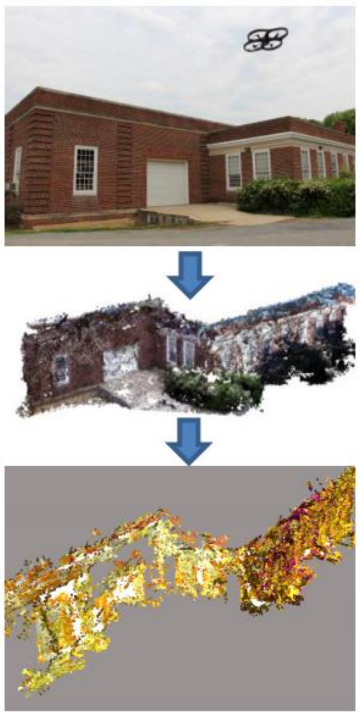

Figure 1: Example of partial 3D reconstruction using UAV and data from our thermal camera.

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Abstract

With increases in energy demand and problems due to climate change, governments are increasingly focused on building efficiency retrofits and renovations. To help inform these improvements, energy audits are often performed with thermal cameras that can detect poor insulation and air leakage; however, the data collection process is labor intensive and does not offer a comprehensive view of the buildings. We introduce our vision for a new, more scalable approach: automated 3D thermal profiling of buildings using unmanned aerial vehicles (UAV) and 3D-reconstruction. To demonstrate feasibility, we used an unmodified Parrot AR.Drone 2.0 and a FLIR thermal camera to collect RGB and thermal images of a building and generate 3D reconstructions.

http://dx.doi.org/10.1145/2638728.2638731

Author Keywords

3D thermography; Aerial robotics; Automated energy auditing; Building assessment; Sustainability

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

The building sector accounts for 41% of primary energy consumption in the US, far more than any other sector, and contributes an increasing portion of total carbon dioxide emissions—40% in 2009 compared to 33% in 1980 [9]. One reason for these high emissions is building age. Residential buildings, for example, constitute 95% of all buildings in the US and are on average over 50 years old [11]. Most were constructed with energy inefficient designs and their materials suffer from degradation effects due to weather and wear, further impacting efficiency. To address these issues, renovations and retrofits of existing building stock has become a national priority. The US Department of Energy has set a goal of reducing housing energy use by up to 70% [6].

[Source:: Mauriello & Froehlich, *UbiComp'14 Extended Abstracts*]

Source: Automation Group, Jacobs University Bremen, http://goo.gl/ZTN4Re, https://youtu.be/TPoCebERysc]


Irma3D Ground Robot
Equipped with Reigl VZ-400 laser scanner & Optris Imager PI thermal camera
Source: Automation Group, Jacobs University Bremen, http://goo.gl/ZTN4Re]

UbiComp'14: Reviewer 3

…There are actually many factors that need to be taken into account when doing exterior thermal scans…

It's not as simple as just taking thermal images. Temperature, sunlight, wind are some of the factors that need to be accounted for. It'd be great to do a formative study with energy auditors before proceeding too far with the research so that what is built improves upon the current/existing practices.

UbiComp'14: Reviewer 3

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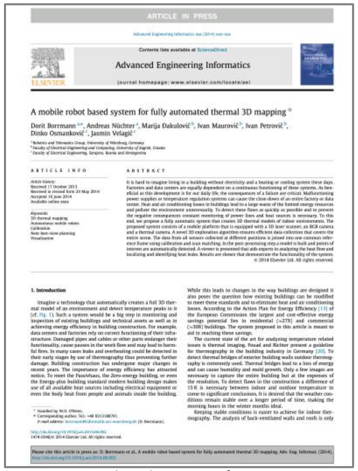
No Human Perspective in Automated Thermography Literature

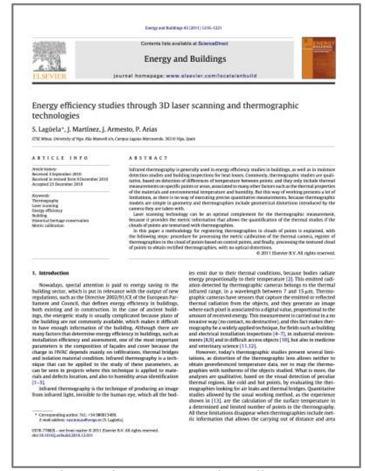
Reviewed over 30 papers in 'automated thermography.' No user studies, no investigations of how professional auditors may use or perceive emerging systems, no discussions of human-centered design, etc.

Previtali *et al.,Applied Geomatics'14*



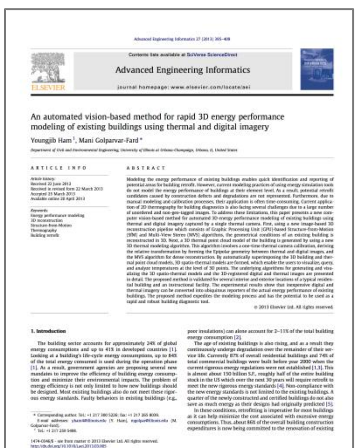
Bormann *et al., Adv. Eng. Informatics'14*

Laguela *et al., Q. Infrared Thermography'14*

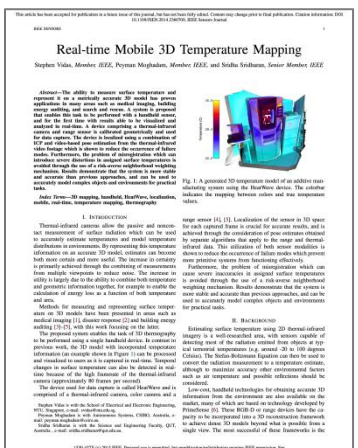


Laguela *et al., Energy and Buidlings'14*

Previtali *et al., J. Mobile Multimedia'14*

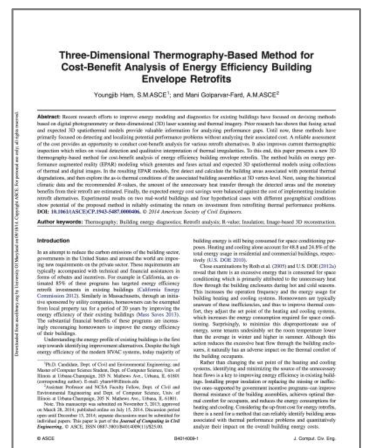


Ham*et al., Adv. Eng. Informatics'13*

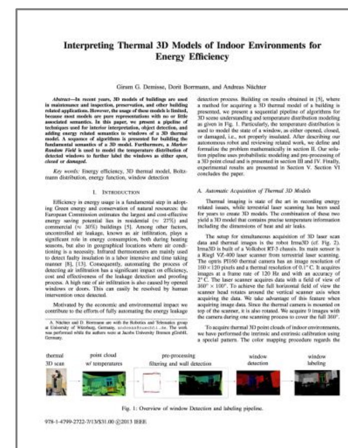


Vidas *et al., IEEE Sensors'14*

Wang *et al., J. Comp. Civil Engineering'13*



Ham *et al., J. Comp. Civil Engineering'14*



Demisse *et al., Intl. Conf. Adv. Robotics'13*

N... MOGRAPHY LITERATURE

R... vestigations of how professional
a... tered design, etc.

Interpreting Thermal 3D Models of Indoor Environments for Energy Efficiency

Girum G. Demisse, Dorit Borrmann, and Andreas Nüchter

***Abstract*—In recent years, 3D models of buildings are used in maintenance and inspection, preservation, and other building related applications. However, the usage of these models is limited, because most models are pure representations with no or little associated semantics. In this paper, we present a pipeline of techniques used for interior interpretation, object detection, and adding energy related semantics to windows of a 3D thermal model. A sequence of algorithms is presented for building the fundamental semantics of a 3D model. Furthermore, a *Markov Random Field* is used to model the temperature distribution of detected windows to further label the windows as either *open*, *closed* or *damaged*.**

Key words: Energy efficiency, 3D thermal model, Boltzmann distribution, energy function, window detection

I. Introduction

Efficiency in energy usage is a fundamental step in adopting Green energy and conservation of natural resources: the European Commission estimates the largest and cost-effective energy saving potential lies in residential ($\approx$ 27%) and commercial ($\approx$ 30%) buildings [5]. Among other factors, uncontrolled air leakage, known as air infiltration, plays a significant role in energy consumption, both during heating seasons, but also in geographical locations where air conditioning is a necessity. Infrared thermometers are mainly used to detect faulty insulation in a labor intensive and time taking manner [8], [13]. Consequently, automating the process of detecting air infiltration has a significant impact on efficiency, cost and effectiveness of the leakage detection and proofing process. A high rate of air infiltration is also caused by opened windows or doors. This can easily be resolved by human intervention once detected.

Motivated by the economic and environmental impact we contribute to the efforts of fully automating the energy leakage detection process. Building on results obtained in [5], where a method for acquiring a 3D thermal model of a building is presented, we present a sequential pipeline of algorithms for 3D scene understanding and temperature distribution modeling as given in Fig. 1. Particularly, the temperature distribution is used to model the state of a window, as either opened, closed, or damaged, i.e., not properly insulated. After describing our autonomous robot and reviewing related work, we define and formalize the problem mathematically in section II. Our solution pipeline uses probabilistic modeling and pre-processing of a 3D point cloud and is presented in section III and IV. Finally, experimental results are presented in Section V. Section VI concludes the paper.

A. Automatic Acquisition of Thermal 3D Models

Thermal imaging is state of the art in recording energy related issues, while terrestrial laser scanning has been used for years to create 3D models. The combination of these two yield a 3D model that contains precise temperature information including the dimensions of heat and air leaks.

The setup for simultaneous acquisition of 3D laser scan data and thermal images is the robot Irma3D (cf. Fig. 2). Irma3D is built of a Volksbot RT-3 chassis. Its main sensor is a Riegl VZ-400 laser scanner from terrestrial laser scanning. The optris PI160 thermal camera has an image resolution of 160×120 pixels and a thermal resolution of $0.1°$ C. It acquires images at a frame rate of 120 Hz and with an accuracy of $2°$ C. The laser scanner acquires data with a field of view of $360° \times 100°$. To achieve the full horizontal field of view the scanner head rotates around the vertical scanner axis when acquiring the data. We take advantage of this feature when acquiring image data. Since the thermal camera is mounted on top of the scanner, it is also rotated. We acquire 9 images with the camera during one scanning process to cover the full 360°.

To acquire thermal 3D point clouds of indoor environments, we have performed the intrinsic and extrinsic calibration using a special pattern. The color mapping procedure regards the

A. Nüchter and D. Borrmann are with the Robotics and Telematics group at University of Würzburg, Germany, andreas@nuechti.de. The work was performed while the authors were at Jacobs University Bremen gGmbH, Germany.

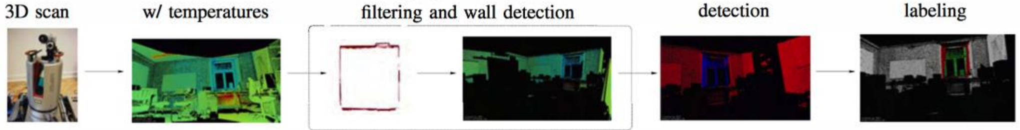
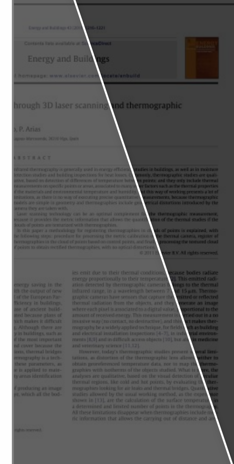
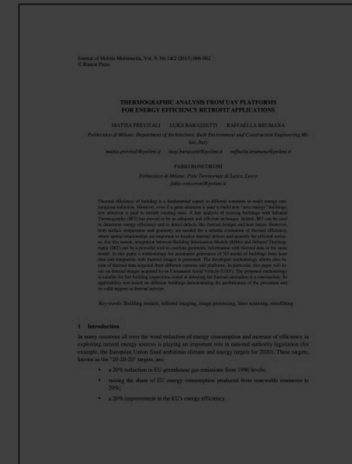


Fig. 1: Overview of window Detection and labeling pipeline.

978-1-4799-2722-7/13/$31.00 ©2013 IEEE



Energy and Buidlings'14



Previtali *et al.*, *J. Mobile Multimedia'14*

Comp. Civil Engineering'14

Demisse *et al., Intl. Conf. Adv. Robotics'13*

Prev...

Han...

Source: Mauriello, Norooz, & Froehlich, *CHI'15*

Understanding the Role of Thermography in Energy Auditing: Current Practices and the Potential for Automated Solutions

Matthew Louis Mauriello[1], Leyla Norooz[2], Jon E. Froehlich[1]
Makeability Lab | Human-Computer Interaction Lab (HCIL)
Department of Computer Science[1], College of Information Studies[2]
University of Maryland, College Park
{mattm401, leylan, jonf}@umd.edu

ABSTRACT
The building sector accounts for 41% of primary energy consumption in the US, contributing an increasing portion of the country's carbon dioxide emissions. With recent sensor improvements and falling costs, auditors are increasingly using thermography—infrared (IR) cameras—to detect thermal defects and analyze building efficiency. Research in *automated* thermography has grown commensurately, aimed at reducing manual labor and improving thermal models. Though promising, we could find no prior work exploring the professional auditor's perspectives of thermography or reactions to emerging automation. To address this gap, we present results from two studies: a semi-structured interview with 10 professional energy auditors, which includes design probes of five automated thermography scenarios, and an observational case study of a residential audit. We report on common perspectives, concerns, and benefits related to thermography and summarize reactions to our automated scenarios. Our findings have implications for thermography tool designers as well as researchers working on automated solutions in robotics, computer science, and engineering.

Author Keywords
Energy audits; thermography; robotics; formative inquiry; design probes; Sustainable HCI; human-robotic interaction

ACM Classification Keywords
H.5.m. Information interfaces and presentation (*e.g.*, HCI)

INTRODUCTION
The building sector accounts for 41% of primary energy consumption in the US, far more than any other sector, and contributes an increasing portion of total carbon dioxide emissions—40% in 2009 compared to 33% in 1980 [46]. One reason for these high emissions is building age.

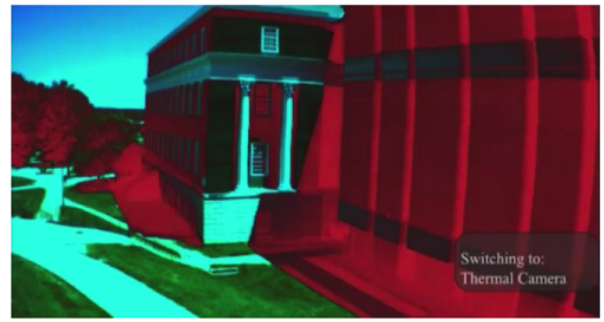


Figure 1: We developed five automated thermography scenarios inspired by the research literature (*e.g.*, [6,10,35,41]) to help elicit reactions to envisioned automated solutions. Above, a screen capture from our unmanned aerial vehicle (UAV) design probe. See supplementary video.

designs and their materials have degraded over time. To address these issues, renovations and retrofits of existing building stock has become a pressing need. The US Department of Energy (DOE), for example, has set a goal of reducing housing energy use by up to 70% [37]

As a response, professional energy auditing has seen a resurgence of interest [25,39]. Audits help identify building inefficiencies through walk-through inspections, on-site measurements, and computer simulations [45]. The DOE recommends home energy audits because of their impact on reducing energy usage (*e.g.*, 5-30% reductions in monthly utility bills) and increasing structural safety [49]. With recent improvements in handheld sensor technology and falling costs, auditors are increasingly using thermography—infrared (IR) scanning with thermal cameras—to detect thermal defects and air leakage [2,8,28,47].

Work in *automated* thermography has also grown markedly in the past three years, encompassing disciplines from

Automated Thermography

9 of 10 energy auditors agreed that there was **value in automated data collection**, especially related to:

- saving time and money
- assessing otherwise inaccessible parts of buildings (*e.g.,* rooftops)
- scaling up what can be surveyed (*e.g.,* entire neighborhoods)
- enabling new types of analyses (*e.g.,* track building over time)
- automatic anomaly detection
- higher fidelity model generation (*e.g,* 3D reconstructions)

CONCERNS

The most common concerns:

- **data quality:** automated approaches lack control of environment
- **data overload:** how to manage orders of magnitude more data?
- **social process:** energy auditing is a socio-technical process
- **fear and privacy:** who owns data? how can you opt-out?

MIT News
ON CAMPUS AND AROUND THE WORLD

FULL SCREEN

A heat map of a home captured by one of Essess' thermal-imaging cars.

Courtesy of Essess

Drive-by heat mapping

Startup's thermal-imaging cars can quickly track energy leaks in thousands of homes and buildings.

Rob Matheson | MIT News Office
January 5, 2015

In 2007, Google unleashed a fleet of cars with roof-mounted cameras to provide street-level images of roads around the world. Now MIT spinout Essess is bringing similar "drive-by" innovations to energy efficiency in homes and businesses.

RELATED
Essess
Sanja Sarma

Essess Car

http://www.essess.com

THERMAL ANALYSIS PROGRAM

Helping to make your home stronger.

0001

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Congratulations, you have been selected to participate in <Client's> Thermal Analysis Program to help make your home stronger.

Get Started Here

Thermal imaging is a new technology that helps you identify energy leaks in your home that result in loss of comfort and wasted energy. Review the sample home to the left and the information below to learn how to spot and fix common energy leaks.

Next month you will receive a thermal image of your own home in the mail. Please save this report to use as a reference guide when reviewing your home. This will help you identify and fix leaks that will make your home stronger and more comfortable while lowering your energy bills.

1 

INSULATE YOUR BASEMENT WALLS. The area of the basement that is above ground is often poorly insulated, and is a major source of escaped heat from your home. Sealing leaks and adding a bit of insulation can help cut down your energy bill.

2 

SEAL EDGES AROUND YOUR CHIMNEY. The area where the chimney meets the house can be a major source of leaks. Using caulk or insulated plates can be a relatively low-cost way to seal it up.

3 

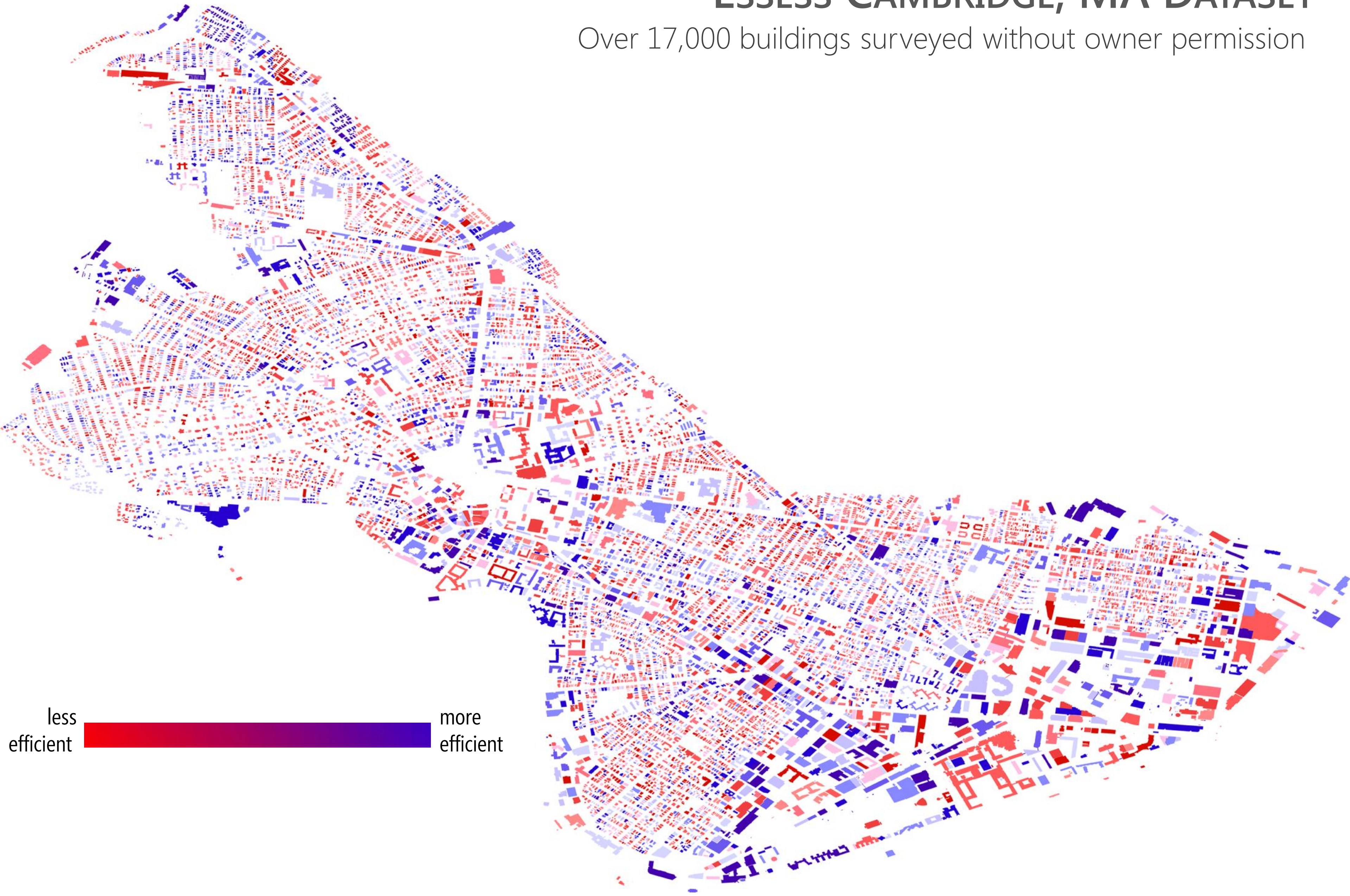
MAKE SURE YOUR WINDOW FRAMES DON'T LEAK. Bright areas around the edges of windows means that they are leaking air out of the house. A bit of caulk can easily seal them up.

4 

IMPROVE YOUR ATTIC INSULATION. Heat rises, and a lot of it escapes through poorly insulated attics. Adding attic insulation is easy to do and can save you big on your heating bills.

Essess Cambridge, MA Dataset

Over 17,000 buildings surveyed without owner permission



[Source: http://www.essess.com/technology/scale/]

Venture Capital Dispatch

An inside look from VentureWire at high-tech startups and their investors.

ASIA
China Venture Investing, Driven by Mobile, Soared to Record Level in 2014

DATA
Venture Investors Seeded Fewer Companies in 2014

DATA | COMPANY FUNDING | VENTURE FUNDS | M&A | IPOS | PEOPLE

10:30 am ET
Nov 20, 2014 BIG DATA

Heat-Mapping Startup Essess Picks Up $10.8 Million to Scan for Energy Leaks

ARTICLE COMMENTS

BIG DATA CLEANTECH ENERGY ENERGY EFFICIENCY ESSESS

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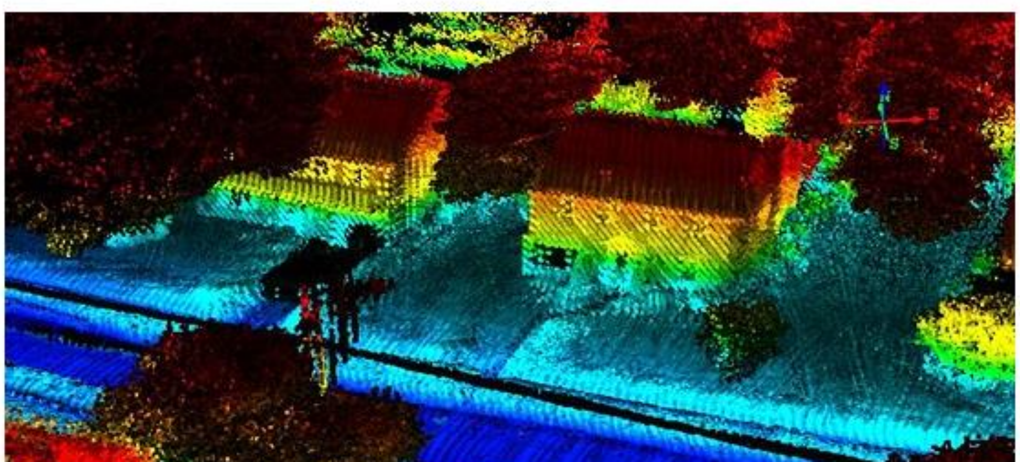
By YULIYA CHERNOVA CONNECT



PREVIOUS
Techstars Graduates' Survival Rates: What the Numbers Show

NEXT
Uber's Massive Fundraising Campaign Forges Ahead Amid Controversy

SEARCH VENTURE CAPITAL DISPATCH GO

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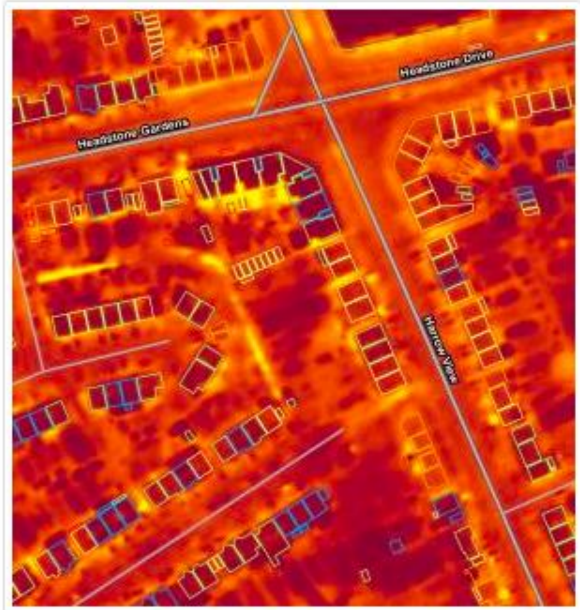
Bluesky Aerial Survey Data Helps London's Harrow Council Identify Illegal Dwellings



Thermal imaging and laser scan data collected by aircraft is helping London's Harrow Council tackle the growing problem of unscrupulous landlords renting out sheds and outbuildings as dwellings. Supplied by aerial mapping company Bluesky, the map accurate thermal images are combined with detailed LiDAR measurements to give staff at Harrow Council a much better understanding of where unpermitted developments may have been erected and their potential occupation evidenced as "hot spots" in the data.

Bluesky Aerial Survey Data Helps London's Harrow Council Identify Illegal Dwellings

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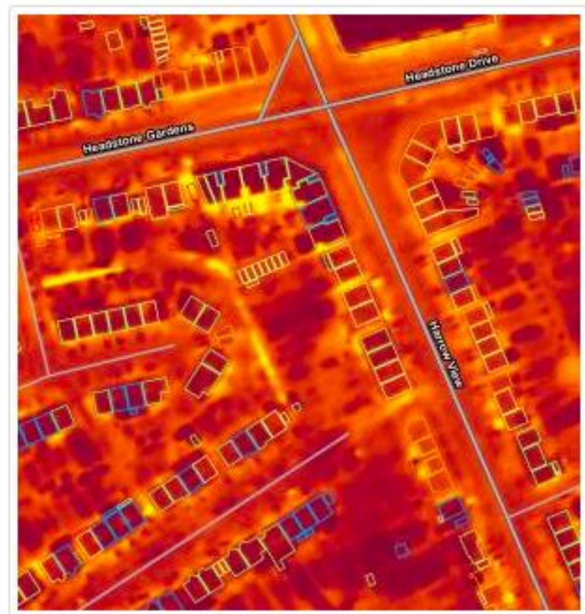


Future Work

Engage in participatory design with auditors and continue ethnographic fieldwork

Investigate computer vision to automatically infer building structures such as windows & doors (*e.g.,* to calculate window-to-wall ratios)

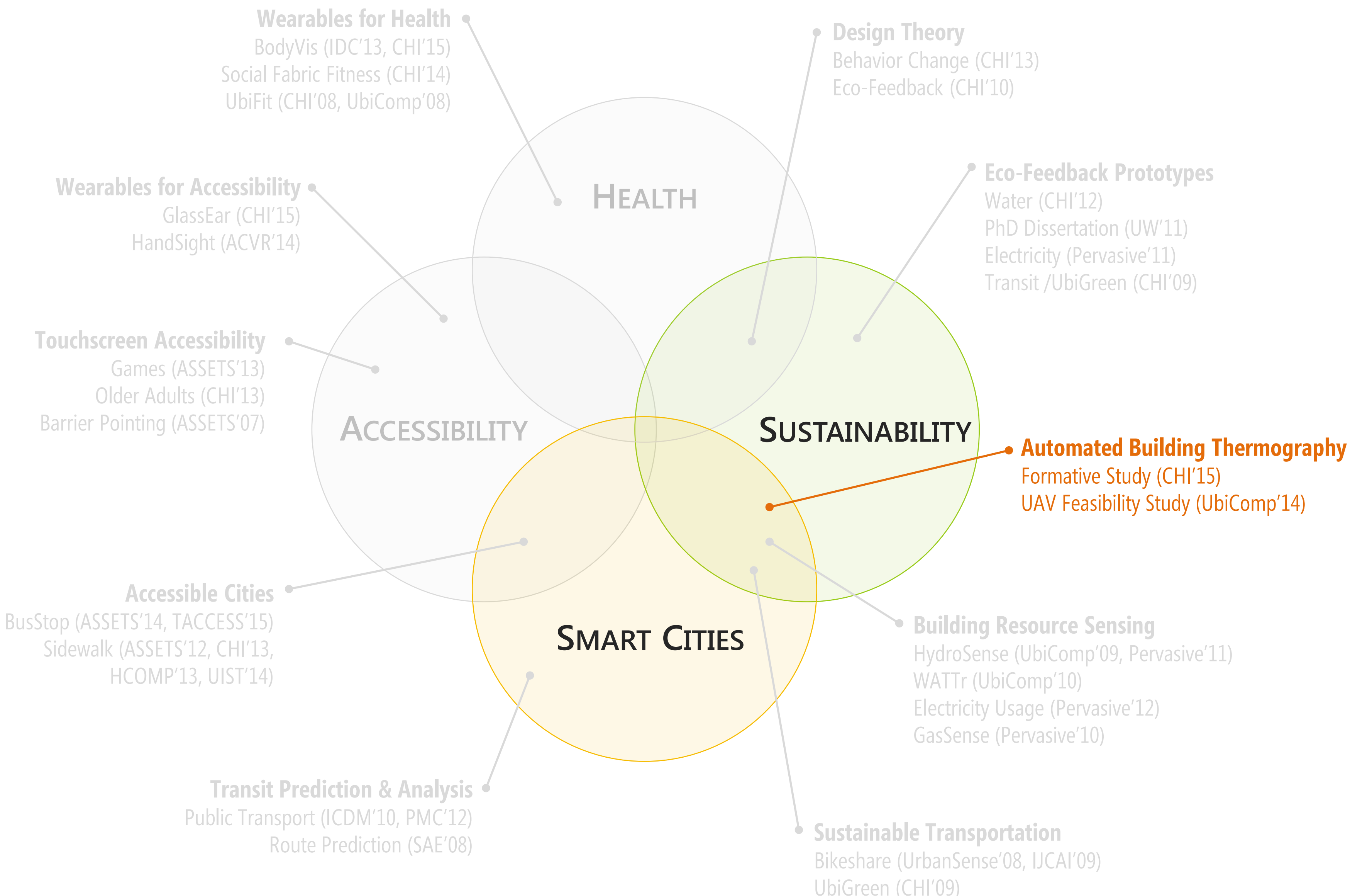
Explore benefits of temporal analyses, anomaly detection, and 3D reconstruction

Examine opportunities for automating indoor thermographic inspections

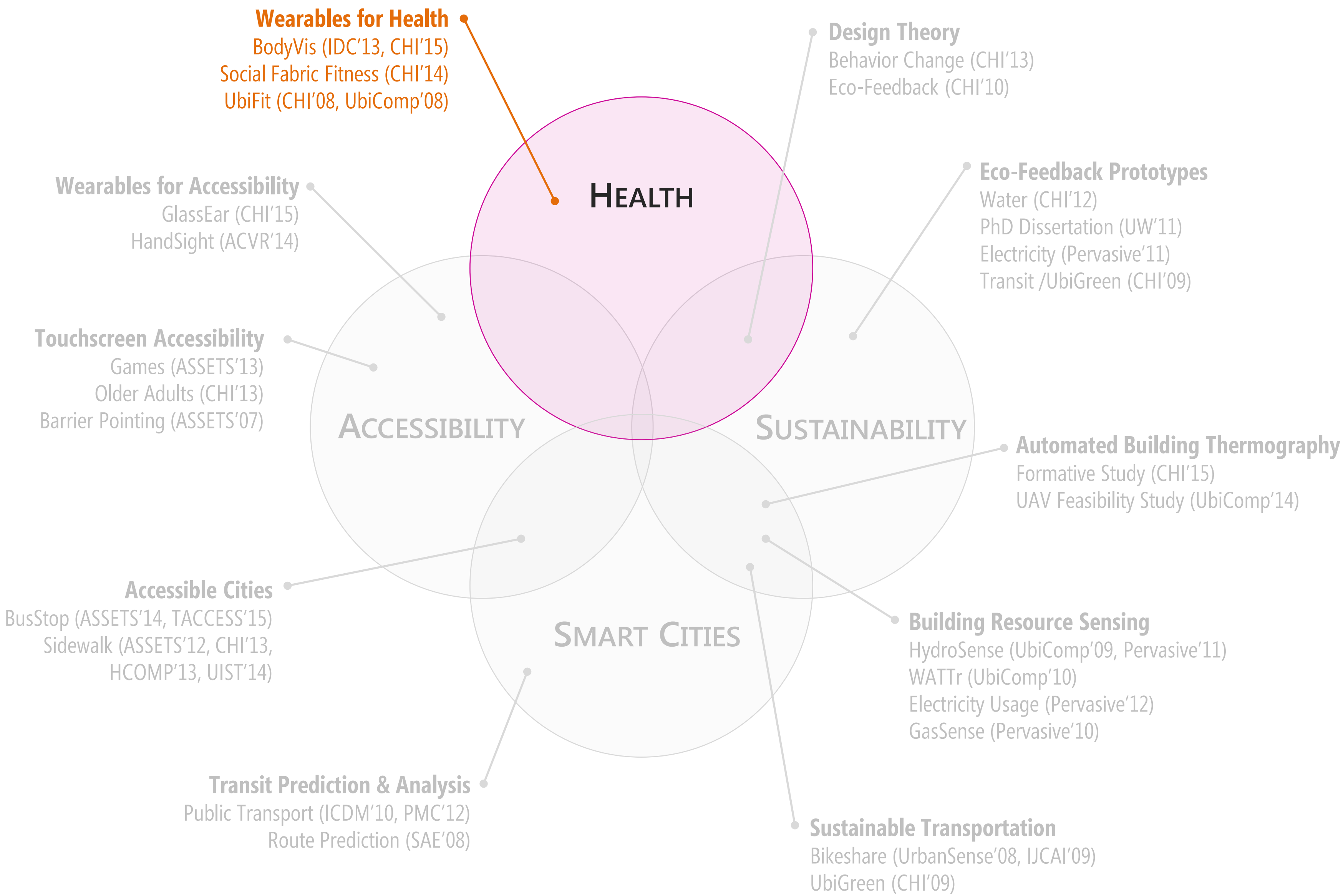
Explore privacy and policy implications

Source: UAV Workswell Thermal Vision Pro, https://youtu.be/f3suOumbmrU

My Research


Wearables for Health
BodyVis (IDC'13, CHI'15)
Social Fabric Fitness (CHI'14)
UbiFit (CHI'08, UbiComp'08)
Design Theory
Behavior Change (CHI'13)
Eco-Feedback (CHI'10)
Wearables for Accessibility
GlassEar (CHI'15)
HandSight (ACVR'14)
Eco-Feedback Prototypes
Water (CHI'12)
PhD Dissertation (UW'11)
Electricity (Pervasive'11)
Transit /UbiGreen (CHI'09)
Health
Touchscreen Accessibility
Games (ASSETS'13)
Older Adults (CHI'13)
Barrier Pointing (ASSETS'07)
Accessibility
Sustainability
Automated Building Thermography
Formative Study (CHI'15)
UAV Feasibility Study (UbiComp'14)
Accessible Cities
BusStop (ASSETS'14, TACCESS'15)
Sidewalk (ASSETS'12, CHI'13,
HCOMP'13, UIST'14)
Smart Cities
Building Resource Sensing
HydroSense (UbiComp'09, Pervasive'11)
WATTr (UbiComp'10)
Electricity Usage (Pervasive'12)
GasSense (Pervasive'10)
Transit Prediction & Analysis
Public Transport (ICDM'10, PMC'12)
Route Prediction (SAE'08)
Sustainable Transportation
Bikeshare (UrbanSense'08, IJCAI'09)
UbiGreen (CHI'09)

My Research



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Bikeshare (UrbanSense'08, IJCAI'09)
UbiGreen (CHI'09)

Most of my recent work in this space has been with **e-textiles**

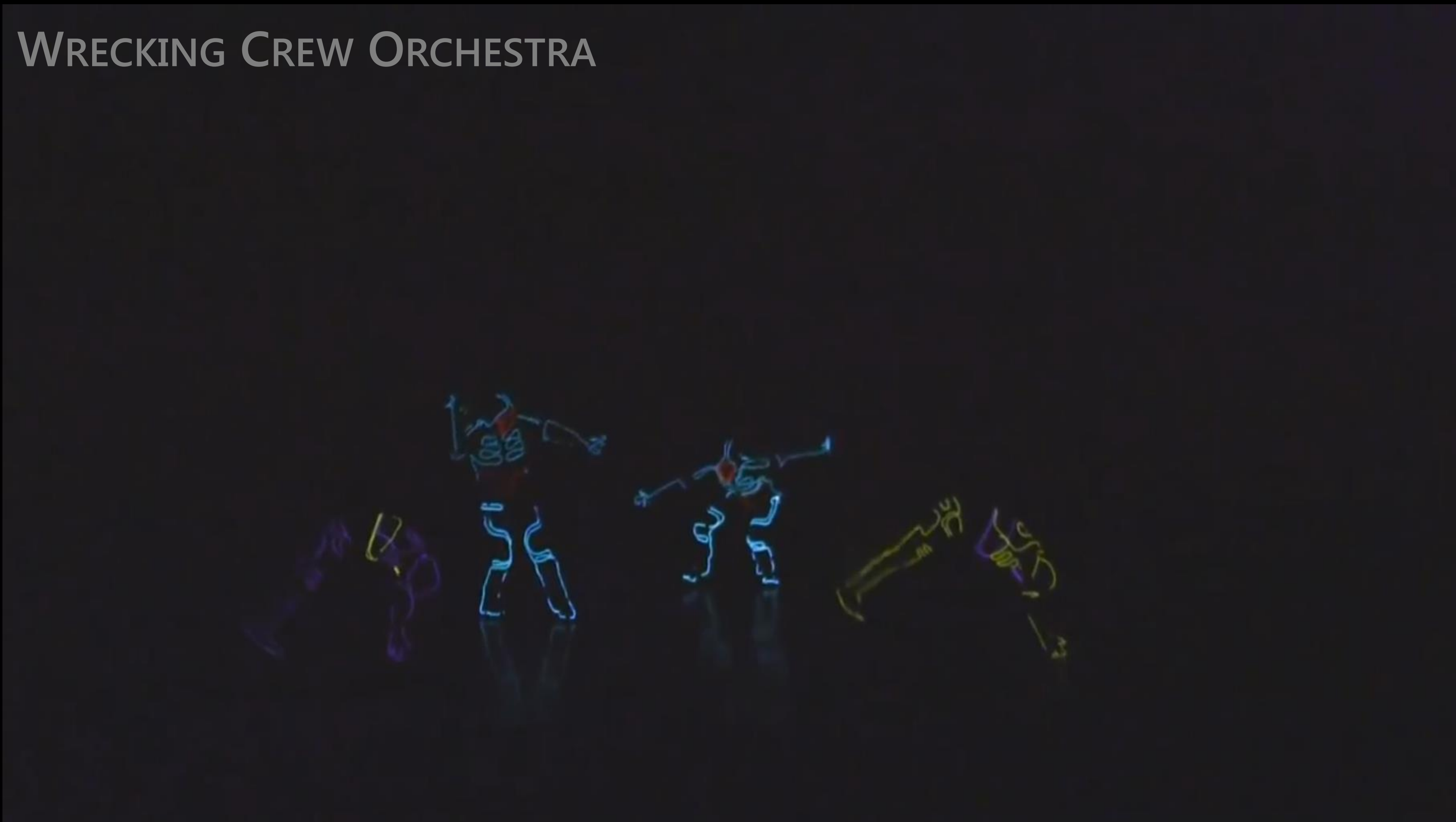
WHAT ARE?

ELECTRONIC TEXTILES

E-textiles are **textiles** with **embedded electronics**/digital components (including small computers)

Wrecking Crew Orchestra

Source: http://youtu.be/6ydeY0tTtF4


WRECKING CREW ORCHESTRA

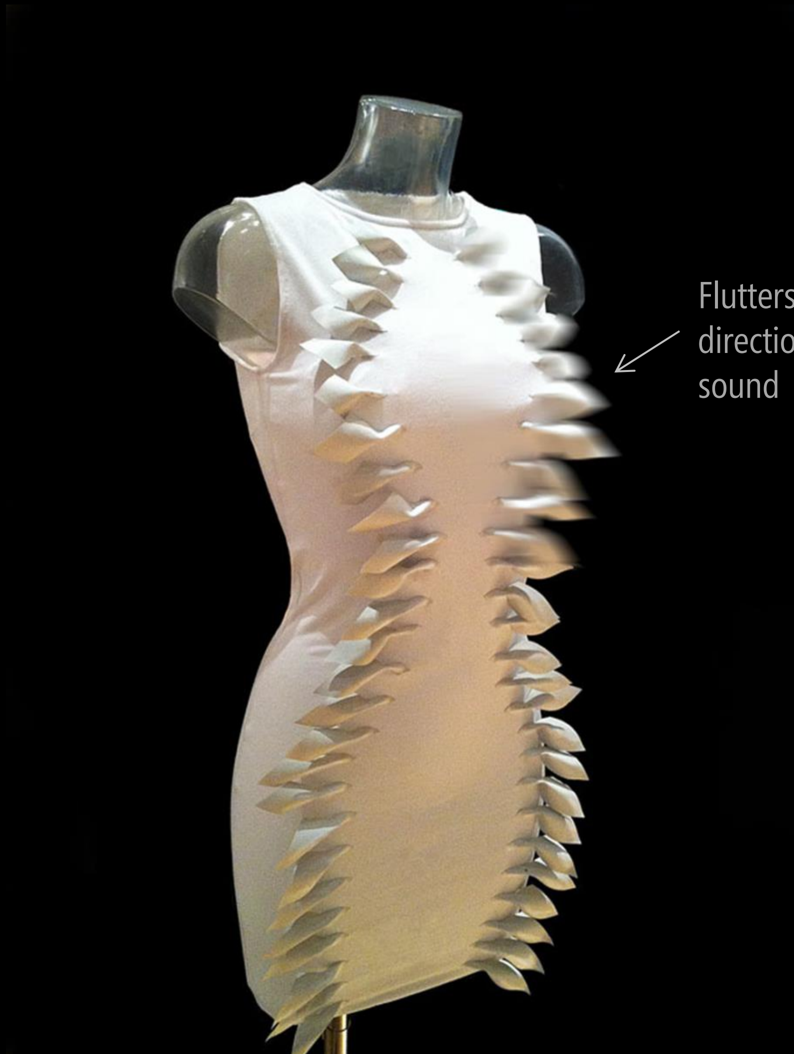
Carrie Underwood's Dress
2013 Grammy Awards

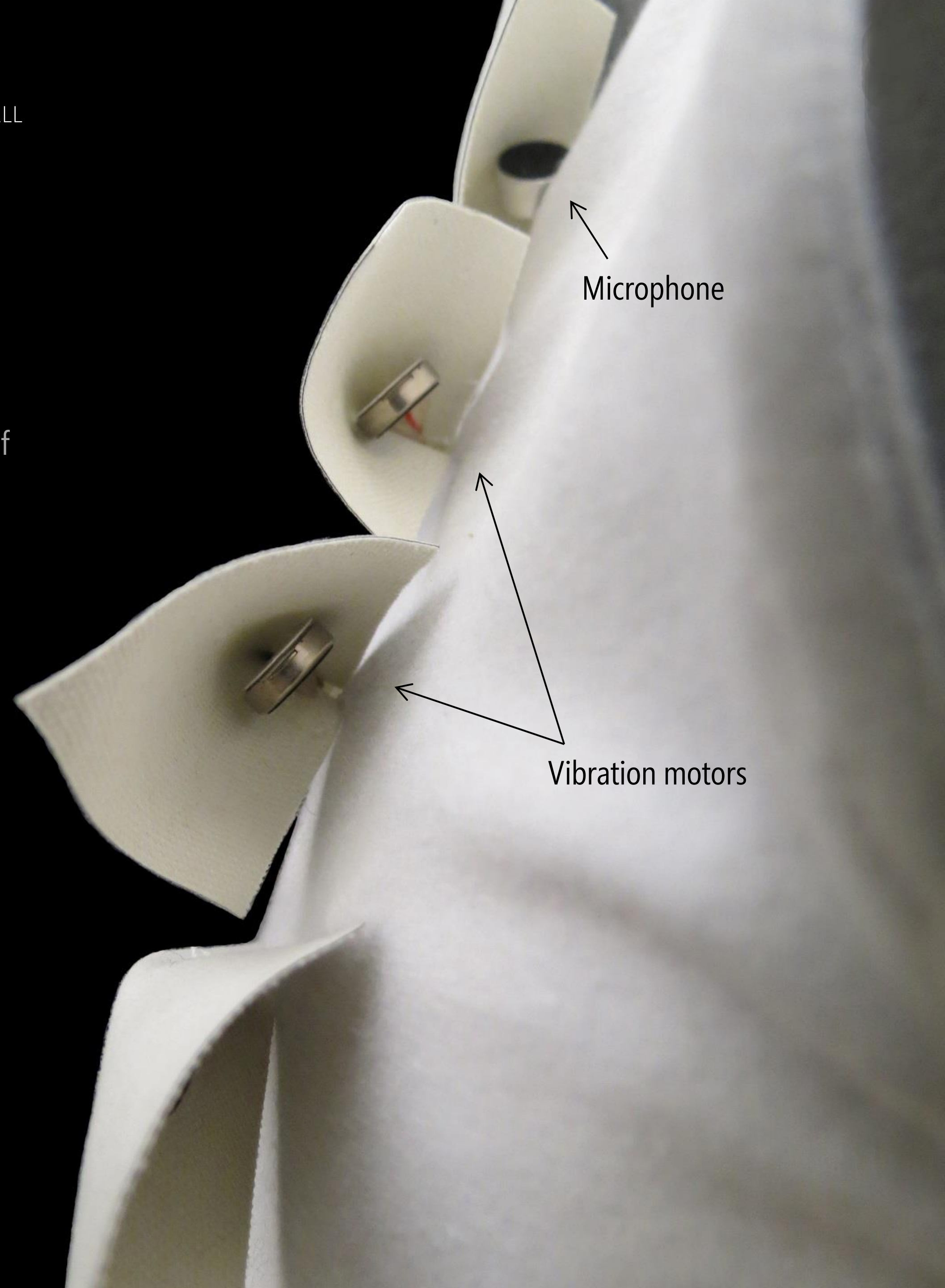
The Printing Dress
Asta Roseway
Microsoft Research

Source: http://youtu.be/_9EVo2RicS0

Flutter

Designers: Halley Profita, Nicholas Farrow,,Nikolaus Correll



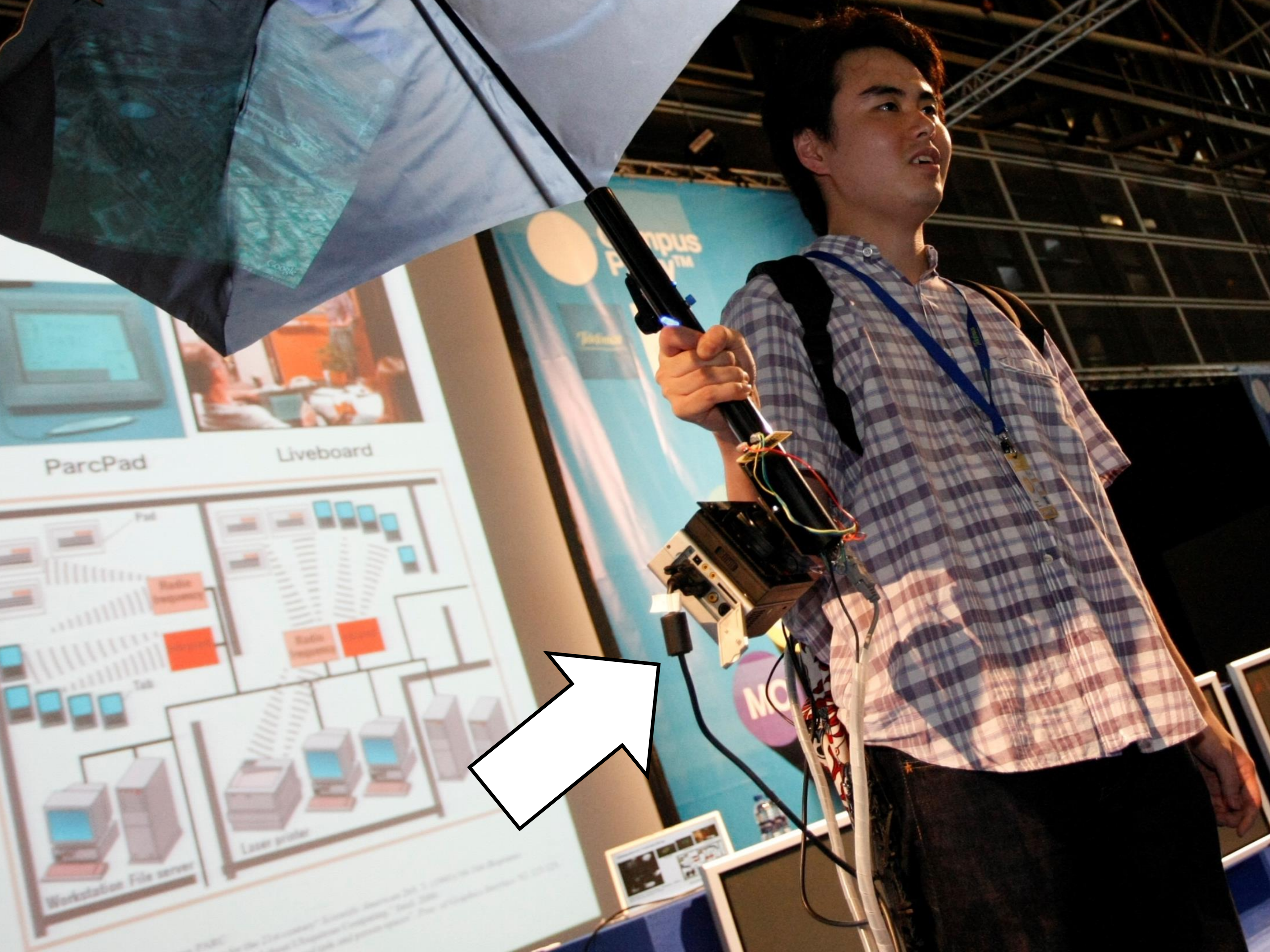


Source: IWSC2012

Pileus: The Internet Umbrella

Designers: Sho Hashimoto & Takashi Matsumoto

Source: http://www.pileus.net/

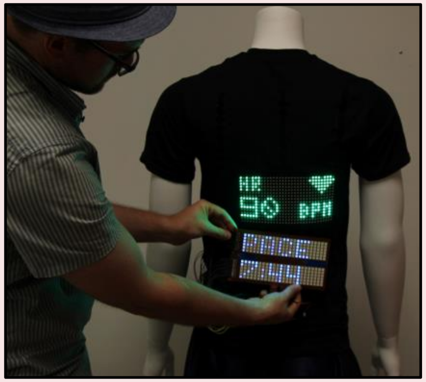

ParcPad
Liveboard
Pad
Tab
Laser printer
Workstation
File server

HOW CAN E-TEXTILES

BE USED TO SUPPORT:

- LEARNING
- SOCIAL INTERACTIONS
- HEALTH & WELLNESS
- INTROSPECTION
- PLAY
- PERSONAL EXPRESSION

2 BRIEF EXAMPLES



SOCIAL FABRIC FITNESS

BODYVIS

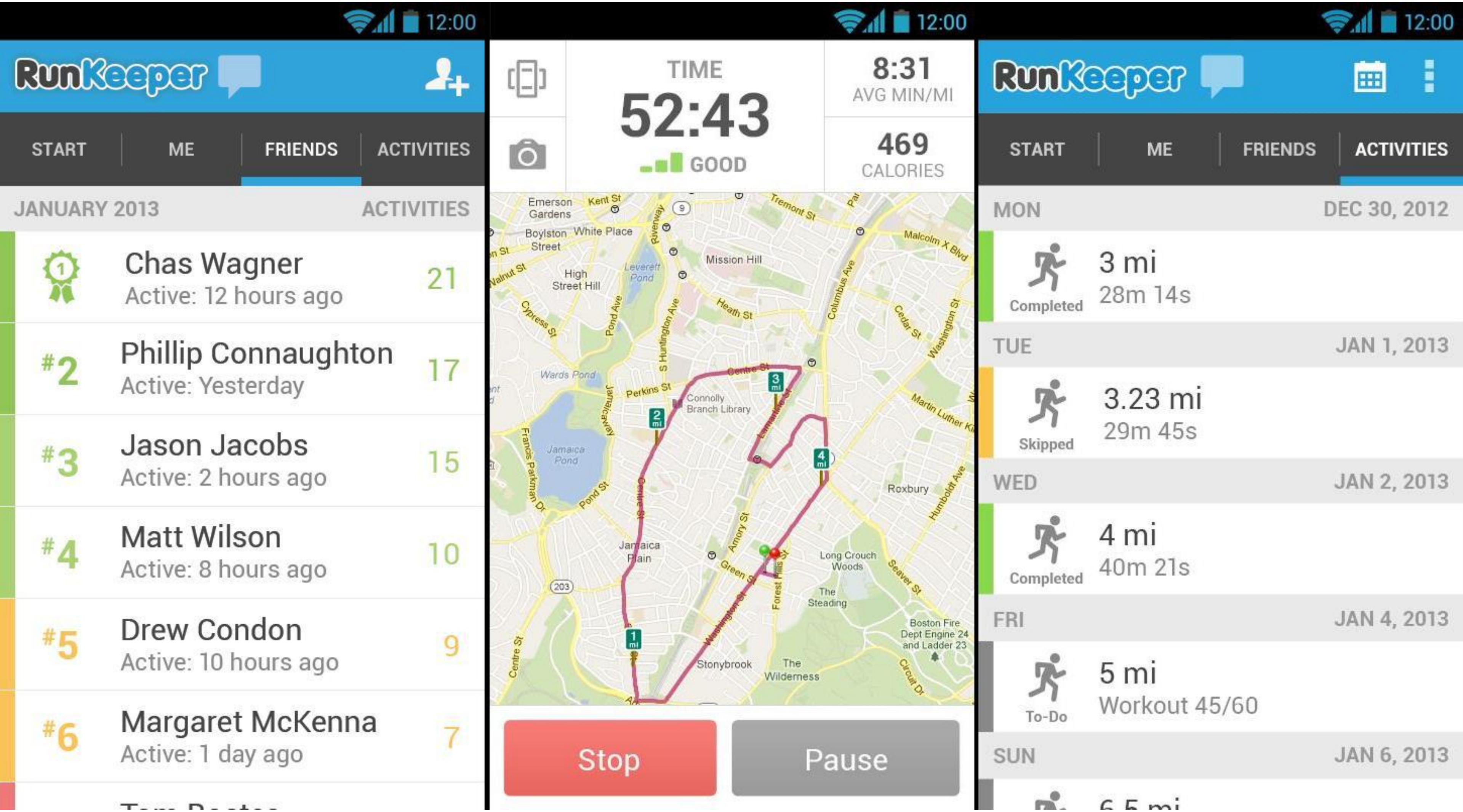
2 BRIEF EXAMPLES

SOCIAL FABRIC FITNESS

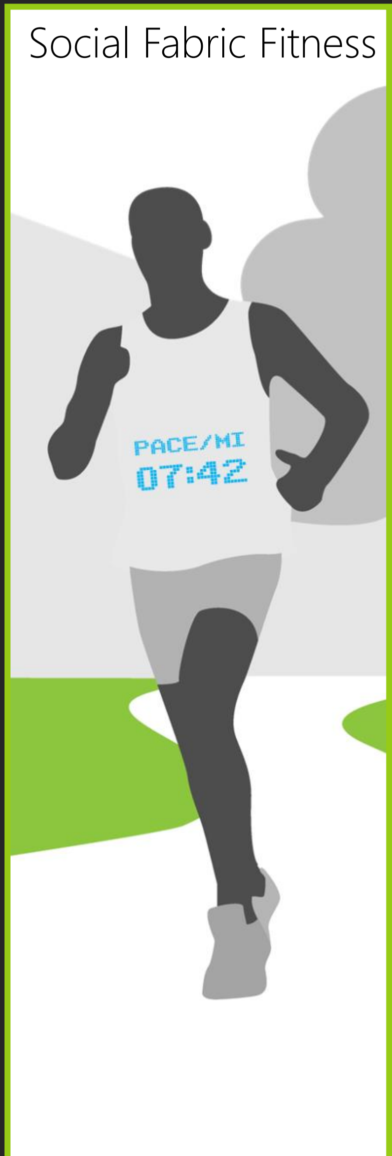
BODYVIS


ORIGINAL FITBIT


FITBIT FORCE
5.89MI


12:00
RunKeeper
START
ME
FRIENDS
ACTIVITIES
JANUARY 2013
ACTIVITIES
Chas Wagner
Active: 12 hours ago
21
#2
Phillip Connaughton
Active: Yesterday
17
#3
Jason Jacobs
Active: 2 hours ago
15
#4
Matt Wilson
Active: 8 hours ago
10
#5
Drew Condon
Active: 10 hours ago
9
#6
Margaret McKenna
Active: 1 day ago
7
12:00
TIME
52:43
GOOD
8:31
AVG MIN/MI
469
CALORIES
Emerson Gardens
Kent St
Tremont St
Boylston Street
White Place
Mission Hill
Malcolm X Blvd
High Street Hill
Leverett Pond
Heath St
Columbus Ave
Cedar St
Washington St
Wards Pond
Perkins St
Centre St
Connolly Branch Library
Martin Luther King
Jamaica Pond
Roxbury
Jamaica Plain
Amory St
Long Crouch Woods
Green St
The Steading
Boston Fire Dept Engine 24 and Ladder 23
Stonybrook
The Wilderness
Stop
Pause
12:00
RunKeeper
START
ME
FRIENDS
ACTIVITIES
MON
DEC 30, 2012
3 mi
28m 14s
Completed
TUE
JAN 1, 2013
3.23 mi
29m 45s
Skipped
WED
JAN 2, 2013
4 mi
40m 21s
Completed
FRI
JAN 4, 2013
5 mi
Workout 45/60
To-Do
SUN
JAN 6, 2013

What if Our Clothes Could Show How Fast We Run?

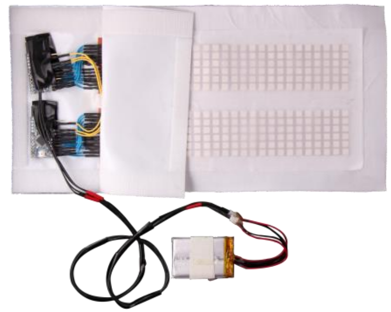


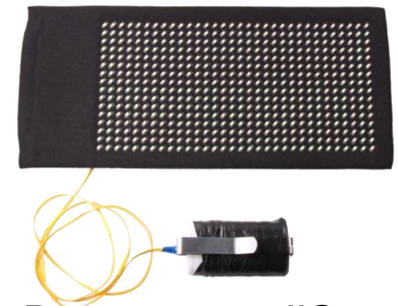
HOW WOULD A SEMI-PUBLIC DISPLAY CHANGE THE EXPERIENCE OF RUNNING?

WOULD RUNNERS FEEL STRESS OR ADDITIONAL MOTIVATION?

COULD THE DISPLAYS BE USED TO SUPPORT RACES OR IN RUNNING GROUPS?

SFF: Three Interactive Prototypes



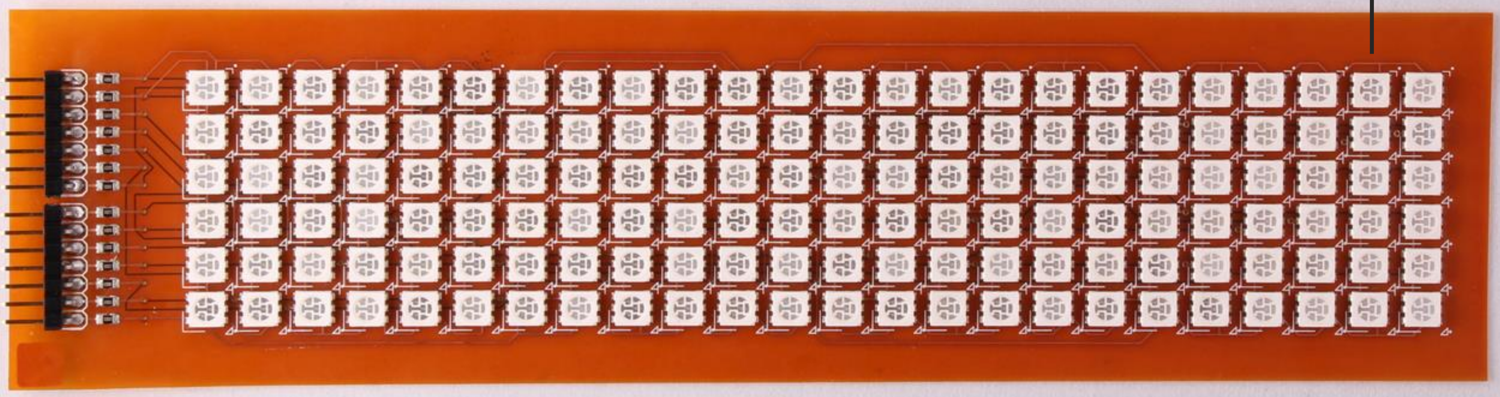


	Prototype #1	Prototype #2	Prototype #3
Manufacturer	Our Team	Plastic Logic	Erogear
Display Weight	66.9 g	25.4 g	46.8 g
Total Weight	152.9 g	411.7 g	161.2 g
Pixels	24 x 12	320 x 240	32 x 16
Refresh Rate	5 Hz	1.1 Hz	38 Hz
Dimensions*	21.3 x 12.2 cm	18.4 x 14 cm	20.3 x 15.2 cm
Display Thickness*	13.5 mm	4.9 mm	4.8 mm

* With enclosure

Prototype #1

Manufactured Flexible PCB

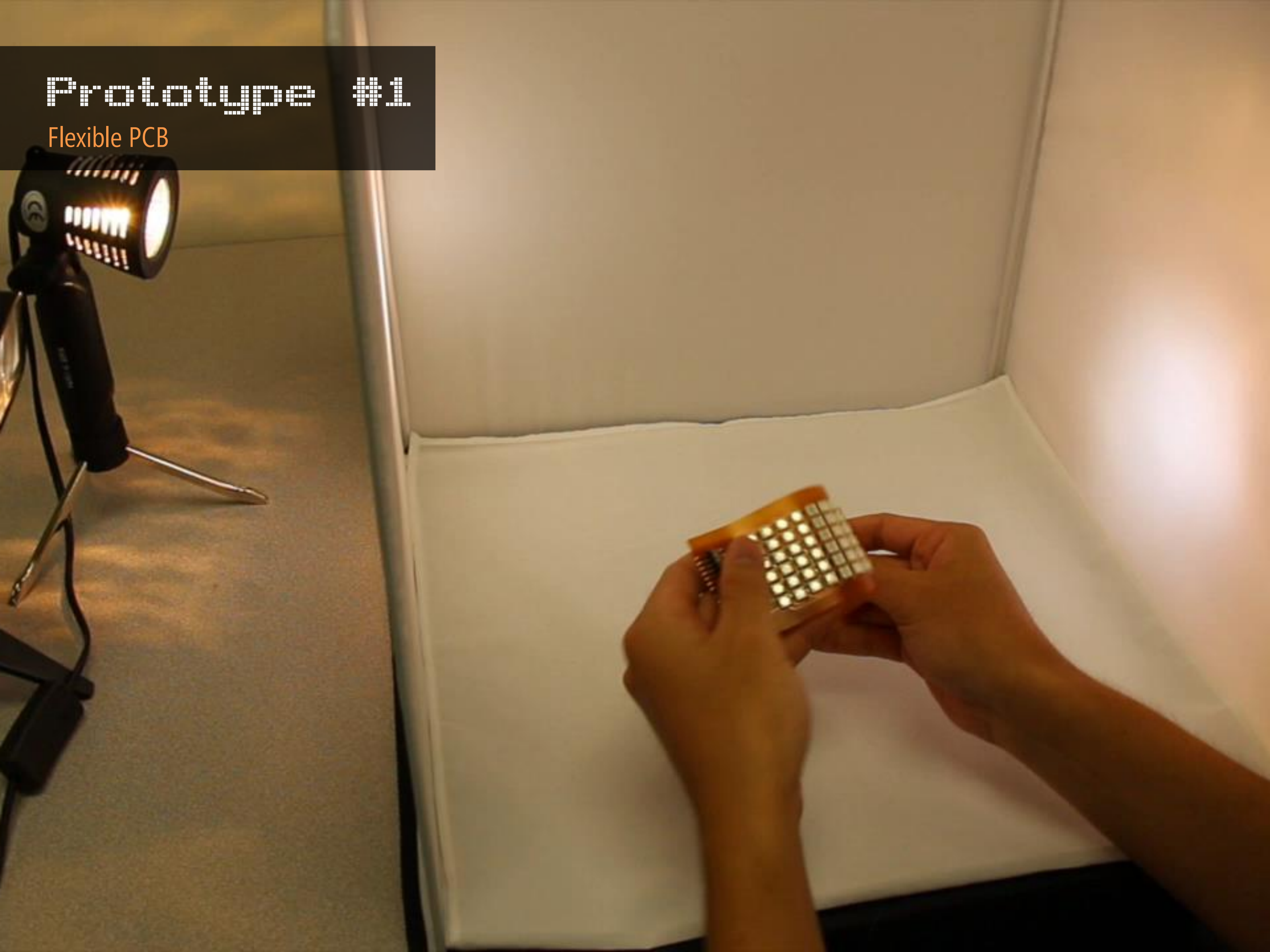


Flexible PCB

24 x 6 Matrix

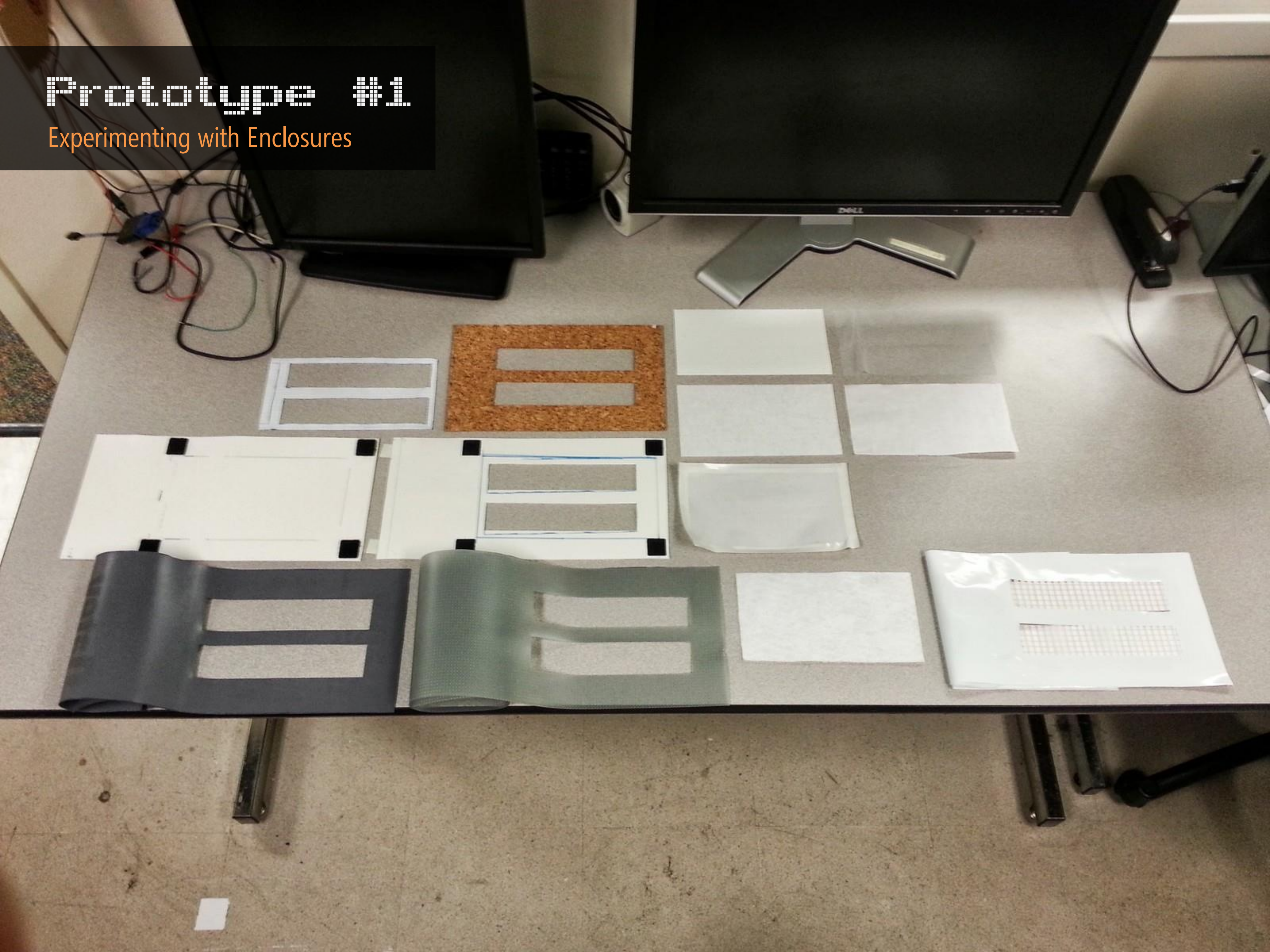
Green or Blue LEDs

Manufactured at PCBUniverse.com and pick-and-place performed by Tristate Electronics


Prototype #1
Flexible PCB

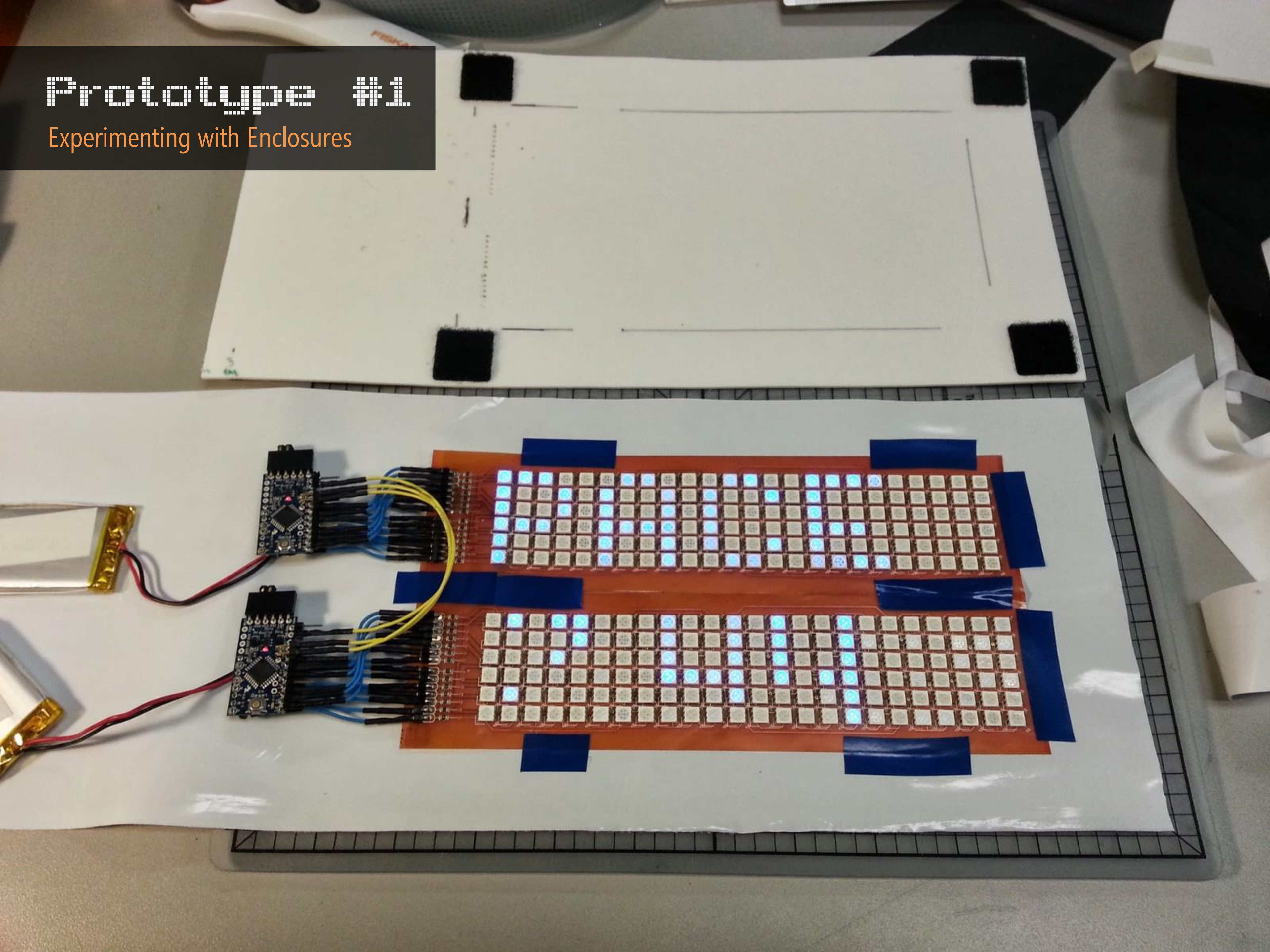
Prototype #1

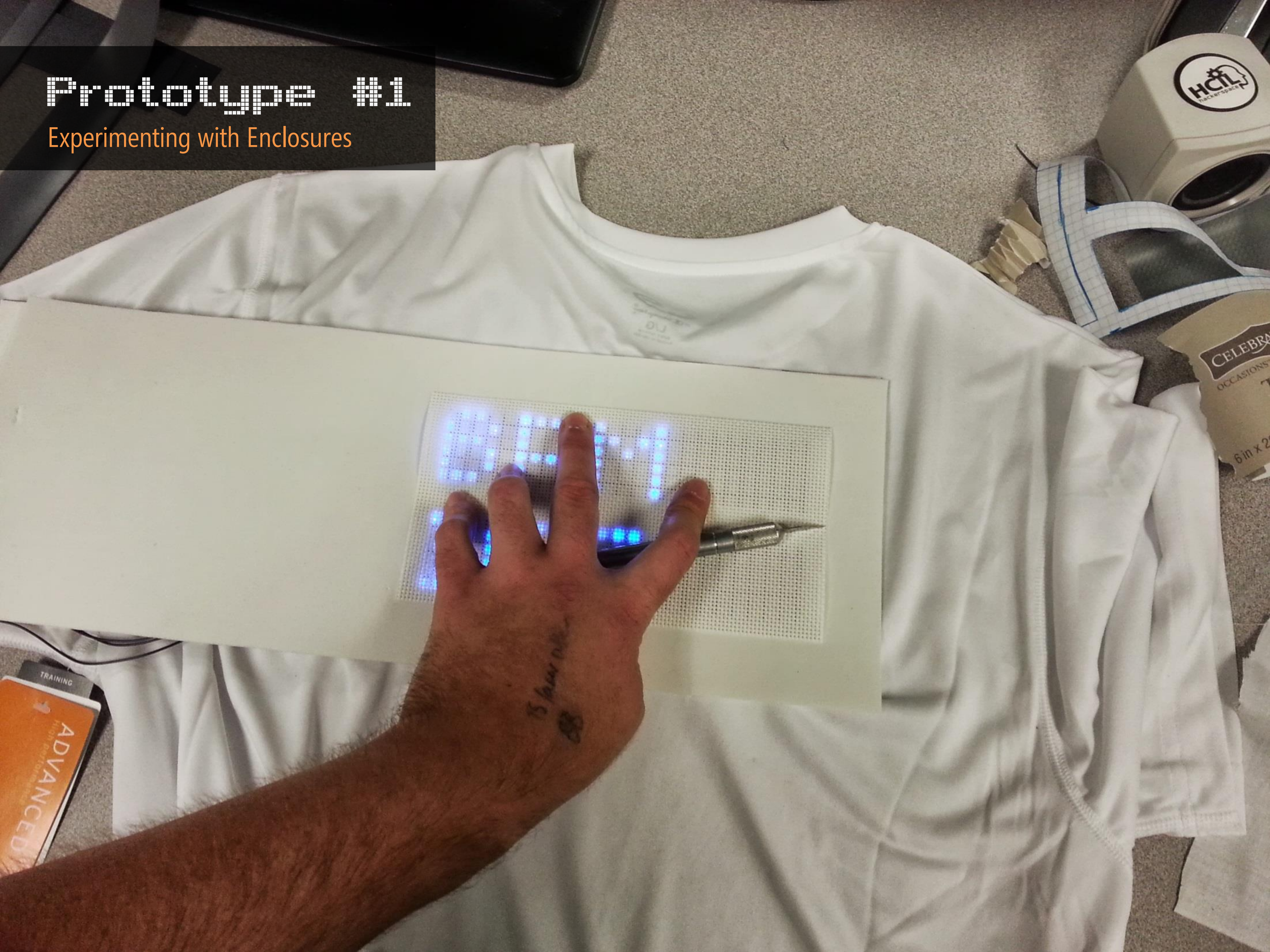
Experimenting with Enclosures



Prototype #1

Experimenting with Enclosures

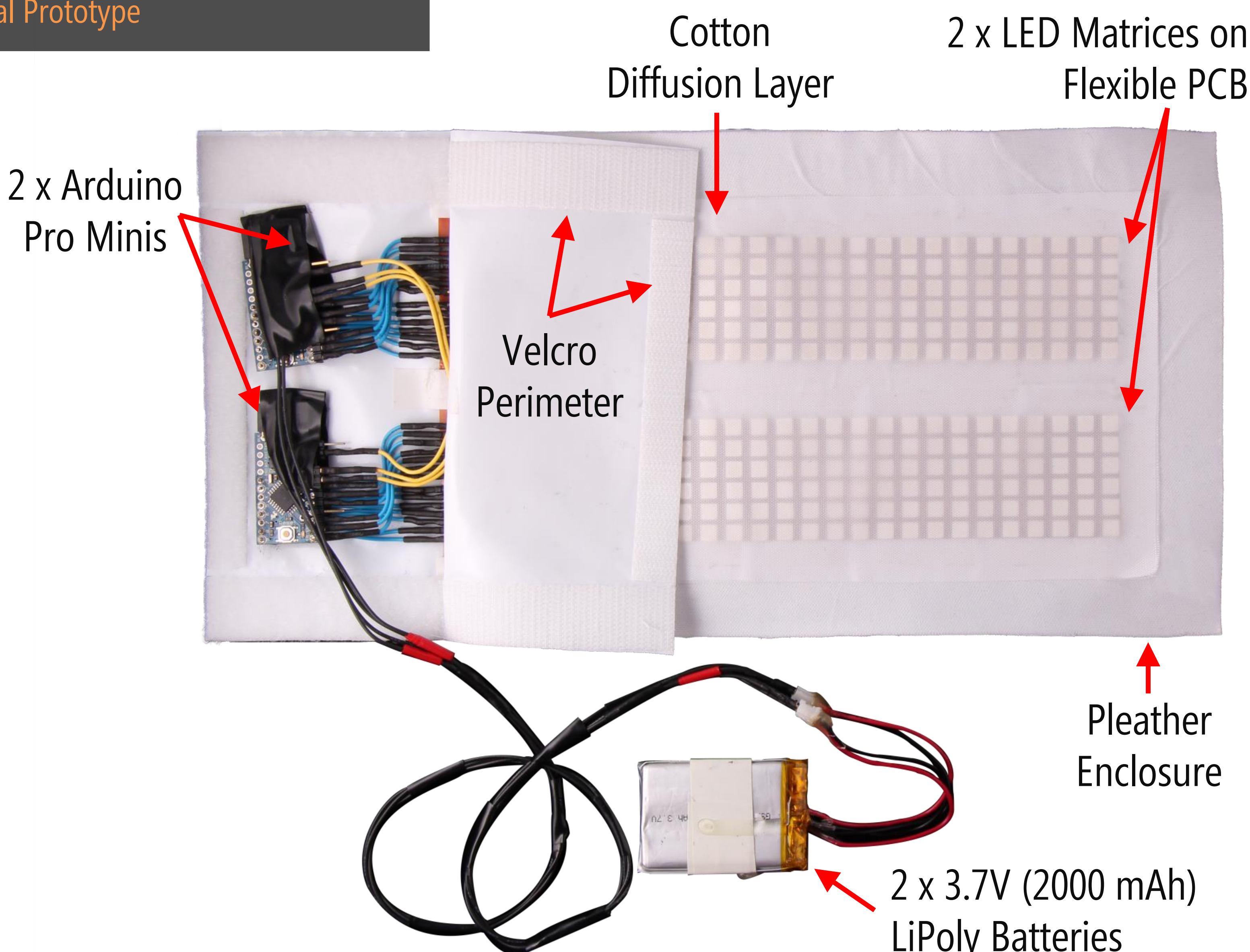




Prototype #1
Experimenting with Enclosures
HCIL
hackerspace
TRAINING
ADVANCED

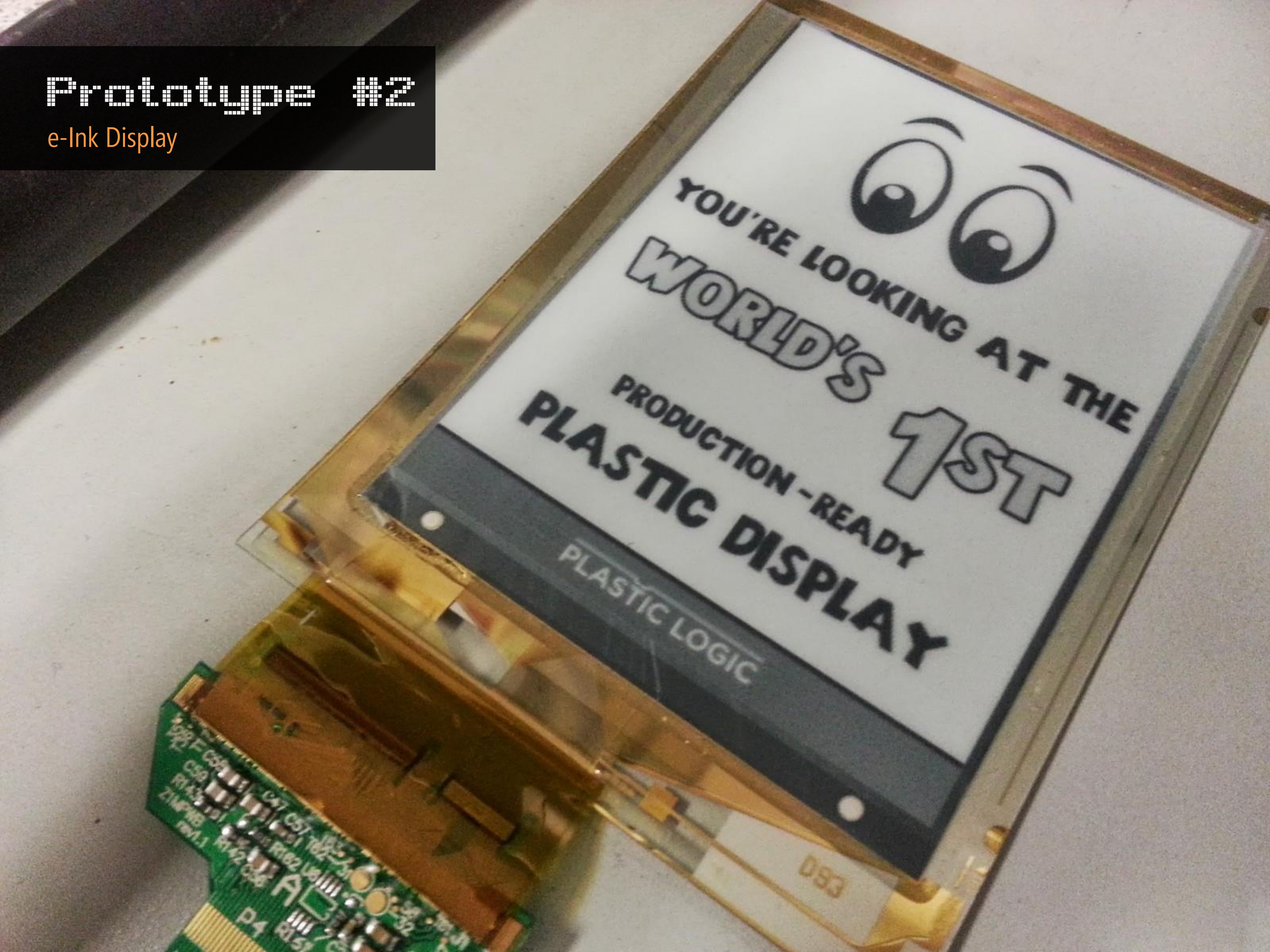
Prototype #1

Final Prototype



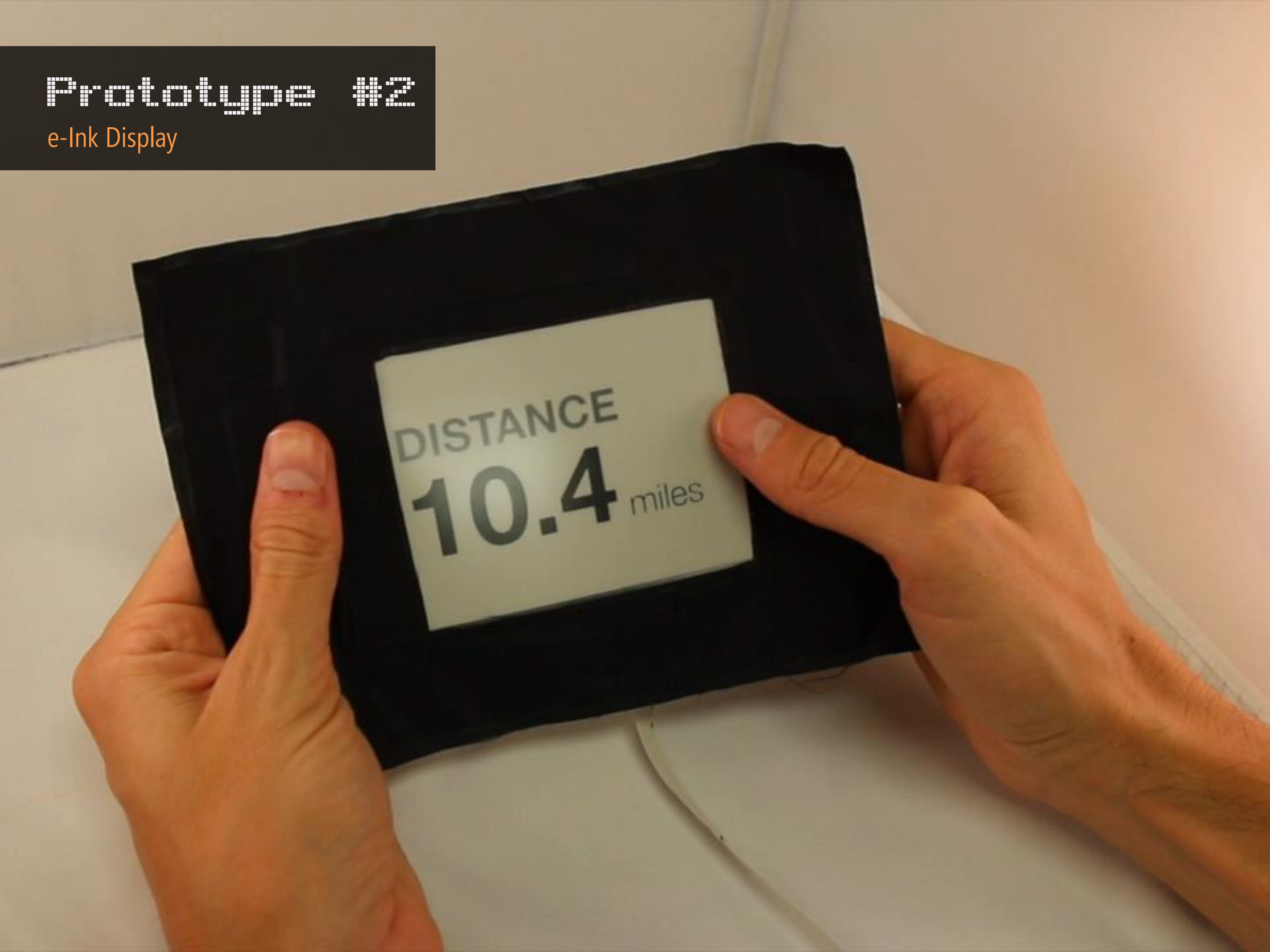
Prototype #2

e-Ink Display



Prototype #2

e-Ink Display



Prototype #2

Final e-Ink Prototype

Plastic Logic Flexible e-Ink Display 4.7″ (320 x240)

Nylon Enclosure

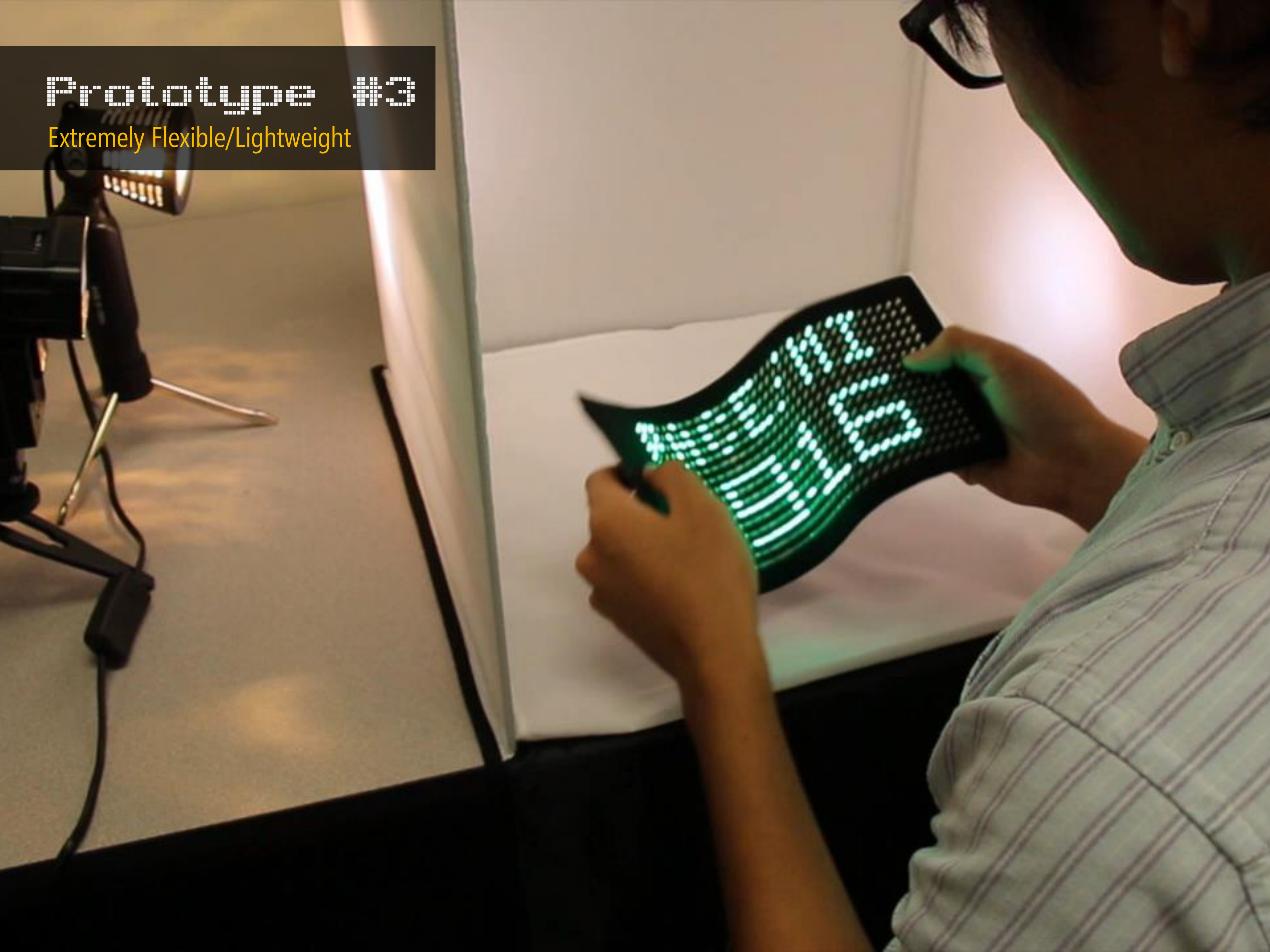
4 x 1.5V (2000 mAh) AA Batteries

32-bit BeagleBone (AM335x 720MHz ARM)

Plastic Logic Display Controller (HummingBird)

Prototype #3

Early Erogear Visualizations

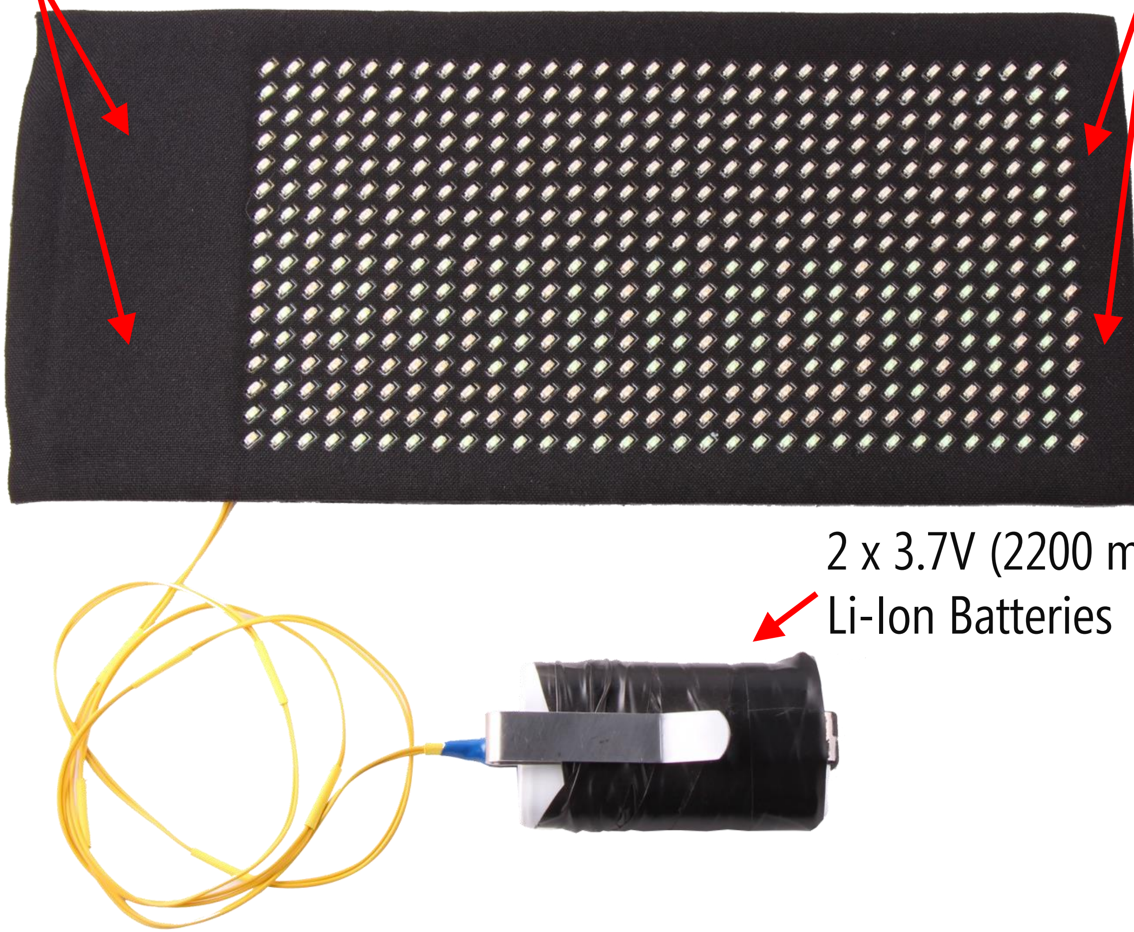

Prototype #3
Extremely Flexible/Lightweight

Prototype #3

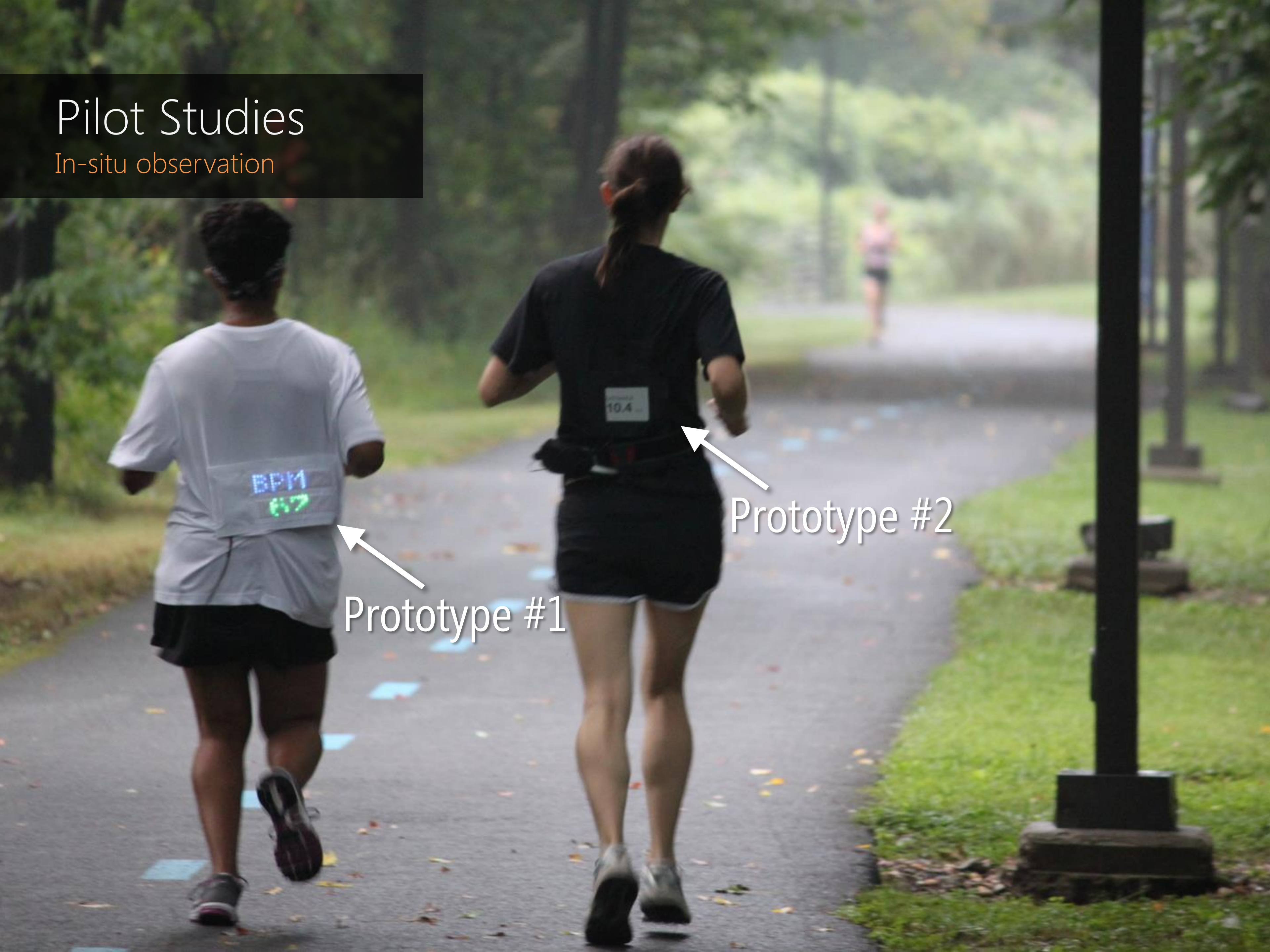
Final Erogear Prototype

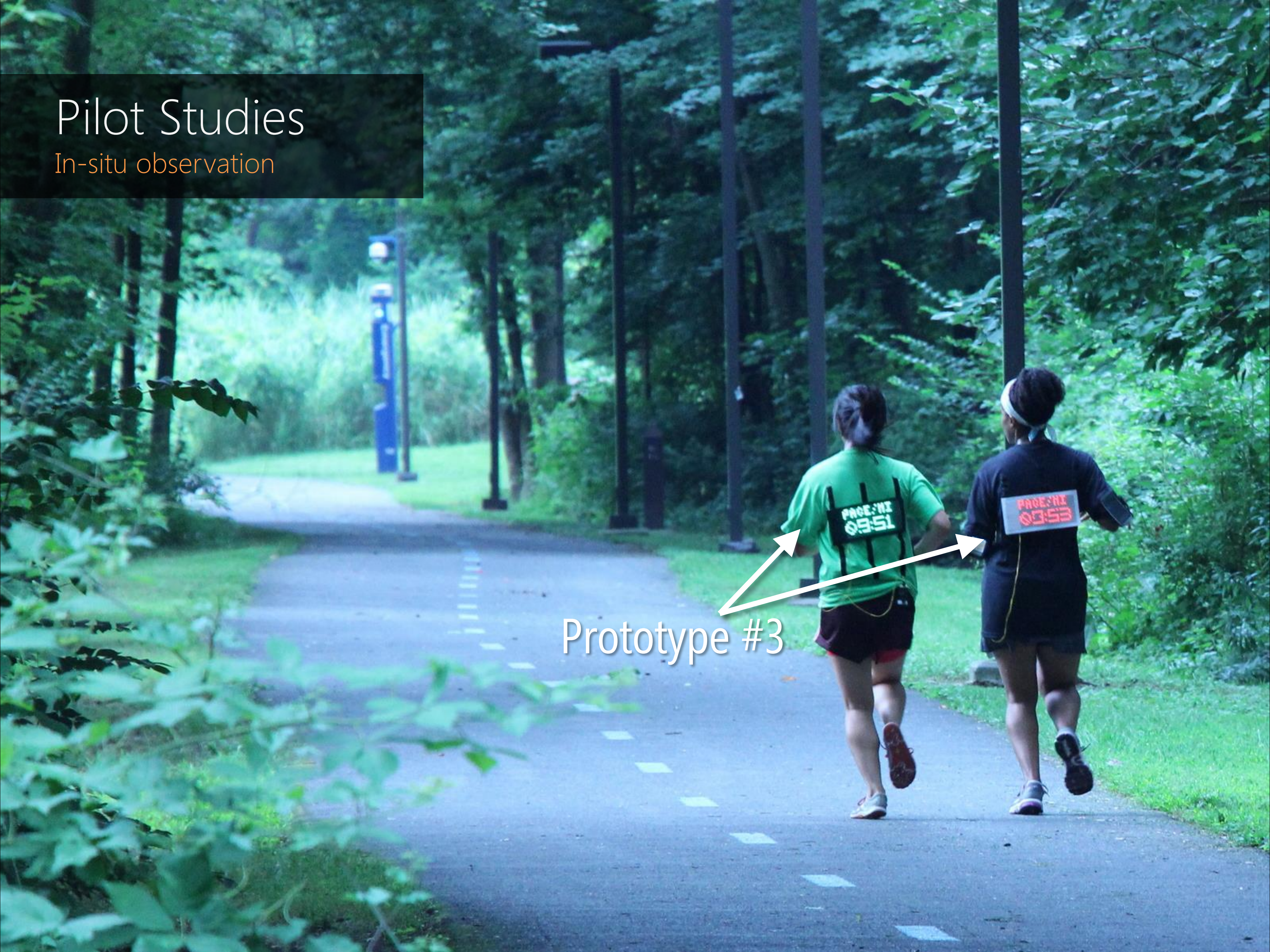
2 x 32-bit MCU; 16-bit LED Matrix Driver; Bluetooth Modem

2 x 32x8 Erogear LED Matrices

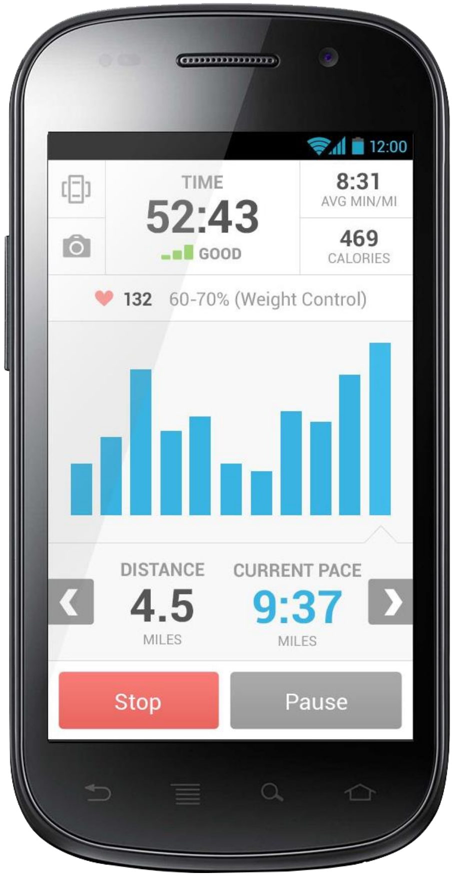


2 x 3.7V (2200 mAh) Li-Ion Batteries


Pilot Studies
In-situ observation
BPM
67
10.4
Prototype #1
Prototype #2


Pilot Studies
In-situ observation
PACE:MI
09:51
PACE:MI
09:53
Prototype #3

SFF: Final Visualizations



Final Prototype

Social Goal Pace Tracking Visualization

Field Study Participants

10 Groups; 52 Individuals (35 Female)

Avg Group Size:
5

Avg Age:
40.7

Avg Target Pace:
10:14

Avg Distance:
3.5 mi

Race Study Participants

4 Individuals (1 Female)

Male, 34
Target Pace: 6:10
County 8K

Female, 33
Target Pace: 8:20
County 8K

Male, 26
Target Pace: 7:45
Labor Day 10K

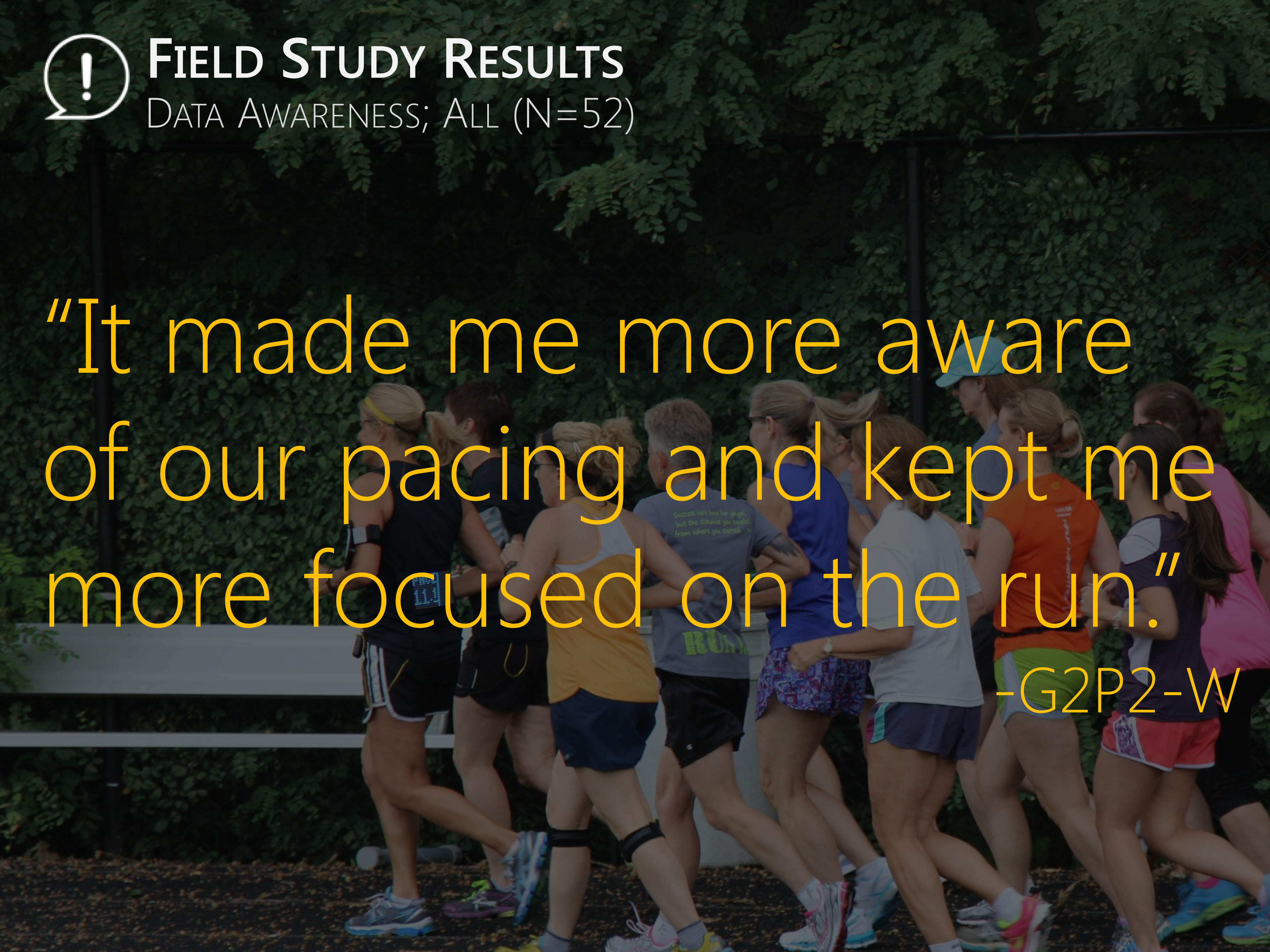
Male, 18
Target Pace: 8:30
Labor Day 10K

Race Deployment

Competitive Interactions

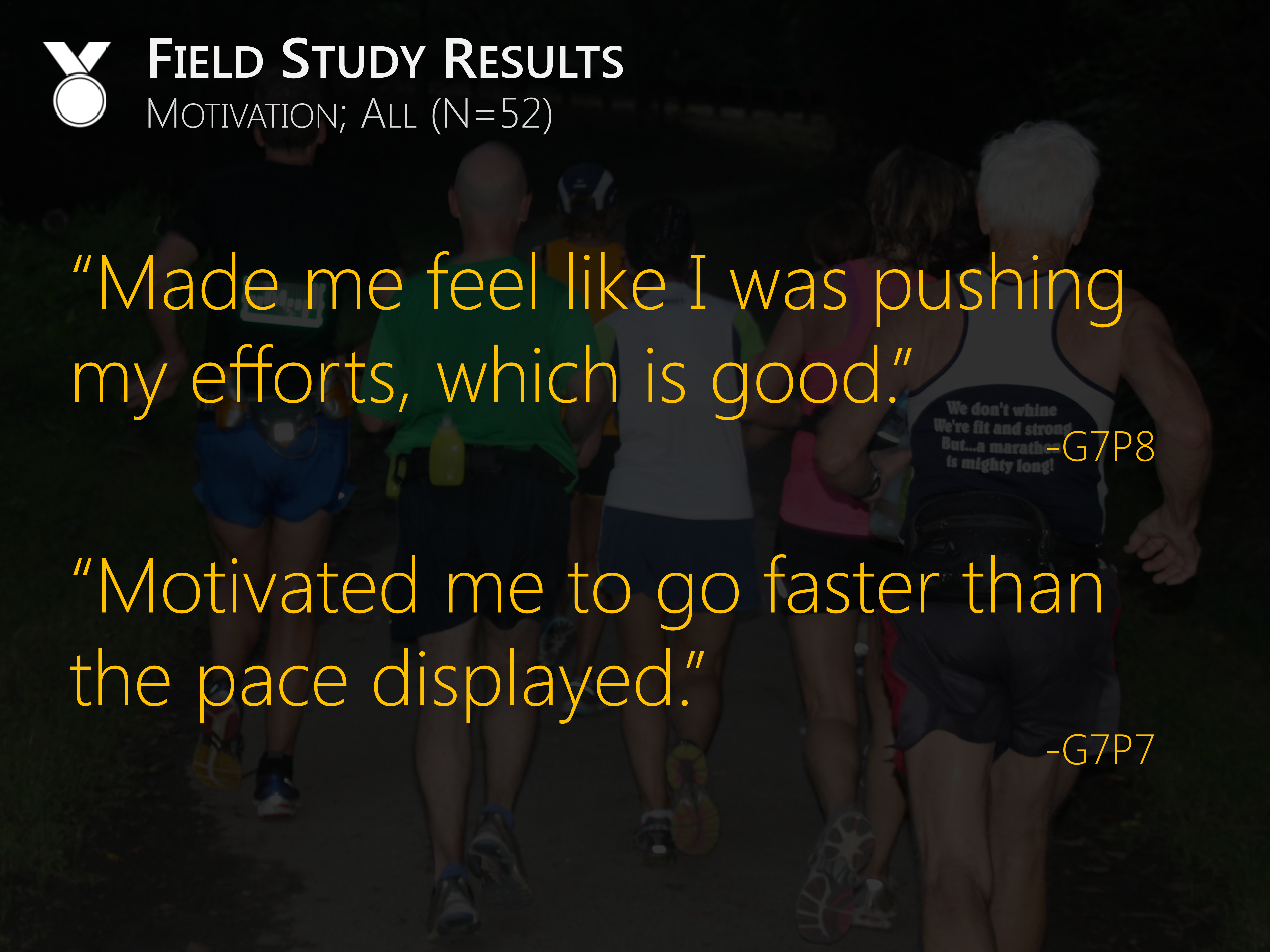
Field Study Results

Data Awareness; All (N=52)



"It made me more aware of our pacing and kept me more focused on the run."

-G2P2-W



Field Study Results

Motivation; All (N=52)

"Made me feel like I was pushing my efforts, which is good."

-G7P8

"Motivated me to go faster than the pace displayed."

-G7P7


Gold Medal
Step Away from Cancer
5K Run/Walk
prevent cancer
FOUNDATION

Race Study Results

Motivation; Wearers (N=4)

"It made me run faster because my performance was on display."

-R2P1-W


Potential Dichotomy
Increased motivation
vs. increased anxiety
PACE:MI
08:21
SFF Externalizes
Performance

New Erogear Fos Display

Source: http://www.erogear.com/

2 BRIEF EXAMPLES

SOCIAL FABRIC FITNESS

BODYVIS

2 BRIEF EXAMPLES

SOCIAL FABRIC FITNESS

BODYVIS

WHAT IF OUR CLOTHES REVEALED HOW OUR BODY'S FUNCTIONED?

HOW COULD THIS CHANGE THE WAY CHILDREN LEARN ABOUT AND UNDERSTAND THEIR BODIES?

COULD A T-SHIRT BE A PLATFORM FOR EXPERIMENTATION AND INQUIRY

"Does my heart beat faster when running *vs.* reading a book? Why?"

"How does my breathing rate compare to my classmate's and why may this be?"

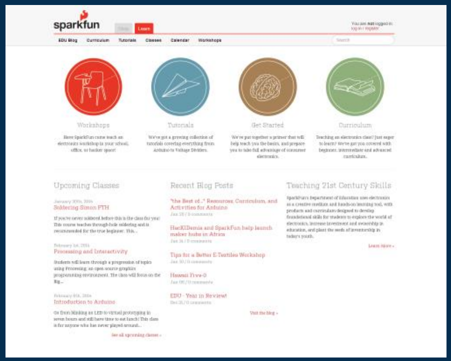
"How does food travel through my body?"

[Source: Norooz, Mauriello, & Froehlich, *CHI'15*, https://youtu.be/3zh_yaslOnY]

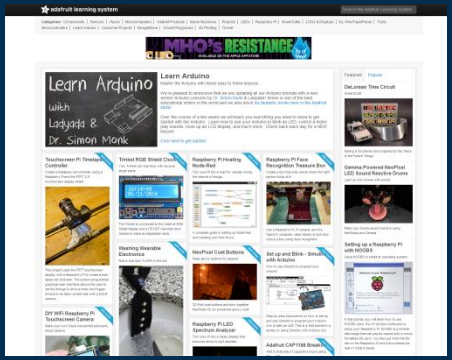
E-TEXTILES ARE NOT JUST EMBEDDED ELECTRONICS IN CLOTHING, THEY ARE NEW OPPORTUNITIES TO AUGMENT AND TRANSFORM THE HUMAN EXPERIENCE


E-TEXTILES
GENERATION ONE
WHERE SHOULD
WE GO FROM HERE?
commodore
commodore
1541

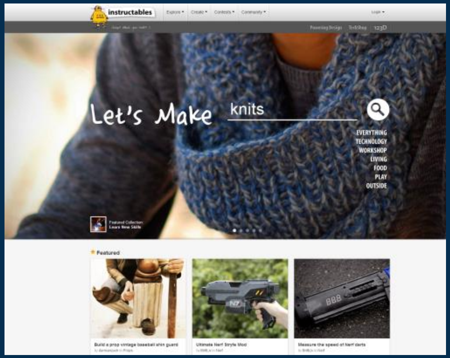
Join Us! Online Resources



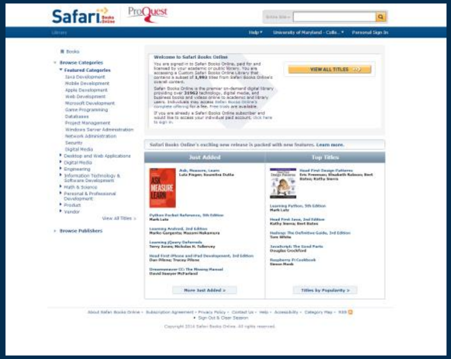
http://learn.sparkfun.com



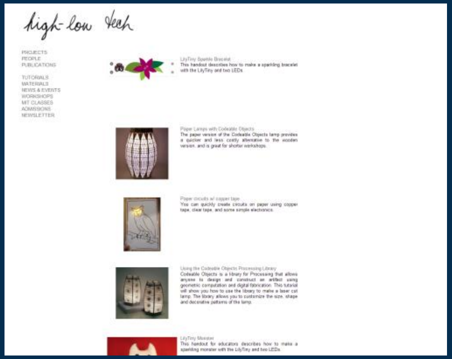
http://learn.adafruit.com/



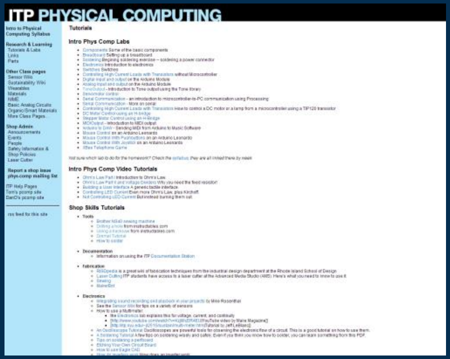
http://www.instructables.com/



proquest.safaribooksonline.com/



http://highlowtech.org/



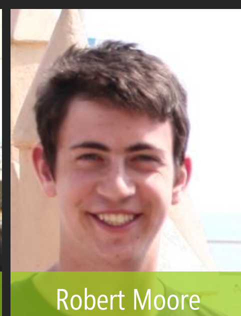
itp.nyu.edu/physcomp/Tutorials

HydroSense Collaborators

Graduate Student | Undergraduate | Professor

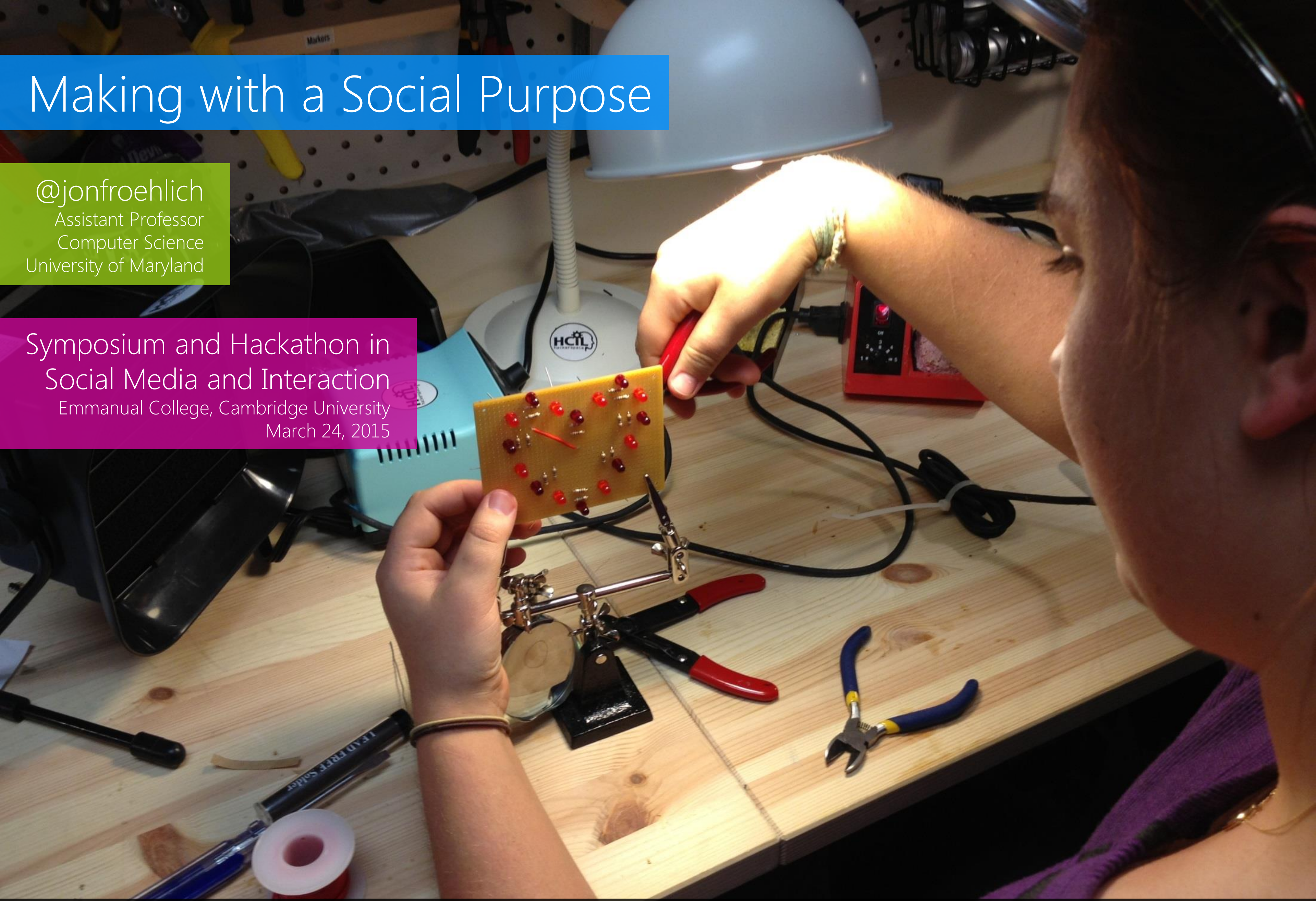
UMD Collaborators

Graduate Student | Undergraduate | High School | Professor



Funding

NSF Google 3M NOKIA



Making with a Social Purpose

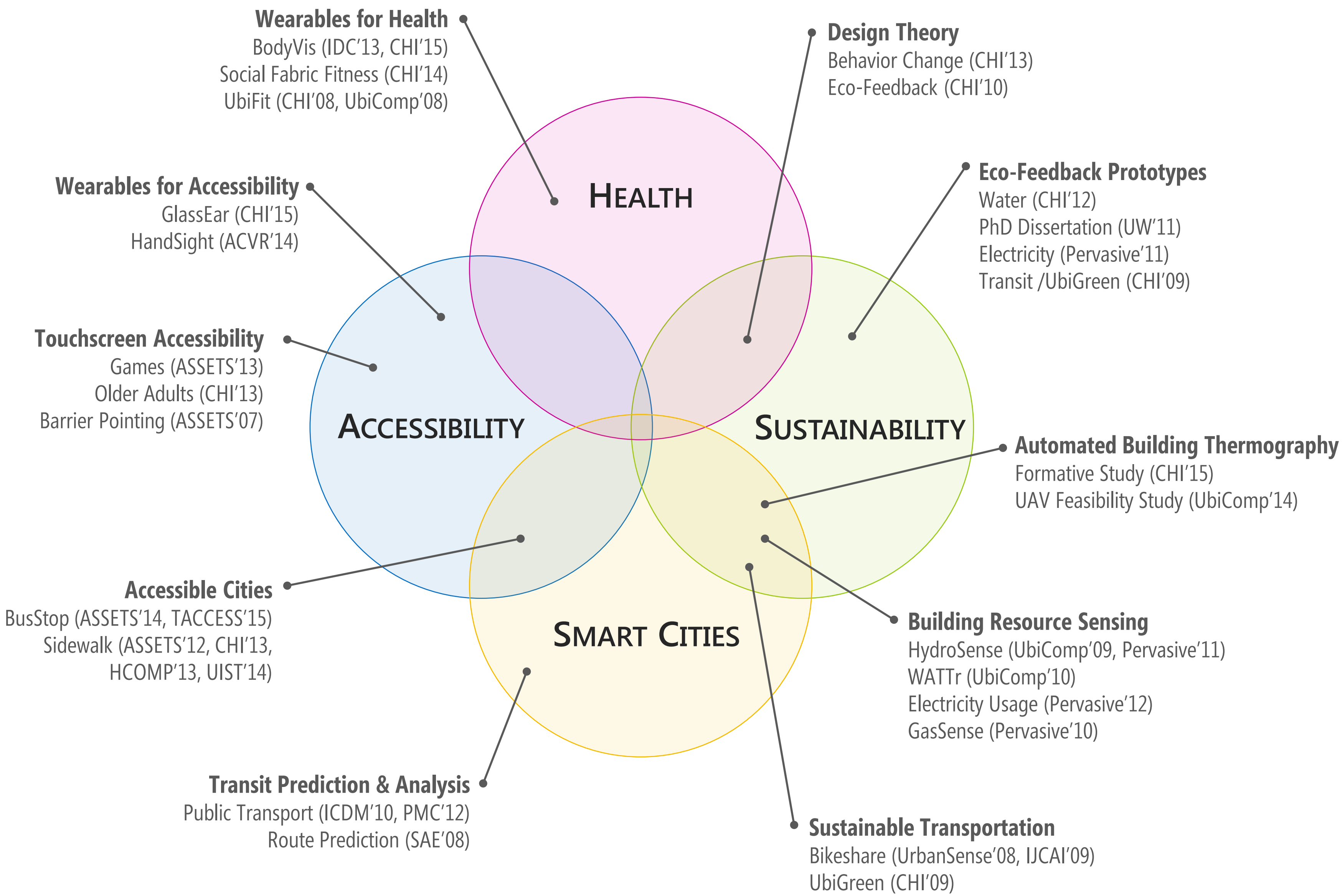
@jonfroehlich
Assistant Professor
Computer Science
University of Maryland

Symposium and Hackathon in Social Media and Interaction
Emmanual College, Cambridge University
March 24, 2015

@jonfroehlich

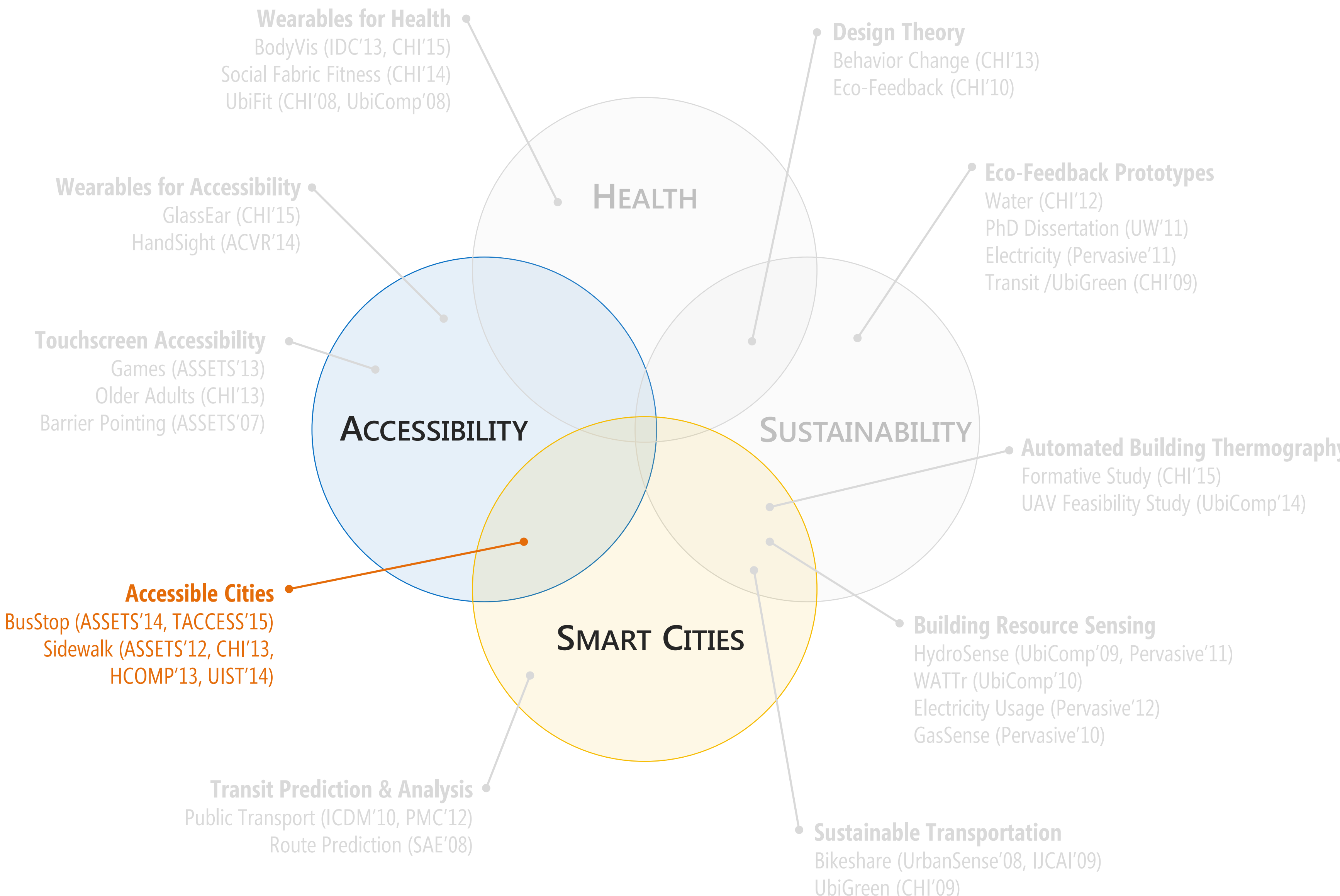
makeability lab

COMPUTER SCIENCE
AT UNIVERSITY OF MARYLAND



Back-up slides: **crowd-powered streetview accessibility**

My Research

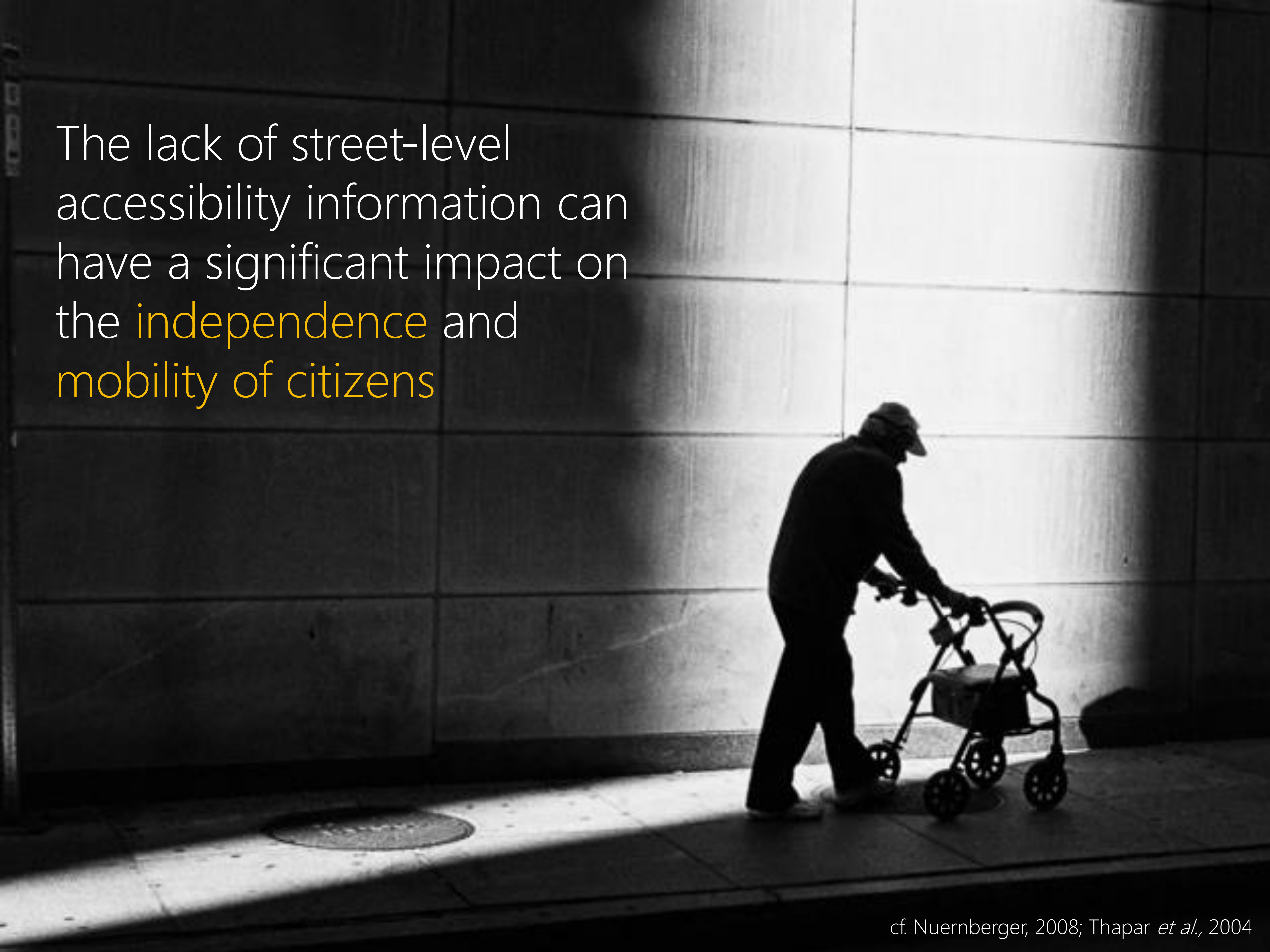


Wearables for Health
BodyVis (IDC'13, CHI'15)
Social Fabric Fitness (CHI'14)
UbiFit (CHI'08, UbiComp'08)
Design Theory
Behavior Change (CHI'13)
Eco-Feedback (CHI'10)
Wearables for Accessibility
GlassEar (CHI'15)
HandSight (ACVR'14)
Health
Eco-Feedback Prototypes
Water (CHI'12)
PhD Dissertation (UW'11)
Electricity (Pervasive'11)
Transit /UbiGreen (CHI'09)
Touchscreen Accessibility
Games (ASSETS'13)
Older Adults (CHI'13)
Barrier Pointing (ASSETS'07)
Accessibility
Sustainability
Automated Building Thermography
Formative Study (CHI'15)
UAV Feasibility Study (UbiComp'14)
Accessible Cities
BusStop (ASSETS'14, TACCESS'15)
Sidewalk (ASSETS'12, CHI'13, HCOMP'13, UIST'14)
Smart Cities
Building Resource Sensing
HydroSense (UbiComp'09, Pervasive'11)
WATTr (UbiComp'10)
Electricity Usage (Pervasive'12)
GasSense (Pervasive'10)
Transit Prediction & Analysis
Public Transport (ICDM'10, PMC'12)
Route Prediction (SAE'08)
Sustainable Transportation
Bikeshare (UrbanSense'08, IJCAI'09)
UbiGreen (CHI'09)

The National Council on Disability noted that there is **no comprehensive information** on "the degree to which sidewalks are accessible" in cities.

National Council on Disability, 2007
The impact of the Americans with Disabilities Act: Assessing the progress toward achieving the goals of the ADA

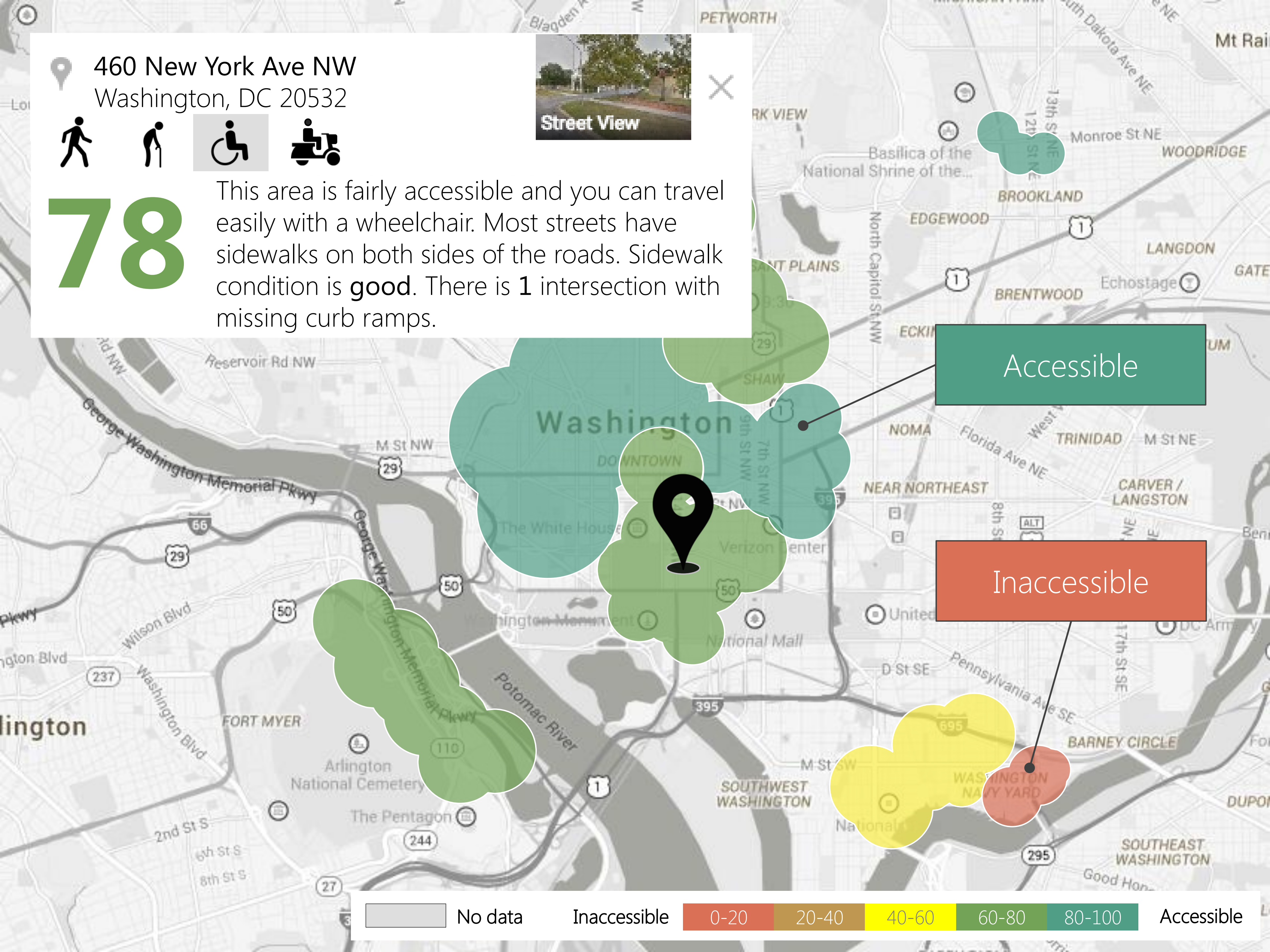

Incomplete Sidewalks
Physical Obstacles
Surface Problems
No Curb Ramps
Stairs/Businesses
HESS
DO NOT
ENTER


The lack of street-level accessibility information can have a significant impact on the independence and mobility of citizens
cf. Nuernberger, 2008; Thapar *et al.,* 2004

Situational Impairments

Accessible cities can impact everyone: affecting health, sustainability, community


OUR VISION:
TRANSFORM THE WAY STREET-LEVEL
ACCESSIBILITY INFORMATION IS
COLLECTED AND VISUALIZED


460 New York Ave NW
Washington, DC 20532
Street View
78
This area is fairly accessible and you can travel easily with a wheelchair. Most streets have sidewalks on both sides of the roads. Sidewalk condition is **good**. There is **1** intersection with missing curb ramps.
Accessible
Inaccessible
Washington
No data
Inaccessible
0-20
20-40
40-60
60-80
80-100
Accessible

How might a tool like AccessScore:

Change the way people think about and understand their neighborhoods

Influence property values

Impact where people choose to live

Change how governments/citizens make decisions about infrastructural investments

Our Approach: Use Google Street View (GSV) as a massive data source for scalably finding and characterizing street-level accessibility

High-Level Research Questions

1. Can we use Google Street View (GSV) to find street-level accessibility problems?
2. Can we create interactive systems to allow minimally trained crowdworkers to quickly and accurately perform remote audit tasks?
3. Can we use computer vision and machine learning to scale our approach?