SENSING AND VISUALIZING HUMAN BEHAVIOR THROUGH CITY INFRASTRUCTURE

Workshop on Visualization Technologies to Support Research on Human-Environment Interactions
SeSync: National Socio-Environmental Synthesis Center
July 23-24, 2012, Annapolis, Maryland

@jonfroehlich
Assistant Professor Computer Science
How can we use machine learning and visualization to understand, encourage, and optimize shared bicycling?

What can we learn about a city from shared bicycling?

[Froehlich et al., UrbanSense2008; IJCAI2009]
Washington DC, Capital Bikeshare (CaBi) Flows

[MV Jantzen, http://www.youtube.com/watch?v=-h0rV7tw1Eo]
Sensing and Visualizing Human Behavior Through City Infrastructure

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I study human behavior
how human behavior can be sensed
modeled
predicted
visualized
changed
individual
household
city
earth

scale
ubigreen | reflect\textsubscript{2}O | smartcities

individual | household | city | earth

scale
eco-feedback
sensing and visualizing behavior to reduce environmental impact
**Toyota Prius**

**Consumption**

- 50Wh Regenerated

**Outside Temp** 61°F

**Energy** 60.5 MPG 204 miles

**Reset**
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 Hirsches 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-foot."  They don't contest her story.

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's helpful information for drivers who can change driving in startling ways, making drivers who do not have a Prius envious of their driving habits, then adjusting them accordingly.

Hirsche averages 43 mpg with his Prius, while Katie Sebastian, who drives a Prius with her son, Cole, averages 41 mpg. The drivers have friendly competitions over their mpg scores, fueled by the Prius hybrid’s realtime mileage readings.

"They have to go to a lot more trouble," Hirsche said.

In the world of hybrid cars, the Prius is setting the standard for other hybrid cars. The Prius has been a marketing success, offering a fuel-efficient way for family-friendly drivers to get around.

In fact, the Prius is so popular that dealerships are limiting sales to ensure that the car is not driving down highway speed limits. The Prius is not a car that is designed for speed, but rather for efficiency. It is a car that is designed to get the most miles out of every gallon of gas.

"The Prius is not a car for speed," said a Prius owner.

The Prius is not a car for speed, but rather for efficiency. It is a car that is designed to get the most miles out of every gallon of gas. The Prius is not a car that is designed for speed, but rather for efficiency. It is a car that is designed to get the most miles out of every gallon of gas. The Prius is not a car that is designed for speed, but rather for efficiency. It is a car that is designed to get the most miles out of every gallon of gas. The Prius is not a car that is designed for speed, but rather for efficiency. It is a car that is designed to get the most miles out of every gallon of gas. The Prius is not a car that is designed for speed, but rather for efficiency. It is a car that is designed to get the most miles out of every gallon of gas. The Prius is not a car that is designed for speed, but rather for efficiency. It is a car that is designed to get the most miles out of every gallon of gas. The Prius is not a car that is designed for speed, but rather for efficiency. It is a car that is designed to get the most miles out of every gallon of gas. The Prius is not a car that is designed for speed, but rather for efficiency. It is a car that is designed to get the most miles out of every gallon of gas. The Prius is not a car that is designed for speed, but rather for efficiency. It is a car that is designed to get the most miles out of every gallon of gas.
eco-feedback
sensing and visualizing behavior to reduce environmental impact

you

sensing feedback
Toyota Prius

Power-aware Cord

Jetsam visualization allows pedestrians to view amount and type of garbage at-a-glance (Paulos and Jenkins, CHI 2005)

Microsoft Hohm

Energy Detective

Wattson

Control4 Dashboard

Google Powermeter

Heat Sink (Arrigo et al., CHI 2005)
light bulb?

Kohlenberg et al., J. of Applied Behavior Analysis, 1976
What makes an eco-feedback design effective?

How can we better understand the tradeoffs, constraints, and motivational strategies of eco-feedback designs?
advances in **sensing** and machine learning

philips directlife activity sensor
plethora of display mediums
how can we design and evaluate eco-feedback systems?
Froehlich et al., HCIC2009; CHI2010; UW PhD Dissertation 2011
why is the prius effective?
- Graphical
- Textual
- Temporal

- Real-time
- Spatially co-located
- Constrained environment

- Real-time mpg
- In-car display

- Educates
- Reason to care

- Informs only one action

- To self

-• Data representation
-• Information access
-• Display medium
-• Comparison
-• Actionability
-• Motivational strategies
-• Social
-• Behavioral models

-• Inputs
behavioral models
social inputs
data representation
information access
display medium
actionability
motivational strategies
social
comparison
behavioral models
data representation
information access
display medium
actionability
motivational strategies
social
comparison
data representation
information access
inputs
display medium
behavioral models
social
motivational strategies
actionability
comparison
comparison

display medium comparison

easy challenging
to a goal easy

to others past projected

to self past projected

historic average last 30 mins

historic average

energy 51.4 MPG 329 miles

Consumption

average

=50Wh Regenerated

outside temp 61 F

30 min 25 20 15 10 5 0

MPG

current

projected
ubigreen activities

walk  bike  train  carpool  bus  drive alone

Green Transportation
ubigreen activities
transit sensing infrastructure

walk
bike
train
carpool
bus
drive alone

mobile sensing platform
cell towers
user
ubigreen eco-feedback

mobile sensing platform
ubigreen
personal ambient display

- current activity
- value icon bar
- evolving image
- phone background (wallpaper)
ubigreen
personal ambient display

tree design:

everything resets on sunday
tree
polar bear
motivational strategies

playful

measured progress

levels

role playing

rewards
ubigreen study results

“i liked the tree because it was, to my mind, a pretty progress bar. i could tell the difference at a glance” [p11]

“i liked how stories were used” [p8]

“i want different stories every week” [p8]

“i would like to see some graph or raw data—a breakdown of transit activity by type for the week” [p13]

“it would be nice to see your carbon footprint” [p15]
“i liked that we didn’t know what the background was going to do” [p15]

“negative feedback would also be good; maybe my polar bear should drown if i don’t take green transit” [p14]

“i wanted to see the final stage i could get to” [p7]

“i don’t like incentives for getting points artificially by taking unnecessary green trips” [p11]

“if i didn’t get a leaf or a flower after, i felt like I was getting cheated out of my points” [p15]
reflect_2O

[Froehlich et al., CHI 2011]
what are the most water consuming activities in the average North American home?
Top Water Usage Activities

- Outdoor Use: 31.4%
- Toilets: 18.3%
- Laundry Machine: 14.9%
- Showers: 11.5%
- Faucets: 10.8%
- Leaks: 9.4%
- Other: 1.6%
- Baths: 1.2%
- Dishwasher: 1.0%

[Vickers, Handbook of Water Use and Conservation, 2001]
we asked 656 people the same thing

select the top 3 most water consuming activities in an average home

[Froehlich, PhD Dissertation, 2011]
Survey Results

Selected in top 3 by only 33%

- Outdoor Use: 31.4%
- Toilets: 18.3%
- Laundry Machine: 14.9%
- Showers: 11.5%
- Faucets: 10.8%
- Leaks: 9.4%
- Other: 1.6%
- Baths: 1.2%
- Dishwasher: 1.0%

Selected in top 3 by ~50%

Selected in top 3 by 26%
why the disconnect?
**Municipal Services Statement**

**Account Number:** 100687-00154711

**Utility Amount Due:** 127.52

**Voluntary Donation:** 1.00

**Total + Voluntary Donation:** 129.52

**Date Due:** 1/8/2007

**Billing period:** 12/2006

**Previous meter reading:** 16939

**Current meter reading:** 28,000

**Gallons delivered:** 28,000

**Service Address:** 7450 S. KENWOOD DR

**Water read date:** 11/20/2006

### Account Activity

<table>
<thead>
<tr>
<th>Date Description</th>
<th>Amounts</th>
<th>Date of Service</th>
<th>Date Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payments Received</td>
<td>103.00</td>
<td>12/12</td>
<td>Water Consumption</td>
<td>28.11</td>
</tr>
<tr>
<td>Thank You</td>
<td>9.19</td>
<td>12/12</td>
<td>Water Service Charge</td>
<td>15.89</td>
</tr>
<tr>
<td></td>
<td>6.81</td>
<td>12/12</td>
<td>10% Discount Five</td>
<td>11.49</td>
</tr>
<tr>
<td></td>
<td>2.45</td>
<td>12/12</td>
<td>Power Charge</td>
<td>6.40</td>
</tr>
<tr>
<td></td>
<td>7.20</td>
<td>12/12</td>
<td>Residential Rates</td>
<td>17.41</td>
</tr>
</tbody>
</table>

**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 write only the "Utility Amount Due."
10,230 gallons
10,230 gallons
direct sensing
toilet 78.4 gallons
bath 6.5 gallons
bathroom sink 1 4.2 gallons
bathroom sink 2 0.8 gallons
shower 62.4 gallons

direct sensing
shower 52.4 gallons
shower 62.4 gallons
bath 6.5 gallons
bath 6.5 gallons
toilet 78.4 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
indirect sensing

- Shower: 52.4 gallons
- Bathroom sink 1: 3.2 gallons
- Bathroom sink 1: 4.2 gallons
- Bathroom sink 2: 2.4 gallons
- Bathroom sink 2: 0.8 gallons
- Bath: 6.5 gallons
- Bath: 6.5 gallons
- Toilet: 78.4 gallons
HydroSense attempts to infer fixture-level usage for the entire home from a single point.

[Froehlich et al., UbiComp 2009]
[Larson et al., PMC 2010]
[Froehlich et al., Pervasive 2011]
What do we do with all this data?
Key Questions

1. **What** are the key gaps in residential water usage understanding amongst home occupants?

2. **What** aspects of disaggregated data are potential users interested in and what sort of reactions do the visualizations provoke?

3. **How** might these visualizations impact behavior?
Key Questions

1. **What** are the key gaps in residential water usage understanding amongst home occupants?

2. **What** aspects of disaggregated data are potential users interested in and what sort of reactions do the visualizations provoke?

3. **How** might these visualizations impact behavior?
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.

[Froehlich et al., CHI2012]
Iterative Design Process

- Sketch
- Lo-to-Mid Fidelity Mockup
- Higher Fidelity Mockup
Online interactive survey of designs (N=651 respondents)
In-home interviews (10 households, 20 adults)
Online interactive survey of designs (N=651 respondents)
In-home interviews (10 households, 20 adults)
the help[s] structure both our design process and our evaluations
Design Dimensions Explored

① **Data** Granularity

② **Time** Granularity

③ **Measurement** Unit

④ **Comparison**

These 3 are sub-dimensions of the eco-feedback design space.
DESIGN SET 1: ISOLATING DESIGN DIMENSIONS

**Measurement**

<table>
<thead>
<tr>
<th>Resource</th>
<th>Rate of Consumption</th>
<th>Cost</th>
<th>Time</th>
<th>Activity</th>
<th>Metaphor</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 gallons of water</td>
<td>3 gpm</td>
<td>9 cents</td>
<td>12 minutes</td>
<td>1 shower</td>
<td>20 jugs of water</td>
</tr>
</tbody>
</table>


This Month’s Water Usage
Fixture Category View | In Gallons

Friday June 15th | 9:30 PM

- Showers: 1,814 gallons
- Bathtubs: 177 gallons
- Toilets: 614 gallons
- Bathroom Sinks: 1,323 gallons
- Kitchen Sink: 150 gallons
- Dishwasher: 2,346 gallons
- Laundry Machine: 4,310 gallons
- Outdoor: 0 gallons
This Month’s Water Usage
Fixure Category View | In Dollars

Friday June 15th | 9:30 PM
Your Current Water Rate:
1,000 gal = $7.68

- Showers: $13.93
- Bathtubs: $1.36
- Toilets: $22.31
- Bathroom Sinks: $4.72
- Kitchen Sink: $10.16
- Dishwasher: $1.15
- Laundry Machine: $18.02
- Outdoor: $33.10
DESIGN SET 1: ISOLATING DESIGN DIMENSIONS

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
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 Probes Explored

**Time-Series**

- Water Usage in Gallons
  - Today
  - This Year

**Spatial**

- Today’s Water Usage in Gallons
  - Bathroom
  - Kitchen
  - Laundry

**Per-Occupant**

- Personal Usage Totals
  - Name
  - Personal Usage (gallons)

**Aquatic Eco-system**

- Rainflow

**Other**

- Aquatic Eco-system
- Rainflow
DESIGN SET 2: DESIGN PROBES

Design Probes Explored

Time-Series

Aquatic Eco-system

Spatial

Rainflow

Per-Occupant

Other
DESIGN SET 2: DESIGN PROBES

Aquatic Ecosystem View

Water savings tracker

- Water savings goal met
- "Frank" the fish meets his mate
- "Frank" the fish
- Frank and his mate have children
- and so on...

Display is also interactive so fish respond to touch
Design Probes Explored

**Time-Series**

**Spatial**

**Aquatic Eco-system**

**Rainflow**

**Per-Occupant**

**Other**
DESIGN SET 2: DESIGN PROBES

Rainflow View

Diagram showing various water flow rates and goals, with colored bars indicating average and goal levels for different appliances.
DESIGN SET 2: DESIGN PROBES

Rainflow View Movie
Design Probes Explored

**Time-Series**
- Water Usage in Gallons Today
- Water Usage in Gallons This Year

**Spatial**
- Today's Water Usage in Gallons
- Per-Occupant

**Aquatic Eco-system**
- Rainflow

**Other**
- Other

**Design Set 2: Design Probes**
DESIGN SET 2: DESIGN PROBES

Other Design Probes

Geographic Comparisons

Dashboards

Metaphorical Unit Designs

Recommendations
Findings
71% of respondents preferred to see both gallons and cost.

Seeing the gallon amount triggers the ‘save the environment’ impulse to conserve, while the dollar amount is helpful because almost everyone is motivated by money to some extent.

I don't think very well in ‘thousands of gallons’, but $20 I can understand. That’s a case of beer down the drain, if you will.
Comparisons were the most uniformly desired pieces of information of all the dimensions.
Self-comparison was most preferred 91% compared with goal-based and social-comparisons.
Emergent Themes

1. Competition and Cooperation
2. Accountability and Blame
3. Playfulness and Functionality
4. Sense of Privacy
5. Display Placement
Playfulness and Functionality

I like the idea of getting rewards for saving water

It’s like unlocking badges in Foursquare. No matter how trivial it can be to make a fish appear on this screen, you still want to do it

It doesn’t appeal to me as much. I don’t do Foursquare. This distracts me a little bit and it doesn’t make me think about my usage
Useful as an educational tool?

This display could set up a 'competitive' environment that we are trying not to create in our household.

Would seem to lead to plenty of arguments about usage.
“This display could set up a ‘competitive’ environment that we are trying not to create in our household.”

“Would seem to lead to plenty of arguments about usage.”
Revealing Activity

**Today’s Real-Time Water Usage**

<table>
<thead>
<tr>
<th>Fixture</th>
<th>Today’s Usage Over Time</th>
<th>Today’s Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Showers</td>
<td></td>
<td>96</td>
</tr>
<tr>
<td>Bathtubs</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Toilets</td>
<td></td>
<td>68</td>
</tr>
<tr>
<td>Bathroom Sinks</td>
<td></td>
<td>37</td>
</tr>
<tr>
<td>Kitchen Sink</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Dishwasher</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Laundry Machine</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>Outdoor</td>
<td></td>
<td>80</td>
</tr>
</tbody>
</table>

*Fixture Category View*

Friday June 15th | 9:30 PM

“This display could set up a ‘competitive’ environment that we are trying not to create in our household.”

---

- R493
- R144

*Would seem to lead to plenty of arguments about usage.*
Display Location Preferences
If we placed the display here, the kids couldn’t see it.
**Display Location Preferences**

- **kitchen**
- **near thermostat**
- **high traffic areas**
- **accessible when needed**
reflect\textsubscript{2}O

ubigreen

smartcities

city

household

individnal

scale

earth

eco-feedback

persuasive technology

personal informatics

quantified self

green
The social sciences can finally have access to masses of data that are of the same order of magnitude of their older sisters, the natural sciences.

Bruno Latour, 2007
French philosopher and sociologist
# Route Prediction from Trip Observations

14,468 trips / 240 subjects

<table>
<thead>
<tr>
<th>Description</th>
<th>Average</th>
<th>Median</th>
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</thead>
<tbody>
<tr>
<td>trip distance (miles)</td>
<td>7.7</td>
<td>4.2</td>
</tr>
<tr>
<td>trip time (min)</td>
<td>16.3</td>
<td>11.5</td>
</tr>
<tr>
<td>num trips / day</td>
<td>4</td>
<td>3.9</td>
</tr>
<tr>
<td>num trips / subject</td>
<td>60.3</td>
<td>50</td>
</tr>
<tr>
<td>num days of data / subject</td>
<td>15.1</td>
<td>13</td>
</tr>
</tbody>
</table>

**High Level Trip Stats**

[Greater Seattle Area](https://example.com)

[Froehlich & Krumm, *Route Prediction From Trip Observations*, SAE 2008]
if we can predict where you’re going, we can suggest more sustainable forms of transit or better optimize your route
After approximately 1 month of observation, the number of repeat trips reaches 50%
The most frequently traveled route accounts for 12% of a driver’s trips.

The top ten most frequently traveled routes account for 50% of a driver’s trips.
sensing and predicting the movement of a city via shared bicycling

[Froehlich et al., UrbanSense2008; IJCAI2009]
summer 2008:
- 373 stations
- 6,000 bicycles
- 150,000 subscribers

bicin
barcelona, spain
num checked-out bicycles across all stations

evening commute
late spanish lunch
morning commute

Mon | Tues | Wed | Thur | Fri | Sat | Sun

sleeping in on weekends

time of week

# of checked-out

0  1000  1500
available bicycle clusters

**Flat**
- Cluster B1 (N=106)
- Cluster B2 (N=72)

**Outgoing**
- Cluster B3 (N=42)
- Cluster B4 (N=62)

**Incoming**
- Cluster B5 (N=50)
- Cluster B6 (N=38)
biases of human behavior
what can we learn if we combine data from other sources?

[Lathia, Froehlich & Capra, ICDM2010]
how should this real-time information be visualized and accessed?
can we use this data to automatically detect events in the city?
In Closing
become a better

you

sensing feedback
I’ll be giving a talk on: Applying Iterative Design to the Eco-Feedback Design Process

http://beccconference.org/
research publications

smartcities
Sensing and Predicting the Pulse of the City through Shared Bicycling
Jon Froehlich, Joachim Neumann, Nuria Oliver, *Proceedings of IJCAI 2010*

Measuring the Pulse of the City through Shared Bicycle Programs
Jon Froehlich, Joachim Neumann, Nuria Oliver, *Proceedings of UrbanSense 2008*

Mining Public Transport Usage for Personalised Intelligent Transport Systems
Neal Lathia, Jon Froehlich, Licia Capra, *Proceedings of ICDM 2010*

hydrosense
HydroSense: Infrastructure-Mediated Single-Point Sensing of Whole-Home Water Activity
Jon Froehlich, Eric Larson, Tim Campbell, Conor Haggerty, James Fogarty, Shwetak N. Patel, *Proceedings of Ubicomp 2009*

Disaggregated Water Sensing from a Single, Pressure-Based Sensor: An Extended Analysis of HydroSense Using Staged Experiments

A Longitudinal Study of Pressure Sensing to Infer Real-World Water Usage Events in the Home

ubigreen
UbiGreen: Investigating a Mobile Tool for Tracking and Supporting Green Transportation Habits
Jon Froehlich, Tawanna Dillahunt, Predrag Klasnja, Jennifer Mankoff, Sunny Consolvo, Beverly Harrison, James A. Landay, *Proceedings of CHI 2009*

reflect2O
The Design and Evaluation of Prototype Eco-Feedback Displays for Fixture-Level Water Usage Data

Sensing and Feedback of Everyday Activities to Promote Environmental Behaviors
Jon Froehlich, *University of Washington Doctoral Dissertation 2011*
THANK YOU!
@jonfroehlich
• Benefits of bikeshare:

• The Washington, D.C. region's Capital Bikeshare (CaBi) service released the third-party analysis of its 2011 member survey yesterday and it has some impressive results. Analysis shows that members save an average of $891 per year and collectively reduce their driving miles by 5 million annually.

• Other highlights include:
  • 83% of respondents said they were more likely to patronize a business that was CaBi-accessible
  • 82% of respondents reported increased bike use since joining Capital Bikeshare and 70% said CaBi was an important reason for this
  • CaBi was a major or main factor for 56% who reduced car use
Help Build Bikeshare!

Register or Login now and contribute to the enhancement of Capital Bikeshare.

To start suggesting new Capital Bikeshare station locations, log in with your username, your e-mail address, and your zip code of residence. Your username will be displayed to any suggestions you make. Your e-mail will not be shown publicly and will only be used to communicate with you about your suggestion if necessary.

Login to Start!
<table>
<thead>
<tr>
<th>City</th>
<th>Code</th>
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<tbody>
<tr>
<td>Nantong</td>
<td>1738</td>
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<tr>
<td>Changshu</td>
<td>3536</td>
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<tr>
<td>Taipei</td>
<td>718</td>
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<tr>
<td>Cardiff</td>
<td>189</td>
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<tr>
<td>La Spezia</td>
<td>151</td>
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