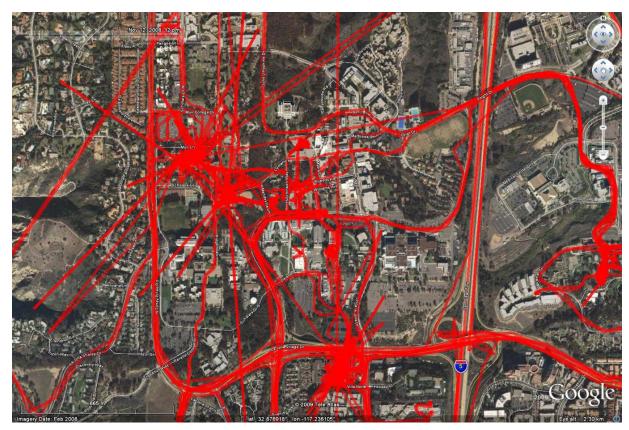
#### Best Practices in Data Reduction & Analysis of GPS Data

Jacqueline Kerr Fred Raab Ernesto Ramirez University of California, San Diego

## Audience Poll

- Who has collected GPS data?
- Who has analyzed or mapped the data?



# Context of GPS work

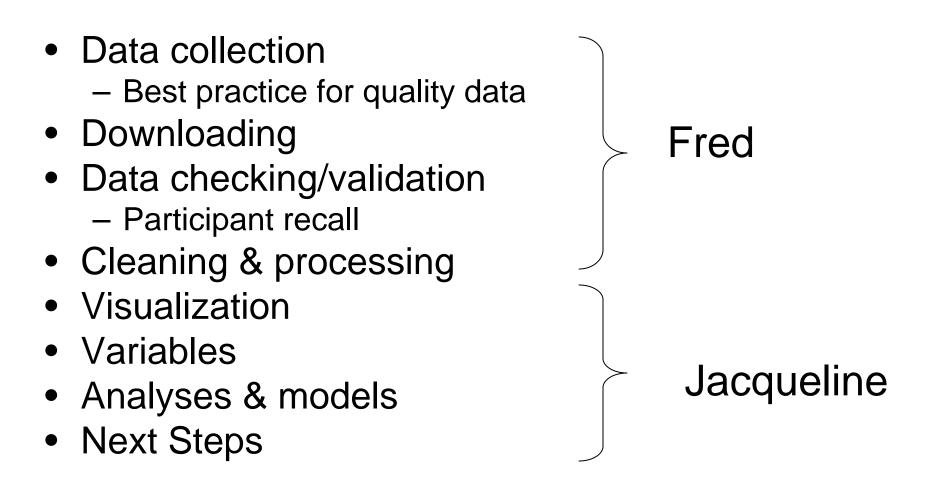
- Older adults walking routes
- TEAN adolescents travel
- GEI project: GEI/GPS/GIS workshop
- PALMS participants & interviews
- PALMS system
  - Calculations



# Multiple data sources

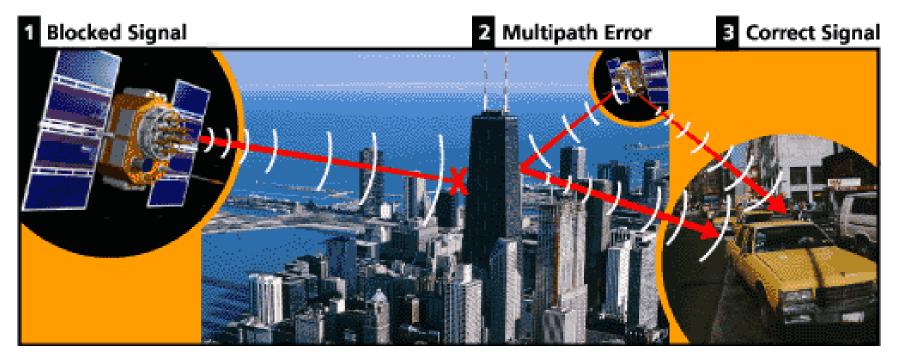
- GPS (vs pedometer)
  - Walking/biking
  - Location
  - Time
  - Low cost
- Time stamped (survey) data
- Photos
- Accelerometer
- Heart rate
- Microscale
- GIS

# GPS data process



Additional information: handouts/roundtable

## Sources of GPS Error Terrestrial

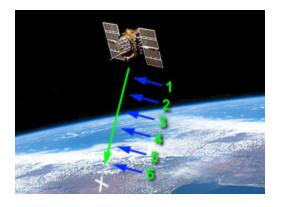


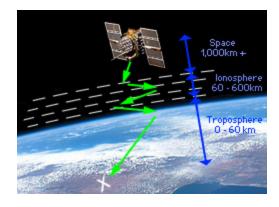
Also:

- Tree coverage when outdoors
- Electronic interference

www.garmin.com

#### Sources of GPS Error Atmospheric Delays





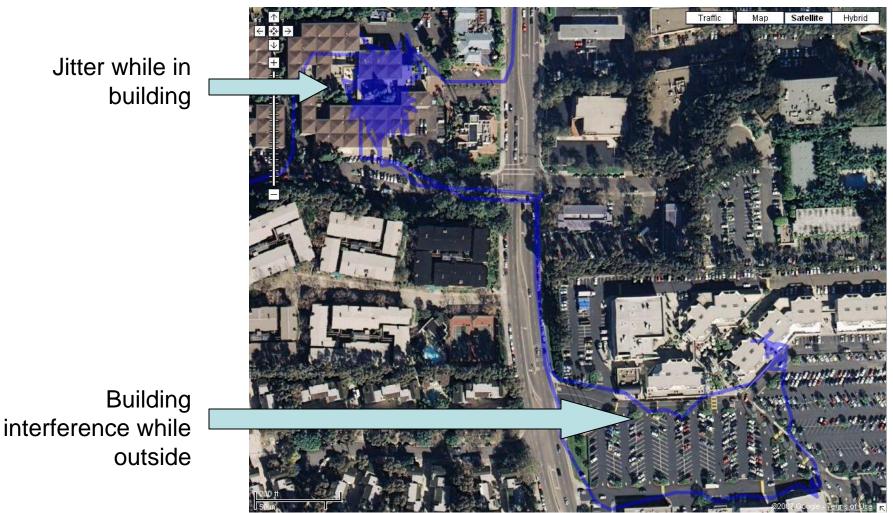
Low Elevation Satellite

Position of the satellite in the sky effects accuracy; the higher the better.

Other sources of inference include sunspots and water vapor.

www.geoplane.com

#### GPS Issues Jitter and Building Interference



#### GPS Issues Urban Canyons



#### GPS Issues Time to Acquire Fix



# **GPS** Issues - Human

- Forgetfulness
  - Keeping device charged
  - Powering device on / off
  - Keeping in bag instead of on person
- Two device problem GPS gets separated from accelerometer
- Leaving GPS in car
- Auto travel before acquiring fix

### GPS Issues – Human The Parking Lot Problem



Subject leaves GPS in car over multiple trips.

# GPS Mitigations - Human

- Keeping device charged
  - GPS with battery life > 20 hours
  - Reminder messages via email or text
- Powering on / off
  - Instruction on meaning of LED indicators
- Keeping on person, leaving in car
  - Make devices as wearable as possible
- Two device problem
  - One holder for both devices if possible
- Time to acquire fix
  - Instruction on meaning of LED indicators

# **Configuration Decisions**

- What data to save
- Sampling rate
- On device filtering

Device Configuration		×
Data logging format Only position Position, Time, Date, Speed Position, Time, Date, Speed, Altitude	Operation Mode © Data Logger © GPS only © GPS and Data Logger	OK Cancel
<ul> <li>Enable WAAS/EGNOS/MSAS</li> <li>Disable data logging if speed falls below a th</li> <li>Disable data logging if distance is less than t</li> <li>Set the default logging interval</li> </ul>		meters
Data logging interval Mode A	System Information Memory Usage: 53 %	

# **BT-335** Tradeoffs

- 1.4 MB Memory can store:
  - 100,000 position only
  - 62,000 position, date, time, speed
  - 43,000 position, date, time, speed, elevation
- Assuming 43,000 entries:
  - -15 seconds = 179 hrs (7.4 days)
  - -20 seconds = 238 hrs (9.9 days)
  - -60 seconds = 716 hrs (29.8 days)
- Problem with on-device filtering
  - Are gaps in time stamps caused by filtering or by loss of signal (or loss of power)? Was person really at the "filtered" location?

# Downloading Data from GPS

	Untitled - MapSource File Edit Find Transfer View Tools Utilities Help	
	PC Basemap 💽 🍳 🔍 3 mi	- Medium - 🛃 🏭 🔽 🍳 🕅 🎤 🗦 🕻
	Maps         Waypoints         Routes         Tracks(2)           Name         A         Points         Start Time         B           6         9640         1/27/2009 5:13:22         5           7         3628         2/2/2009 5:31:51         2	
Save As Save in: C Freds GPX files	? X • • • • • • •	56
My Recent Documents Desktop My Documents My Computer		Pacific Ocean Une Mester Active Active Act
Garmin GPS Datab Garmin GPS Datab MPS Files (*.mps)	Save Save Save Cancel Sase Version 3 (*.gdb) Sase Version 2 (*.gdb) Sase Version 2 (*.gdb)	1
Text (⊺ab delimited) DXF (".dxf) GPS eXchange For		

#### Which file format(s) to use?

# **GPS File Formats**

- Proprietary
  - Garmin, US GlobalSat, numerous others
- Standard
  - GPX
  - NMEA (National Marine Electronics Association)
- Other
  - CSV, TXT columns are vendor-specific
  - KML encoding is vendor-specific

Recommendation: Save in both vendor's format and GPX

## **GPX** Example

```
<trk>
```

<name>174,2008-10-02:12:28:23</name> <trkseg>

```
<trkpt lat="32.87053" lon="-117.23485">
<ele>137.0</ele><time>2008-09-30T17:55:26Z</time>
</trkpt>
```

```
<trkpt lat="32.87093" lon="-117.23480">
<ele>112.0</ele><time>2008-09-30T17:55:38Z</time>
</trkpt>
```

```
</trkseg>
```

Specification at http://www.topografix.com/gpx.asp

# Types of GPS points

- Tracks and Trackpoints
  - Tracks consist of track segments which contain trackpoints
  - Typically used for a moving location
  - Lat/Lon, elevation, timestamp, speed, course
  - Most often displayed as a line segment connecting the trackpoints
- Waypoints
  - Typically used for a fixed location
  - Lat/Lon, elevation, creation / modification timestamp, name, type, icon
  - Displayed as a circle or specified icon

# Types of GPS points

- Routes
  - Set of waypoints to help you navigate from one point to another.
  - Navigation systems compute routes dynamically
- Track logs
  - Some handheld GPS devices offer the option of saving track logs on the device. BEWARE: timestamps may be removed to save space.

#### Lat/Lon Formats

- Degree / Minutes / Seconds (DMS) 38° 24' 57.63" N 122° 50' 27.34" W (one second = 100 feet)
- Degree / Decimal Minutes
   38° 24.96' -122° 50.45'
- Decimal Degrees
   38.4160 -122.8381

# **Time Formats**

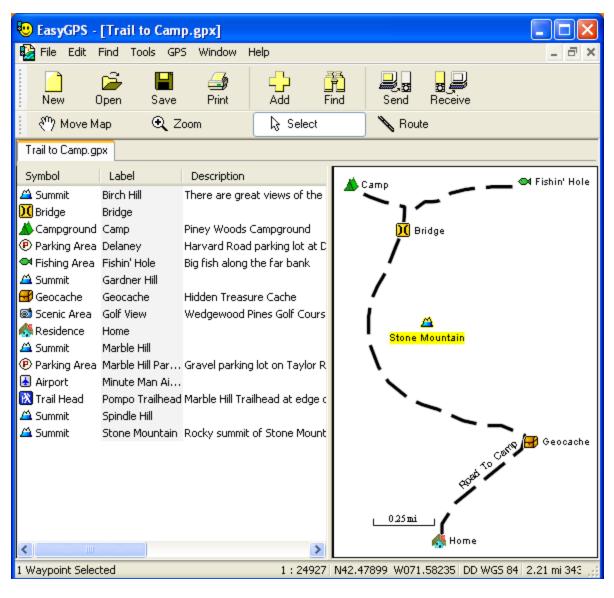
- GPS time typically reported in UTC 2008-09-30T17:55:26Z
- Does not automatically adjust for timezone or daylight savings
- GPS hardware reports:
  - Date in year, month, day
  - Time in hours, minutes, seconds, milliseconds
  - Milliseconds often truncated by software
- NOTE: Other devices (accelerometers, heart rate monitors) report in subject's local time

# Other GPS Software

EasyGPS

Works directly with Garmin & Magellan hardware units

www.easygps.com



# **GPS Software Tools**

#### **GPSBabel**

Translates between GPS file formats

Can also filter data

www.gpsbabel.org

00	Quick GP	SBabel		
Operating Mode			using	gpsbabel 1.3.(
Waypoints	Tracks		Route	25
Not all file	formats support wa	ypoints, tracks o	r routes.	
Input Options				
O Use file				
<none></none>			S	elect)
			C	Clear
Input File Type:				•
• Use GPS receiver				
Type: Garmin	•	Port:	usb	:
Output Options				
💽 Use file. Type: 🛛	eocaching.com	.loc		;
Use GPS receiver				
Type: Garmin	4 *	Port:		\$
Filters				
Smart shortnames, Mer	ge points separate	d by 100f	Se	elect)
Use selections as defaul	t		5	ave File

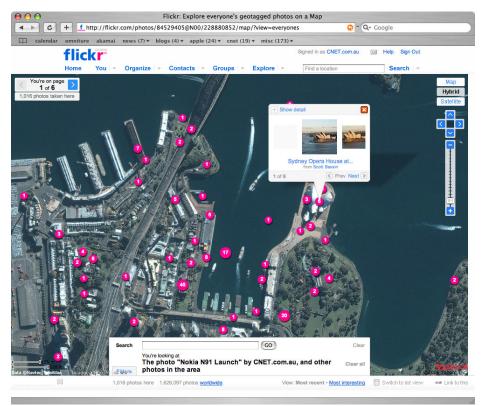
# Geotagging

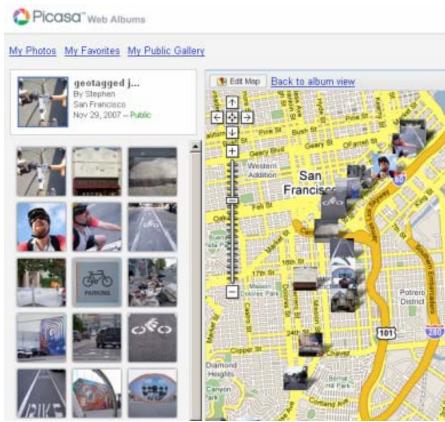
- Adds GPS data to digital photos (.jpg files)
- Data stored in Exif header
- Matches timestamps
- Available as desktop program and web applications

ate	Name	Latitude	Longitude Flac +
4G 9258.JPG	23.08.2006 18:58:35	(52,25963	) (10,53043)
4G 9259.JPG	23.08.2006 18:59:13	(52,25968	(10,53029)
	23.08.2006 19:00:05	(52,25885	
	23.08.2006 19:00:27	(52,25863	
	23.08.2006 19:00:40	(52,25845	
	23.08.2006 19:00:48	(52,25848	
	23.08.2006 19:01:11	(52,25831	
	23.08.2006 19:01:29	(52,25819	
	23.08.2006 19:01:43	(52,25760	
	23.08.2006 19:01:47	(52,25749	
	23.08.2006 19:02:30	(52,25725	
	23.08.2006 19:02:39	(52,25739	
	23.08.2006 19:02:47	(52,25745	
	23.08.2006 19:03:28	(52,25639	
	23.08.2006 19:03:33	(52,25643	(10,52784)
	23.08.2006 19:03:38	(52,25637	
	23.08.2006 19:04:06	(52,25529	
	23.08.2006 19:04:08	(52,25526	
	23.08.2006 19:04:13	(52,25525	
	23.08.2006 19:04:35	(52,25541	
	23.08.2006 19:04:35	(52,2554)	
	23.08.2006 19:05:26	(52,25533	
	23.08.2006 19:06:27 23.08.2006 19:06:40	(52,25410	
	23.08.2006 19:07:54	(52,2542)	
10_0002.01 G			
	22 NO 2006 10-07-50	160 06066	
		(62.26266	
Add		163 36366	Remove
201 COCO 21		162 26266	
Add		163 36360	
Add	22 NO 2000 10:07.E0		Remove
Add	99 no 9nnc 10.n7.E0 Start date		Remove
Add	22 NO 2000 10:07.E0		Remove
Add PS Tracks	99 no 9nnc 10.n7.E0 Start date		Remove
Add PS Tracks	99 no 9nnc 10.n7.E0 Start date		Remove
Add	99 no 9nnc 10.n7.E0 Start date		Remove
Add	99 no 9nnc 10.n7.E0 Start date		Remove
Add PS Tracks	99 no 9nnc 10.n7.E0 Start date		Remove
Add PS Tracks	99 no 9nnc 10.n7.E0 Start date		Remove
Add	99 no 9nnc 10.n7.E0 Start date		Remove
Add	99 no 9nnc 10.n7.E0 Start date		Remove
Add PS Tracks	99 no 9nnc 10.n7.E0 Start date		Remove

Locr GPS Photo software included with BT-334 www.locr.com

# **Displaying Geotaged Photos**





Picasaweb.google.com

#### Flicker.com

# **GPS** Data Processing

- Algorithms
  - Derived values calculations
    - Time (duration)
    - Distance
    - Speed
    - Elevation delta
    - Grade
  - Filtering
  - Clustering
  - Trip detection
  - Location detection
  - Mode of transportation
  - Indoors / outdoors

# Using interviews to check data & develop algorithms

- Reviewed raw track logs (displayed in Google Earth) and raw accelerometer / heart rate graphs with study participant
- Created a timeline of the participant's day
- Identified location clusters, trips, and modes of transportation
- Probed periods of peak activity and/or heart rate
- Specifically queried problem areas: gaps in data, GPS in parking lot, odd GPS patterns, indoor activities

#### GPS Algorithms Derived Values

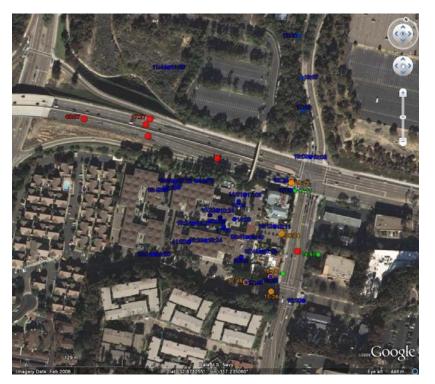
Given two fixes F1, F2 with time, lat, lon, ele

Distance = great\_circle(F1,F2) Duration = F2.time - F1.time Elevation Delta = F2.ele - F1.ele Speed = Distance / Duration Grade = Elevation Delta / Distance (change of 6m over 100m = 6% grade)

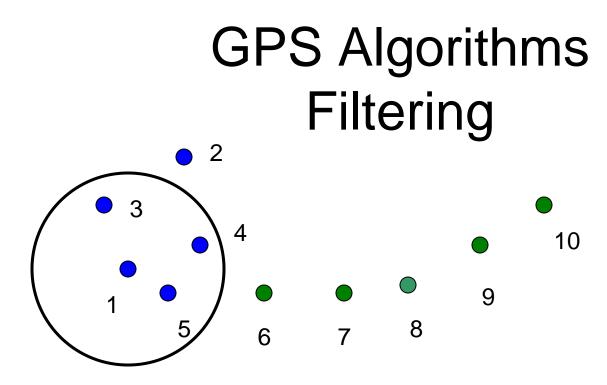
## GPS Algorithms Filtering

# Remove extraneous data points caused by jitter when stationary



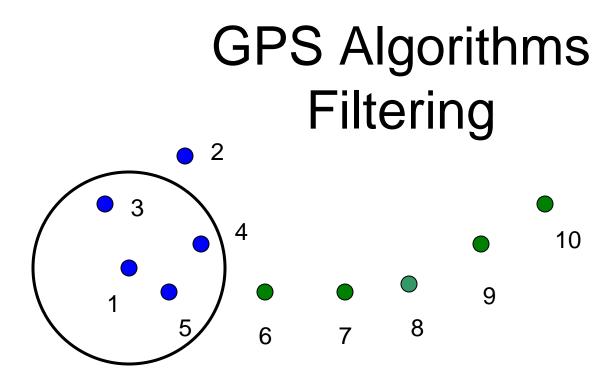


Color coded by speed



#### Goals:

- Identify points 1-5 as stationary fixes at one location and optionally map to one point
- Identify point 6 as start of trip and points 7-10 as points on the trip



If  $D(n,n+1) < minimum_distance$ , then remove n+1 If  $D(n,n+2) < minimum_distance$ , then remove n+1

Other GPS errors typically seen:

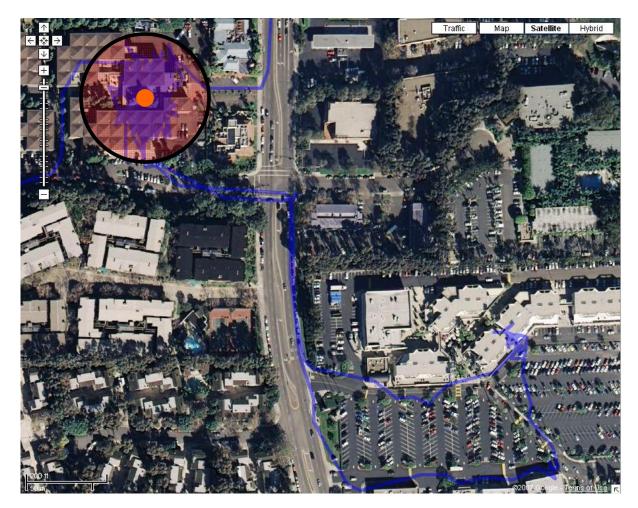
- Improbable change in elevation
- Improbable speed

## GPS Algorithms Clustering

#### Detect clusters of activity, time spent, most visited, etc.



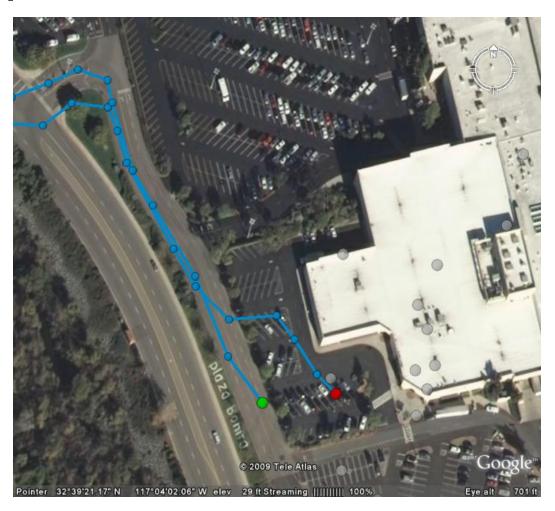
#### GPS Algorithms Location Detection



First cluster, then map all points within a radius to the cluster centroid

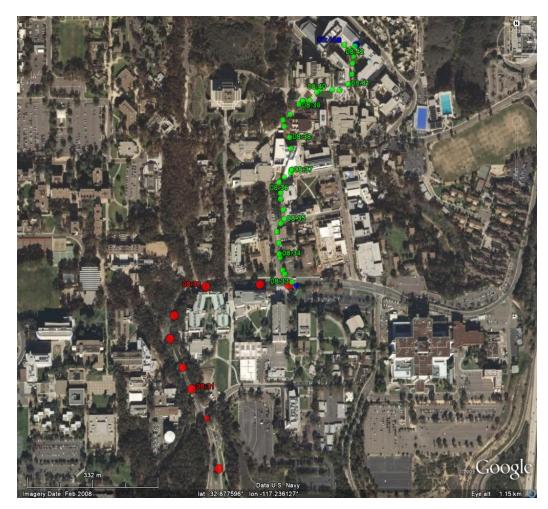
#### GPS Algorithms Trip Detection

 Detects starting and stopping locations of trips, as well as short pauses



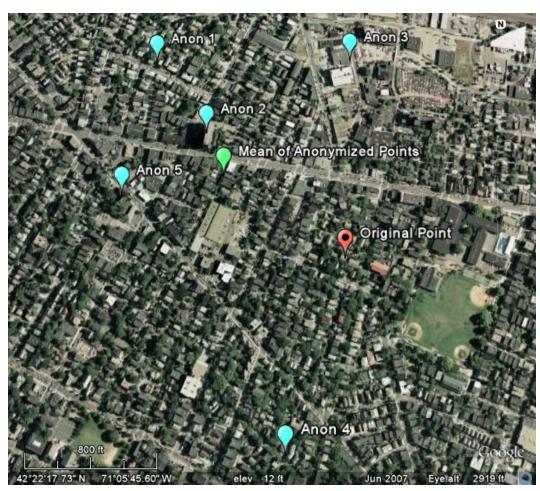
## GPS Algorithms Mode of Transportation

- Classify trips as walking, running, bicycle, vehicle
- Speed used as initial classifier
- Average trip speed is better
- Assisted by use of accelerometer and/or heart rate data



### GPS Algorithms Geodata Anonymization (points)

- Techniques used to hide subject's home (office, etc) location
- Creates n points at random within x distance of subject's actual location
- Show the mean location of the points as the subject's location



#### GPS Algorithms Geodata Anonymization (paths)

Difficult with path data

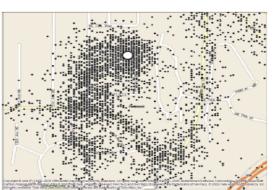
Other approaches:

 If physical location is not important, generate a random offset to apply to lat/lon values.

Source: Inference Attacks on Location Tracks, John Krumm, Microsoft Research, Pervasive 2007



Uncorrupted GPS data



Noise – Added Gaussian noise with 50 meter standard deviation



Spatial Cloaking – Points inside circle deleted. 100 meter radius circle was centered at a random point near the home.



Rounding – Each point snapped to nearest point on 50 meter  $\times$  50 meter grid.

Figure 5: This demonstrates the effect of our three methods of corrupting GPS data to enhance privacy on a set of data from one of our subjects. The upper left image shows the raw, uncorrupted GPS data. The white circle in each image shows the location of the subject's house.

### Time & space

- Physical activity
- Travel
- Environmental context
- Location

- Points
- Lines
- Polygons

TIME

Microscale attributes

# Case studies and research questions

- Participatory photo mapping (Dennis & Gaulocher)
- Activity levels in key locations, school, work, home, neighborhoods (Rodriguez & Cohen, TAAG study)
- Active commuting behavior (Sallis et al. TEAN study)
- Route taken to school (Roemmich)
- Use of park facilities (Troped)
- Avoidance behavior (Patla & Frank)
- Behavior before and after hip surgery (Chang)
- Time spent being active near freeway (Avol)
- SES influences on distance traveled (Matthews)

# Types of data from GPS

- Time spent generally
- Time spent in specific locations
  - With attributes
- Time spent in traveling
  - With attributes
- Travel mode
- Activity locations

# Data Merging

- Need to merge GPS data with sensor data (typically by matching timestamps)
  - Add location, elevation to sensor record
  - Add sensor data to GPS tracklog
- Choice depends on your objectives
  - Identify events (i.e. bouts of activity), then add GPS fixes to events
  - Process GPS fixes into locations and trips, then match events to GPS fixes

#### Issues with Data Fusion

How to match epochs and adjust for gaps in data?

Inputs																			
GPS Samples	x	x	x	x	x	X	x				x	x	x	x			x	x	x
Accelerometer		у		у		у		у				у		у		у		у	
Outputs																			
GPS to acc		ух		ух		ух		у				ух		ух		у		ух	
Acc to GPS	X	ху	x	ху	x	ху	x				x	ху	x	ху			x	ху	x
Avg Acc to GPS	xy/2	xy/2	xy⁄2	xy⁄2	xy⁄2	xy/2	xy/2				x2y	xy	xy/2	xy⁄2			xy	xy/2	x
Timeline	xy/2	y⁄2	y⁄2	?	xy/2	xy/2	xy/2	xy/2	y⁄2	y⁄2	xy/2	xy/2	xy⁄2						

- Case 1: Match GPS location to accelerometer reading
- Case 2: Match accelerometer reading to GPS location
- Case 3: Match average accelerometer value to GPS location
- Case 4: Establish a time line and match GPS locations and average accelerometer values to timeline
- In all cases, need to establish rules and cutoffs for missing data

# Visualizing GPS Data

- Vendor Software
  - Good for verifying data as received from subject
  - Typically designed to display track of one subject at a time
- Google Earth
  - Will directly import and display GPX file (but doesn't provide much more functionality than vendor software)
  - Real power is displaying KML files, but you need an application to create the KML file
- Google Map (out of the box)
  - Needs a KML file to display
  - KML file resides on Google server potential privacy concerns
  - Google Map can be used as the mapping engine in a custom web application without the need to send data to Google

# Visualizing GPS Data

#### Websites

www.geovisualizer.com

- Provides some filtering and analysis functions
- Can process data from multiple subjects
- Typically has a data size limitation
- Potential privacy concerns
- Good for prototyping with non-sensitive data



Plot data on a map

This is a special version of the GPS Visualizer map form that's designed for plotting quantifiable data on a map. You can colorize and/or repoints according to a generic field named "N", or you can use a more typical field, such as altitude, population, or category. (If this isn't w were looking for, return to the <u>Google Maps form</u>, the <u>Google Earth KML form</u>, or the <u>JPEG/PNG/SVG form</u>.)

The coordinates of your data can be given as latitude/longitude, as geographic places (city-state pairs, states, or countries), U.S. ZIP cod Canadian postal codes. For instance, if you wanted to see how many people in each ZIP code responsed to a survey you sent out, this would be a minin valid.csv file: zip, N [new line] 97202,12 [new line] 97205,5 [new line] 97209,20. If you have a raw list of locations such as ZIP codes (i.e., appear more often in the list than others) and you haven't calculated the frequencies yet, you can set the "Calculate frequency" option to "auto," and GF will create an "N" (frequency) column for you.

Contact me at the address on the bottom of this page if you need more information.

Upload your GPS data files	here: ?	General map parameters	show advanced options [+]
(Total size of all files cannot exceed	11.5 MB)	Output format: Google Maps	
File #1	Browse		auto 🛛
File #2	Browse	Margin: 45 🖬 Title:	?
File #3	Browse	Background map: Google hybrid (streets+sa	tellite) 🔽 🛛
Or paste your data here: ?		Data point options	show advanced options [+]
name, desc, latitude, lon	gitude,n	Spectrum direction: UP Y Hue 1: 0 Resize using this field: N / frequency Minimum radius: 6 pixels M Max	tion: 100% 🔽 🖁
4	Þ	Calculate frequency: No	(creates a field called "N")
Force plain text to be this type:	waypoints 💌	Show point names: Yes 💌 🕅 Show point names: Test 🕅 Show point Default marker color:	nt descriptions: Yes 💌 🛿
Or provide the URL of data	on the Web:	Google Maps options	show more Google options [+]
	/////	Default icon: large blank circles 💌	2 6990000
CAM	20254	Google Earth options	show more Google Earth options [+]
Draw th	e map	Default icon: Large blank circle 💌 🖁	

# Visualizing GPS Data

#### **GIS Systems**

ESRI ArcGIS Quantum GIS

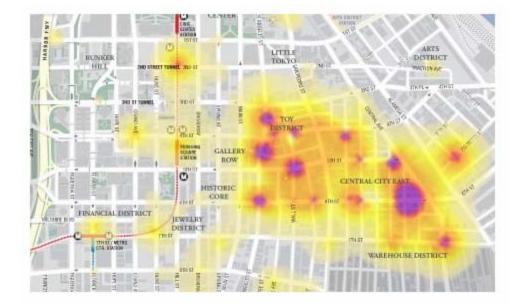
- Desktop systems data never leaves your control
- Can process large data sets from multiple subjects
- Many analytical functions available
- Many datasets (layers) publicly available detailing the natural and built environment



# GPS Processing openGTS

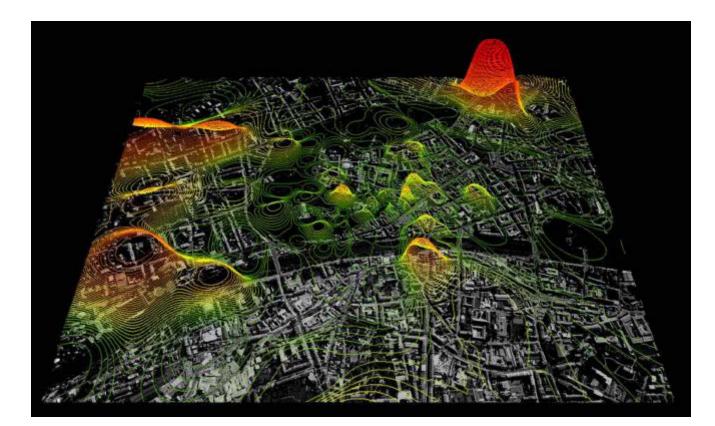
1.1	F					(including do			e on SourceForge. project web-site at	
Den	no Account (0	penGTS Use	r)		nttp://www.c	pengts.org/			 Detail Reports   Main Menu	
	·				Event	Detail				
Refr	esh			12007	Demo Devid		De e16-1		Map KML	
#	Date	Time	Status	Lat	/03/13' through '20	Speed	Altitude	Odometer	Address	
						mph	feet	Miles		
1	2007/03/13	11:05:37 11:10:44	Start InMotion	38.6457	-121.3808	13.7 W 64.6 SW	23		I-80, North Highlands, CA I-80, Sacramento, CA	
2	2007/03/13	11:10:44	InMotion	38.6384	-121.4916	64.6 SW 63.4 W	16		I-80, West Sacramento, CA	
4	2007/03/13	11:20:58	InMotion	38.5568	-121.6781	64.6 W	16		45217 E Chiles Rd, University of California-Davis Campus, CA 95616	
5	2007/03/13	11:26:05	InMotion	38.5152	-121.7753	65.2 SW	33		Dixon, CA 95620	
6	2007/03/13	11:31:15	InMotion	38.4465	-121.8580	65.9 SW	62		Dixon, CA	
7	2007/03/13	11:36:26	InMotion	38.3820	-121.9425	64.0 SW	82		I-80, Vacaville, CA	
8	2007/03/13	11:41:34	InMotion	38.3225	-122.0259	🟉 Open Gl	PS Tracking	) System - Wi	ndows Internet Explorer	
9	2007/03/13	11:46:43	InMotion	38.2446	-122.0820					
10	2007/03/13	11:51:44	InMotion	38.1904	-122.1696			<		k
11	2007/03/13	11:56:52	InMotion	38.1189	-122.2303		$\sim$			
12 13	2007/03/13	12:01:59	InMotion	38.0387	-122.2473		5		Woodland	- 7
13	2007/03/13	12:07:08	InMotion InMotion	37.9756	-122.3187			$\sim$		·
15	2007/03/13	12:12:14	InMotion	37.8973	-122.3091		and the			acramento
16	2007/03/13	12:22:24	InMotion	37.8223	-122.3012	- and	NºV		Pavie Pavie	The
17	2007/03/13	12:27:32	InMotion	37.8077	-122.3677	3 5	36	1 Low		AL F.
18	2007/03/13	12:32:32	InMotion	37.7889	-122.3879	a.Rosa	X	Ken (	Dixon	MAN
19	2007/03/13	12:37:34	InMotion	37.7916	-122.3994		15	$\langle \rangle$		ElkGr
20	2007/03/13	12:42:40	InMotion	37.7855	-122.4002	phnert	\$ 2	V	Portie	
21	2007/03/13	12:47:41	InMotion	37.7834	-122.4025		4	Napa		
22	2007/03/13	12:52:46	Stop	37.7847	-122.3991	Petalun		mil	Constraintield	At Com
							lovato	Ameri Cany Value	Benicia	

#### Visualization Examples - Population Heat Maps





#### Visualization Examples - Population 3D Overlay





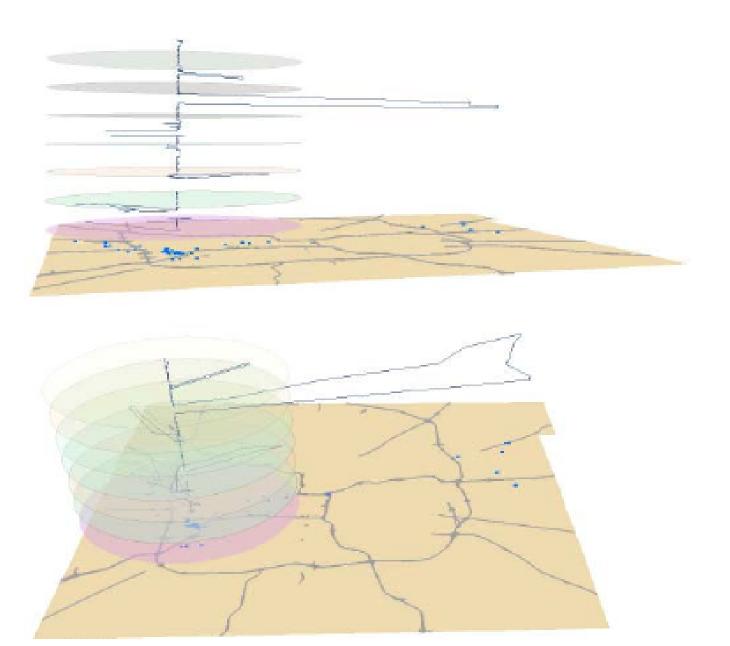


Figure 2 Brample of space-time path in GIS.

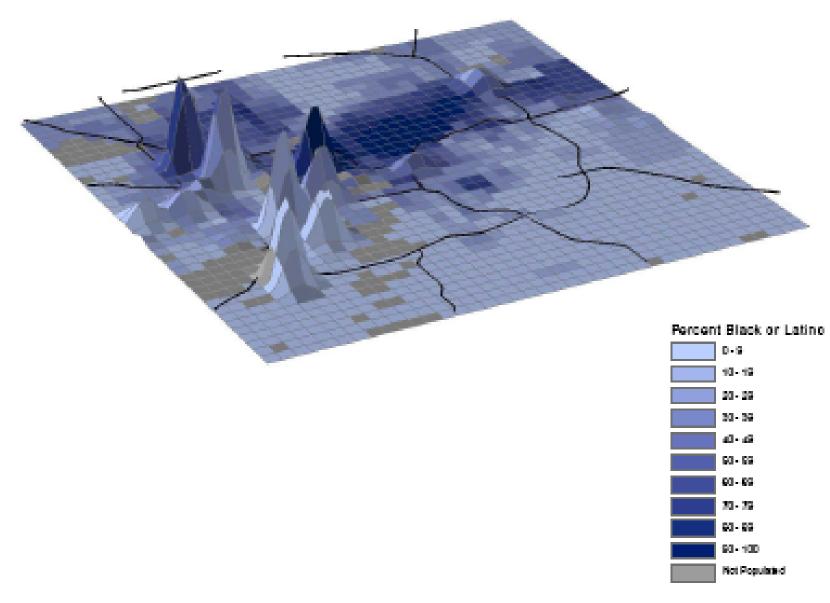


Figure 3 Time density map of Marion County by percent of black or Latino population.

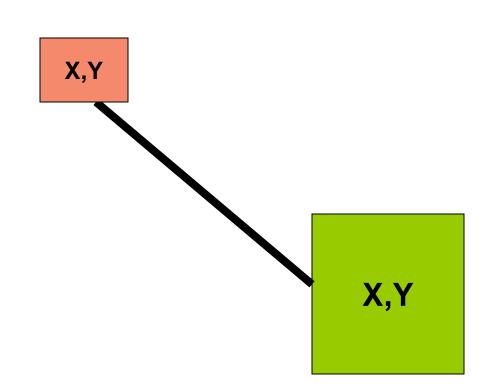
# Specific location: park

- Park location
  - Where in park
- Frequency of visit to park
- Time spent in park
  - Total/min/max/average
  - % of total time
- Time of day, day of week
- Time/location since last visit (latencies)
- Attributes of park
- Intensity of activity in park
  - When, where, how long
  - Bouts/ guidelines

X,Y	

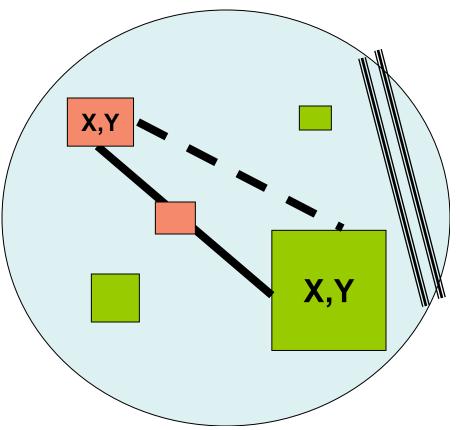
### Travel to park

- Start location, time
- Journey time
- Route taken
- Distance traveled
- Speed traveled
- Elevation
- Mode of transport
- Energy expenditure



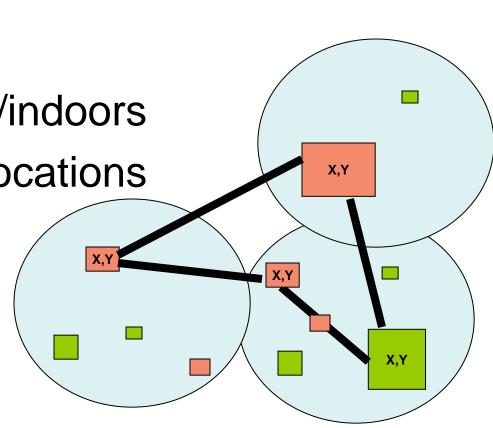
# Context of park visit

- Why this park?
  - Was it the closest?
  - Within a neighborhood buffer?
- Why this route?
  - Was it shortest?
  - How do you attribute
    GIS characteristics to
    the route?
- Where stop on way?
- What exposures?



# Day in a life

- Percent time in home neighborhood
- Distance traveled
- Time spent in car
- Time spent outside/indoors
- Least/most active locations
- Exposure history



### Research <u>methods</u> questions arising from GPS data

- Sampling
  - How many people, how long?
- Missing data
- Distance & time spent outside of home neighborhood
  - What buffers do we use?
  - How sample locations for quality data?
  - Definitions of neighborhood
- Points, polygons, lines and TIME
  - Point data
    - Point pattern analysis used for incidents
    - Clusters
  - Moving point data
    - Agent based modeling
  - Multiple data points
    - Time points nested within people
    - Intensive longitudinal data analysis: multiple time series analysis

#### What models & frameworks can we use?

- Spatial analysis
  - Spatial interaction or "gravity models" estimate the flow of people between locations in geo-space
  - Kwan M: geovisualization; time-geographic approach
  - Geographically weighted regression
- Artificial Neural Networks/ Supervised Learning Algorithms /Complex Adaptive Systems
- Agent Based Modeling
- Pattern Analysis/Recognition
- Markov Model (to predict movement (in time))
- State-Space Approach
- Ecological Momentary Assessment
  - Walls TA, Schafer JL, eds. 2006. *Models for Intensive Longitudinal Data*. New York: Oxford Univ. Press.
- Training: http://csiss.ncgia.ucsb.edu/GISPopSci/

### 3Gs Workshop & report

- Current state of field
- Challenges
- Best practice
- What is holding field back
- Next steps, research questions & technical expectations
- Location based prompts

# What questions do you have?

- We will try to raise unanswered questions at the 3Gs workshop with the "uber" experts.
- ALR
  - Active Learning Research
  - New transdisiplinary partners
- Roundtable
  - Thurs 7.30am (!)
- What research questions have you attempted to answer?
- How have you analyzed or mapped the data?



#### **Additional Slides**

### Some references

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- Barnett, A., & Cerin, E. (2006). Individual calibration for estimating free-living walking speed using the MTI monitor. *Medicine and Science in Sports and Exercise, 38*(4), 761-767.
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- Elgethun K, Fenske RA, Yost MG, Palcisko GJ. 2003. Time-location analysis for exposure assessment studies of children using a novel global positioning system instrument. *Environmental Health Perspectives* 111:115-22.
- Elgethun K, Yost MG, Fitzpatrick CT, Nyerges TL, Fenske RA. 2007. Comparison of global positioning system (GPS) tracking and parent-report diaries to characterize children's time-location patterns. *Journal of Exposure Science and Environmental Epidemiology* 17:196-206.
- Ermes, M., Parkka, J., Mantyjarvi, J., & Korhonen, I. 2008. Detection of daily activities and sports with wearable sensors in controlled and uncontrolled conditions. *IEEE Transactions on Information Technology in Biomedicine*, *12*(1), 20-26.
- Le Faucheur A, Abraham P, Jaquinandi V, Bouye P, Saumet JL, Noury-Desvaux B. 2007. Study of human outdoor walking with a low-cost GPS and simple spreadsheet analysis. *Medicine and Science in Sports and Exercise*, 39(9):1570-1578.
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- Michael K, McNamee A, Michael MG, Tootell H. 2006. Location-based intelligence modeling behavior in humans using GPS. Proceedings of the International Symposium on technology and Society, New York, June 2006 (Paper available online at <u>http://ro.uow.edu.au/infopapers/386</u>)
- Ohmori N, Nakazato M, Harata N, Sasaki K, Nishii, K. 2005. Activity diary survey using GPS mobile phones and PDA presented at the 85th TRB Annual Meeting CD-ROM, 06-3039 (Paper available online at <a href="http://www.ut.t.u-tokyo.ac.jp/members/nobuaki/06-3039.pdf">http://www.ut.t.u-tokyo.ac.jp/members/nobuaki/06-3039.pdf</a>).
- Phillips ML, Hall TA, Esmen NA, Lynch R, Johnson DL. 2001. Use of global positioning system technology to track subject's location during environmental exposure sampling. *Journal of Exposure Analysis and Environmental Epidemiology* 11:207-215.
- Nusser SM, Intille SS, Maitra R. 2006. Emerging technologies and next-generation intensive longitudinal data collection. Chapter 11 in Walls TA, Schafer JL (Editors) *Models for Intesive Longitudinal Data*. Oxford, UK: Oxford University Press,
- Rainham D, Krewski D, McDowell I, et al. 2008. Development of a wearable global positioning system for place and health research. *International Journal of Health Geographics* (available online at <a href="http://www.ij-healthgeographics.com/content/7/1/59">http://www.ij-healthgeographics.com/content/7/1/59</a>)

# GPS Systems: Data Logger

GlobalSat DG-100

- Cost: \$70
- Battery Life: 25 hours
- Memory: 60,000 points
- Data Capture Settings
   Enochs
  - Epochs
  - Radius
  - $\circ$  Speed
- Data Export:
  - KML/Google Maps
  - o Text
  - Excel file
  - RMC
  - GPX format



# GPS Systems: Data Logger

**Globalsat BT-335** 

- Cost: \$70
- Battery Life: 25 hours
- Memory: 60,000 points
- Data Capture Settings
  - Epochs
  - Radius
  - $\circ$  Speed
- Data Export:
  - KML/Google Maps
  - o Text
  - Excel file
  - RMC
  - GPX format
- Bluetooth compatable



# **GPS Systems: Wearable**

Garmin Forerunner 405

- Battery Life: 8 hrs of data capture
- Cost: \$300-350
- Displays continuous user data
- Data export
  - o Garmin Software
  - Garmin web-based application
  - Excel
  - o KML
- Easily wearable: watch style
- Wireless Data Download (ANT)



### **GPS**: Vendor Websites

#### **GPS Vendors**

**GlobalSat GPS and Dataloggers** 

• www.globalstat.com.tw/eng/index.htm

#### **GPS** Dataloggers

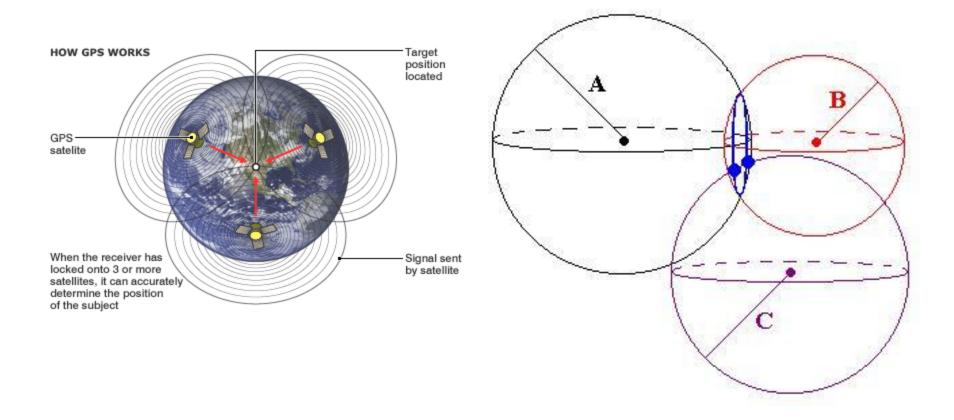
• www.semsons.com/datalogger.html

Garmin

• www.garmin.com

#### How GPS Works

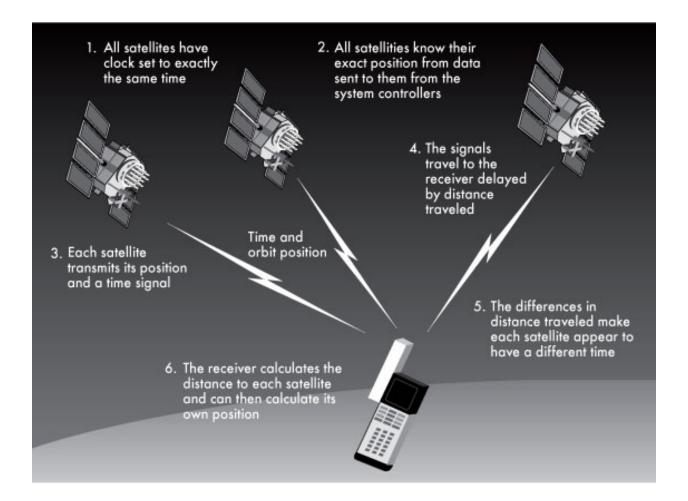
#### GPS receiver uses triangulation to determine location



newsimg.bbc.co.uk

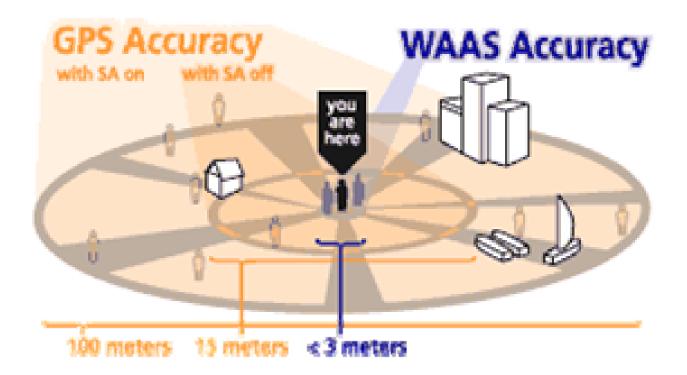
www.nasa.gov

#### How GPS Works



www.aero.org

#### GPS Accuracy Best Case



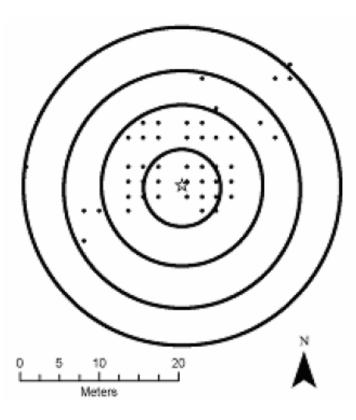
SA – Selective Availability – error injected by DOD, turned off 5/1/2000

WAAS – Wide Area Augmentation System, turned on 2003

garmin

#### GPS Issues – Accuracy Testing at Fixed Location

- Six Garmin Foretrex 201 GPS
- Each recorded 121 observations during 1 hour period (n = 726)
- Average distance from geodetic point: 3.02 m (SD 2.51)
- 81% within 5 meters
- 99.4% within 15 meters



Daniel Rodriguez & Elizabeth Shay, 2008 ALR Conference Presentation http://www.activelivingresearch.org/files/GPS-Accelerometers\_Workshop.pdf

#### GPS Issues – Accuracy In the field

- Wore units along route in three built environment scenarios
  - Open space, clustered development and urban
  - Route withing each scenario had 25 locations
  - Each scenario was tested three times
- Inter-unit reliability
  - Comparison of the distance between each unit's recorded location and the average location recored by the other 5 units.

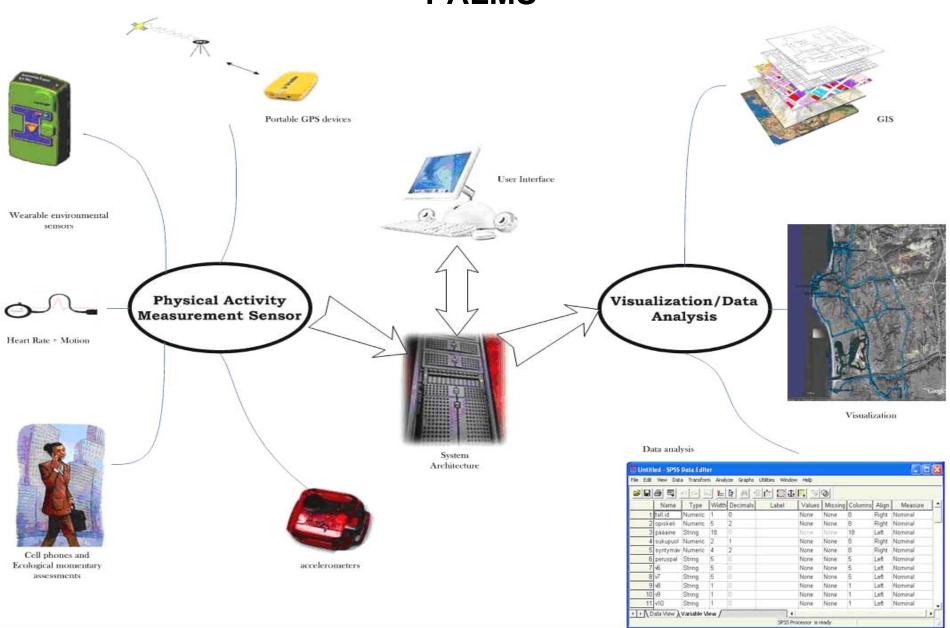
Daniel Rodriguez & Elizabeth Shay, 2008 ALR Conference Presentation http://www.activelivingresearch.org/files/GPS-Accelerometers\_Workshop.pdf

#### GPS Issues – Accuracy In the field

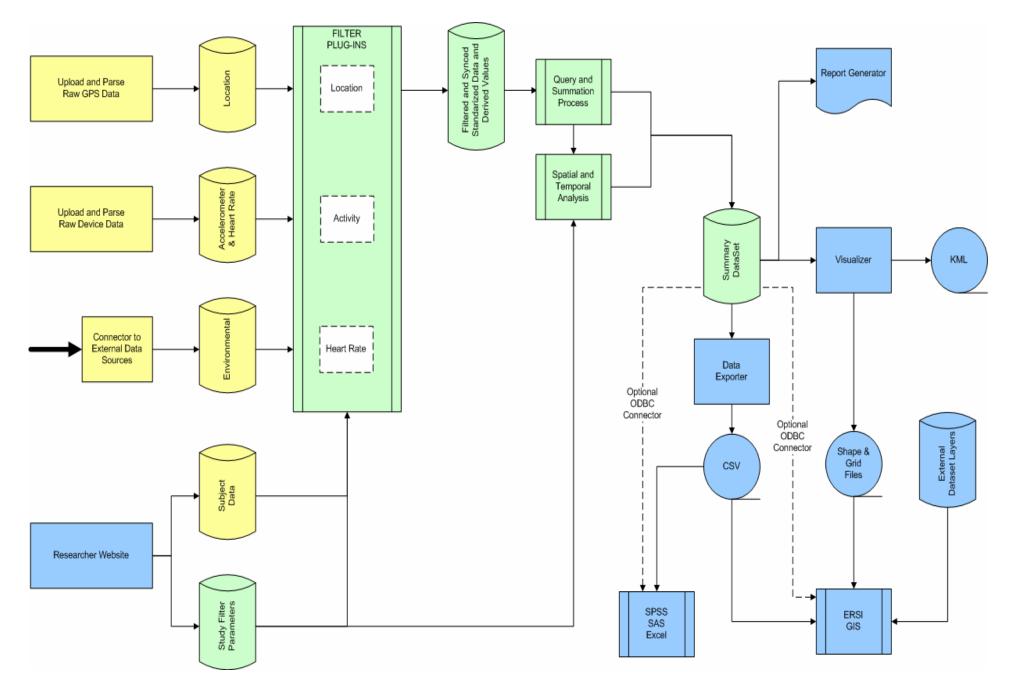
	Average distance		
Scenario	(m)	SD	Ν
Open space	10.7	11.9	450
Clustered development	20.1	21.8	450
Urban	18.5	18.4	450

Daniel Rodriguez & Elizabeth Shay, 2008 ALR Conference Presentation http://www.activelivingresearch.org/files/GPS-Accelerometers\_Workshop.pdf

#### UCSD Physical Activity Measurement System PALMS



#### **PALMS** data flow diagram



## PALMS GPS processing

- Trap within participant-provided locations (home, work, market, etc.)
   If A is within X meters of B, then A = B
- Filter GPS errors
   If distance between A & B > X meters
   AND distance between A & C < Y meters,</p>
   then mark B as invalid

# PALMS GPS Processing

- Detect location clusters and trap within centroid
- Detect trips: start, end, pause
- Classify trips based on speed walking, jogging, running, vehicle (heart rate aids in classification)
- Attempt to fill-in gaps (typically when user is in a building.)

#### PALMS accelerometer processing

- Detect non-wearing conditions defined as a # of zeros in a row
- Detect sedentary periods
- Detect bouts of activity counts > X for at least Y minutes allowing for Z minutes of counts < X</li>

### PALMS heartrate processing

- Detect non-wearing conditions defined as a # of zeros in a row
- Detect and mark noise
- Replace noise with average HR
- Compute Energy Expenditure (ee)
- Detect bouts of activity HR > X for at least Y minutes allowing for Z minutes of counts < X</li>

### PALMS Data Fusion

- Create timeframe based on:
  - Starting date
  - Ending date
  - Interval
- Align GPS, accelerometer, heart rate data timestamps to timeframe
- Detect and mark gaps in data

# PALMS Data Summary

- Summarize data by
  - Day
  - Hour
  - Location
  - Mode of transportation
  - Activity levels
  - Duration
  - Etc

# PALMS Data Analysis (under development)

- Issues:
  - How much statistical / spatial analysis to do within PALMS vs GIS / SPSS?
  - How to merge data from multiple participants in a meaningful way?

### PALMS Export

 Export of raw data, processed data or merged data as KML (Google Earth) or CSV (ArcGIS)

#### GPS Algorithms Distance using Great Circle Formula

- Radius\_Feet = 20889108
- Radius\_KM = 6367
- a = toRadians(90 F1.lat)
- b = toRadians(90 F2.lat)
- t = toRadians(F2.lon F1.lon)
- c = acos( cos(a) \* cos(b) + sin(a) \* sin(b) \* cos(t) )
- Distance = c \* Radius\_xx

www.mappinghacks.com/project/distance

#### GPS Algorithms Problem with Great Circle Formula

- Assumes Earth is a perfect sphere with radius of 6367km
- Actual equatorial radius = 6378
- Actual polar radius = 6356
- Difference of 22km
- Error using 6367 = 0.00175

Mapping Hacks, pg 119-120