

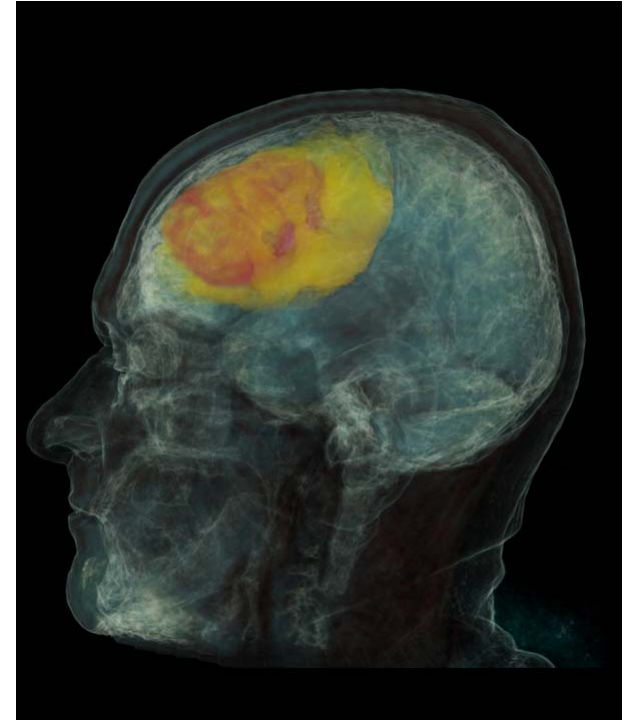
# Machine Learning for Gerontechnology

# What is *Machine Learning*?

- A *computer program* that **improves its performance** at some **task** through **experience**.

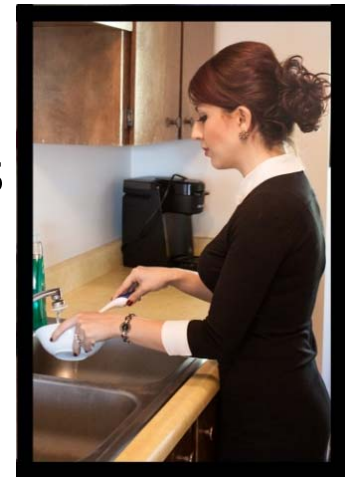
# Examples of Supervised Learning

- Example: Learn to Diagnose Patients
  - T: Diagnose tumors from images
  - P: Percent of patients correctly diagnosed
  - E: Pre-diagnosed tumors (supervision)



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  - T: Identify activities of daily living
  - P: Accuracy of activity labels
  - E: Labeled sequences of sensor events



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- Example: Learn Activities of Smart Home Residents
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  - P: Accuracy of activity labels
  - E: Labeled sequences of sensor events
- Example: Epidemic Outbreak Prediction
  - T: Predict malaria outbreaks
  - P:  $\# \text{Predicted cases} - \# \text{Actual cases}$
  - E: Climate, current cases



# Example – Handwriting Recognition



0.0	1.0	1.0	1.0	0.0
1.0	0.0	0.0	0.0	1.0
0.0	0.0	0.0	0.0	1.0
0.0	0.0	0.0	1.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	1.0	0.0	0.0	0.0
1.0	1.0	1.0	1.0	1.0

Can this be automated?

<https://webdemo.myscript.com/#/demo/write>

# Example

0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0

# Example

0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0

If  $(\text{cell\# mod } 5) = 3$  and cell value = 1.0  
and  
All other cell values = 0.0



# Example

0.0	0.0	1.0	0.0	0.0
0.0	1.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0

If  $(\text{cell\# mod } 5) = 3$  and cell value = 1.0  
and  
All other cell values = 0.0

# Example

0.0	0.0	1.0	0.0	0.0
0.0	1.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0

If (cell# mod 5) = 3 and cell value = 1.0  
or  
If (cell# = 7) and cell value = 1.0  
and  
All other cell values = 0.0

# Example

0.0	0.0	1.0	0.0	0.0
0.0	1.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	1.0	1.0	1.0	0.0

If (cell# mod 5) = 3 and cell value = 1.0  
or  
If (cell# = 7) and cell value = 1.0  
and  
All other cell values = 0.0

# Example

0.0	0.0	1.0	0.0	0.0
0.0	1.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0
0.0	1.0	1.0	1.0	0.0

If (cell# mod 5) = 3 and cell value = 1.0  
or  
If (cell# = 7) and cell value = 1.0  
or  
If (cell# = 22) and cell value = 1.0 AND  
(cell# 23 = 1.0) AND  
(cell# 24 = 1.0)  
and  
All other cell values = 0.0

# Example

0.0	0.0	0.8	0.0	0.0
0.0	0.0	0.7	0.0	0.0
0.0	0.0	0.8	0.0	0.0
0.0	0.0	0.7	0.0	0.0
0.5	0.0	0.7	0.0	0.0
0.0	0.0	0.5	0.0	0.0
0.0	0.0	0.3	0.0	0.0

If (cell# mod 5) = 3 and cell value = 1.0  
or  
If (cell# = 7) and cell value = 1.0  
or  
If (cell# = 22) and cell value = 1.0 AND  
(cell# 23 = 1.0) AND  
(cell# 24 = 1.0)  
and  
All other cell values = 0.0

# Example

0.0	0.0	0.8	0.0	0.0
0.0	0.0	0.7	0.0	0.0
0.0	0.0	0.8	0.0	0.0
0.0	0.0	0.7	0.0	0.0
0.5	0.0	0.7	0.0	0.0
0.0	0.0	0.5	0.0	0.0
0.0	0.0	0.3	0.0	0.0

If (cell# mod 5) = 3 and cell value  
between 0.7 and 1.0  
or

If (cell# = 7) and cell value  
between 0.7 and 1.0  
or

If (cell# = 22) and cell value  
between 0.7 and 1.0 AND  
(cell# 23  
between 0.7 and 1.0 AND  
(cell# 24  
between 0.7 and 1.0)  
and

All other cell values between 0.0 and 0.5

# Example

0.0	0.0	0.8	0.0	0.0
0.0	0.0	0.7	0.0	0.0
0.0	0.0	0.8	0.0	0.0
0.0	0.0	0.7	0.0	0.0
0.5	0.0	0.7	0.0	0.0
0.0	0.0	0.5	0.0	0.0
0.0	0.0	0.3	0.0	0.0

If (cell# mod 5) = 3 and cell value  
between 0.7 and 1.0  
or

If (cell# = 7) and cell value  
between 0.7 and 1.0  
or

If (cell# = 22) and cell value  
between 0.7 and 1.0 AND  
(cell# 23  
between 0.7 and 1.0 AND  
(cell# 24  
between 0.7 and 1.0)  
and

All other cell values between 0.0 and 0.5  
0.3?  
0.5?  
Shorter?  
Crooked?

# Example



- Too many combinations to consider manually
- Might forget (not know) some possible combinations

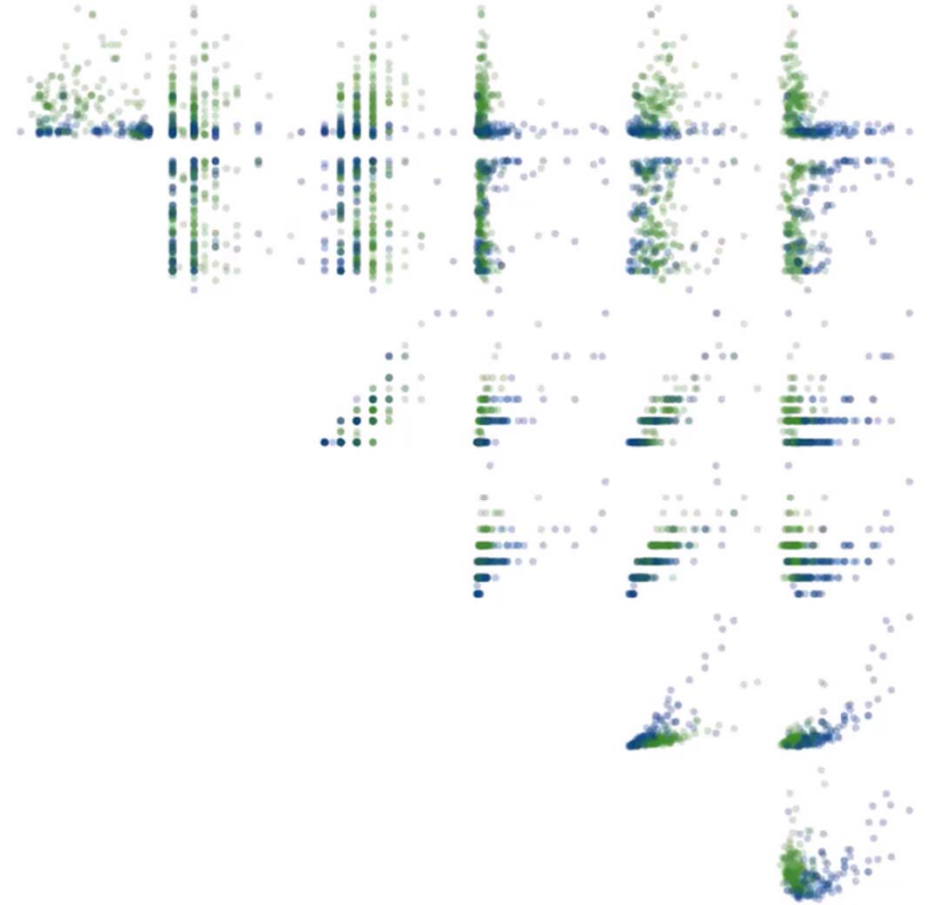
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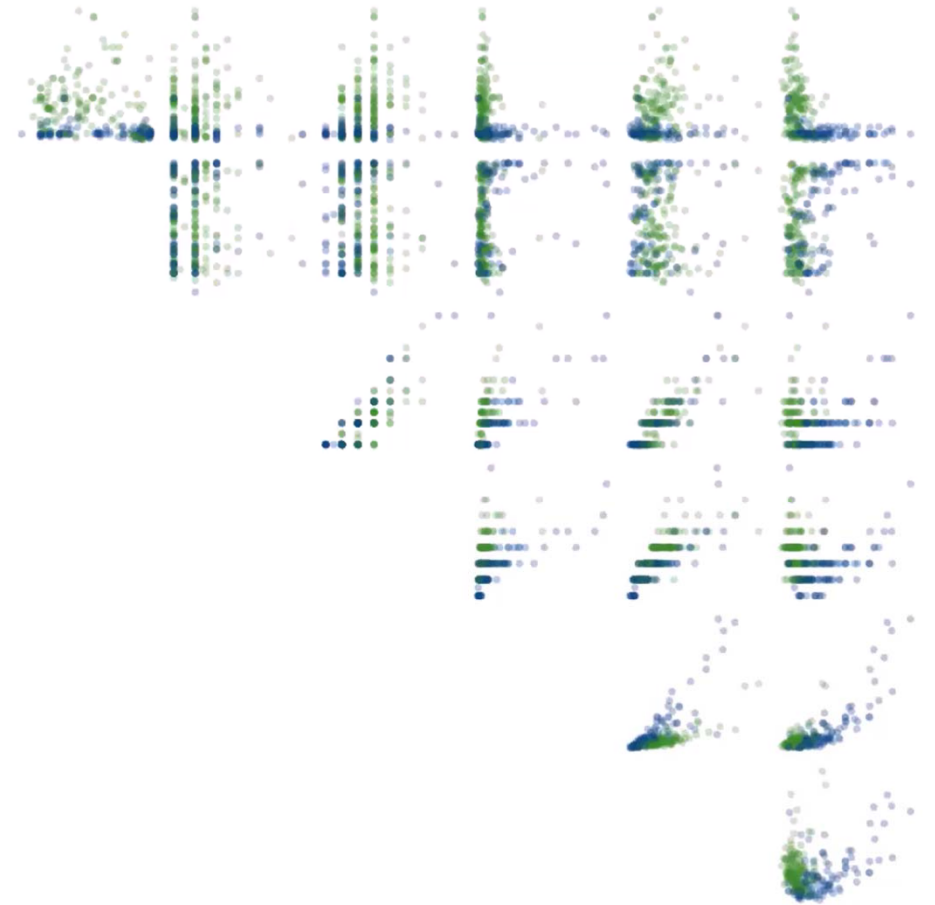
# Supervised Learning

- Learning task
  - Learn to classify whether a home is in San Francisco or New York
  - Represent each home by elevation



# Supervised Learning

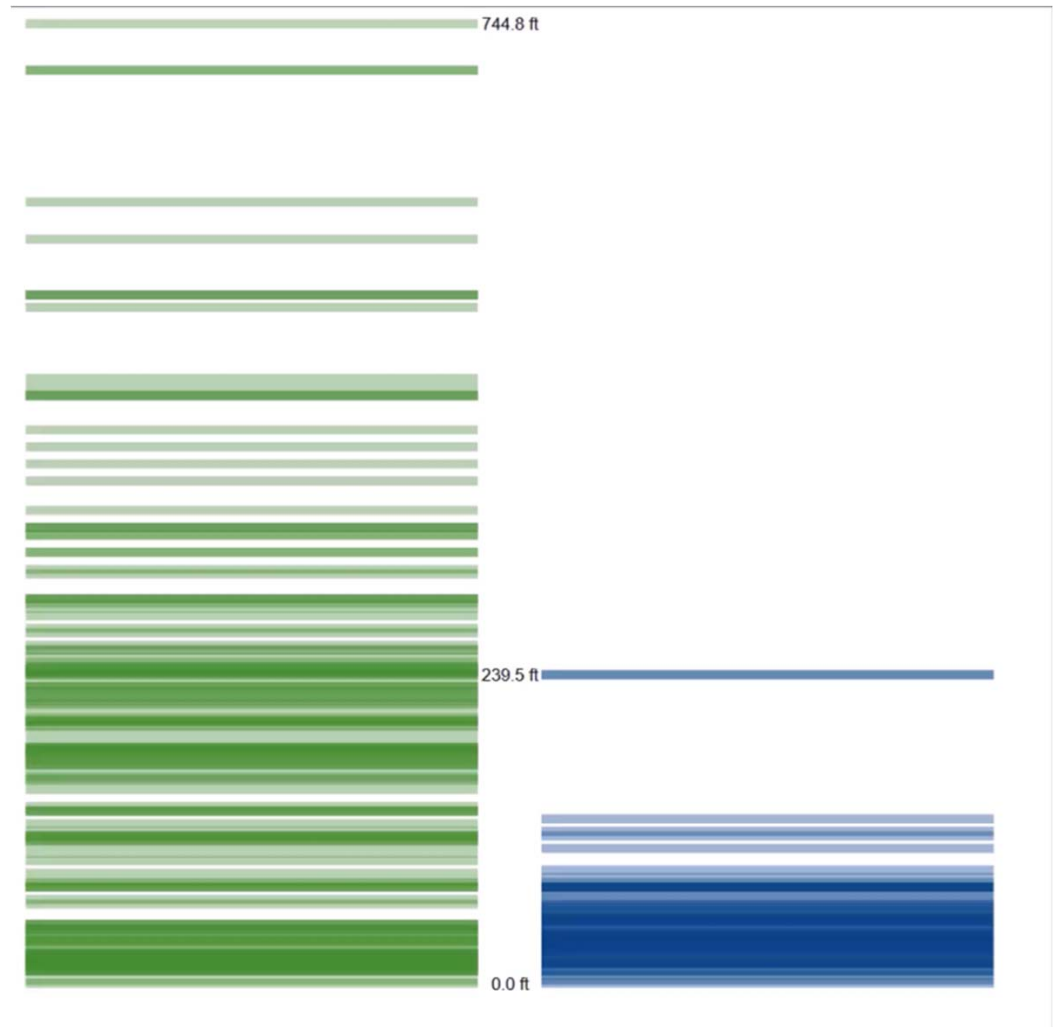
- Learning task
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# Supervised Learning

- Learning task
  - Learn to classify whether a home is in San Francisco or New York
  - Represent each home by elevation

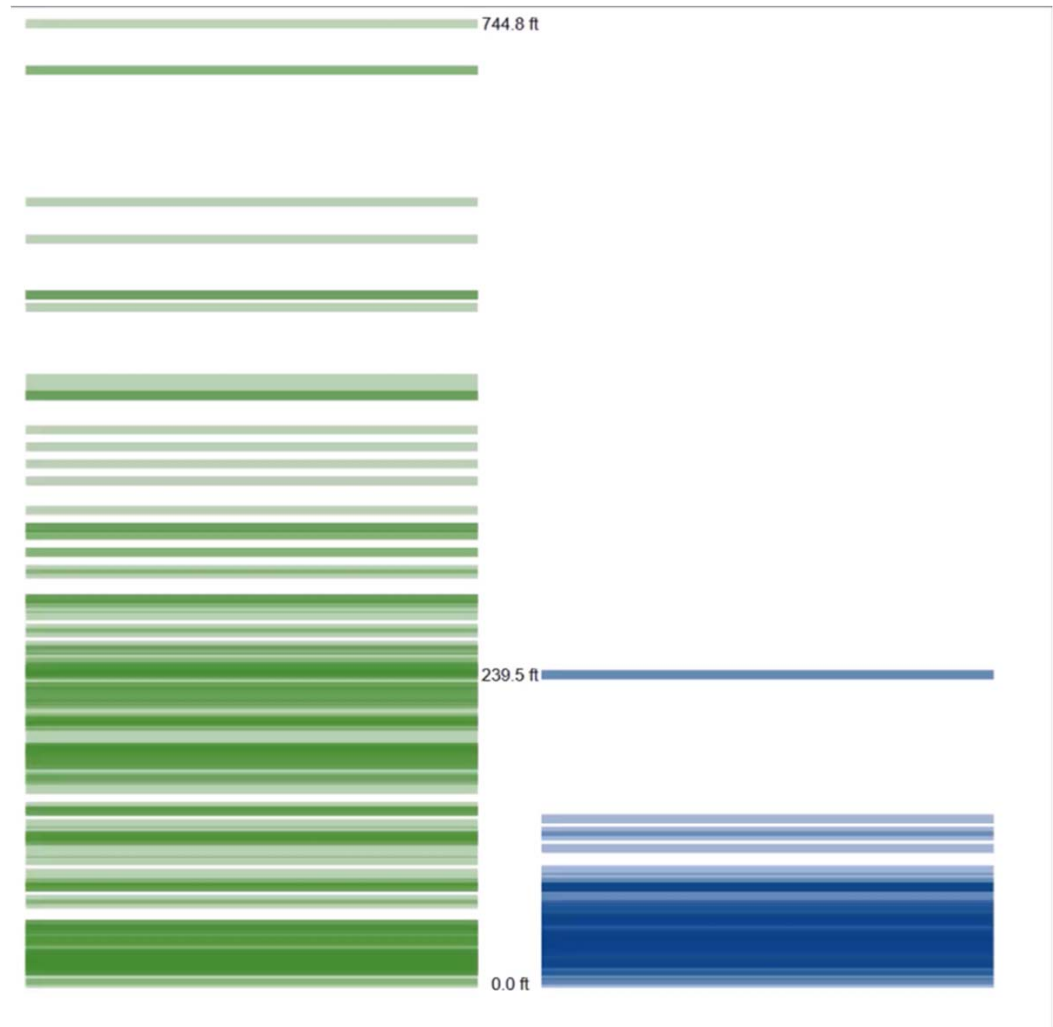
If elevation  $> 240'$   
then San Francisco



# Supervised Learning

- Add another dimension
  - Home is in San Francisco or New York
  - New feature: price per sq ft

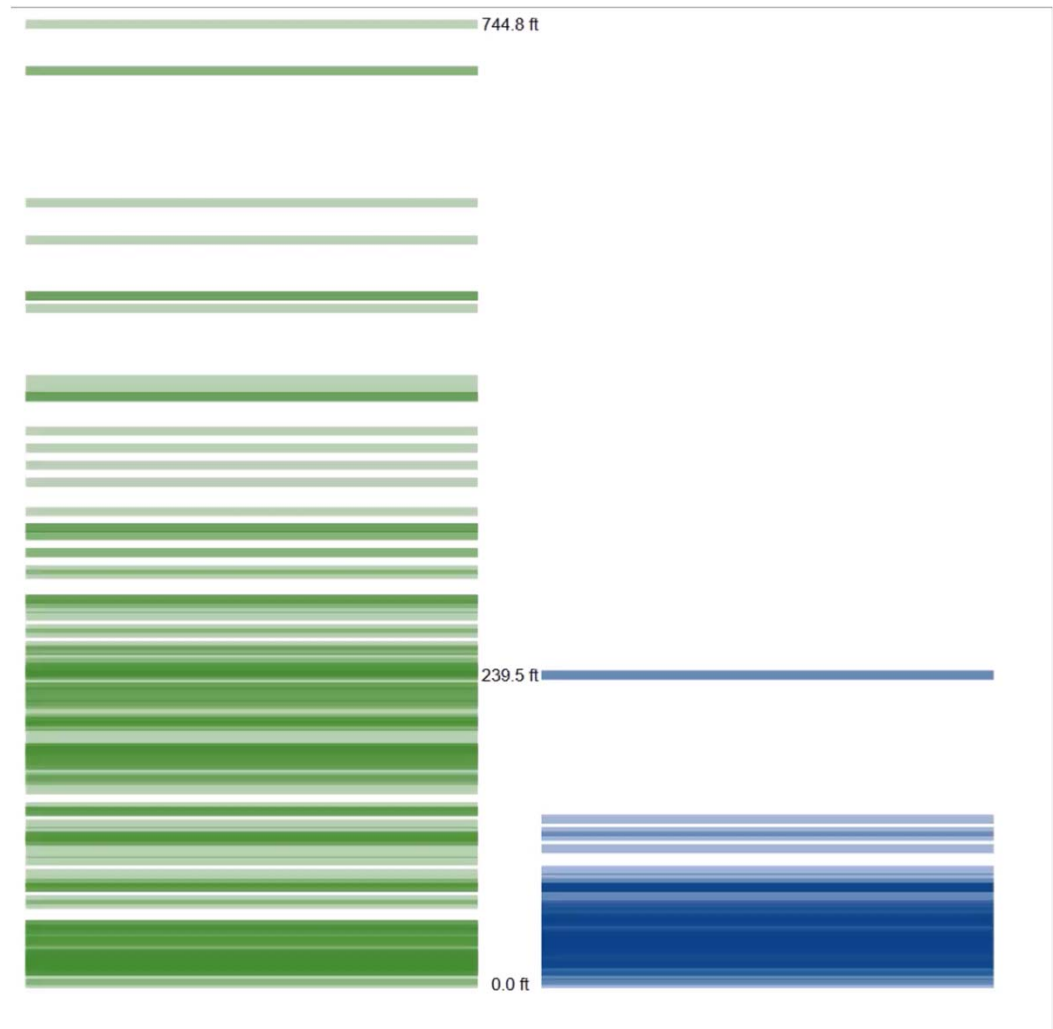
If elevation  $> 240'$   
then San Francisco



# Supervised Learning

- Add another dimension
  - Home is in San Francisco or New York
  - New feature: price per sq ft

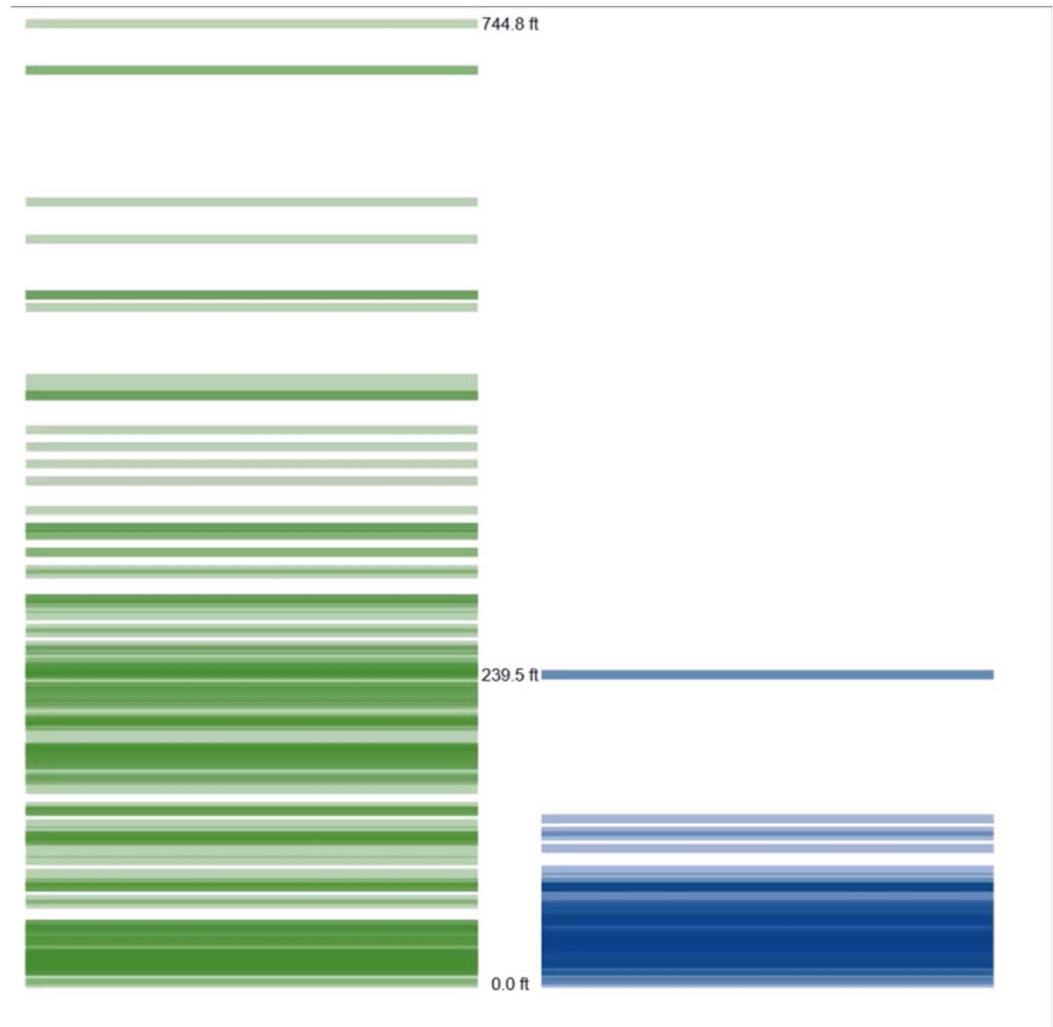
If elevation  $> 240'$   
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# Supervised Learning

- Add another dimension
  - Home is in San Francisco or New York
  - New feature: price per sq ft

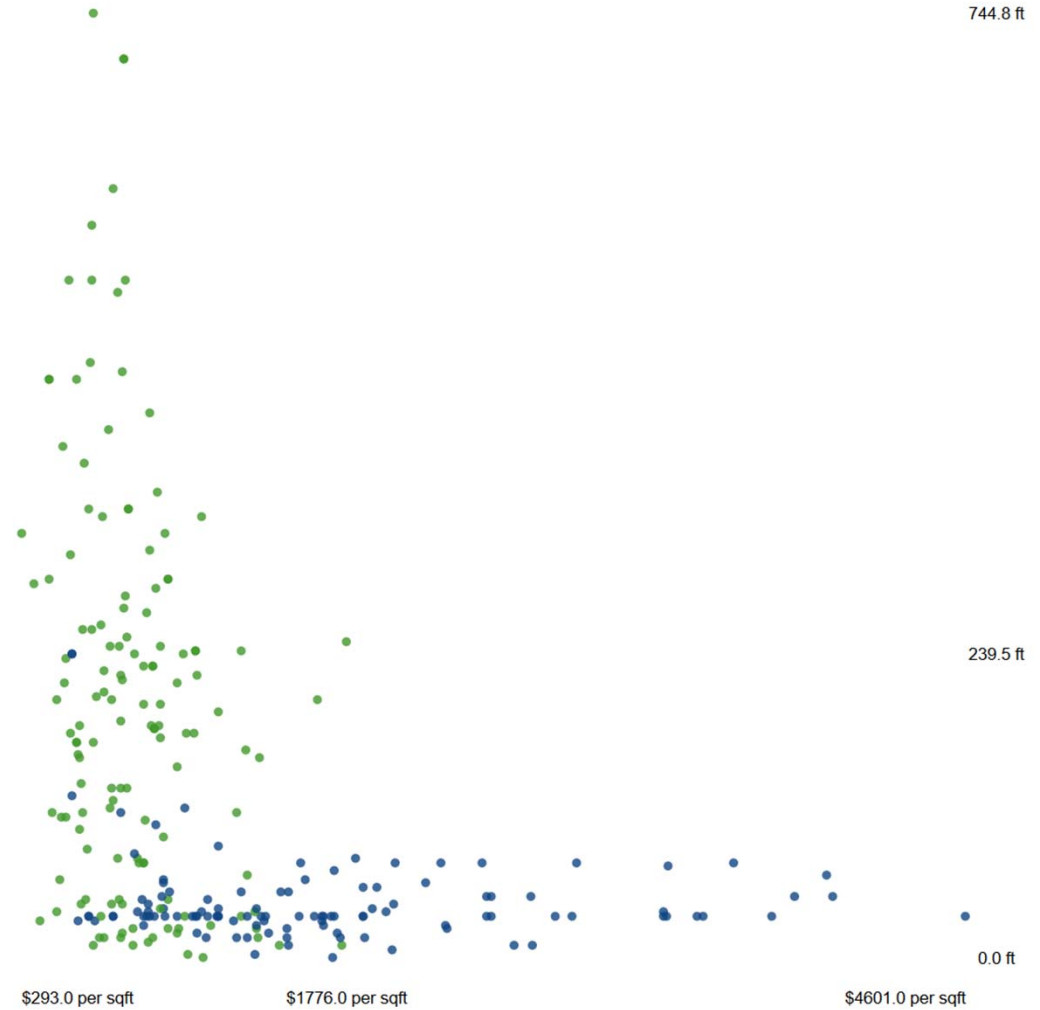
If elevation > 240' then  
San Francisco  
else if price > \$1777/sqft  
then New York



# Drawing Boundaries

- Visualize rule as boundaries of regions in scatterplot

If elevation > 240' then  
San Francisco  
else if price > \$1777/sqft  
then New York



744.8 ft

239.5 ft

0.0 ft

\$293.0 per sqft

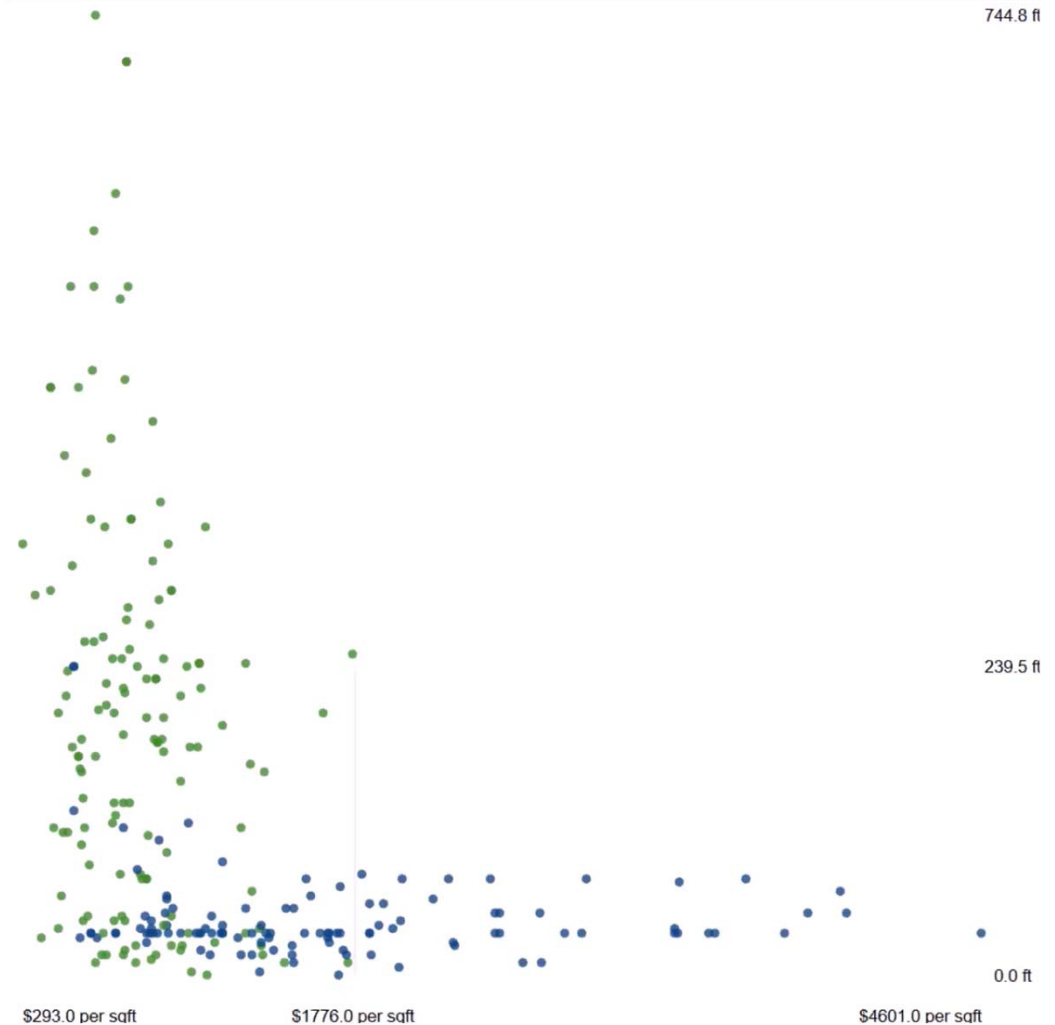
\$1776.0 per sqft

\$4601.0 per sqft

# Drawing Boundaries

- Visualize rule as boundaries of regions in scatterplot

If elevation > 240' then  
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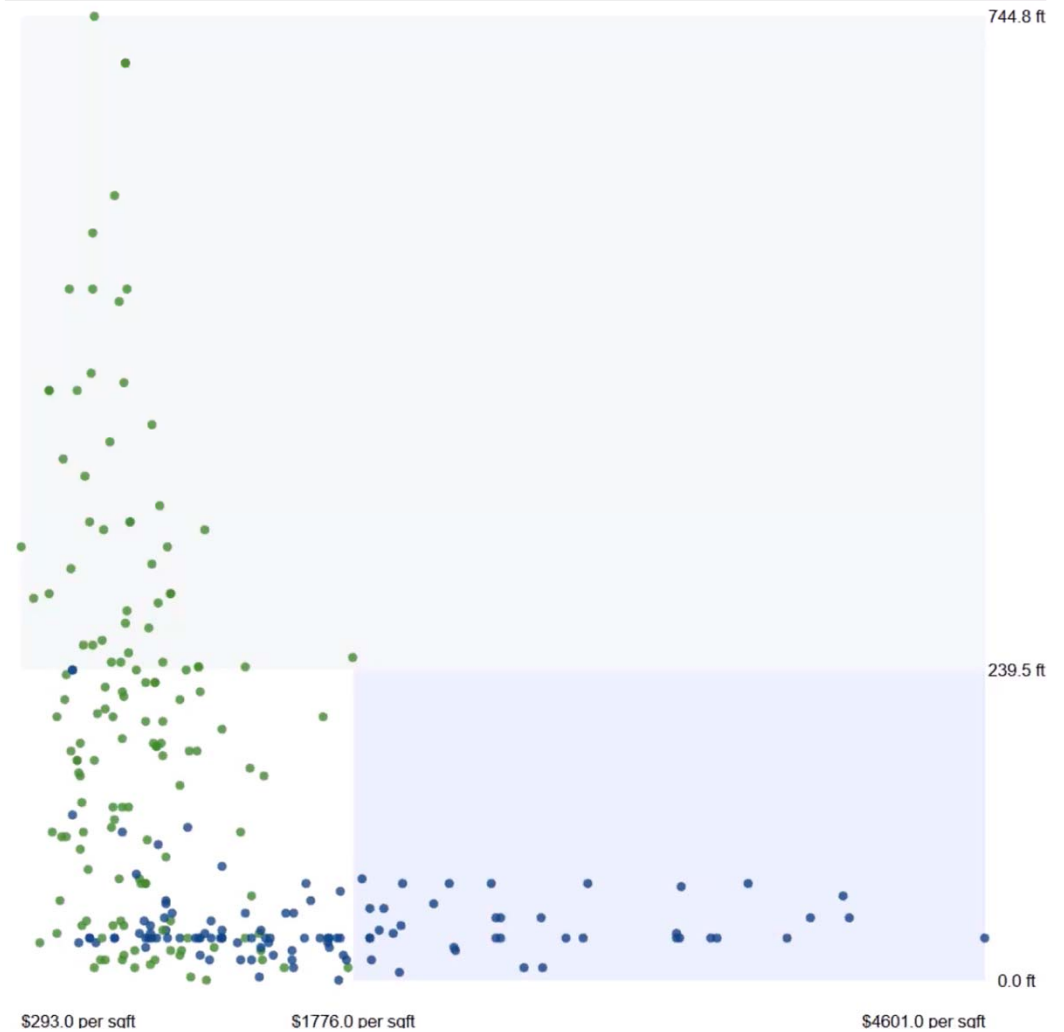
\$1776.0 per sqft

\$4601.0 per sqft

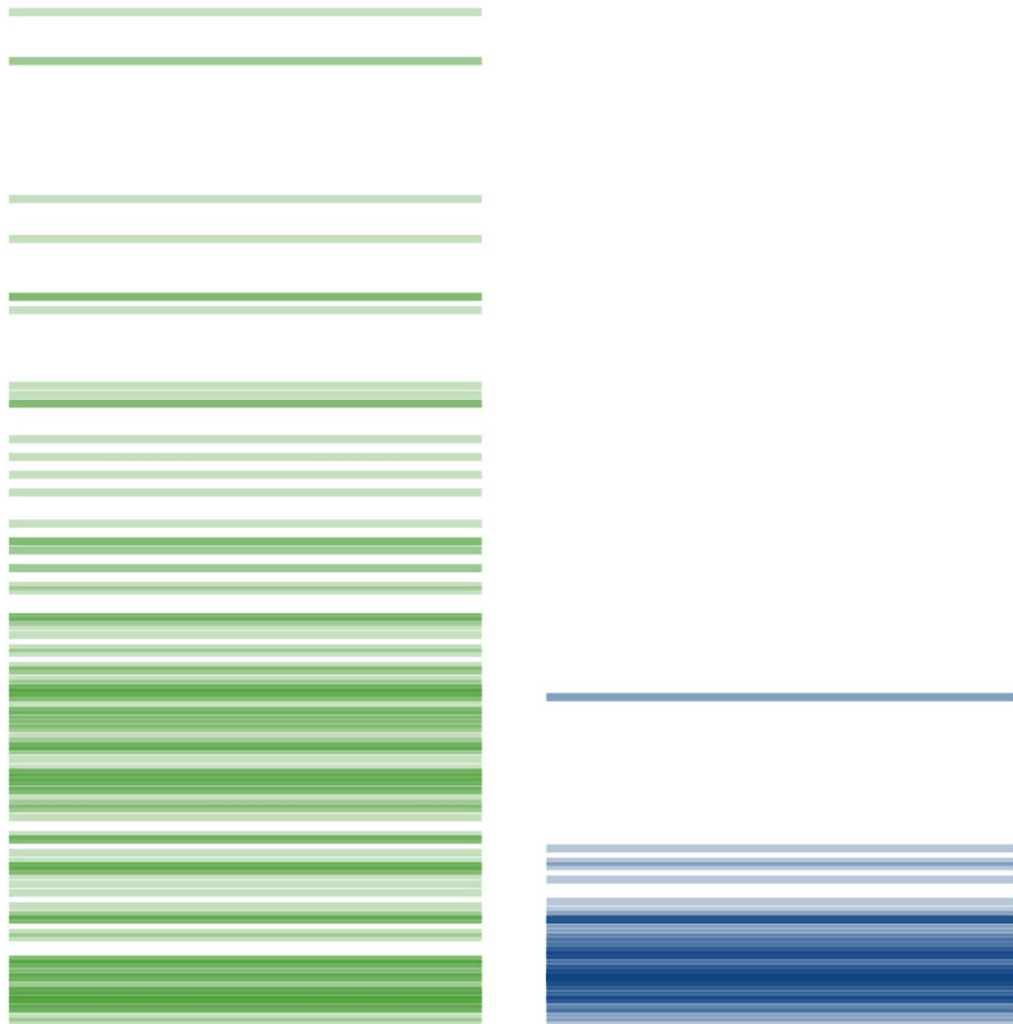


# Final dataset

- Seven dimensions



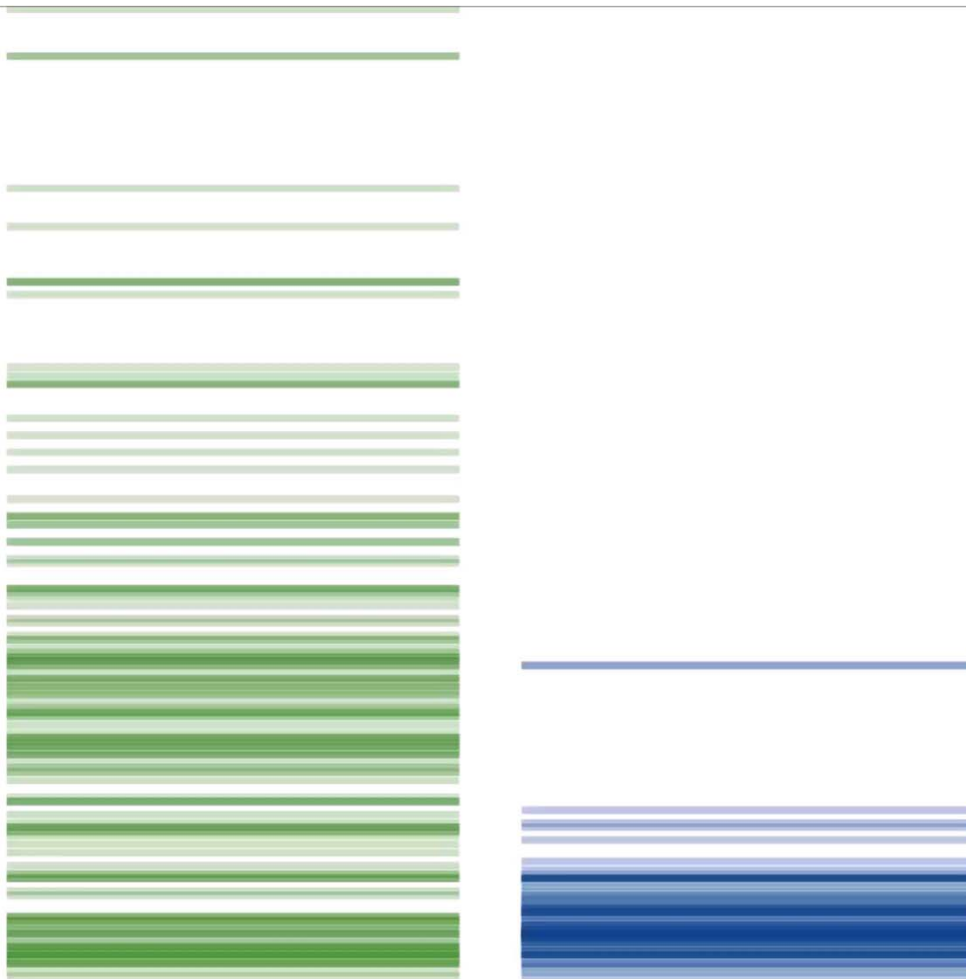
# Classifier – Decision Tree



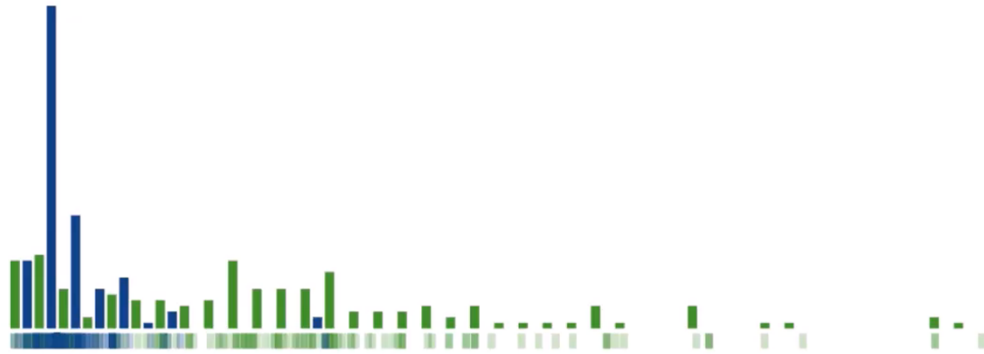
- View elevation histogram

# Classifier – Decision Tree

- View elevation histogram

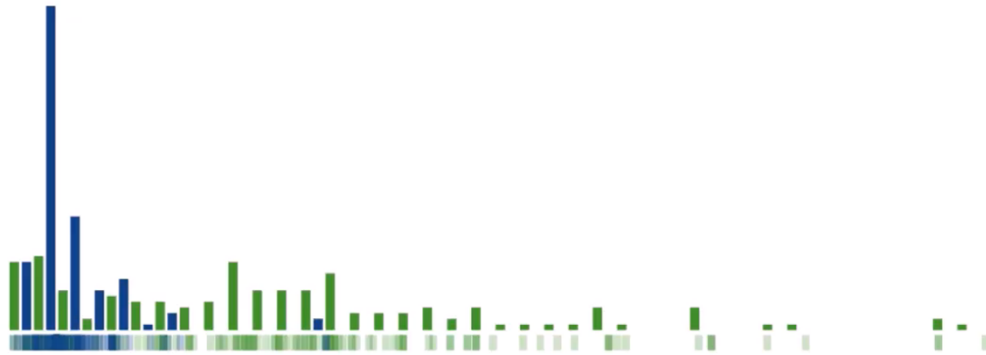


# Classifier – Decision Tree



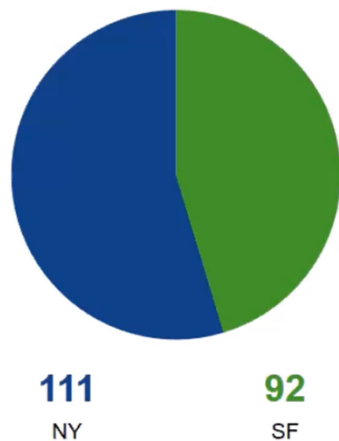
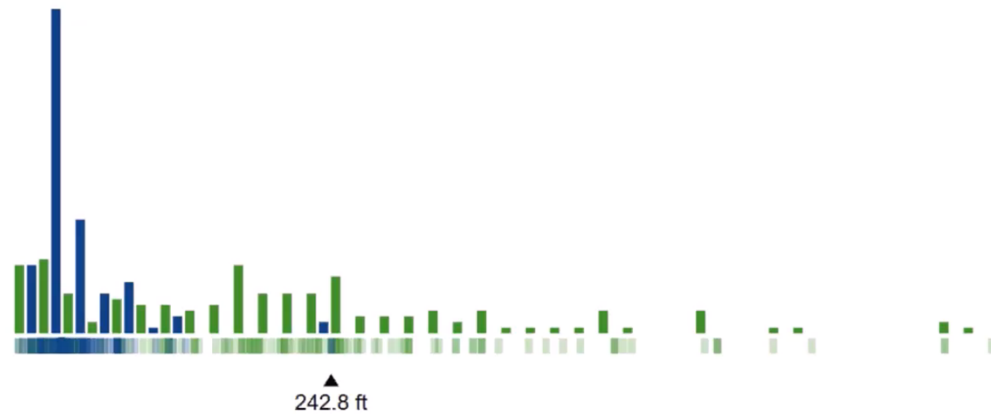
- Decision tree uses if-then statements to form boundaries
- If  $\text{elevation} > x$  then home in **San Francisco**
- These statements are forks
- Forks split the data into **branches** based feature values
- Homes to the left of a **split point** get one label
- Homes to the right get another label

# Classifier – Decision Tree



- If **elevation > 240'** then home in **San Francisco**
- This split incorrectly classifies some San Francisco homes as New York homes
- Accuracy is 63% correct
- All the green incorrect labels are **false negatives**

# Classifier – Decision Tree



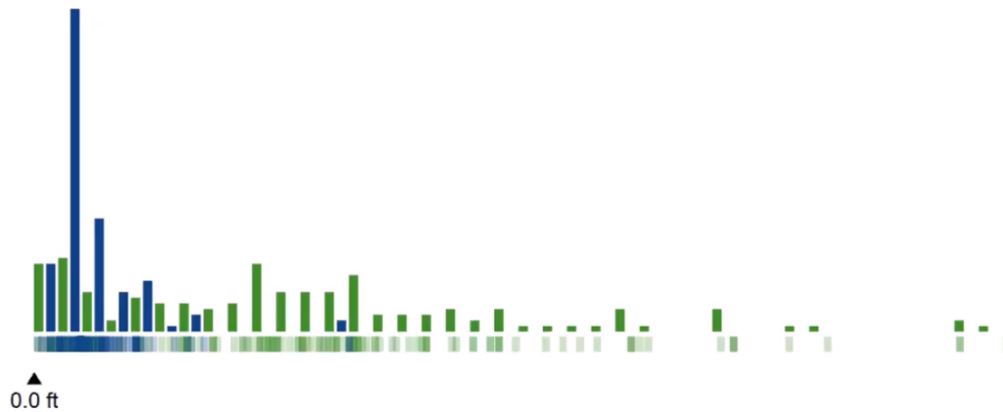
63  
% correct

0  
NY

47  
SF

- If **elevation > 0'** then home in **San Francisco**
- If we try to capture every San Francisco home we will include New York homes
- These will be **false positives**

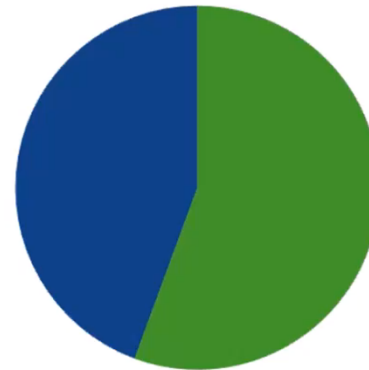
# Classifier – Decision Tree



0  
NY

0  
SF

56  
% correct



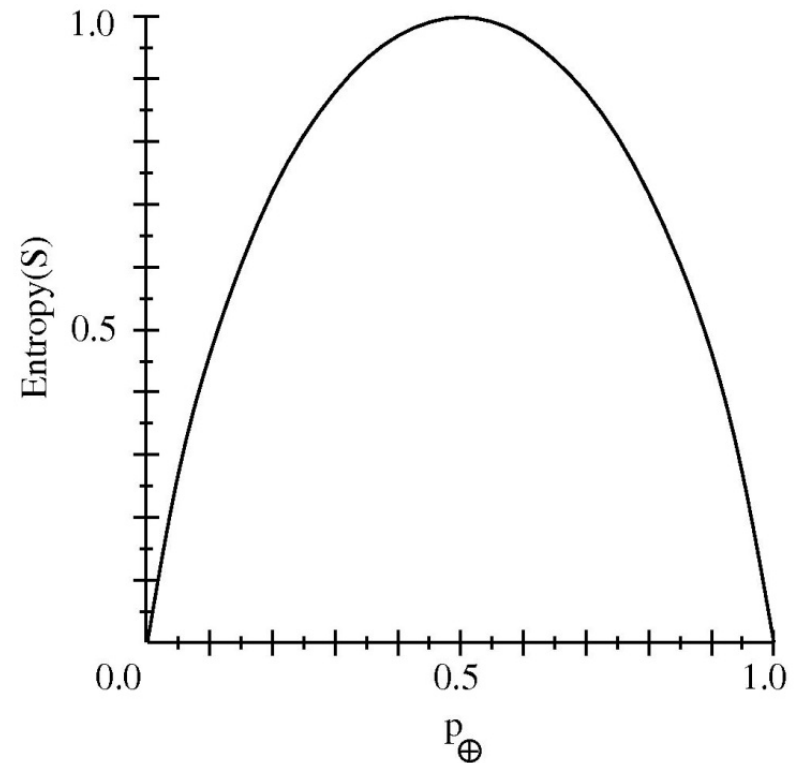
111  
NY

139  
SF

- The best split makes the groups as homogeneous as possible
- If **elevation > 92'** then home in **San Francisco**
- Entropy

# Technical detail: Entropy

- Assume classes are  $\oplus$  and  $\ominus$
- Entropy measures the impurity of the dataset
- Entropy  $\equiv$   
$$-p_{\oplus} \log_2 p_{\oplus} - p_{\ominus} \log_2 p_{\ominus}$$





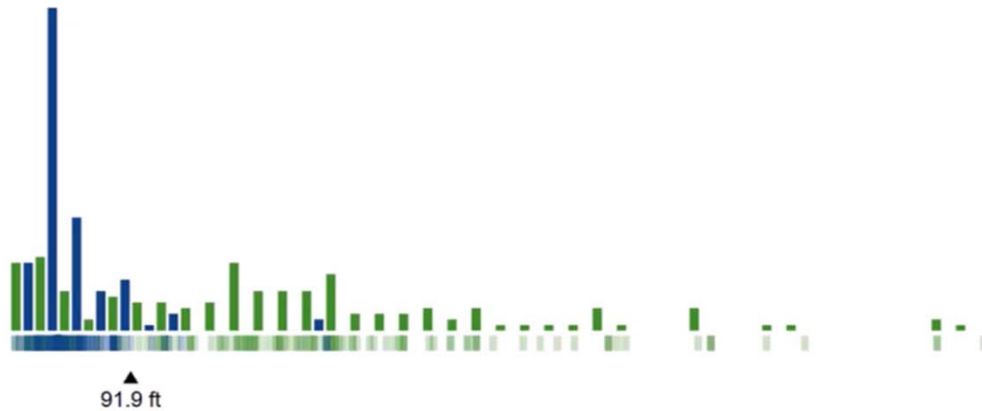
# Technical detail: Information Gain

- $Gain(S, F)$  = expected reduction in entropy due to sorting on feature  $F$

$$Gain(S, F) \equiv Entropy(S) - \sum_{v \in Values(F)} \frac{|S_v|}{|S|} Entropy(S_v)$$

# Classifier – Decision Tree

- Even the best split does not fully separate the classes



105  
NY

40  
SF

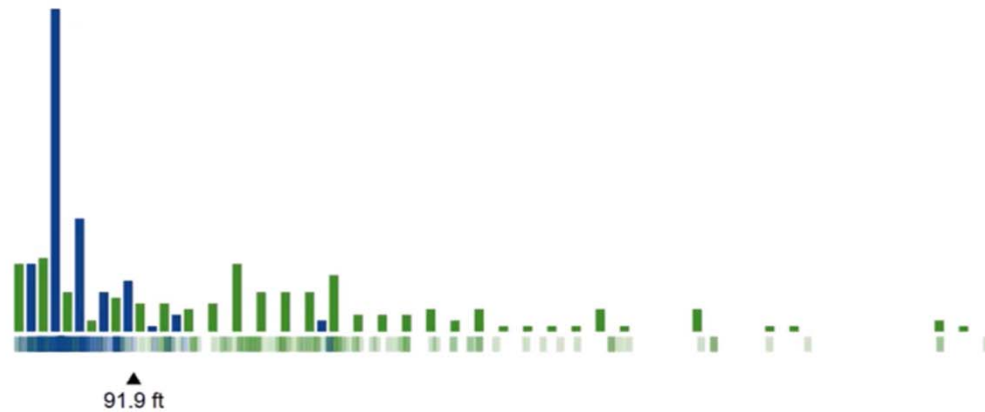
82  
% correct



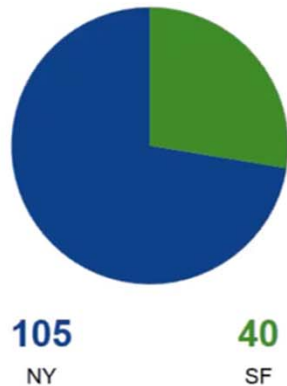
6  
NY

99  
SF

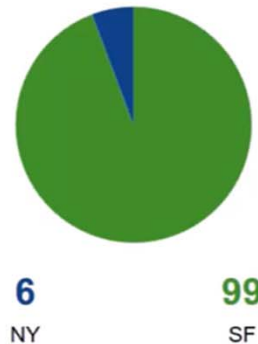
# Classifier – Decision Tree



- Solution? Add another split point
- Repeat process on subsets of data
- Recursion

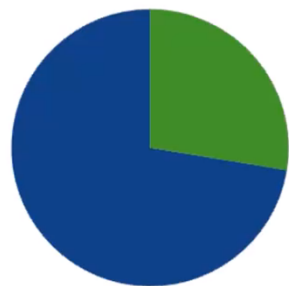
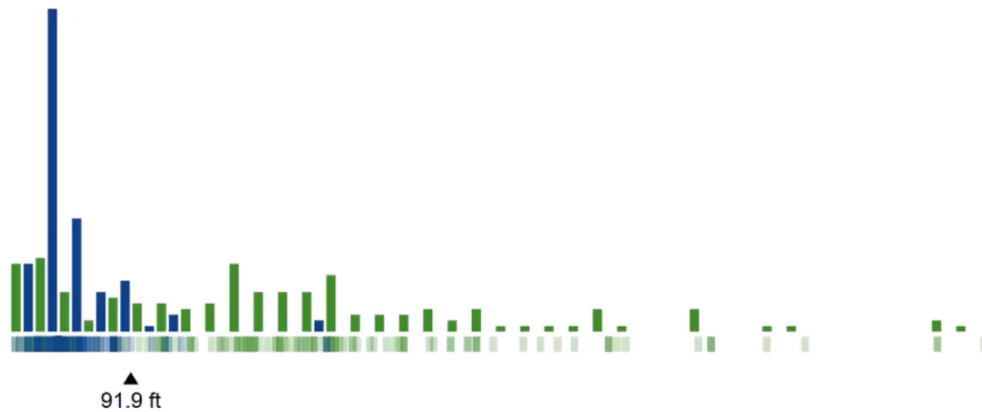


82  
% correct



# Classifier – Decision Tree

- Consider distribution for each subset



105  
NY

40  
SF

82  
% correct

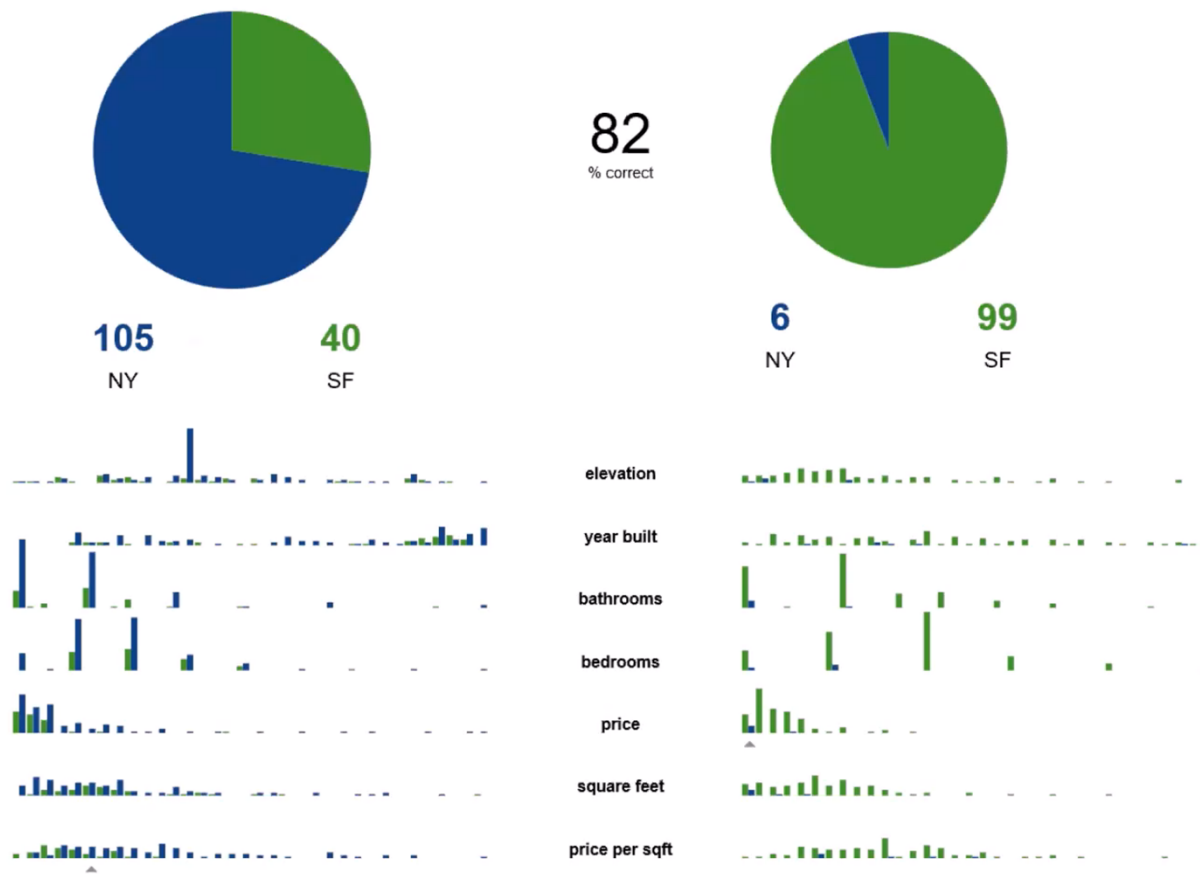


6  
NY

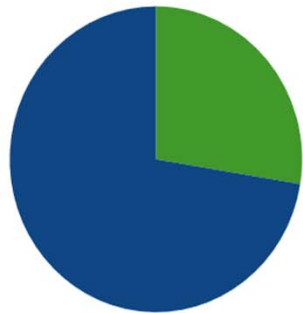
99  
SF

# Classifier – Decision Tree

- Consider distribution for each subset



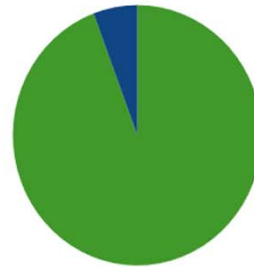
# Classifier – Decision Tree



105 NY 40 SF

82

% correct

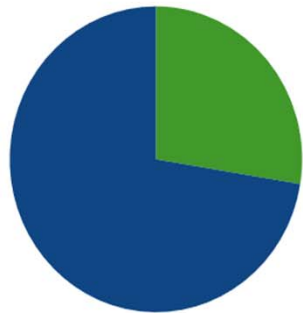


6 NY 99 SF



- Best split varies for each subset
- Lower elevation homes
  - Best split variable is price per square foot (\$1061)
- Higher elevation homes
  - Best split variable is price of home (\$514,500)

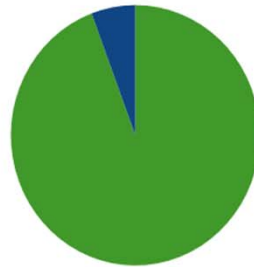
# Classifier – Decision Tree



105 NY 40 SF

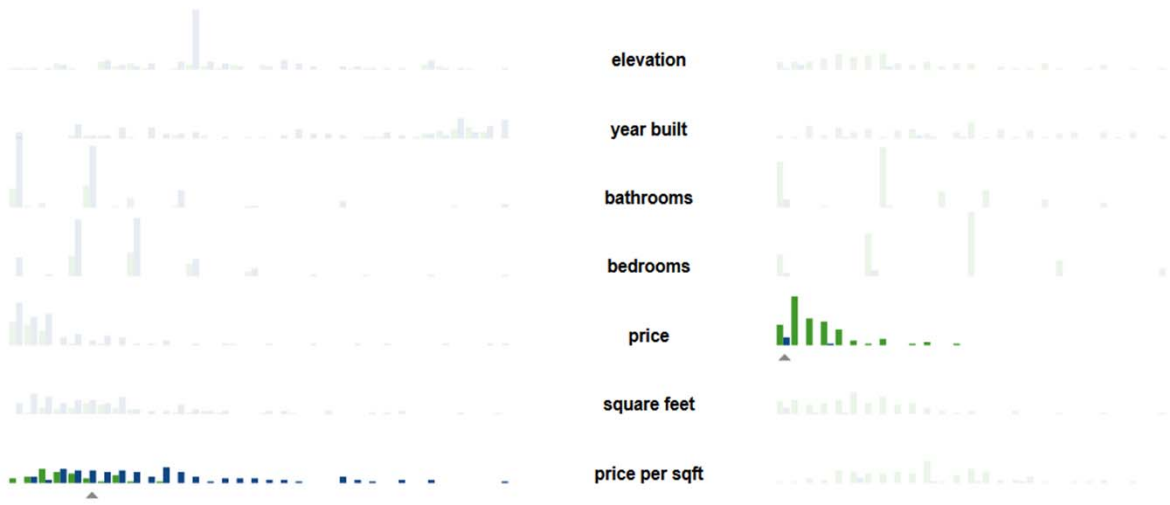
82

% correct



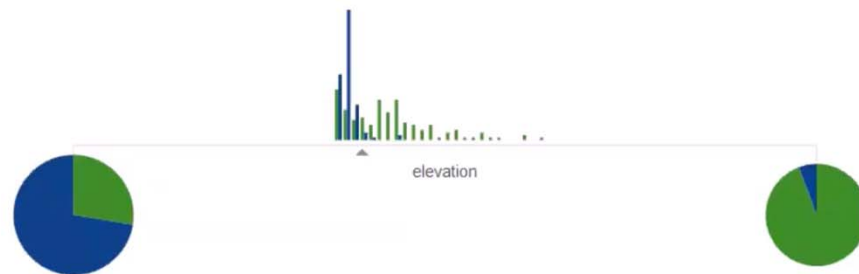
6 NY 99 SF

- Additional forks add new rule details
- This can increase the tree's accuracy



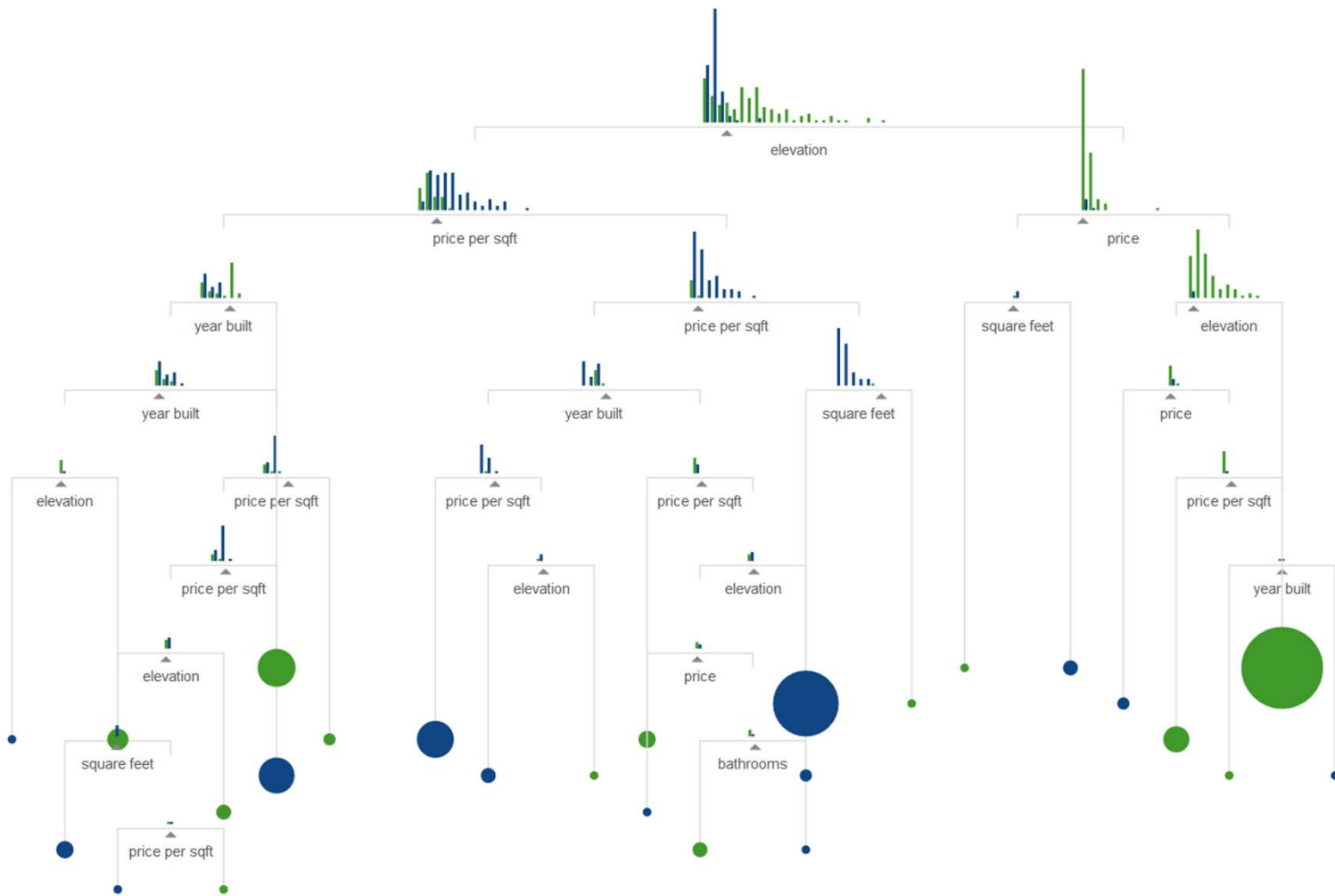
# Classifier – Decision Tree

cutree  
rand.mca

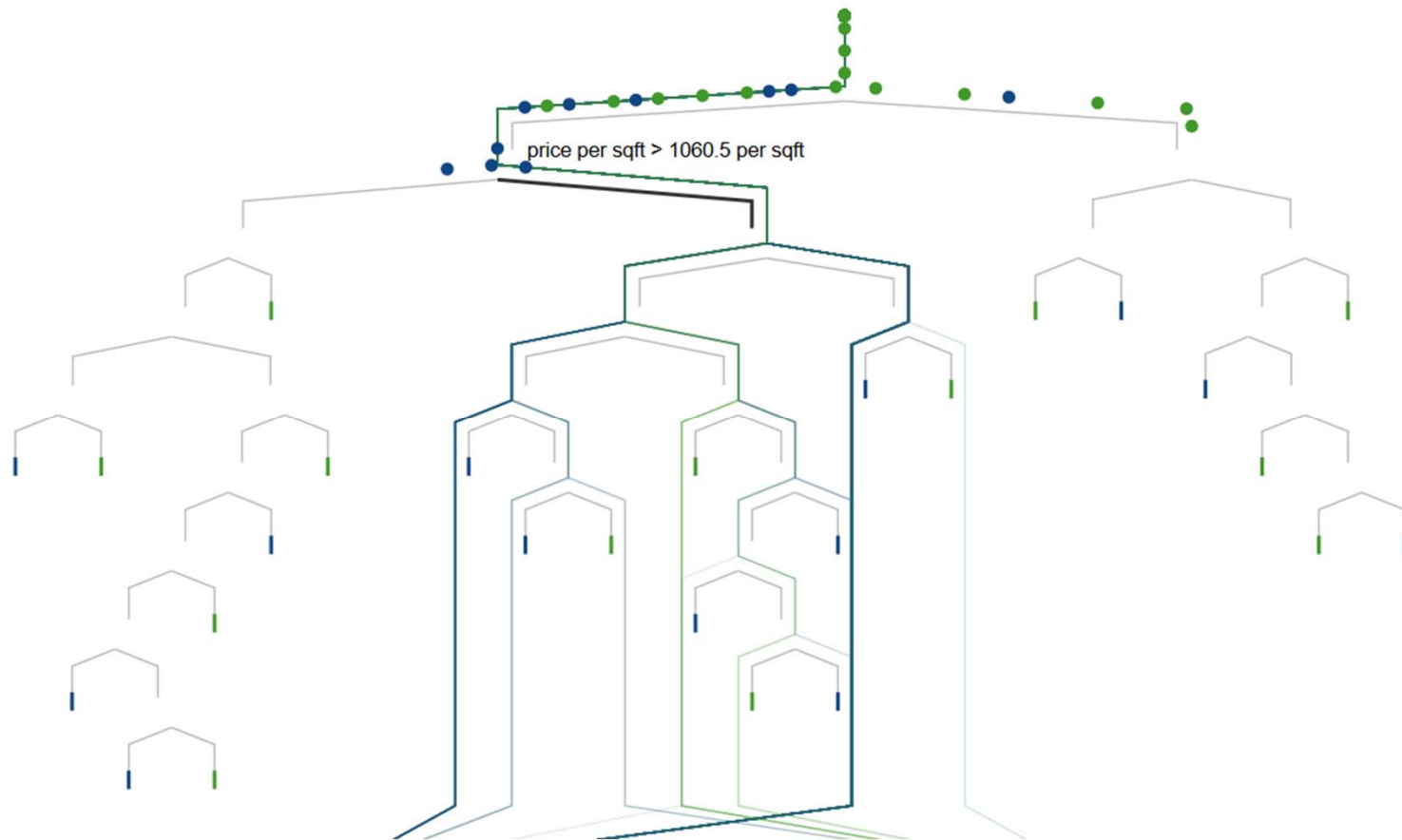




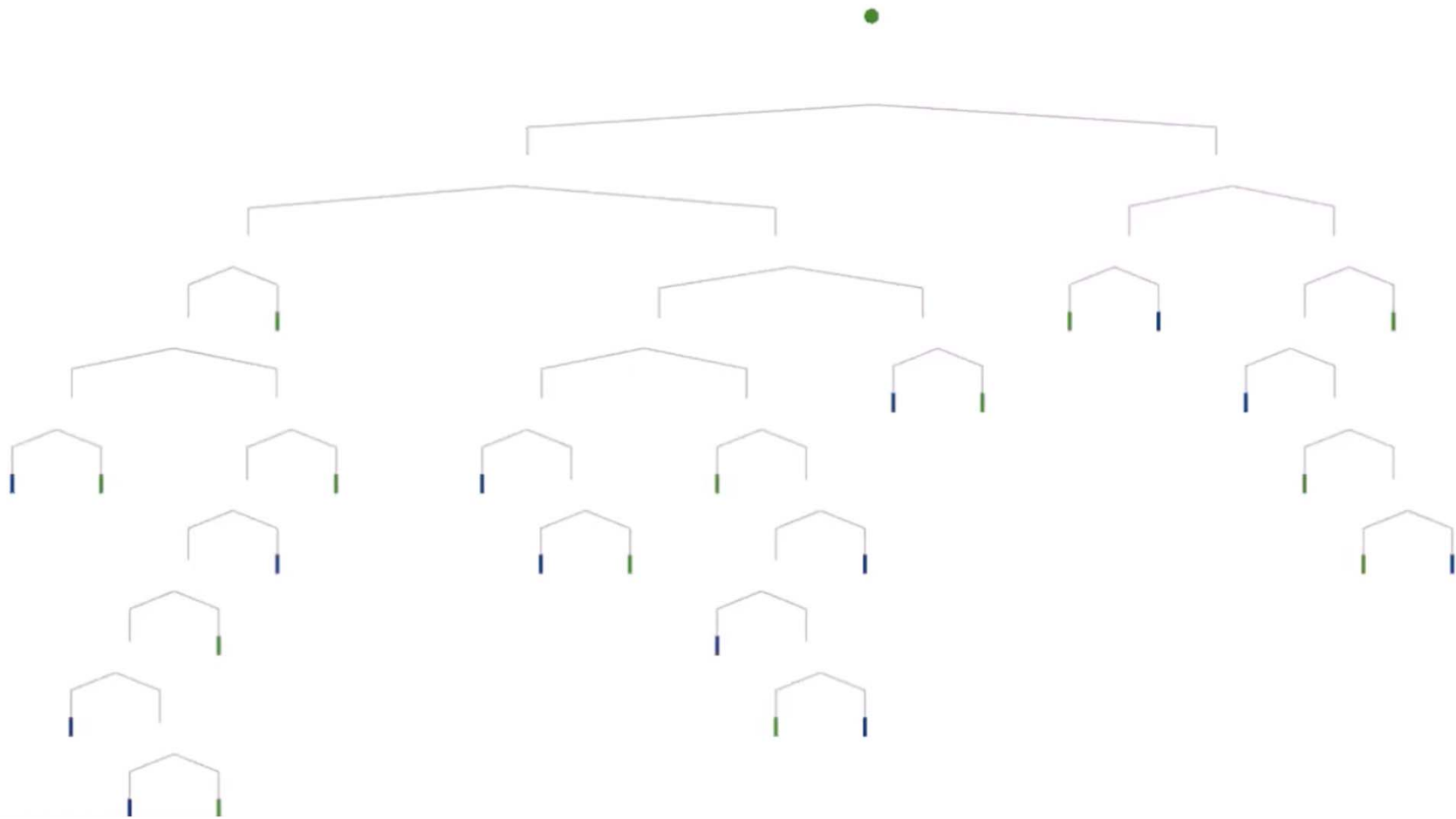
# Predict Class of New Data Point



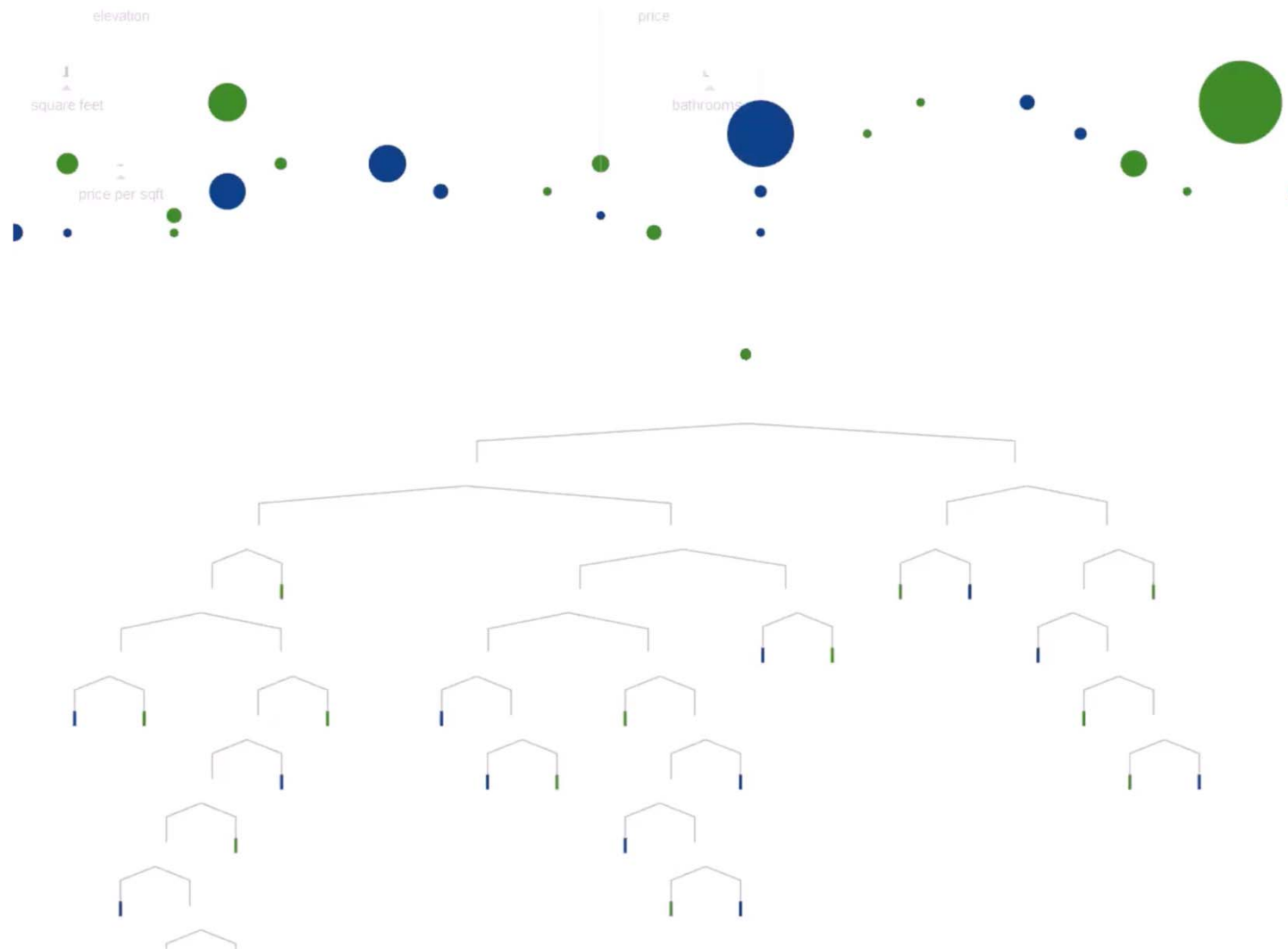
# Predict Using Decision Tree



# Predict Using Decision Tree

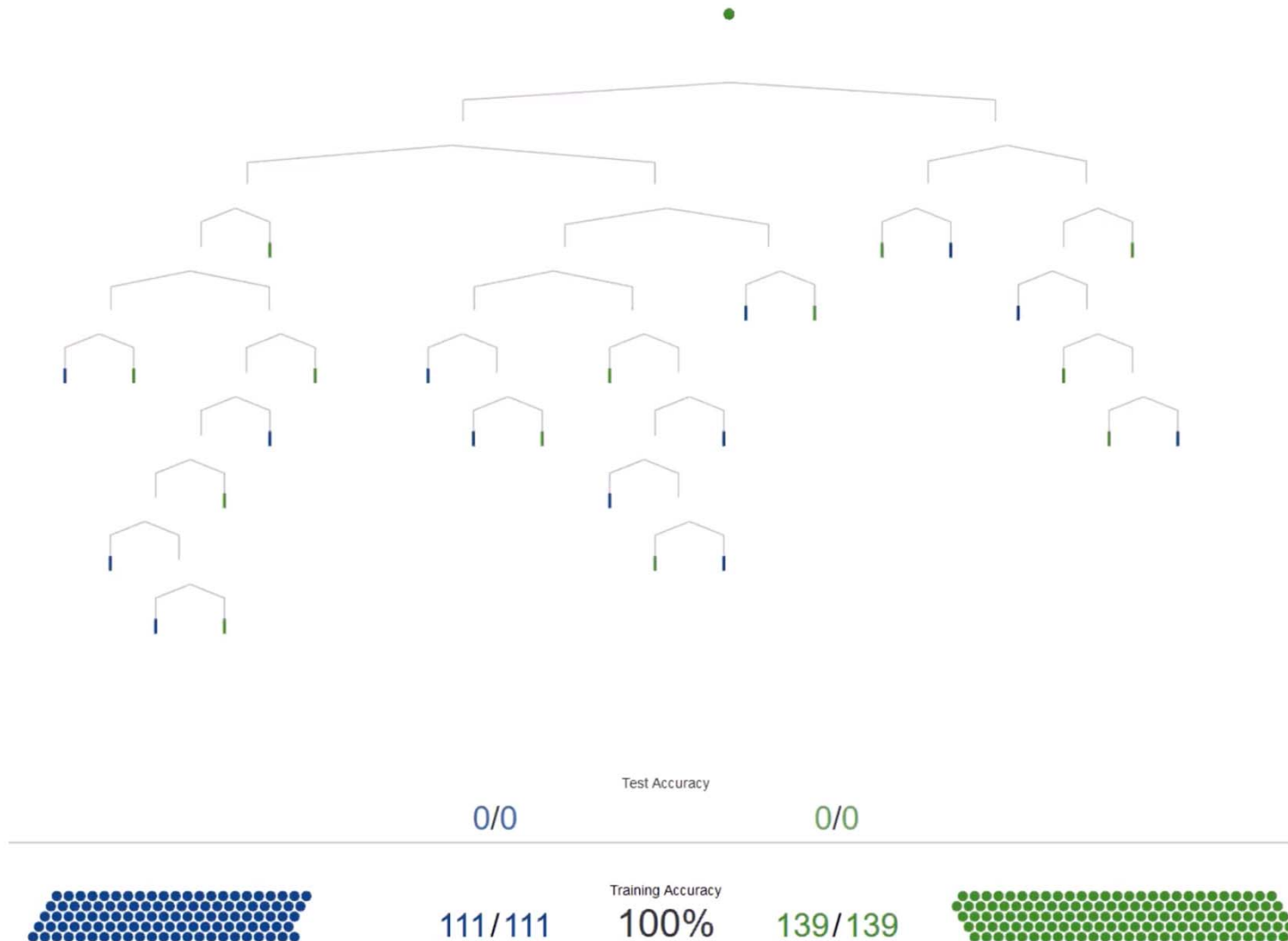


# Prediction Accuracy



# The Bigger Question?

## Prediction accuracy on new test data



# Why the Error?

- Overfit
- Noise
- Not enough features

# Weka

# ML in Gerontechnology

- Activity recognition



# Activity Learning

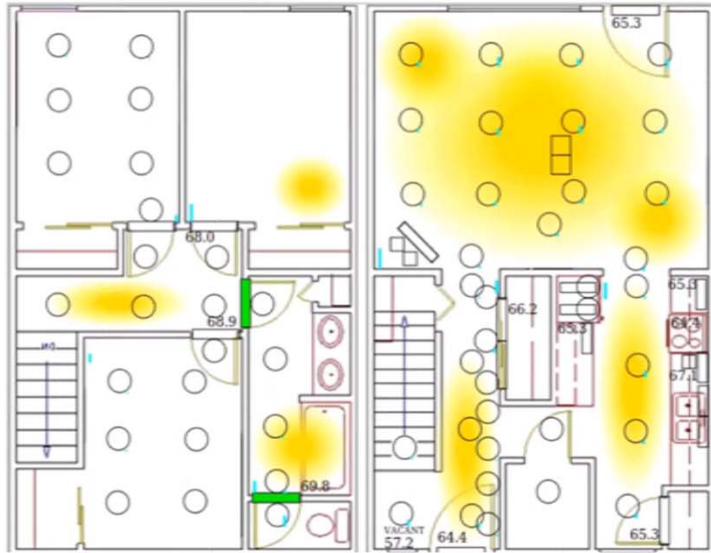
- Understand behavior
- Correlate with parameters of interest
- Design activity-aware services



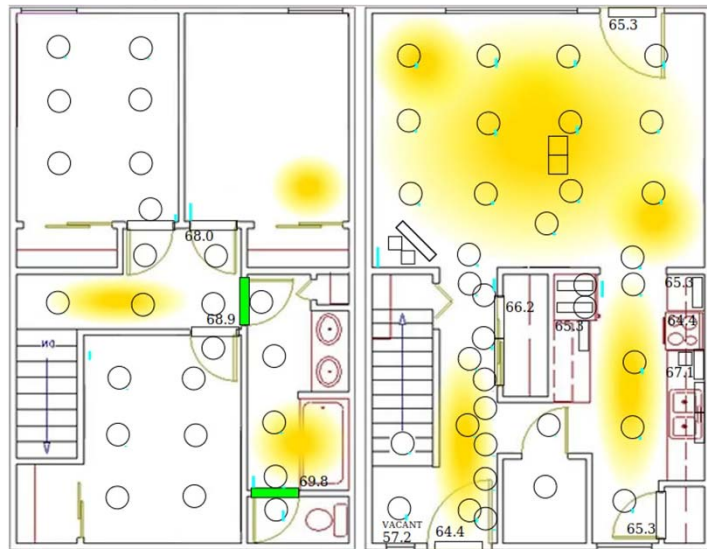
# Sensor Data Sources



2017-02-22 11:42:48.400547 LS207 50

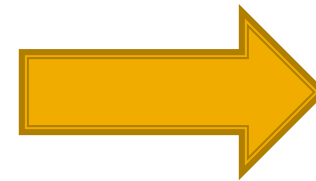


2017-02-22 11:42:48.400547 LS207 50



# Activity Recognition

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
2017-02-22	11:42:55.74	Entry
2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall
2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
2017-02-22	11:43:08.21	Kitchen
2017-02-22	11:43:09.47	Kitchen
2017-02-22	11:43:11.02	Kitchen
2017-02-22	11:43:13.84	Kitchen
2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen
2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom



# First step: Extract features

- More information context than appears on each line

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
2017-02-22	11:42:55.74	Entry
2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall
2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
2017-02-22	11:43:08.21	Kitchen
2017-02-22	11:43:09.47	Kitchen
2017-02-22	11:43:11.02	Kitchen
2017-02-22	11:43:13.84	Kitchen
2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen
2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

- Define a context *window*

- Data *segmented* into individual activities
- Sliding window
  - Based on #sensor events
  - Based on amount of time
  - Overlapping or nonoverlapping

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
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2017-02-22	11:43:09.47	Kitchen
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2017-02-22	11:43:13.84	Kitchen
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2017-02-22	11:43:19.27	Kitchen
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2017-02-22	11:42:51.15	Entry
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- Define a context *window*
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2017-02-22	11:43:56.64	LivingRoom

- Define a context *window*
  - Data *segmented* into individual activities
  - Sliding window
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    - Based on amount of time
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2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

# Window Features

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
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2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

# Window Features

- Window duration
- Date  
(days since 01-01)
- Day of week
- Time of day  
(hours, minutes,  
seconds past  
midnight)

8

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
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2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall

27

2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
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2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen

29

2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
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2017-02-22	11:43:56.64	LivingRoom

# Window Features

- Window duration
- Date  
(days since 01-01)
- Day of week
- Time of day  
(hours, minutes,  
seconds past  
midnight)

53  
4

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
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2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

53  
4

53  
4



# Window Features

- Window duration
- Date  
(days since 01-01)
- Day of week
- Time of day  
(hours, minutes,  
seconds past  
midnight)

11  
702  
42,178

11  
703  
42,206

11  
703  
42,236

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
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# Sensor Features

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2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

# Sensor Features

## ■ Sensor counts 2,6,2,0,0,0,0,0

(FrontDoor, Entry, Hall, Kitchen, KitchenCabinet, LivingRoom, Bathroom, Bedroom)

## ■ Sensor elapsed times 0,0,1,9,0,0,0,0

(FrontDoor, Entry, Hall, Kitchen, KitchenCabinet, LivingRoom, Bathroom, Bedroom)

0,0,0,7,2,1,0,0

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2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

# Sensor Features

## ■ Sensor counts

4,1,0,362,

1801,363,372,422

(FrontDoor, Entry, Hall, Kitchen,  
KitchenCabinet, LivingRoom,  
Bathroom, Bedroom)

## ■ Sensor elapsed times

32,29,27,0,

1829,391,400,450

(FrontDoor, Entry, Hall, Kitchen,  
KitchenCabinet, LivingRoom,  
Bathroom, Bedroom)

62,59,57,0,

12,0,430,480

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
2017-02-22	11:42:55.74	Entry
2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall
2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
2017-02-22	11:43:08.21	Kitchen
2017-02-22	11:43:09.47	Kitchen
2017-02-22	11:43:11.02	Kitchen
2017-02-22	11:43:13.84	Kitchen
2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen
2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

# Additional Features

- Activity labels in previous windows
- Change in activity level
- Complexity
- Statistical features for numeric values

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
2017-02-22	11:42:55.74	Entry
2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall
2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
2017-02-22	11:43:08.21	Kitchen
2017-02-22	11:43:09.47	Kitchen
2017-02-22	11:43:11.02	Kitchen
2017-02-22	11:43:13.84	Kitchen
2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen
2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

# Final Feature Vector

8, 53, 4, 11, 702, 42178, 2, 6, 2, 0, 0, 0,  
0, 0, 4, 1, 0, 362, 1801, 363, 372, 422,  
5, 4, 0.5, 1.72, ...

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
2017-02-22	11:42:55.74	Entry
2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall
2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
2017-02-22	11:43:08.21	Kitchen
2017-02-22	11:43:09.47	Kitchen
2017-02-22	11:43:11.02	Kitchen
2017-02-22	11:43:13.84	Kitchen
2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen
2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

# Activity Recognition

$v = \langle 8, 53, 4, 11, 702, 42178, 2, 6, 2, 0, 0, 0, 0, 0, 4, 1, 0, 362, 1801, 363, 372, 422, 5, 4, 0.5, 1.72 \rangle$

Activity recognition maps the feature vector,  $v$ , onto an activity from a set  $A$  of possible activity classes

$AR: v \rightarrow A$

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
2017-02-22	11:42:55.74	Entry
2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall
2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
2017-02-22	11:43:08.21	Kitchen
2017-02-22	11:43:09.47	Kitchen
2017-02-22	11:43:11.02	Kitchen
2017-02-22	11:43:13.84	Kitchen
2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen
2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

$v = \langle 8, 53, 4, 11, 702, 42178, 2, 6, 2, 0, 0, 0, 0, 0, 4, 1, 0, 362, 1801, 363, 372, 422, 5, 4, 0.5, 1.72 \rangle$

$AR: v \rightarrow A$

$A = \{\text{Enter Home, Leave Home, Sleep, Bed/Toilet Transition, Relax, Work, Cook, Eat, Wash Dishes, Housekeeping, Laundry, Put Away Groceries, ..., Other}\}$

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
2017-02-22	11:42:55.74	Entry
2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall
2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
2017-02-22	11:43:08.21	Kitchen
2017-02-22	11:43:09.47	Kitchen
2017-02-22	11:43:11.02	Kitchen
2017-02-22	11:43:13.84	Kitchen
2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen
2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom



v1 = <8, 53, 4, 11, 702, 42178, 2, 6, 2, 0, 0, 0, 0, 0, 4, 1, 0, 362, 1801, 363, 372, 422, 5, 4, 0.5, 1.72>

*AR: v1 → Enter Home*

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
2017-02-22	11:42:55.74	Entry
2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall
2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
2017-02-22	11:43:08.21	Kitchen
2017-02-22	11:43:09.47	Kitchen
2017-02-22	11:43:11.02	Kitchen
2017-02-22	11:43:13.84	Kitchen
2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen
2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

v2 = <27, 53, 4, 11, 703, 42206, 0, 0, 1, 9, 0, 0, 0, 0, 32, 29, 27, 0, 1829, 391, 400, 425, 5, 4, 0.6, 1.62>

*AR: v2 → Put Away Groceries*

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
2017-02-22	11:42:55.74	Entry
2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall
2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
2017-02-22	11:43:08.21	Kitchen
2017-02-22	11:43:09.47	Kitchen
2017-02-22	11:43:11.02	Kitchen
2017-02-22	11:43:13.84	Kitchen
2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen
2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

v3 = <29, 53, 4, 11, 703, 42236, 0, 0, 0,  
7, 2, 0, 0, 0, 62, 59, 57, 0, 12, 0, 430,  
480, 425, 5, 2, 0.2, 1.51>

AR: v3 → ?

2017-02-22	11:42:50.57	FrontDoor
2017-02-22	11:42:51.15	Entry
2017-02-22	11:42:51.57	Hall
2017-02-22	11:42:51.99	Entry
2017-02-22	11:42:53.01	Entry
2017-02-22	11:42:54.82	FrontDoor
2017-02-22	11:42:55.74	Entry
2017-02-22	11:42:56.95	Entry
2017-02-22	11:42:57.18	Entry
2017-02-22	11:42:58.15	Hall
2017-02-22	11:42:59.78	Hall
2017-02-22	11:43:00.22	Kitchen
2017-02-22	11:43:08.21	Kitchen
2017-02-22	11:43:09.47	Kitchen
2017-02-22	11:43:11.02	Kitchen
2017-02-22	11:43:13.84	Kitchen
2017-02-22	11:43:14.91	Kitchen
2017-02-22	11:43:19.27	Kitchen
2017-02-22	11:43:21.71	Kitchen
2017-02-22	11:43:26.15	Kitchen
2017-02-22	11:43:27.44	KitchenCabinet
2017-02-22	11:43:36.90	Kitchen
2017-02-22	11:43:38.03	Kitchen
2017-02-22	11:43:43.40	Kitchen
2017-02-22	11:43:44.67	KitchenCabinet
2017-02-22	11:43:49.21	Kitchen
2017-02-22	11:43:50.95	Kitchen
2017-02-22	11:43:53.96	Kitchen
2017-02-22	11:43:56.01	Kitchen
2017-02-22	11:43:56.64	LivingRoom

# Weka

# Confusion Matrix

True class	Predicted class		Total
	Positive	Negative	
Positive	TP: true positive	FN: false negative	P
Negative	FP: false positive	TN: true negative	N
Total	P'	N'	M

## Naïve Bayes

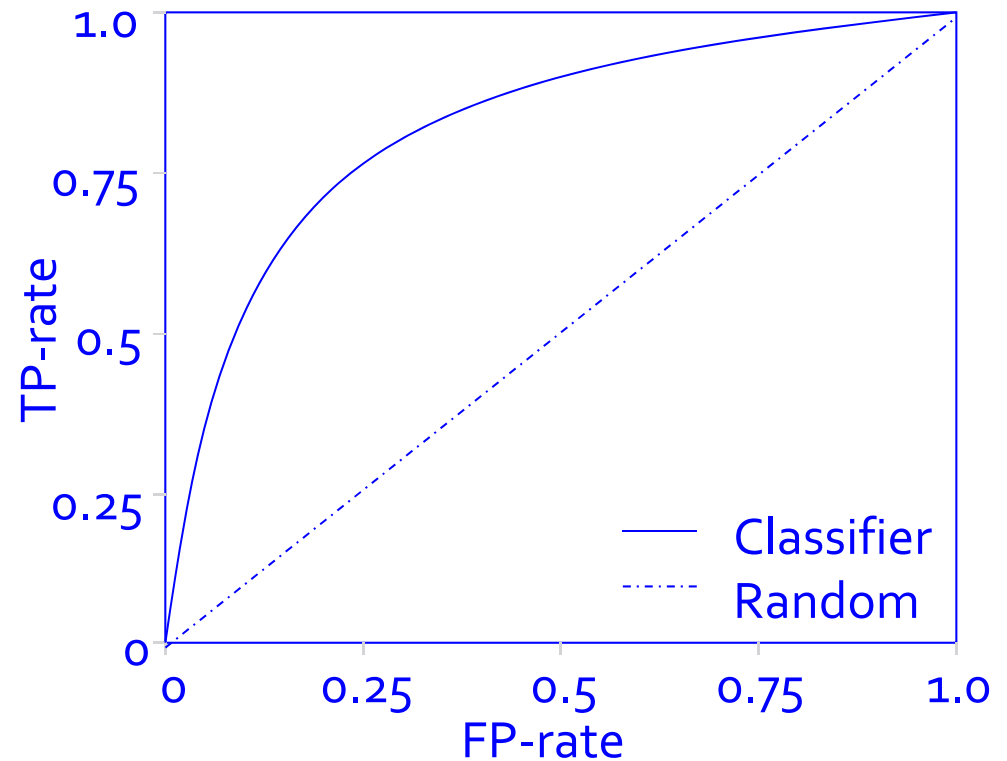
True class	Predicted class		Total
	Sleep	Eat	
Sleep	460	47	30
Eat	7	2330	2337
Total	467	2377	2844

# Evaluation Metrics

Metric	Formula	Naïve Bayes Example
Accuracy	$\frac{(TP + TN)}{M}$	0.98
Error	$\frac{(FP + FN)}{M}$	0.02
Precision	$\frac{TP}{(TP + FP)}$	0.98
Recall, TP-Rate	$\frac{TP}{(TP + FN)} = \frac{TP}{P}$	0.98
F-measure	$2 * \frac{Precision * Recall}{(Precision + Recall)}$	0.98

# Receiver Operating Characteristic (ROC) Curve

- Classify using  $P(\text{class}|x) > \theta$  as  $\theta$  varies from 0.0 to 1.0
- Plot FP-rate and TP-rate for each  $\theta$
- Area under curve (AUC) measure of performance
- AR: AUC = 1.0



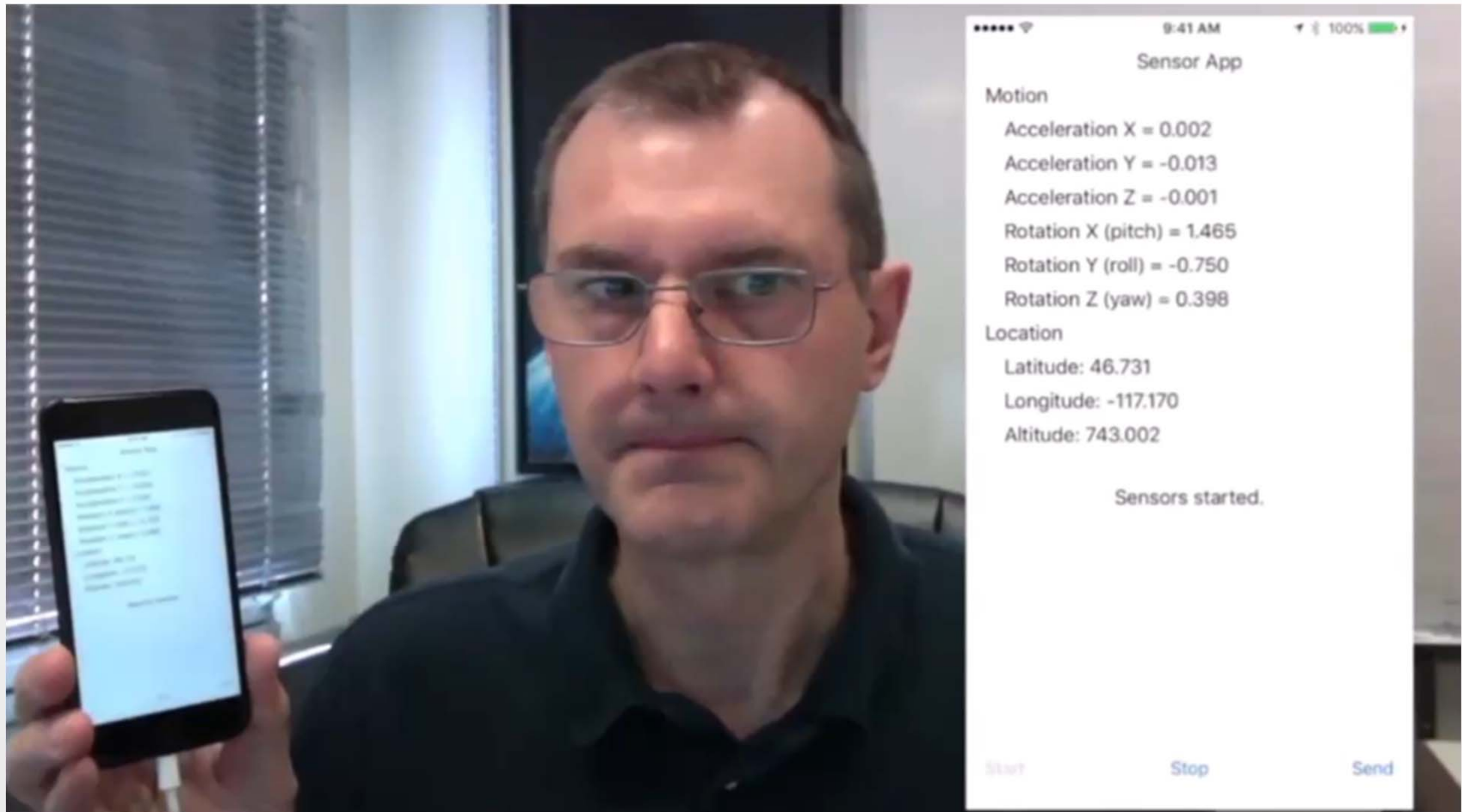
# Cross Validation

- What data should to train and test?





# But what about mobile data?



# Sensor Data

2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				

# Sensor Data

2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				

# Sensor Data

2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				

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2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				

# Sensor Data

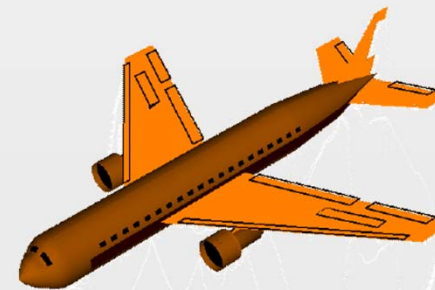
2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				

# Sensor Data

2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				

# Sensor Data

2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				





# Sensor Data

2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
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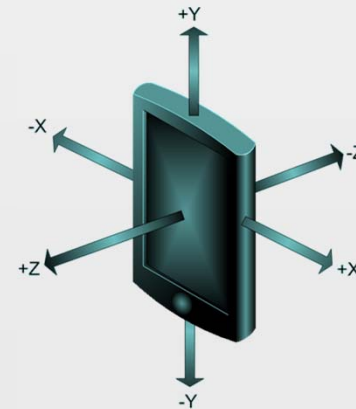
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2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				



# Sensor Data

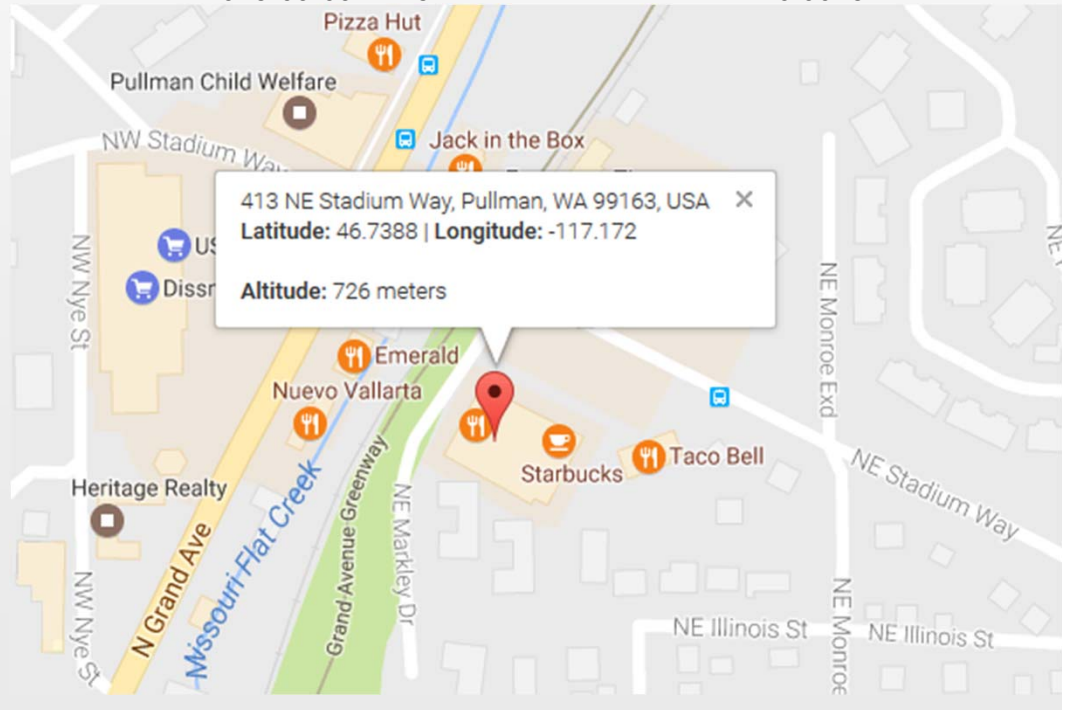
2015-09-09 21:57:08	Yaw	-1.7854	2015-09-09 21:57:11	Yaw	-1.0639
2015-09-09 21:57:08	Pitch	0.1206	2015-09-09 21:57:11	Pitch	0.4596
2015-09-09 21:57:08	Roll	0.8295	2015-09-09 21:57:11	Roll	-0.2751
2015-09-09 21:57:08	AccelerationX	0.0380	2015-09-09 21:57:11	AccelerationX	0.2281
2015-09-09 21:57:08	AccelerationY	-0.0987	2015-09-09 21:57:11	AccelerationY	-0.1197
2015-09-09 21:57:08	AccelerationZ	0.0860	2015-09-09 21:57:11	AccelerationZ	-0.3376
2015-09-09 21:57:08	Latitude	46.7388	2015-09-09 21:57:11	Latitude	46.7388
2015-09-09 21:57:08	Longitude	-117.1720	2015-09-09 21:57:11	Longitude	-117.1720
2015-09-09 21:57:08	Altitude	729.6390	2015-09-09 21:57:11	Altitude	729.3890
2015-09-09 21:57:08	Course	286.5230	2015-09-09 21:57:11	Course	15.4688
2015-09-09 21:57:08	Speed	0.0000	2015-09-09 21:57:11	Speed	0.0000
2015-09-09 21:57:09	Yaw	-1.6375	2015-09-09 21:57:12	Yaw	-1.1032
2015-09-09 21:57:09	Pitch	0.2450	2015-09-09 21:57:12	Pitch	0.4854
2015-09-09 21:57:09	Roll	0.6756	2015-09-09 21:57:12	Roll	-0.1308
2015-09-09 21:57:09	AccelerationX	-0.0029	2015-09-09 21:57:12	AccelerationX	-0.0025
2015-09-09 21:57:09	AccelerationY	0.0067	2015-09-09 21:57:12	AccelerationY	0.0114
2015-09-09 21:57:09	AccelerationZ	-0.0120	2015-09-09 21:57:12	AccelerationZ	-0.0011
2015-09-09 21:57:09	Latitude	46.7388	2015-09-09 21:57:12	Latitude	46.7388
2015-09-09 21:57:09	Longitude	-117.1720	2015-09-09 21:57:12	Longitude	-117.1720
2015-09-09 21:57:09	Altitude	729.6810	2015-09-09 21:57:12	Altitude	729.5630
2015-09-09 21:57:09	Course	241.1720	2015-09-09 21:57:12	Course	15.4688
2015-09-09 21:57:09	Speed	0.0000	2015-09-09 21:57:12	Speed	0.0000
2015-09-09 21:57:10	Yaw	-1.2686			
2015-09-09 21:57:10	Pitch	0.1570			
2015-09-09 21:57:10	Roll	-0.3932			
2015-09-09 21:57:10	AccelerationX	0.1057			
2015-09-09 21:57:10	AccelerationY	-0.1179			
2015-09-09 21:57:10	AccelerationZ	-0.0262			
2015-09-09 21:57:10	Latitude	46.7388			
2015-09-09 21:57:10	Longitude	-117.1720			
2015-09-09 21:57:10	Altitude	729.6500			
2015-09-09 21:57:10	Course	273.8670			
2015-09-09 21:57:10	Speed	0.0000			



# Sensor Data

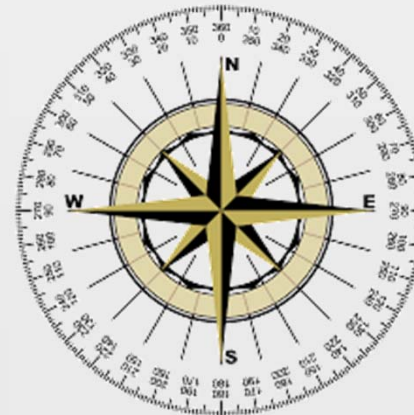
2015-09-09	21:57:08	Yaw	-1.7854
2015-09-09	21:57:08	Pitch	0.1206
2015-09-09	21:57:08	Roll	0.8295
2015-09-09	21:57:08	AccelerationX	0.0380
2015-09-09	21:57:08	AccelerationY	-0.0987
2015-09-09	21:57:08	AccelerationZ	0.0860
2015-09-09	21:57:08	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390
2015-09-09	21:57:08	Course	286.5230
2015-09-09	21:57:08	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375
2015-09-09	21:57:09	Pitch	0.2450
2015-09-09	21:57:09	Roll	0.6756
2015-09-09	21:57:09	AccelerationX	-0.0029
2015-09-09	21:57:09	AccelerationY	0.0067
2015-09-09	21:57:09	AccelerationZ	-0.0120
2015-09-09	21:57:09	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810
2015-09-09	21:57:09	Course	241.1720
2015-09-09	21:57:09	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686
2015-09-09	21:57:10	Pitch	0.1570
2015-09-09	21:57:10	Roll	-0.3932
2015-09-09	21:57:10	AccelerationX	0.1057
2015-09-09	21:57:10	AccelerationY	-0.1179
2015-09-09	21:57:10	AccelerationZ	-0.0262
2015-09-09	21:57:10	Latitude	46.7388
2015-09-09	21:57:10	Longitude	-117.1720
2015-09-09	21:57:10	Altitude	729.6500
2015-09-09	21:57:10	Course	273.8670
2015-09-09	21:57:10	Speed	0.0000

2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:12	AccelerationX	-0.0025



# Sensor Data

2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				



# Feature Window

2015-09-09	21:57:08	Yaw	-1.7854
2015-09-09	21:57:08	Pitch	0.1206
2015-09-09	21:57:08	Roll	0.8295
2015-09-09	21:57:08	AccelerationX	0.0380
2015-09-09	21:57:08	AccelerationY	-0.0987
2015-09-09	21:57:08	AccelerationZ	0.0860
2015-09-09	21:57:08	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390
2015-09-09	21:57:08	Course	286.5230
2015-09-09	21:57:08	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375
2015-09-09	21:57:09	Pitch	0.2450
2015-09-09	21:57:09	Roll	0.6756
2015-09-09	21:57:09	AccelerationX	-0.0029
2015-09-09	21:57:09	AccelerationY	0.0067
2015-09-09	21:57:09	AccelerationZ	-0.0120
2015-09-09	21:57:09	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810
2015-09-09	21:57:09	Course	241.1720
2015-09-09	21:57:09	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686
2015-09-09	21:57:10	Pitch	0.1570
2015-09-09	21:57:10	Roll	-0.3932
2015-09-09	21:57:10	AccelerationX	0.1057
2015-09-09	21:57:10	AccelerationY	-0.1179
2015-09-09	21:57:10	AccelerationZ	-0.0262
2015-09-09	21:57:10	Latitude	46.7388
2015-09-09	21:57:10	Longitude	-117.1720
2015-09-09	21:57:10	Altitude	729.6500
2015-09-09	21:57:10	Course	273.8670
2015-09-09	21:57:10	Speed	0.0000

- Define a context *window*
  - Data segmented into individual activities
- Sliding window
  - Based on amount of time
  - Overlapping or nonoverlapping

# Window Features

2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				

- Date (days since 01-01): 251
- Day of week: 3
- Time of day (hours, minutes, seconds past midnight): (21, 1260, 75612)

StDev (S) =

# Statistical Features

Yaw	-1.7854	Yaw	-1.0639
Pitch	0.1206	Pitch	0.4596
Roll	0.8295	Roll	-0.2751
AccelerationX	0.0380	AccelerationX	0.2281
AccelerationY	-0.0987	AccelerationY	-0.1197
AccelerationZ	0.0860	AccelerationZ	-0.3376
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6390	Altitude	729.3890
Course	286.5230	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.6375	Yaw	-1.1032
Pitch	0.2450	Pitch	0.4854
Roll	0.6756	Roll	-0.1308
AccelerationX	-0.0029	AccelerationX	-0.0025
AccelerationY	0.0067	AccelerationY	0.0114
AccelerationZ	-0.0120	AccelerationZ	-0.0011
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6810	Altitude	729.5630
Course	241.1720	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.2686		
Pitch	0.1570		
Roll	-0.3932		
AccelerationX	0.1057		
AccelerationY	-0.1179		
AccelerationZ	-0.0262		
Latitude	46.7388		
Longitude	-117.1720		
Altitude	729.6500		
Course	273.8670		
Speed	0.0000		

- Yaw values

- ❖ -1.7854, -1.6375, -1.2686, -1.0639, -1.1032

- Max: -1.0639

- Min: -1.7854

- Sum: -6.8586

- Mean: -1.3717

- Median: -1.2686

- Standard deviation: 0.3238

- ❖  $StDev(S) = \sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (s_i - \bar{s})^2}$

- Mean absolute deviation: 0.2718

- ❖  $MeanAbsDev(S) = \frac{1}{N} \sum_{i=1}^N |s_i - \bar{s}|$

- Median absolute deviation: -1.2686

- ❖  $MedAbsDev(S) = \frac{1}{N} \sum_{i=1}^N |s_i - Median(S)|$



StDev (S) =

# Statistical Features

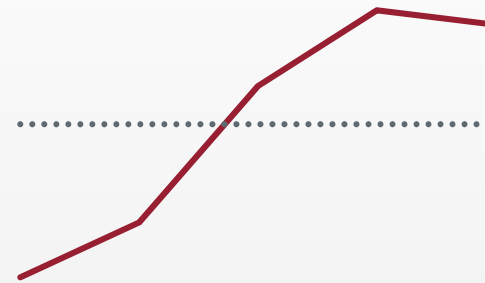
Yaw	-1.7854	Yaw	-1.0639
Pitch	0.1206	Pitch	0.4596
Roll	0.8295	Roll	-0.2751
AccelerationX	0.0380	AccelerationX	0.2281
AccelerationY	-0.0987	AccelerationY	-0.1197
AccelerationZ	0.0860	AccelerationZ	-0.3376
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6390	Altitude	729.3890
Course	286.5230	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.6375	Yaw	-1.1032
Pitch	0.2450	Pitch	0.4854
Roll	0.6756	Roll	-0.1308
AccelerationX	-0.0029	AccelerationX	-0.0025
AccelerationY	0.0067	AccelerationY	0.0114
AccelerationZ	-0.0120	AccelerationZ	-0.0011
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6810	Altitude	729.5630
Course	241.1720	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.2686		
Pitch	0.1570		
Roll	-0.3932		
AccelerationX	0.1057		
AccelerationY	-0.1179		
AccelerationZ	-0.0262		
Latitude	46.7388		
Longitude	-117.1720		
Altitude	729.6500		
Course	273.8670		
Speed	0.0000		

- Yaw values

- ❖ -1.7854, -1.6375, -1.2686, -1.0639, -1.1032

- Zero crossings: 1

- ❖ #times cross median



- Mean crossings: 1

- Interquartile range (IQR): 0.5343

- Sorted (nondecreasing)

- -1.7854, -1.6375, -1.2686, -1.1032, -1.0639

- Measures statistical dispersion

- IQR is difference between 75<sup>th</sup> and 25<sup>th</sup> percentiles

- Here, 25<sup>th</sup> is -1.6375, 75<sup>th</sup> is -1.1032

- IQR is (-1.1032) - (-1.6375)

StDev (S) =

# Statistical Features

Yaw	-1.7854	Yaw	-1.0639
Pitch	0.1206	Pitch	0.4596
Roll	0.8295	Roll	-0.2751
AccelerationX	0.0380	AccelerationX	0.2281
AccelerationY	-0.0987	AccelerationY	-0.1197
AccelerationZ	0.0860	AccelerationZ	-0.3376
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6390	Altitude	729.3890
Course	286.5230	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.6375	Yaw	-1.1032
Pitch	0.2450	Pitch	0.4854
Roll	0.6756	Roll	-0.1308
AccelerationX	-0.0029	AccelerationX	-0.0025
AccelerationY	0.0067	AccelerationY	0.0114
AccelerationZ	-0.0120	AccelerationZ	-0.0011
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6810	Altitude	729.5630
Course	241.1720	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.2686		
Pitch	0.1570		
Roll	-0.3932		
AccelerationX	0.1057		
AccelerationY	-0.1179		
AccelerationZ	-0.0262		
Latitude	46.7388		
Longitude	-117.1720		
Altitude	729.6500		
Course	273.8670		
Speed	0.0000		

- Yaw values

- ❖ -1.7854, -1.6375, -1.2686, -1.0639, -1.1032

- Skewness: -0.3292

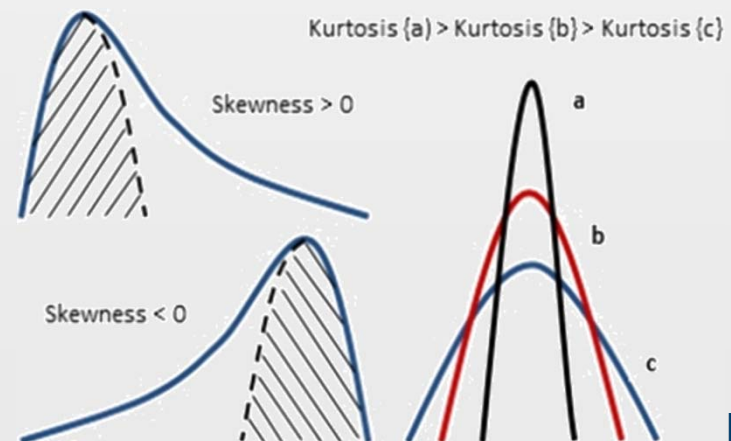
- ❖ Measure asymmetry in distribution of values

$$\text{Skewness}(S) = \frac{\frac{1}{N} \sum_{i=1}^N (s_i - \bar{s})^3}{\left(\frac{1}{N} \sum_{i=1}^N (s_i - \bar{s})^2\right)^{\frac{3}{2}}}$$

- Kurtosis: -2.1163

- ❖ Amount of peakedness or flatness in values

$$\text{Kurtosis}(S) = \frac{\frac{1}{N} \sum_{i=1}^N (s_i - \bar{s})^4}{\left(\frac{1}{N} \sum_{i=1}^N (s_i - \bar{s})^2\right)^2} - 3$$



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StDev (S) =

# Signal Processing Features

Yaw	-1.7854	Yaw	-1.0639
Pitch	0.1206	Pitch	0.4596
Roll	0.8295	Roll	-0.2751
AccelerationX	0.0380	AccelerationX	0.2281
AccelerationY	-0.0987	AccelerationY	-0.1197
AccelerationZ	0.0860	AccelerationZ	-0.3376
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6390	Altitude	729.3890
Course	286.5230	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.6375	Yaw	-1.1032
Pitch	0.2450	Pitch	0.4854
Roll	0.6756	Roll	-0.1308
AccelerationX	-0.0029	AccelerationX	-0.0025
AccelerationY	0.0067	AccelerationY	0.0114
AccelerationZ	-0.0120	AccelerationZ	-0.0011
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6810	Altitude	729.5630
Course	241.1720	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.2686		
Pitch	0.1570		
Roll	-0.3932		
AccelerationX	0.1057		
AccelerationY	-0.1179		
AccelerationZ	-0.0262		
Latitude	46.7388		
Longitude	-117.1720		
Altitude	729.6500		
Course	273.8670		
Speed	0.0000		

- Yaw values

- ❖ -1.7854, -1.6375, -1.2686, -1.0639, -1.1032

- Signal energy: 9.8273

- ❖ The area between the value curve and the time axis

- ❖  $E(S) = \sum_{i=1}^N s_i^2$

- Log energy: 1.2776

- ❖  $LogE(S) = \sum_{i=1}^N \log(s_i^2)$

- Signal power: 1.9655

- ❖  $Power(S) = \frac{1}{N} \sum_{i=1}^N s_i^2$

StDev (S) =

# Relational Features

Yaw	-1.7854	Yaw	-1.0639
Pitch	0.1206	Pitch	0.4596
Roll	0.8295	Roll	-0.2751
AccelerationX	0.0380	AccelerationX	0.2281
AccelerationY	-0.0987	AccelerationY	-0.1197
AccelerationZ	0.0860	AccelerationZ	-0.3376
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6390	Altitude	729.3890
Course	286.5230	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.6375	Yaw	-1.1032
Pitch	0.2450	Pitch	0.4854
Roll	0.6756	Roll	-0.1308
AccelerationX	-0.0029	AccelerationX	-0.0025
AccelerationY	0.0067	AccelerationY	0.0114
AccelerationZ	-0.0120	AccelerationZ	-0.0011
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6810	Altitude	729.5630
Course	241.1720	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.2686		
Pitch	0.1570		
Roll	-0.3932		
AccelerationX	0.1057		
AccelerationY	-0.1179		
AccelerationZ	-0.0262		
Latitude	46.7388		
Longitude	-117.1720		
Altitude	729.6500		
Course	273.8670		
Speed	0.0000		

- Correlation between axes

- ❖ 
$$\text{Corr}(S, V) = \frac{\sum_{i=1}^N (s_i - \bar{s})(v_i - \bar{v})}{\sqrt{\sum_{i=1}^N (s_i - \bar{s})^2 \sum_{i=1}^N (v_i - \bar{v})^2}}$$

- ❖  $\text{Corr}(A_x, A_y) = -0.7784$

- Autocorrelation

- ❖ Correlation between one variable at different points in time (current time and time - lag)

- ❖ 
$$\text{AC}_l(S) = \frac{\sum_{i=1}^{N-1} (s_i - \bar{s})(s_{i+1} - \bar{s})}{\sum_{i=1}^N (s_i - \bar{s})^2}$$

- ❖  $\text{AC}_1(\text{Yaw}) = -0.2150$

StDev (S) =

# Location Features

Yaw	-1.7854	Yaw	-1.0639
Pitch	0.1206	Pitch	0.4596
Roll	0.8295	Roll	-0.2751
AccelerationX	0.0380	AccelerationX	0.2281
AccelerationY	-0.0987	AccelerationY	-0.1197
AccelerationZ	0.0860	AccelerationZ	-0.3376
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6390	Altitude	729.3890
Course	286.5230	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.6375	Yaw	-1.1032
Pitch	0.2450	Pitch	0.4854
Roll	0.6756	Roll	-0.1308
AccelerationX	-0.0029	AccelerationX	-0.0025
AccelerationY	0.0067	AccelerationY	0.0114
AccelerationZ	-0.0120	AccelerationZ	-0.0011
Latitude	46.7388	Latitude	46.7388
Longitude	-117.1720	Longitude	-117.1720
Altitude	729.6810	Altitude	729.5630
Course	241.1720	Course	15.4688
Speed	0.0000	Speed	0.0000
Yaw	-1.2686		
Pitch	0.1570		
Roll	-0.3932		
AccelerationX	0.1057		
AccelerationY	-0.1179		
AccelerationZ	-0.0262		
Latitude	46.7388		
Longitude	-117.1720		
Altitude	729.6500		
Course	273.8670		
Speed	0.0000		

- Heading change rate
  - ❖ Percentage of points in window sequence that change direction (course)
- Stop rate
  - ❖ Percentage of points in window sequence that exhibit significant drop in velocity
- Trajectory
  - ❖ Overall trajectory from start to end of sequence
- All of these require threshold value
- Normalized distance from user center
  - ❖ Distance to user's mean location
  - ❖ Normalized based on user mean radius

# Feature Vector

2015-09-09	21:57:08	Yaw	-1.7854	2015-09-09	21:57:11	Yaw	-1.0639
2015-09-09	21:57:08	Pitch	0.1206	2015-09-09	21:57:11	Pitch	0.4596
2015-09-09	21:57:08	Roll	0.8295	2015-09-09	21:57:11	Roll	-0.2751
2015-09-09	21:57:08	AccelerationX	0.0380	2015-09-09	21:57:11	AccelerationX	0.2281
2015-09-09	21:57:08	AccelerationY	-0.0987	2015-09-09	21:57:11	AccelerationY	-0.1197
2015-09-09	21:57:08	AccelerationZ	0.0860	2015-09-09	21:57:11	AccelerationZ	-0.3376
2015-09-09	21:57:08	Latitude	46.7388	2015-09-09	21:57:11	Latitude	46.7388
2015-09-09	21:57:08	Longitude	-117.1720	2015-09-09	21:57:11	Longitude	-117.1720
2015-09-09	21:57:08	Altitude	729.6390	2015-09-09	21:57:11	Altitude	729.3890
2015-09-09	21:57:08	Course	286.5230	2015-09-09	21:57:11	Course	15.4688
2015-09-09	21:57:08	Speed	0.0000	2015-09-09	21:57:11	Speed	0.0000
2015-09-09	21:57:09	Yaw	-1.6375	2015-09-09	21:57:12	Yaw	-1.1032
2015-09-09	21:57:09	Pitch	0.2450	2015-09-09	21:57:12	Pitch	0.4854
2015-09-09	21:57:09	Roll	0.6756	2015-09-09	21:57:12	Roll	-0.1308
2015-09-09	21:57:09	AccelerationX	-0.0029	2015-09-09	21:57:12	AccelerationX	-0.0025
2015-09-09	21:57:09	AccelerationY	0.0067	2015-09-09	21:57:12	AccelerationY	0.0114
2015-09-09	21:57:09	AccelerationZ	-0.0120	2015-09-09	21:57:12	AccelerationZ	-0.0011
2015-09-09	21:57:09	Latitude	46.7388	2015-09-09	21:57:12	Latitude	46.7388
2015-09-09	21:57:09	Longitude	-117.1720	2015-09-09	21:57:12	Longitude	-117.1720
2015-09-09	21:57:09	Altitude	729.6810	2015-09-09	21:57:12	Altitude	729.5630
2015-09-09	21:57:09	Course	241.1720	2015-09-09	21:57:12	Course	15.4688
2015-09-09	21:57:09	Speed	0.0000	2015-09-09	21:57:12	Speed	0.0000
2015-09-09	21:57:10	Yaw	-1.2686				
2015-09-09	21:57:10	Pitch	0.1570				
2015-09-09	21:57:10	Roll	-0.3932				
2015-09-09	21:57:10	AccelerationX	0.1057				
2015-09-09	21:57:10	AccelerationY	-0.1179				
2015-09-09	21:57:10	AccelerationZ	-0.0262				
2015-09-09	21:57:10	Latitude	46.7388				
2015-09-09	21:57:10	Longitude	-117.1720				
2015-09-09	21:57:10	Altitude	729.6500				
2015-09-09	21:57:10	Course	273.8670				
2015-09-09	21:57:10	Speed	0.0000				

$v = \langle 251, 3, 21, 1260, 75612, -1.0539, -1.7854, -6.8586, -1.3717, -1.2686, 0.3238, 0.2718, -1.2686, 1, 1, -0.5343, -0.3292, -2.1163, 9.8273, 1.2776, 1.9655, -0.7784, -0.2150, \dots \rangle$

# Other ML for Gerontechnology

- Health assessment
  - Features: Activity frequency / duration / variance
  - Class: Clinical scores, diagnosis
- Intervention (activity prompting)
  - Features: Activity features, occur times
  - Class: #seconds until activity occurs again