the **B**uilt **E**nvironment **S**pace-**T**ime **MOVE**ment **S**tudy:

A Framework for Objective Measurement of Behavior, Movement and Exposure in Urban Environments

Philip M. Hurvitz
Urban Form Lab-CBE-UW
2010-12-03

Overview

- Background/relevance
- Behavior & environment
- Previous studies
- Theoretical model
- Research questions
- Measurement & data
- Analysis
- Results
- Conclusion, Limitations, Next Steps
- Acknowledgments

Background/relevance

- Environmental characteristics have been found to play a role in a panoply of behavioral choices
- Environment provides an "opportunity space" for physical activity (PA), foraging/eating, communal/social activities, employment/school
- These behaviors are fundamental to health outcomes
- Little is known about how the full range (in space and time) of experienced environments relates to the full range of behavior
- This research establishes an objective, high-resolution, and spatially & temporally explicit framework for quantifying environment and behavior

Overview

- Background/relevance
- Behavior & environment
- Previous studies
- Theoretical model
- Research questions
- Measurement & data
- Analysis
- Results
- Conclusion, Limitations, Next Steps
- Acknowledgments

Behavior & environment

- Relatively new and heightened focus within planning and public health on notions of:
  - "obesogenic environments"
  - "walkable neighborhoods"
  - "active living by design"
- Can environments be designed for the healthiest choices to be the easiest choices?
  - PA
  - healthy diets

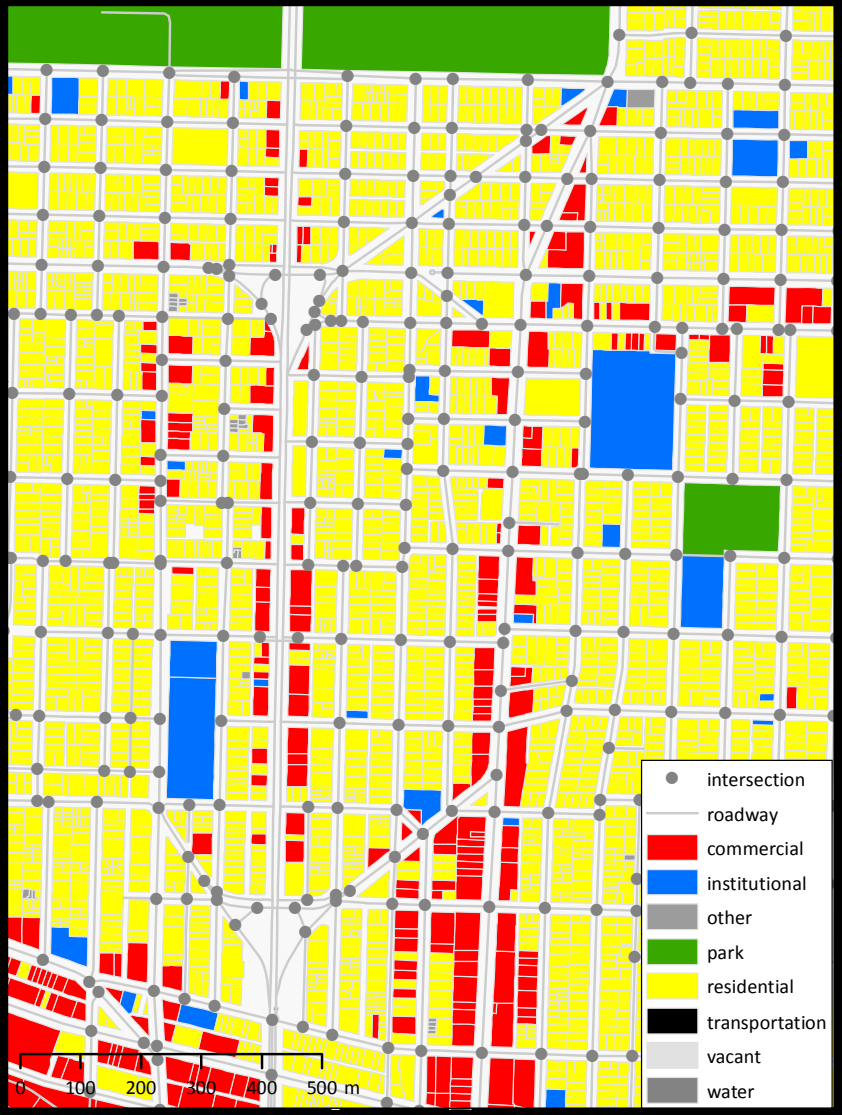
Behavior & environment

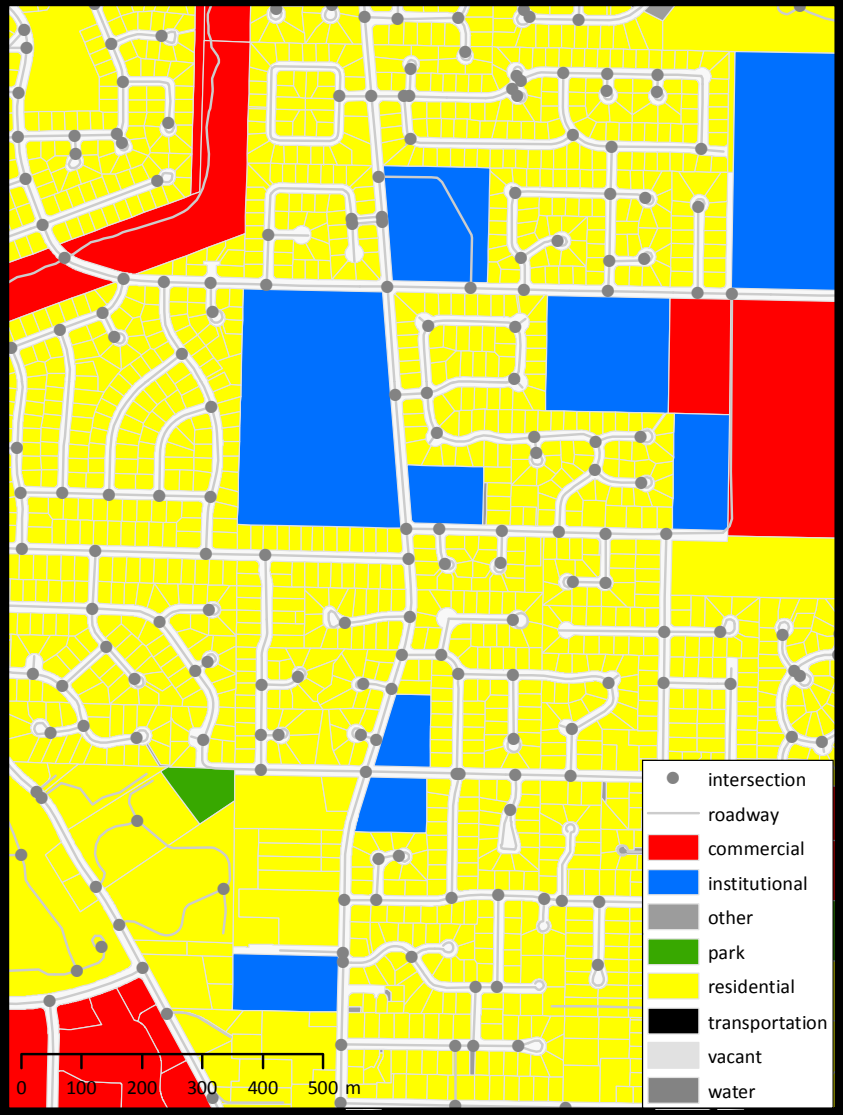
Comparison of characteristically different environments (wrt PA)

- "Active"
  - High density
    - Residential
    - Employment
  - Mixed land use
    - Utilitarian destinations within reasonable walking distance of home
  - Oriented to walking
    - Small street blocks
    - High density of intersections
    - Sidewalks
    - Low traffic volume/speed
- "Not active"
  - Low density
  - Single or segregated land use
  - Oriented to driving
    - Large street blocks
    - Culs-de-sac
    - No sidewalks
    - High traffic volume/speed

Behavior & environment

Comparison of characteristically different environments





Previous studies

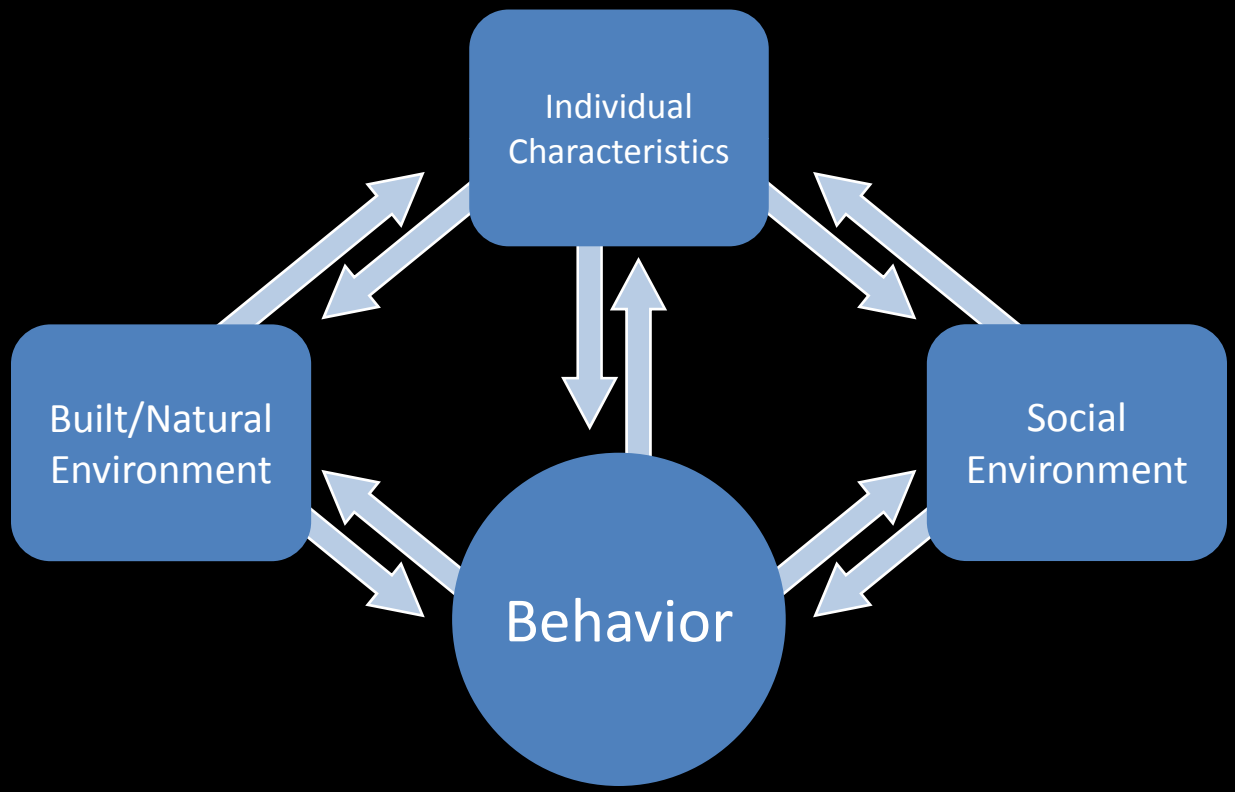
- Evidence linking BE and behavior (walking, physical activity, food access, obesity), e.g.,
  - Frank and Pivo, 1994
  - Cervero & Kockelman, 1997
  - Boarnet & Greenwald, 2000
  - Frank *et al*., 2005
  - Lee & Moudon, 2006
  - Moudon *et al*., 2007
  - Morland et al., 2002
  - Gordon-Larsen et al., 2006
  - Moore & Diez Roux, 2006
  - Powell, Chaloupka, & Bao, 2007
  - Zenk & Powell, 2008
  - Moore et al., 2009

Overview

- Background/relevance
- Behavior & environment
- Previous studies
- Theoretical model
- Research questions
- Measurement & data
- Analysis
- Results
- Conclusion, Limitations, Next Steps
- Acknowledgments

Previous studies

- Social Ecologic Model of Behavior (SEM) (Bronfenbrenner, Lewin)

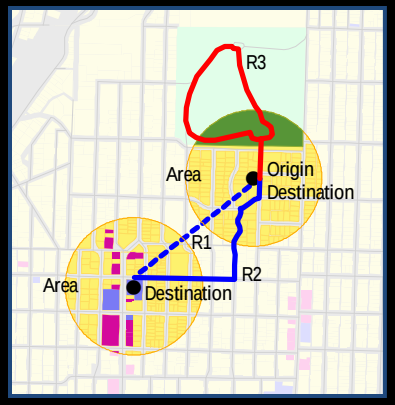


Previous studies

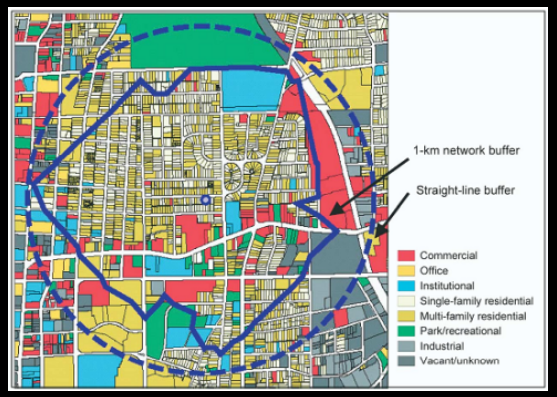
- Strengths and limitations
  - Strengths
    - Empirical Measurement & datas
    - Spatially explicit (some)
    - Individual level data (some)
    - Disaggregate spatial data (some)
  - Limitations
    - Self-report (most)
    - Spatial aggregation/MAUP (most)
    - Amorphous definition of "neighborhood," yet neighborhood tends to be one of the important units of analysis (most)

Previous studies

- These approaches to measuring/estimating exposure are fundamentally limited
- Exposure is continuous in space and time, but environment/behavior studies have focused almost exclusively on the home neighborhood as the single place of BE exposure



Lee & Moudon (2004)



Frank *et al.* (2005)

Previous studies

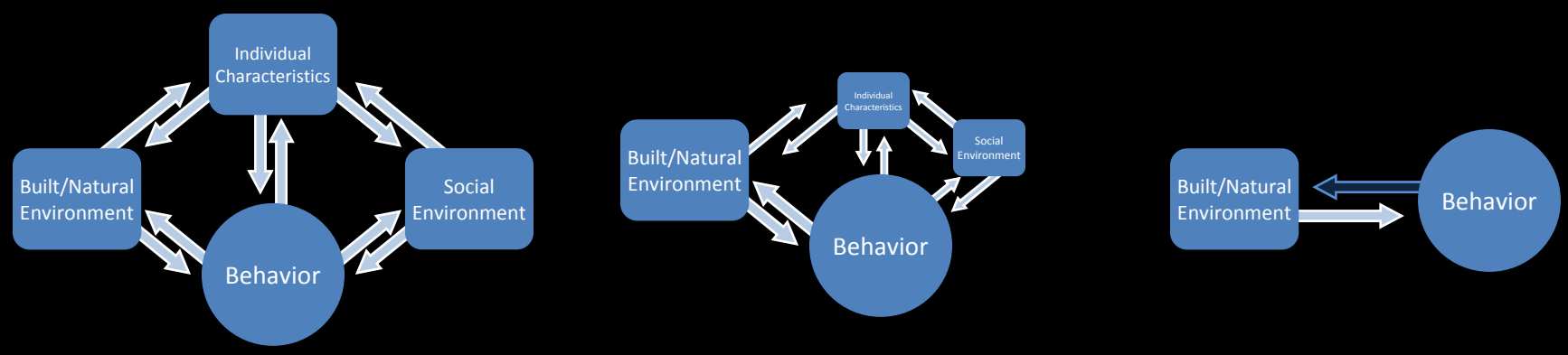
- Simple physical accessibility does not necessarily equal or determine utilization!
- Living in "active" neighborhood $\stackrel{?}{=}$ more PA
- Living close to a park $\stackrel{?}{=}$ using park
- Living near fast food restaurants $\stackrel{?}{=}$ eating lots of fast food
- Living close to a particular supermarket $\neq$ shopping at that supermarket

Overview

- Background/relevance
- Behavior & environment
- Previous studies
- Theoretical model
- Research questions
- Measurement & data
- Analysis
- Results
- Conclusion, Limitations, Next Steps
- Acknowledgments

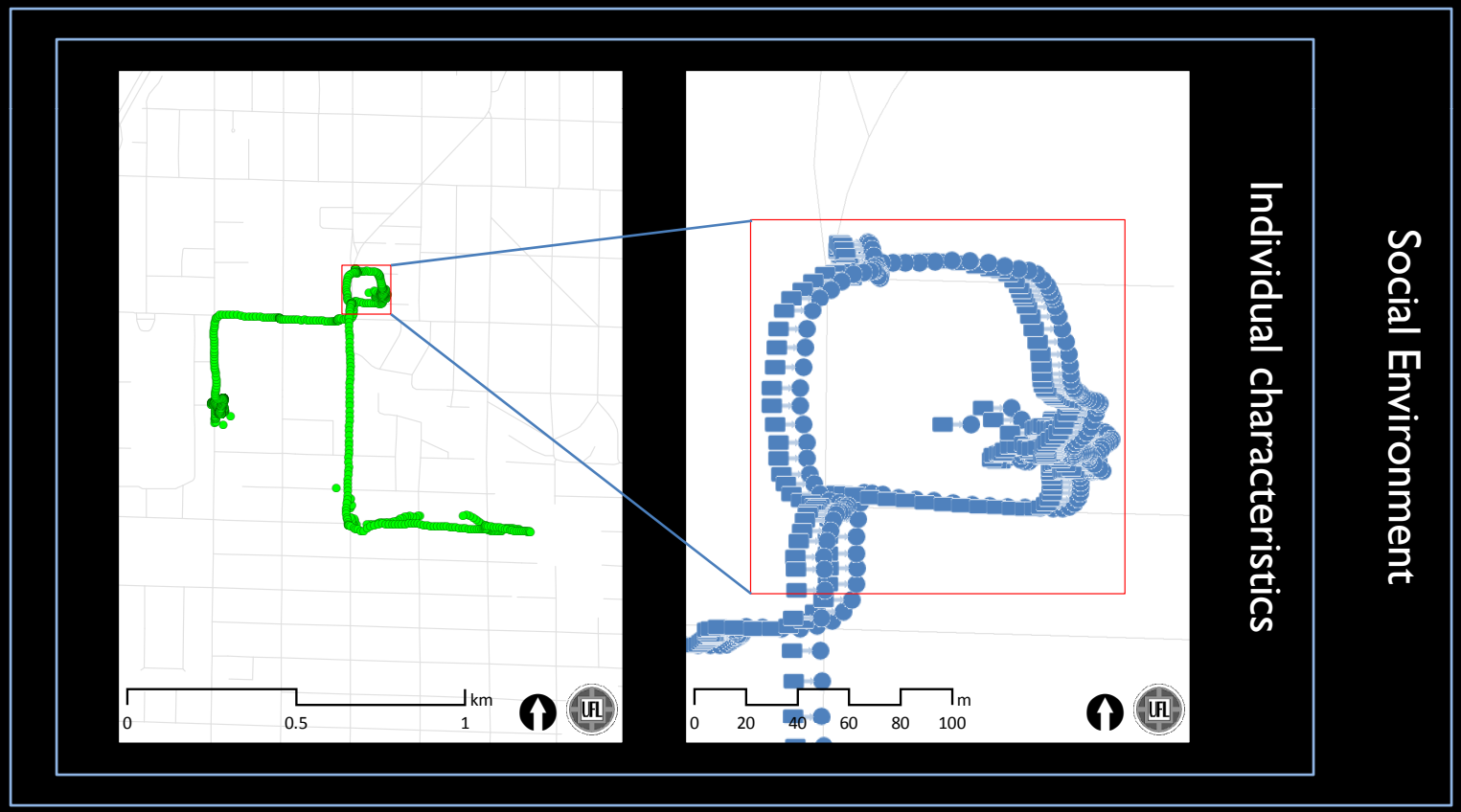
Theoretical model

- Over relatively short time scales, we can expect the <u>individual</u> and <u>social</u> characteristics of the SEM to become space-time constant "background" conditions, while built and natural environmental effects maintain variability



Theoretical model

- A trace through space and time conceptualized as a series of environmental exposures that may affect space-time localized behavior



Theoretical model

- Behaviors occur across space and time
- Environmental exposures occur across space and time
- Understanding the relationships between environmental exposure and behavior requires a measurement and modeling framework that explicitly accounts for <u>both</u> space and time

Overview

- Background/relevance
- Behavior & environment
- Previous studies
- Theoretical model
- Research questions
- Measurement & data
- Analysis
- Results
- Conclusion, Limitations, Next Steps
- Acknowledgments

Research questions

- Are environmental exposures different for the home location and other locations within the space-time realm of movement?
- Do environmental measures (i.e., exposures) vary across movement bouts of different character?
- Do environmental characteristics vary for individuals with different overall physical activity levels?

Overview

- Background/relevance
- Behavior & environment
- Previous studies
- Theoretical model
- Research questions
- Measurement & data
- Analysis
- Results
- Conclusion, Limitations, Next Steps
- Acknowledgments

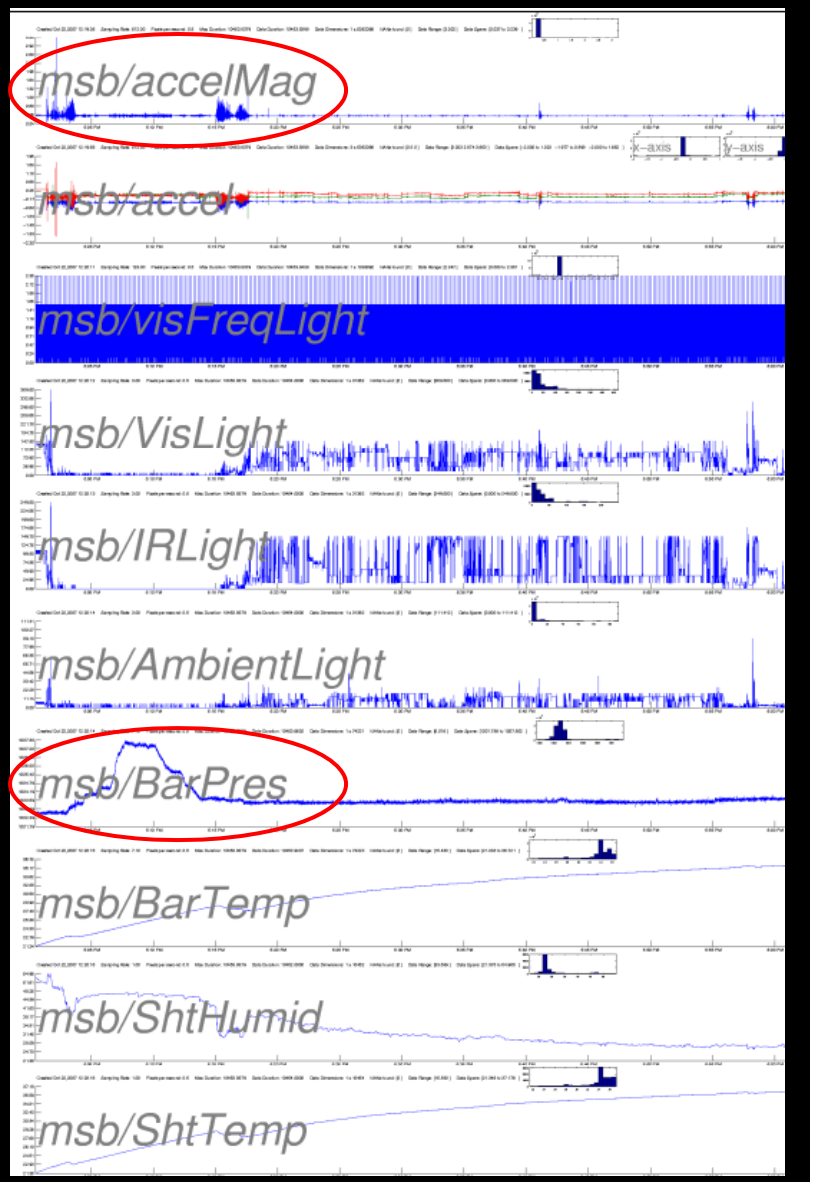
Measurement & data: Activity & Location

- A number of environmental sensors incorporated within a small unobtrusive wearable compartment: the Multi-Sensor Board (MSB)
- 51 subjects
- Worn for 1 week during waking hours

Multi-sensor board (MSB)

Measurement & data: Activity & Location

- Sensation & recording of multiple environmental variables
  - 3d accelerometry
  - barometric pressure
  - light (visible, IR, high-frequency, ambient)
  - temperature
  - humidity
  - audio (not collected)
  - differential GPS @ 1 Hz

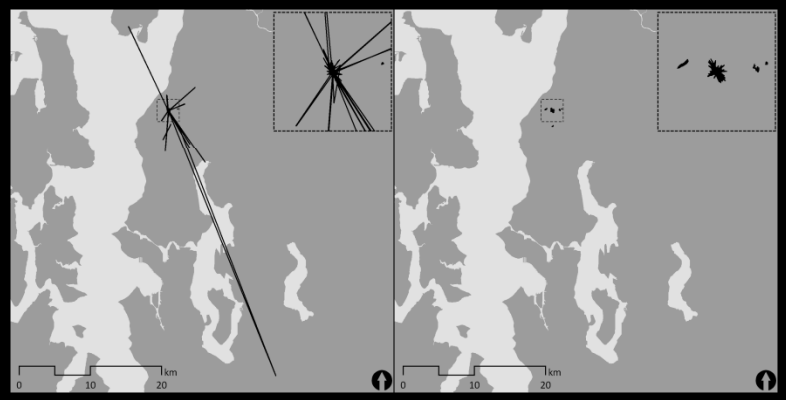


Measurement & data: Additional variables

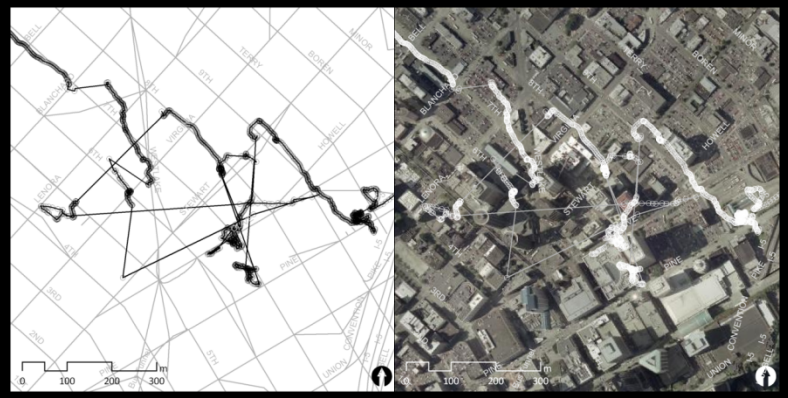
- PA: International Physical Activity Questionnaire (IPAQ), a validated self-report instrument for estimating amounts of time spent in activities of different intensities (weekly total)
- Personal characteristics
  - Sociodemographic survey completed during enrollment (age, sex, race/ethnicity, income, education)
  - Anthropometrics (height & weight)
- BE: GIS measures (described below)

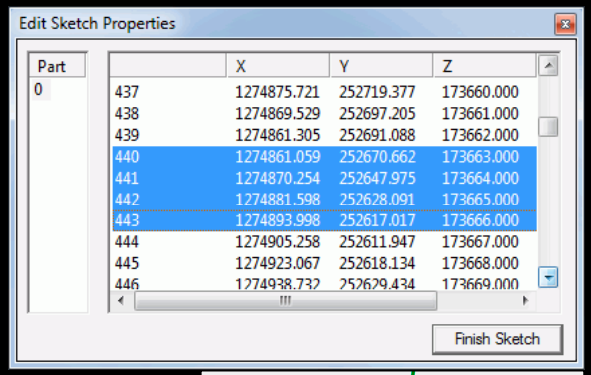
Measurement & data: Cleaning GPS data

HDOP & SVs

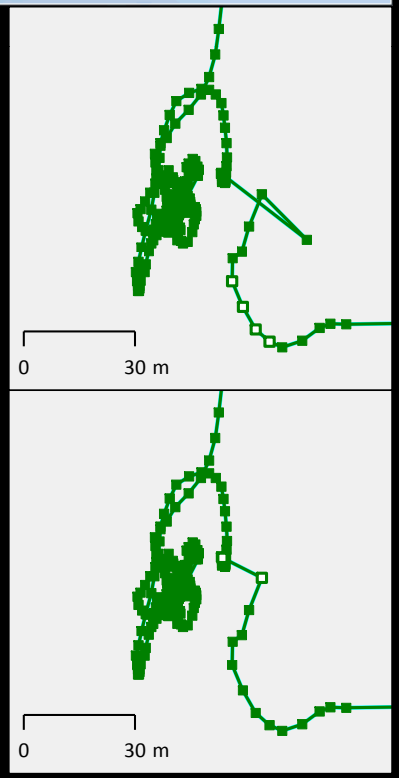


Urban canyon problems





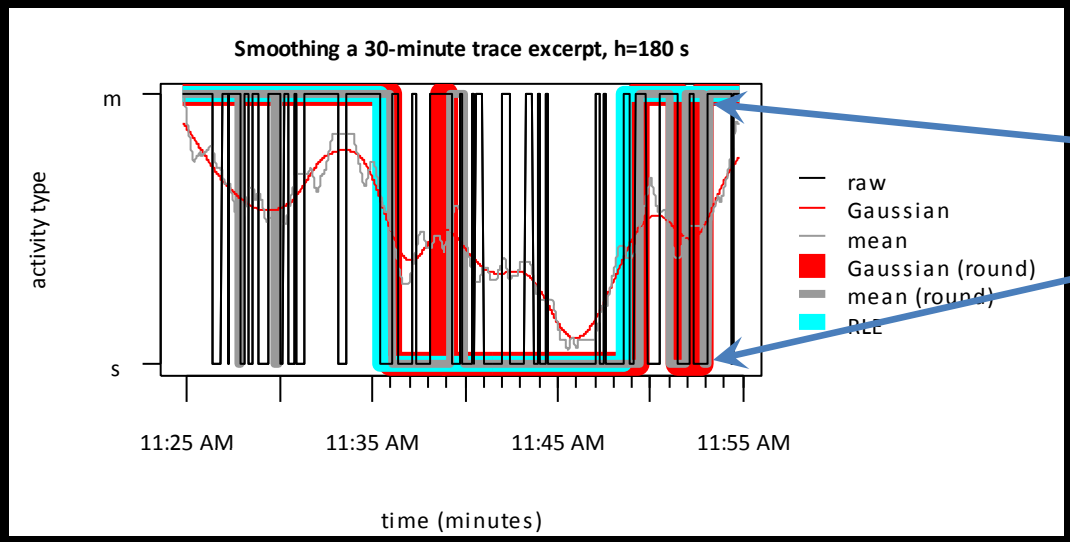
Vertex-level edits



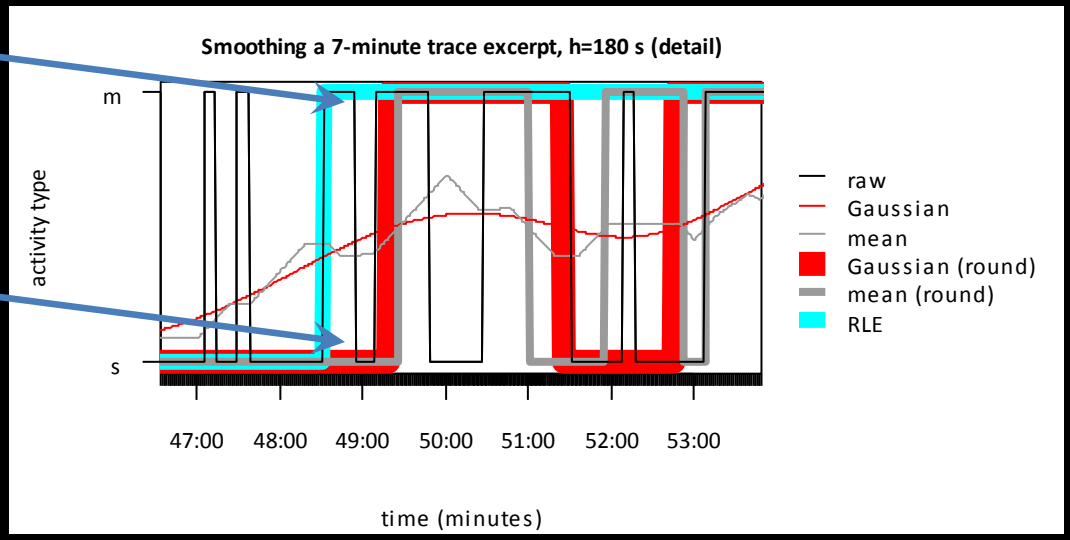
Measurement & data: smoothing movement data

- Raw 1 Hz accelerometry and barometry data were pre-processed and binned into moving in XY and Z space (J. Lester)
- "Staccato" data were smoothed; a number of different automated routines were tested or applied, with varying success
  - kernel filtering (rolling means, Gaussian)
  - image closing
  - run-length encoding (RLE)

Measurement & data: smoothing movement data



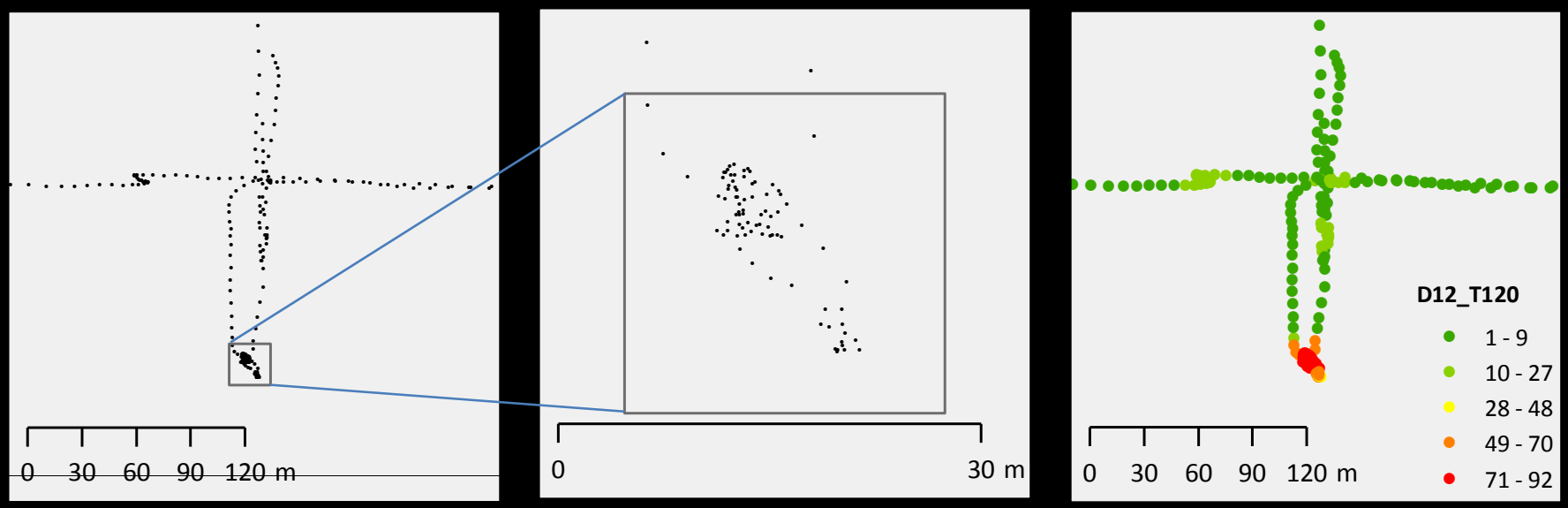
No single automated method of smoothing worked best.



Ended up using a recursive RLE method for identifying temporally contiguous "bouts."

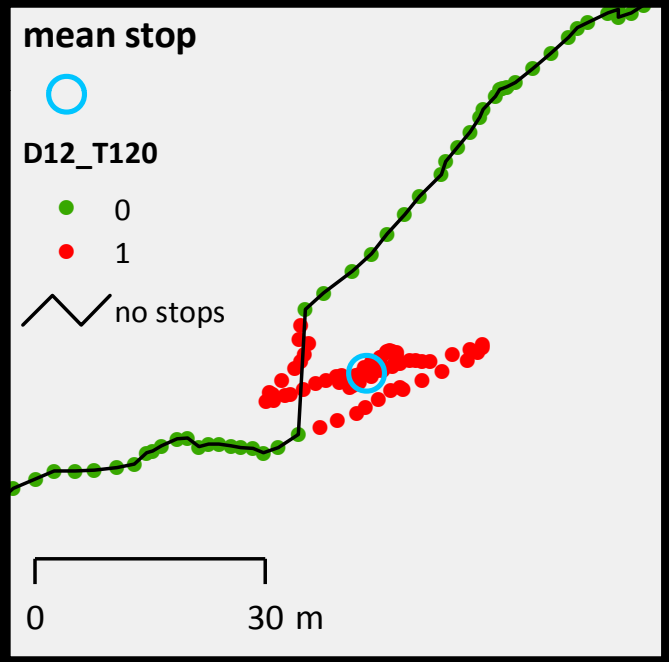
Measurement & data: Detecting stops

- Within a moving trace (a ***trip***), tight space-time clusters indicate in-line ***stops***
- Focal count of points within a spatial and temporal window; high count = a stop



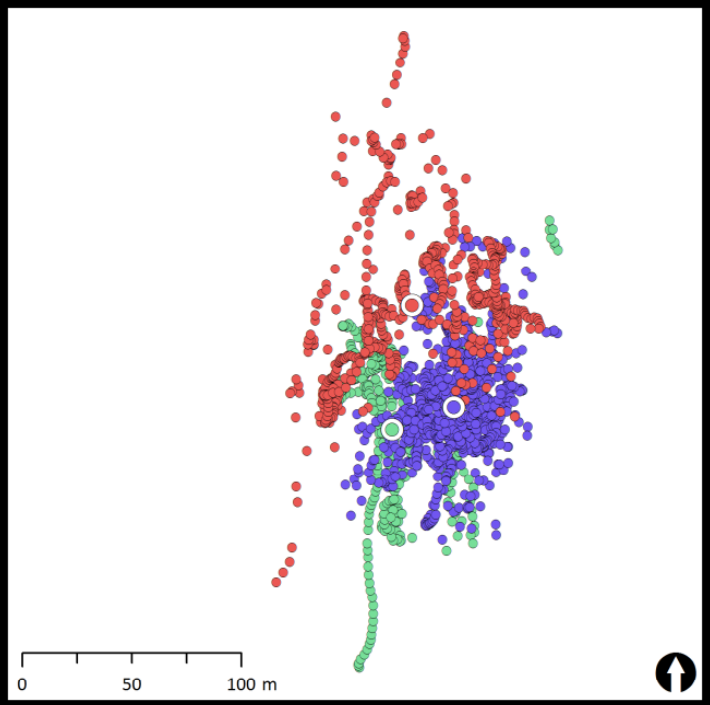
Measurement & data: Detecting stops

- The stop is represented as $(\overline{x}, \overline{y})$
- Stop vertices may be removed from "trip" trace



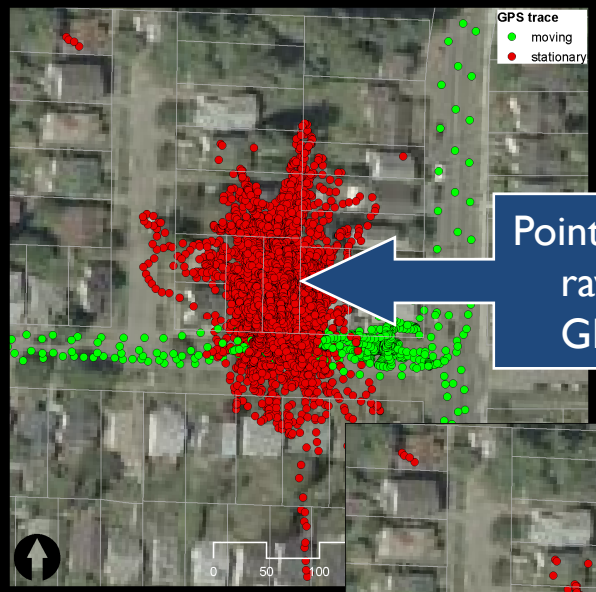
Measurement & data: Dwell locations

- Stationary traces (i.e., composed of non-moving location) were also represented as single point features, with coordinates $(\bar{x}, \bar{y})$ for each bout

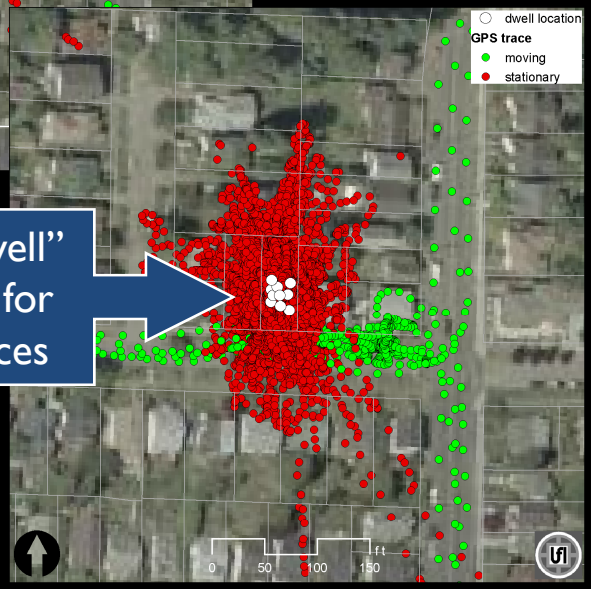


Measurement & data: Trips and dwells

raw GPS trace



Points from several raw "stationary" GPS traces



mean "dwell" locations for those traces

Measurement & data: Environmental data

- Introducing the SmartMap (UFL data)
  - Based on a combination of
    - Point buffer/intersect/feature extraction/summary
    - Focal processing
  - Creates a spatially continuous data set with values at all locations (grid cells) in the spatial data frame
  - Each location's value is the summary of map data within a predefined radius
  - Similar to KDE, FOCAL functions in Arc/GRID
  - Extension from basic functions to GIS analyses performed at focal locations

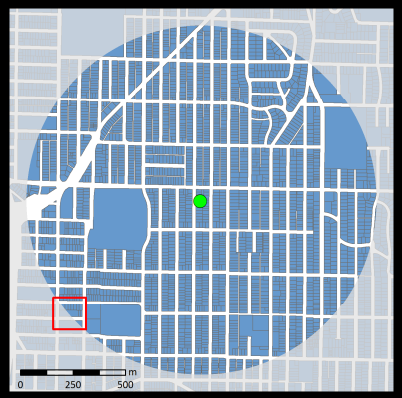
Measurement & data: a SmartMap example

- A SmartMap of residential property value within radial bandwidth
- Data source: UFL parcel data
  - Total value (land + improvements)
  - Number of dwelling units

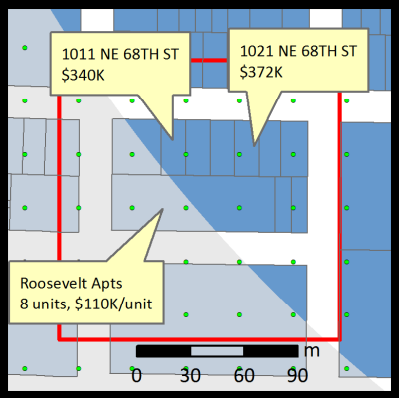
Measurement & data: a SmartMap example

833 m radius
10 minute walking distance

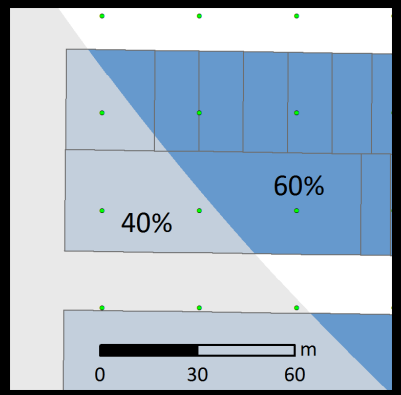
Parcels are selected



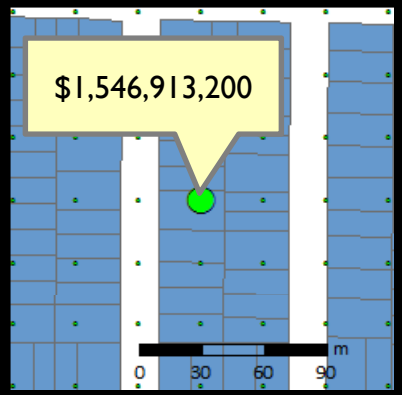
Value and number of units are tallied



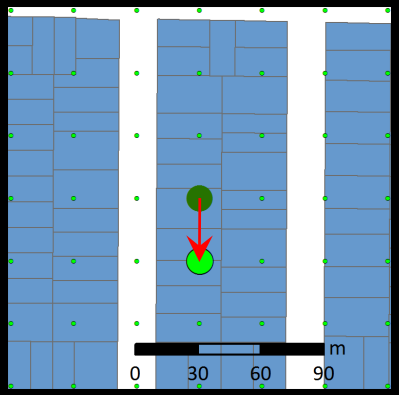
Area-weighted apportioning



Parcel values are summed
Sum placed on focal point

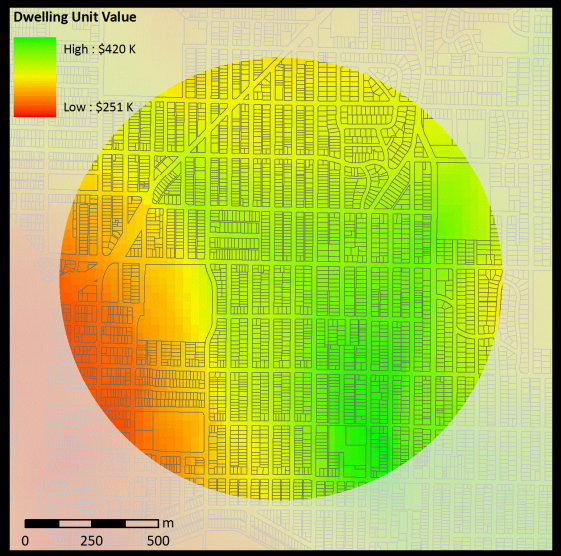


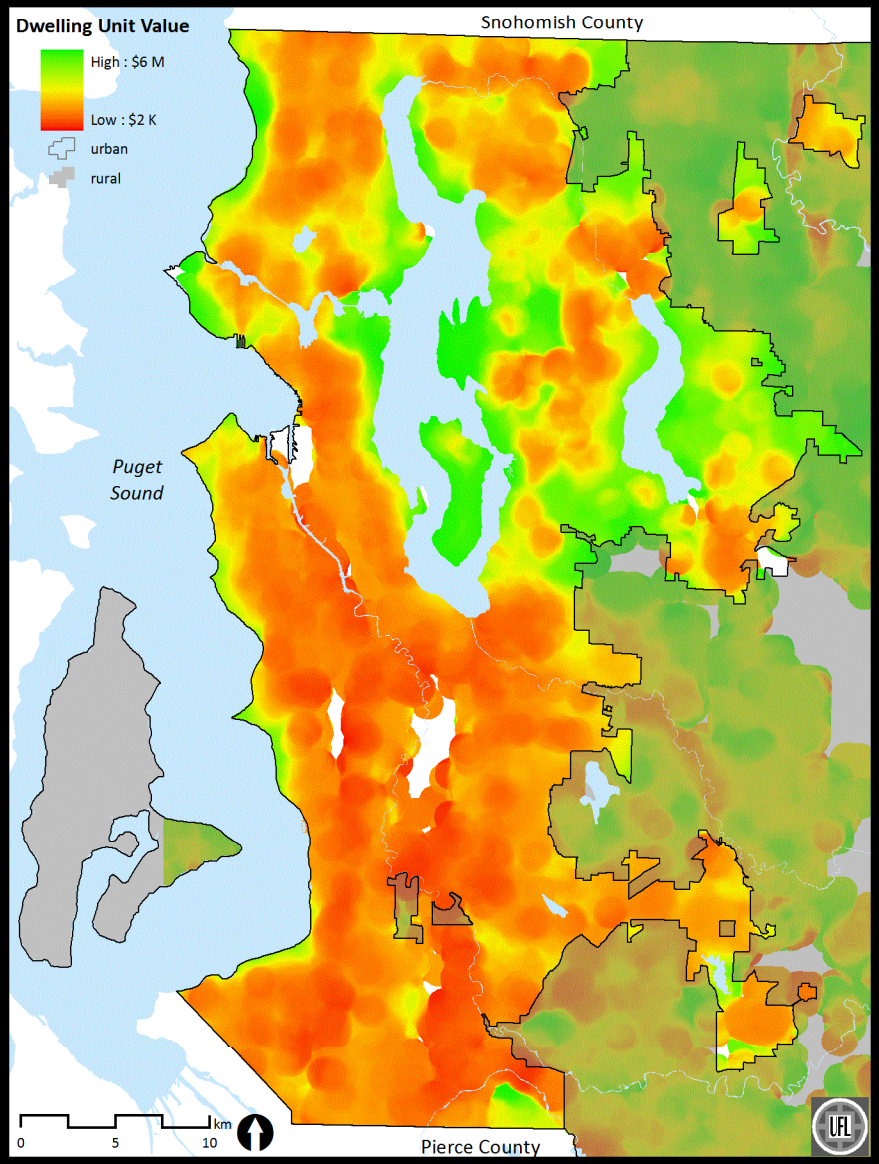
Focus moves to next point



Measurement & data: a SmartMap example

Individual point data values are normalized to a "mean value per dwelling unit" and smoothed to create a spatially continuous surface.

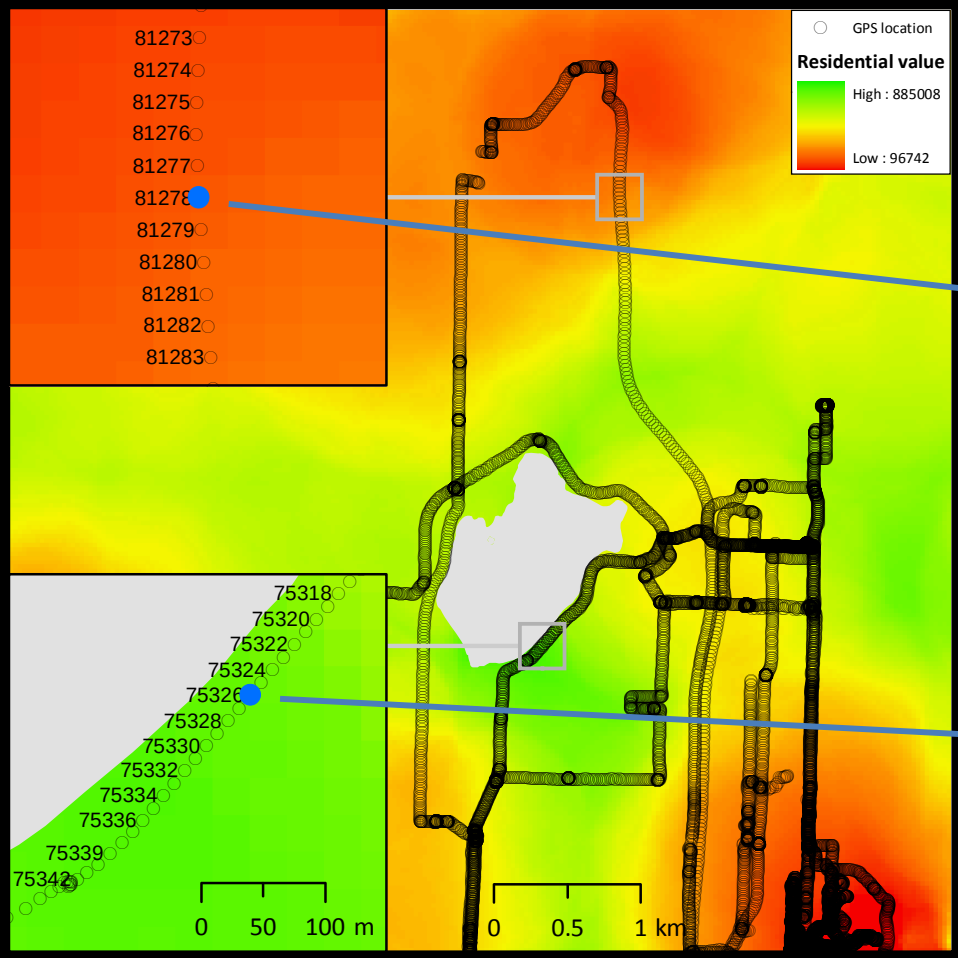




Mean dwelling unit value for the proximal neighborhood can be estimated for *any location in the study area*.

Measurement & data: SmartMap values

- "Surfacespot" to obtain individual location values (4.3 million records, 18 variables)



Attributes of s56_move_point

Shape	BOUT	TRIP	SID	MOVETYPE	SEQ_ID	UTC	res_value
Point ZM	4	28	s56	m	81273	2008-04-21 03:30:36	191476.339688
Point ZM	4	28	s56	m	81274	2008-04-21 03:30:37	193900.168762
Point ZM	4	28	s56	m	81275	2008-04-21 03:30:38	195870.911845
Point ZM	4	28	s56	m	81276	2008-04-21 03:30:39	197546.72109
Point ZM	4	28	s56	m	81277	2008-04-21 03:30:40	199636.209386
Point ZM	4	28	s56	m	81278	2008-04-21 03:30:41	202970.67494
Point ZM	4	28	s56	m	81279	2008-04-21 03:30:42	206879.191457
Point ZM	4	28	s56	m	81280	2008-04-21 03:30:43	209874.767544
Point ZM	4	28	s56	m	81281	2008-04-21 03:30:44	212300.897558
Point ZM	4	28	s56	m	81282	2008-04-21 03:30:45	214175.094747
Point ZM	4	28	s56	m	81283	2008-04-21 03:30:46	216345.507031
Point ZM	4	28	s56	m	81284	2008-04-21 03:30:47	218856.683686

Record: 0 Show: All Selected Records (1 out of 23985 Selected)

Attributes of s56_move_point

Shape	BOUT	TRIP	SID	MOVETYPE	SEQ_ID	UTC	res_value
Point ZM	3	23	s56	m	75320	2008-04-20 23:38:24	401488.641291
Point ZM	3	23	s56	m	75321	2008-04-20 23:38:25	408218.329787
Point ZM	3	23	s56	m	75322	2008-04-20 23:38:26	413025.073584
Point ZM	3	23	s56	m	75323	2008-04-20 23:38:27	416377.23409
Point ZM	3	23	s56	m	75324	2008-04-20 23:38:28	419686.246138
Point ZM	3	23	s56	m	75325	2008-04-20 23:38:29	422869.085999
Point ZM	3	23	s56	m	75326	2008-04-20 23:38:30	424995.702905
Point ZM	3	23	s56	m	75327	2008-04-20 23:38:31	426391.07496
Point ZM	3	23	s56	m	75328	2008-04-20 23:38:32	427181.924228
Point ZM	3	23	s56	m	75329	2008-04-20 23:38:33	428454.355504
Point ZM	3	23	s56	m	75330	2008-04-20 23:38:34	430613.962972
Point ZM	3	23	s56	m	75331	2008-04-20 23:38:35	433600.05277

Record: 0 Show: All Selected Records (1 out of 9000 Selected)

Measurement & data: SmartMap variables

- SmartMap (BE) variables used:

Neighborhood composition
- Count of jobs × 100
- Number of residential units × 100

Destinations
- Count of coffee shops
- Count of fast food restaurants
- Count of fitness facilities
- Area of park (ha)
- Count of parks (any overlap)
- Percent of area of bandwidth covered by park
- Count of supermarkets
- Count of traditional restaurants
- Trail density (km/km^2)

Transportation/traffic
- Bus ridership × 1000
- Intersection density (n/km^2)
- Density of streets (km/km^2, no freeways)
- Estimated traffic volume (1000 vehicles/km^2)

Indices of land use composition & configuration (from FRAGSTATS)
- Aggregation index (AI)
- Interspersion & juxtaposition index (IJI)
- Shannon's diversity index (SHDI also known as "entropy")

Overview

- Background/relevance
- Behavior & environment
- Previous studies
- Theoretical model
- Research questions
- Measurement & data
- Analysis
- Results
- Conclusion, Limitations, Next Steps
- Acknowledgments

Analysis

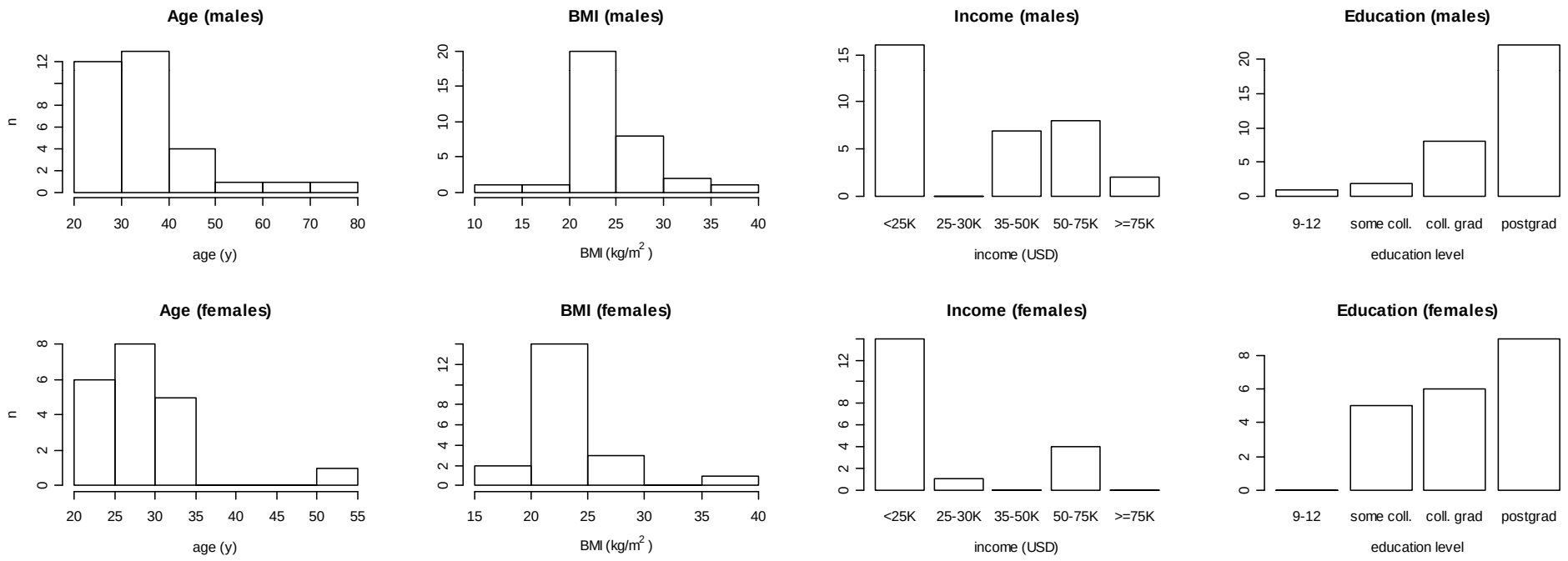
- Marked point location data were dichotomized across several axes (marks = environmental variable values)
  - Overall level of physical activity
  - Dwell vs. trip
  - Near vs. far from home (125 m)
  - Short vs. long trip (1.5 km)
  - Fast vs. slow trip (10 m/s = 22.4 mi/h)
- Comparison of mean values for dichotomized environmental variables (Wilcoxon test)

Overview

- Background/relevance
- Behavior & environment
- Previous studies
- Theoretical model
- Research questions
- Measurement & data
- Analysis
- Results
- Conclusion, Limitations, Next Steps
- Acknowledgments

Results: demographics

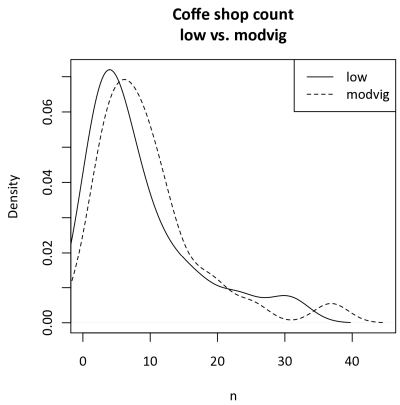
- Generally young, fit, bimodally poor and relatively wealthy, and highly educated

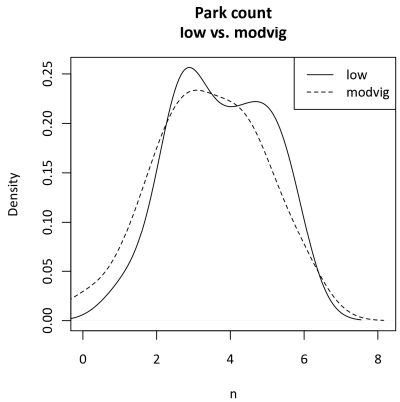


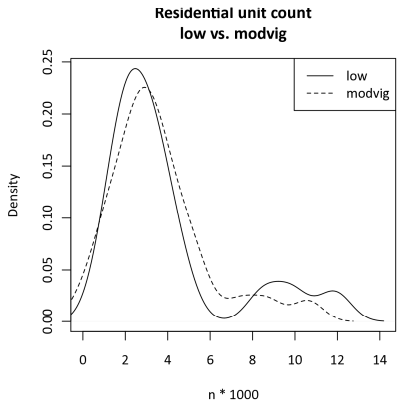
Results: Physical activity

- No significant differences

	low		moderate-vigorous			
	mean	sd	mean	sd	p-value	diff
employment (jobs x 1000)	9.2	6.5	11.4	10.8	0.468	-2.2
residential units (count x 1000)	3.9	3.1	3.6	2.4	0.920	0.4
coffee shops (count)	8.5	8.1	9.7	7.9	0.299	-1.1
fast food restaurants (count)	3.7	2.8	4.1	2.8	0.616	-0.4
fitness facilities (count)	3.4	3.1	3.6	2.8	0.648	-0.2
park area (ha)	23.9	24.2	43.7	77.0	0.366	-19.8
parks (count)	3.7	1.3	3.4	1.5	0.525	0.3
park area (%)	3.9	2.4	5.7	7.8	0.815	-1.8
supermarkets (count)	0.9	1.0	0.9	0.8	0.521	-0.0
traditional restaurant (count)	7.6	6.9	8.8	6.7	0.288	-1.3
trail density (km/km²)	0.4	0.2	0.5	0.3	0.471	-0.1
bus ridership (count x 1000)	14.2	10.4	15.6	9.8	0.585	-1.4
intersection density (count/km²)	181.5	51.0	176.4	61.1	0.815	5.1
street density (km/km²)	13.8	3.1	13.5	4.0	0.938	0.4
traffic volume (1000 vehicles)	113.0	75.3	117.7	75.1	0.648	-4.7
AI	81.6	11.2	78.5	20.9	0.764	3.1
IJI	35.5	14.4	35.7	20.2	0.973	-0.2
SHDI	0.8	0.2	0.8	0.3	0.664	-0.0



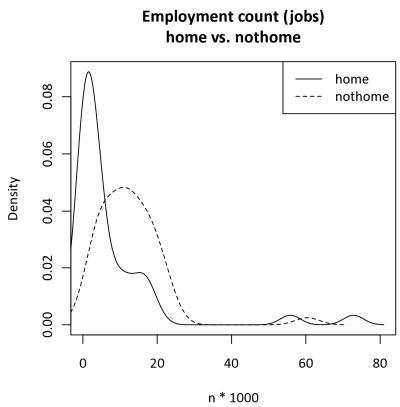


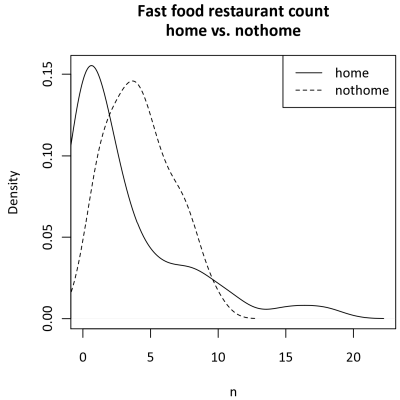


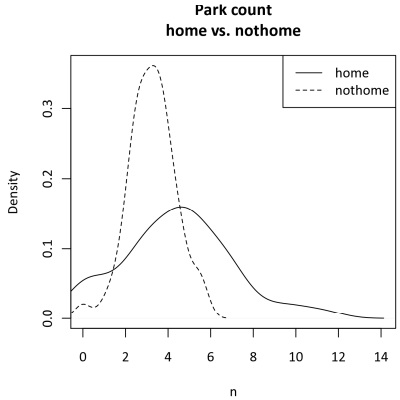
Results: Home vs. not home (125 m)

- Multiple significant differences

	home		not home			
	mean	sd	mean	sd	p-value	diff
employment (jobs x 1000)	7.5	13.9	12.6	9.3	**<0.001**	-5.2
residential units (count x 1000)	4.5	4.0	3.2	2.0	0.244	1.2
coffee shops (count)	8.8	12.4	9.3	6.6	**0.027**	-0.5
fast food restaurants (count)	3.1	4.3	4.2	2.4	**0.001**	-1.1
fitness facilities (count)	4.0	4.2	3.1	2.3	0.826	0.9
park area (ha)	25.1	37.2	43.0	83.6	**<0.001**	-18.0
parks (count)	4.4	2.6	3.2	1.1	**0.006**	1.2
park area (%)	6.4	8.2	4.7	4.8	0.982	1.7
supermarkets (count)	1.0	1.3	0.8	0.7	0.344	0.2
traditional restaurant (count)	8.0	10.4	8.9	6.5	0.080	-0.9
trail density (km/km²)	0.3	0.4	0.5	0.2	**0.002**	-0.2
bus ridership (count x 1000)	8.8	11.7	18.2	11.2	**<0.001**	-9.4
intersection density (count/km²)	181.4	80.5	172.4	53.4	0.256	9.1
street density (km/km²)	14.0	5.1	13.1	3.4	**0.018**	1.0
traffic volume (1000 vehicles)	110.0	109.8	120.3	64.7	0.083	-10.3
AI	76.1	24.7	80.9	17.8	**0.022**	-4.7
HI	29.4	26.4	39.3	16.5	0.123	-9.9
SHDI	0.8	0.4	0.8	0.3	0.614	-0.0



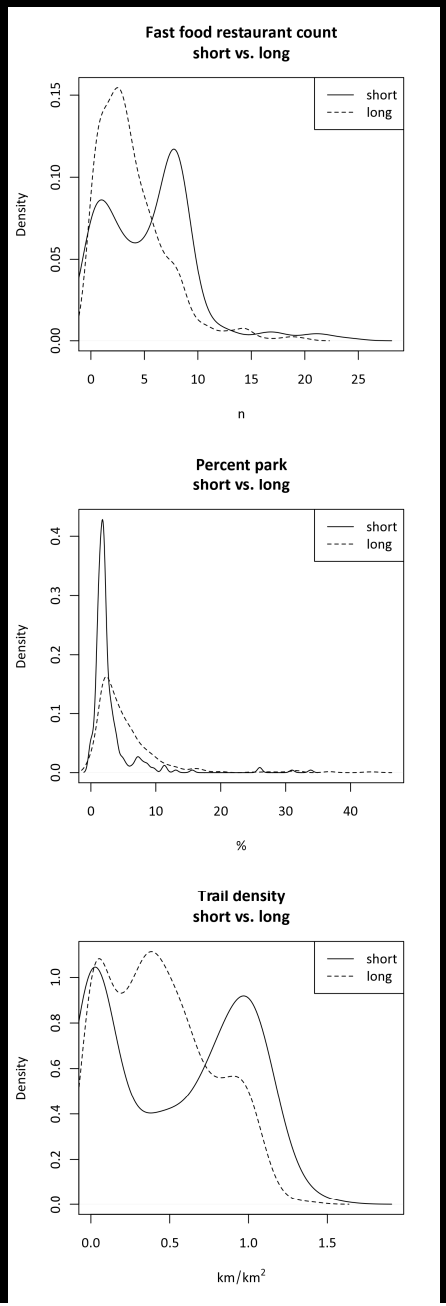




Results: Short vs. long trips (1.5 km)

- Many significant differences

	short		long			
	mean	sd	mean	sd	p-value	diff
employment (jobs x 1000)	15.6	19.0	11.9	14.3	**<0.001**	3.7
residential units (count x 1000)	3.9	3.2	3.5	2.5	0.054	0.5
coffee shops (count)	12.3	13.6	9.6	10.1	**0.001**	2.7
fast food restaurants (count)	5.5	4.4	3.9	3.3	**<0.001**	1.6
fitness facilities (count)	3.7	3.7	3.6	2.8	0.095	0.1
park area (ha)	27.5	24.1	59.4	441.6	0.891	-31.8
parks (count)	3.2	1.8	3.7	1.6	**<0.001**	-0.5
park area (%)	3.0	4.1	5.3	5.5	**<0.001**	-2.3
supermarkets (count)	1.1	1.1	0.9	0.7	0.586	0.2
traditional restaurant (count)	11.5	15.1	9.3	10.5	**<0.001**	2.2
trail density (km/km²)	0.5	0.4	0.4	0.3	**0.020**	0.1
bus ridership (count x 1000)	24.2	24.0	15.5	16.2	**<0.001**	8.7
intersection density (count/km²)	196.2	70.7	174.2	65.3	**<0.001**	21.9
street density (km/km²)	14.8	4.3	13.5	4.1	**<0.001**	1.3
traffic volume (1000 vehicles)	145.0	96.6	132.1	83.1	0.127	13.0
AI	82.7	17.6	83.8	15.3	**0.002**	-1.1
IJI	41.8	23.0	42.3	14.8	**0.034**	-0.4
SHDI	0.9	0.4	0.9	0.3	0.425	-0.0



Overview

- Background/relevance
- Behavior & environment
- Previous studies
- Theoretical model
- Research questions
- Measurement & data
- Analysis
- Results
- Conclusion, Limitations, Next Steps
- Acknowledgments

Conclusion, Limitations, Next Stepss

- BE variables did not vary between low and moderate-vigorous PA individuals
- Different BE variables varied between other groups
  - Home vs. away
  - Dwell vs. trip
  - Long vs. short trip
  - Fast vs. slow trip
- Variables that differed by groups:
  - Employment & residential density
  - Food places
  - Fitness facilities, parks, trails
  - Transportation infrastructure
  - Land use configuration

Limitations

- Limitations
  - Incomplete space-time coverage for subjects (device glitches, battery life, GPS coverage)
  - Small convenience sample: limited generalizability
  - KC UGB unlike many other areas
  - Selected tolerances may not capture the time or distance scales on which environment affects behavior
  - Time lag between exposure and response
  - Directionality of effect (does intention lead to choice of environment <u>or</u> does environment cause a behavioral response?)
  - Spatial dependence/autocorrelation

Contributions to knowledge

- Development of a space-time explicit Measurement & data for estimating environmental exposures
- Extension of the point-buffer environmental summary measurement method to a spatially continuous measurement method
- Environments people move through and dwell in vary tremendously, which should be accounted for in estimating effects of environment on behavior
- Application to the increasing number of studies incorporating temporally high resolution GPS measurements

Next steps

- Application of these methods to a larger data set:
  - The Effect of Light Rail Transit on Physical Activity: A Natural Experiment
  - > 600 persons
  - 7-d GPS, accelerometry, travel diary, sociodemographic survey, IPAQ
  - Longitudinal measures (3 points in time)

Powered By

Overview

- Background/relevance
- Behavior & environment
- Previous studies
- Theoretical model
- Research questions
- Measurement & data
- Analysis
- Results
- Conclusion, Limitations, Next Steps
- Acknowledgments

Acknowledgements

- Funding
  - CBE-UrbDP
  - Intel Labs Seattle, UW CSE (in kind)
  - NIH 1-P20-RR020774-01: UW-Exploratory Center for Obesity Research (A. Drewnowski)
  - NIH 5R01DK076608-03: Food Environment, Diet Quality, And Disparities in Obesity (A. Drewnowski, A. Moudon)
  - NIH 5R01HL091881-03 The Effect of Light Rail Transit on Physical Activity: A Natural Experiment (B. Saelens, A. Moudon)
  - NIH 5R21AG032232-03 BALANCE: Bioengineering Approaches for Lifestyle Activity and Nutrition Continuous Engagement (G. Duncan)
  - UW Graduate School Hall-Ammerer Fellowship
  - UW Royalty Research Fund
  - Washington State Dept. of Transportation

Acknowledgements

- UFL Students & Staff who worked on the SmartMaps
  - Ruizhu Huang
  - Junfeng Jiao
  - Bumjoon Kang
  - Lin Lin
  - Orion Stewart
  - Jared Ulmer

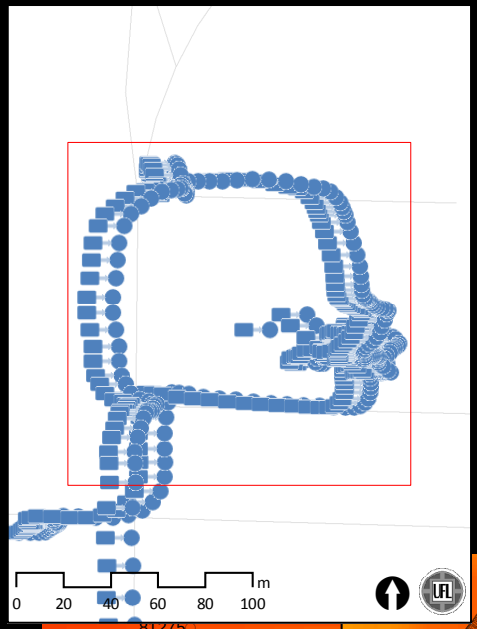
Acknowledgements

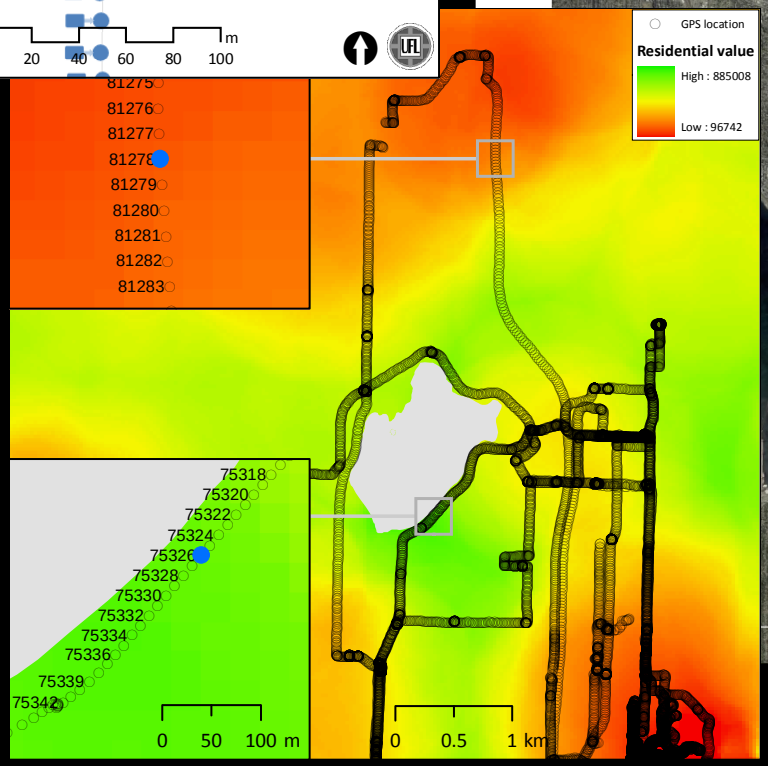
- Collaborators on MSB project
  - Ethan Berke MD (now at Dartmouth College)
  - Prof. Gaetano Borriello (CSE)
  - Prof. Glen Duncan (Epi/CPHN)
  - Jon Froehlich (CSE PhD student)
  - Cark Hartung (CSE PhD student)
  - Harlan Hile (CSE PhD student)
  - Alan Liu (CSE PhD student)
  - Jonathan Lester (CSE/EE PhD student, developer of MSB)

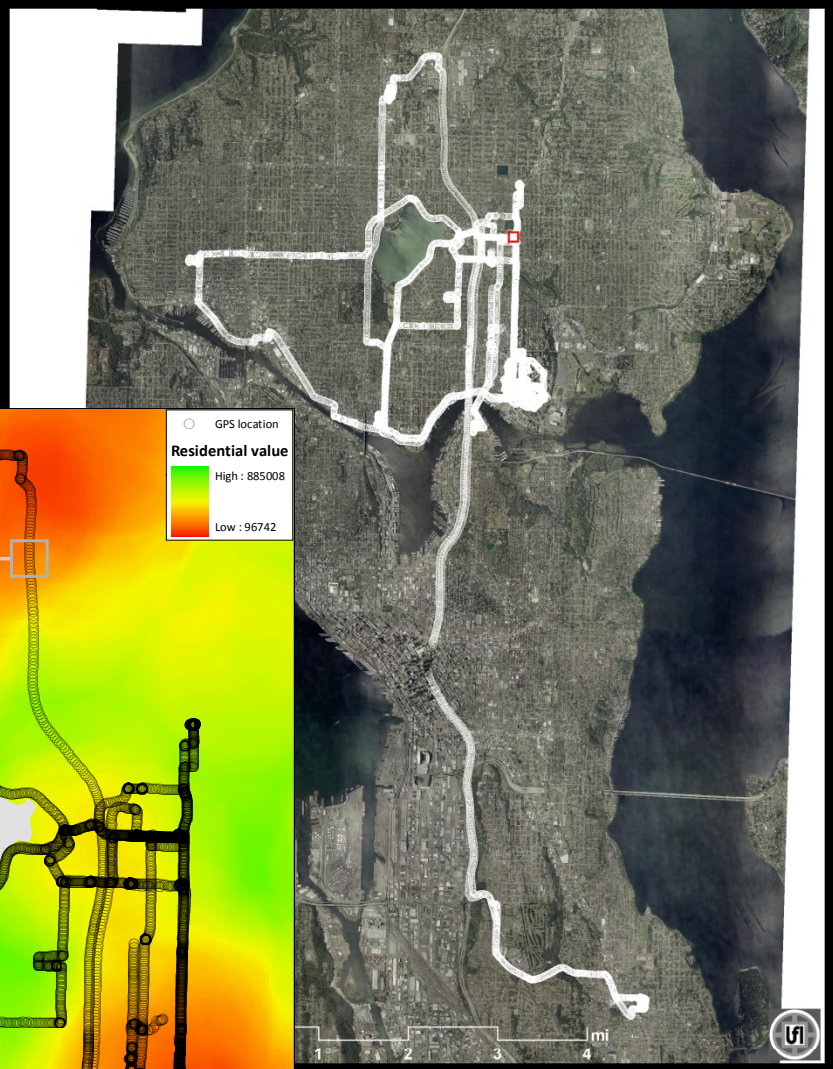
Acknowledgements

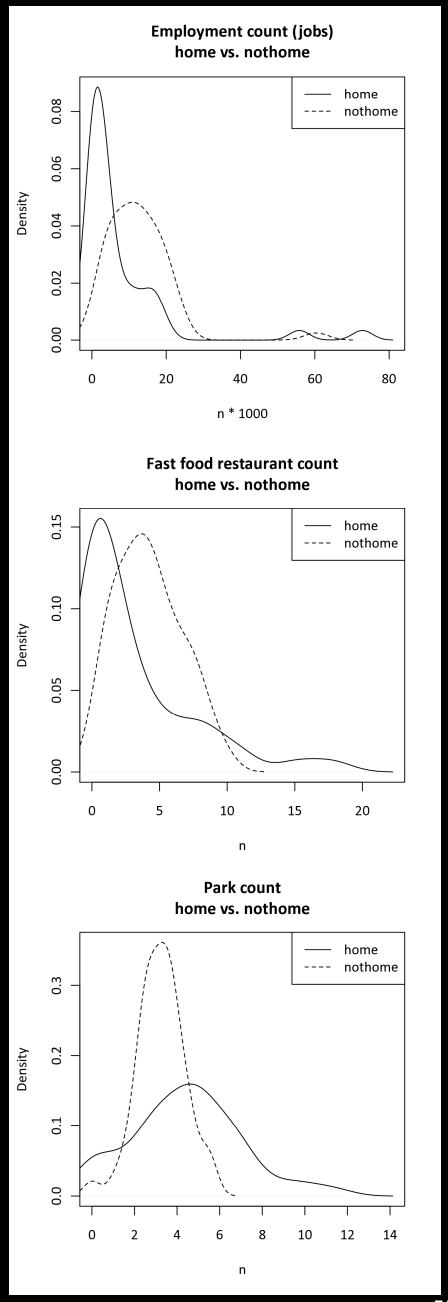
- Supervisory Committee (also discussants)
  - Gaetano Borriello (GSR)
  - Adam Drewnowski
  - Miles Logsdon
  - Anne Vernez Moudon (chair)
- Anonymous study subjects
  - You know who you are
- Internet community of computer users
- Friends, colleagues
- Students
- Family

Questions?


0 20 40 60 80 100 m


GPS location
Residential value
High : 885008
Low : 96742
81275
81276
81277
81278
81279
81280
81281
81282
81283
75318
75320
75322
75324
75326
75328
75330
75332
75334
75336
75339
75342
0 50 100 m
0 0.5 1 km


1 2 3 4 mi


Employment count (jobs)
home vs. nothome
home
nothome
Density
n * 1000
Fast food restaurant count
home vs. nothome
home
nothome
Density
n
Park count
home vs. nothome
home
nothome
Density
n