LAAJ

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Goal of the project…

…was to take a normal set of the U.S electrical power grid data and be able to differentiate between anomalous and normal electrical power usage when given another set

Overview

- Data Exploration
- Approach 1: Point Anomaly Detection
- Approach 2: Training and Testing of Hidden Markov Models

Data Exploration

Data Exploration – Exploring Each Feature

- 3 different time frames:

1. Weekends (Sat and Sun) 7am-3pm,
2. Mon, Wed, Fri 4pm-8pm
3. Monday 12pm-8pm.

-All in 2007-2008

Data Exploration – Training & Testing Dataset

- 80 % Training Dataset ----- 20% Training Dataset -----Testing Dataset

```
Global_active_power
Min.   :0.0960
1st Qu.:0.4280
Median :0.6604
Mean   :1.0495
3rd Qu.:1.5040
Max.   :7.5660
```

```
Global_active_power
Min.   :0.098
1st Qu.:0.550
Median :1.331
Mean   :1.449
3rd Qu.:1.930
Max.   :8.166
```

```
Global_active_power
Min.   :0.0980
1st Qu.:0.4558
Median :0.7737
Mean   :1.2215
3rd Qu.:1.6880
Max.   :9.5900
```

```
Global_active_power
Min.   :0.0780
1st Qu.:0.4160
Median :0.6623
Mean   :0.9543
3rd Qu.:1.4248
Max.   :5.6880
```

```
Global_active_power
Min.   :0.0780
1st Qu.:0.4655
Median :1.2060
Mean   :1.3358
3rd Qu.:1.8860
Max.   :7.6600
```

```
Global_active_power
Min.   :0.0780
1st Qu.:0.4360
Median :0.7797
Mean   :1.1293
3rd Qu.:1.6682
Max.   :6.7340
```

```
Global_active_power
Min.   :-1.818
1st Qu.: 0.635
Median : 1.408
Mean   : 1.585
3rd Qu.: 2.156
Max.   : 8.363
```

```
Global_active_power
Min.   :-2.2776
1st Qu.: 0.7631
Median : 1.5920
Mean   : 1.7738
3rd Qu.: 2.4326
Max.   : 9.9552
```

```
Global_active_power
Min.   :-1.8262
1st Qu.: 0.6823
Median : 1.4140
Mean   : 1.6161
3rd Qu.: 2.2255
Max.   :10.4176
```

Data Exploration – Training & Testing Dataset

```
> sd(play1train$Global_active_power)
[1] 0.9001173
> sd(play1validate$Global_active_power)
[1] 0.7450435
> sd(play1$Global_active_power)
[1] 1.166393
```

```
> sd(play1train$Global_active_power)
[1] 1.085759
> sd(play1validate$Global_active_power)
[1] 1.06367
> sd(play1$Global_active_power)
[1] 1.237981
```

```
> sd(play1train$Global_active_power)
[1] 1.06648
> sd(play1validate$Global_active_power)
[1] 0.9438825
> sd(play1$Global_active_power)
[1] 1.165837
```

- Global active power: consistent min, mean & SD, inconsistent max, testing values generally higher

- Voltage: consistent min, mean, max, max of testing dataset quite a big larger, inconsistent SD

Data Exploration – Training & Testing Dataset

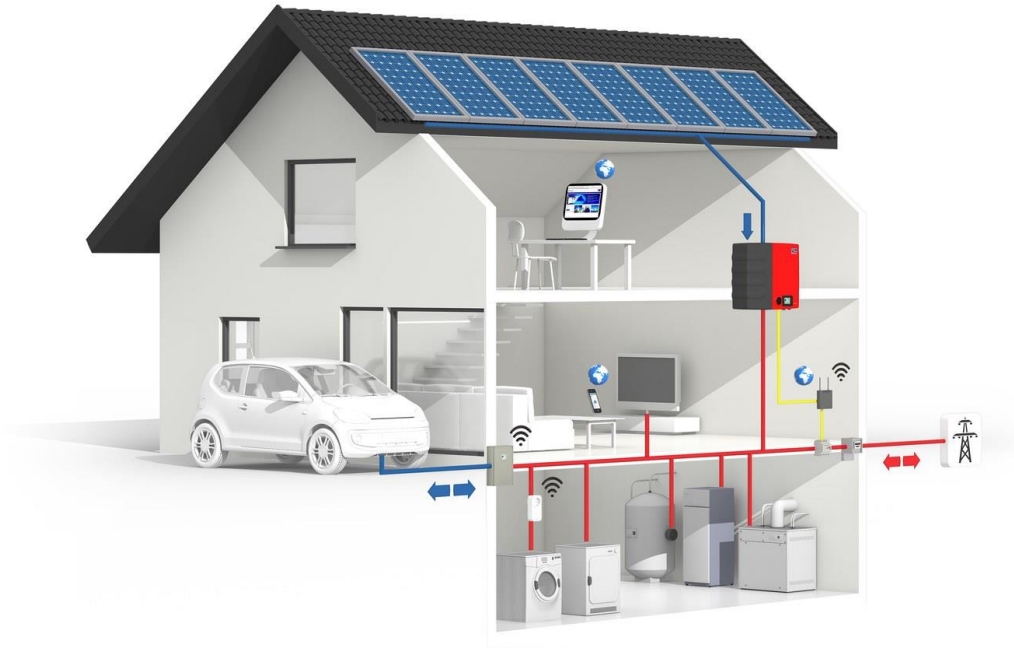
- Global reactive power: consistent min, mean, & SD, inconsistent max
- Global intensity: consistent min w/ 1st 80% generally bigger, inconsistent mean & SD, does not look like training & testing are following similar trend
- Sub Metering 1, 2, & 3: showed similar results
  - Consistent min
  - Inconsistent max, mean, & SD

Data Exploration – Correlation Coefficient

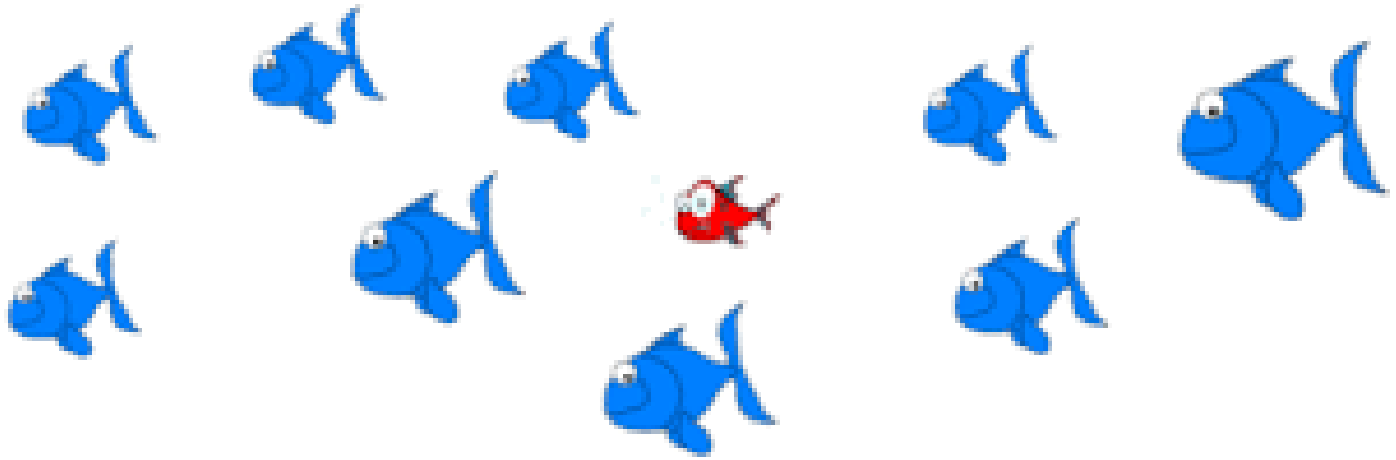
Wed 4-8pm Global active power vs:	Fri 9-12pm Global active power vs:
global_reactive_power =0.18201	global_reactive_power = -0.2746126
global_intensity = 0.9962178	global_intensity = 0.9967875
voltage= -0.2721188	voltage = -0.055234488
sub_metering_1 =0.107927	sub_metering_1 = 0.4424803
sub_metering_2= 0.7268048	sub_metering_2 = -0.2026798
sub_metering_3 =0.449147	sub_metering_3 = 0.9468868
sub_metering_(1,2,3) =0.708217	sub_metering_(1,2,3) =0.8191631

Why Univariate?

- Criteria:
  1. Range
  2. % change in values from 1 SD from mean
  3. Exclude those with strong positive correlation
- Time Frame: 2007-2008



Approach 1: Point Anomaly Detection



Approach 1: Point Anomaly Detection

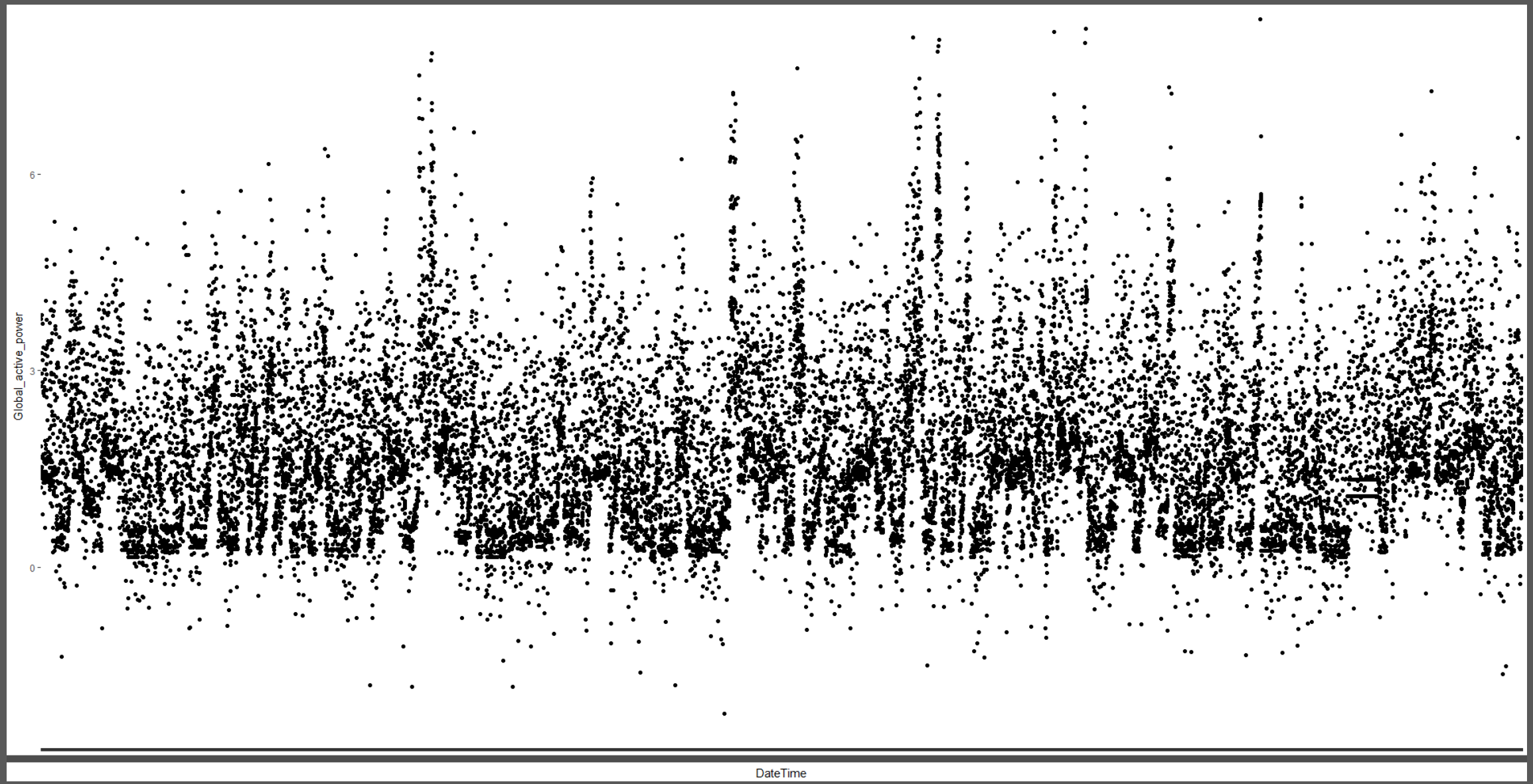
- **Point Anomaly**
  - A single instance of data is anomalous if it's too far off from the rest

- Mondays 12-8PM, 2007 & 2008
  - Global Active Power vs Date/Time

<u>Anomaly Detection Techniques</u>

- Out of Range
  - min/max of training
  - compare with test data

- Moving Average
  - Average specified time window of n observations

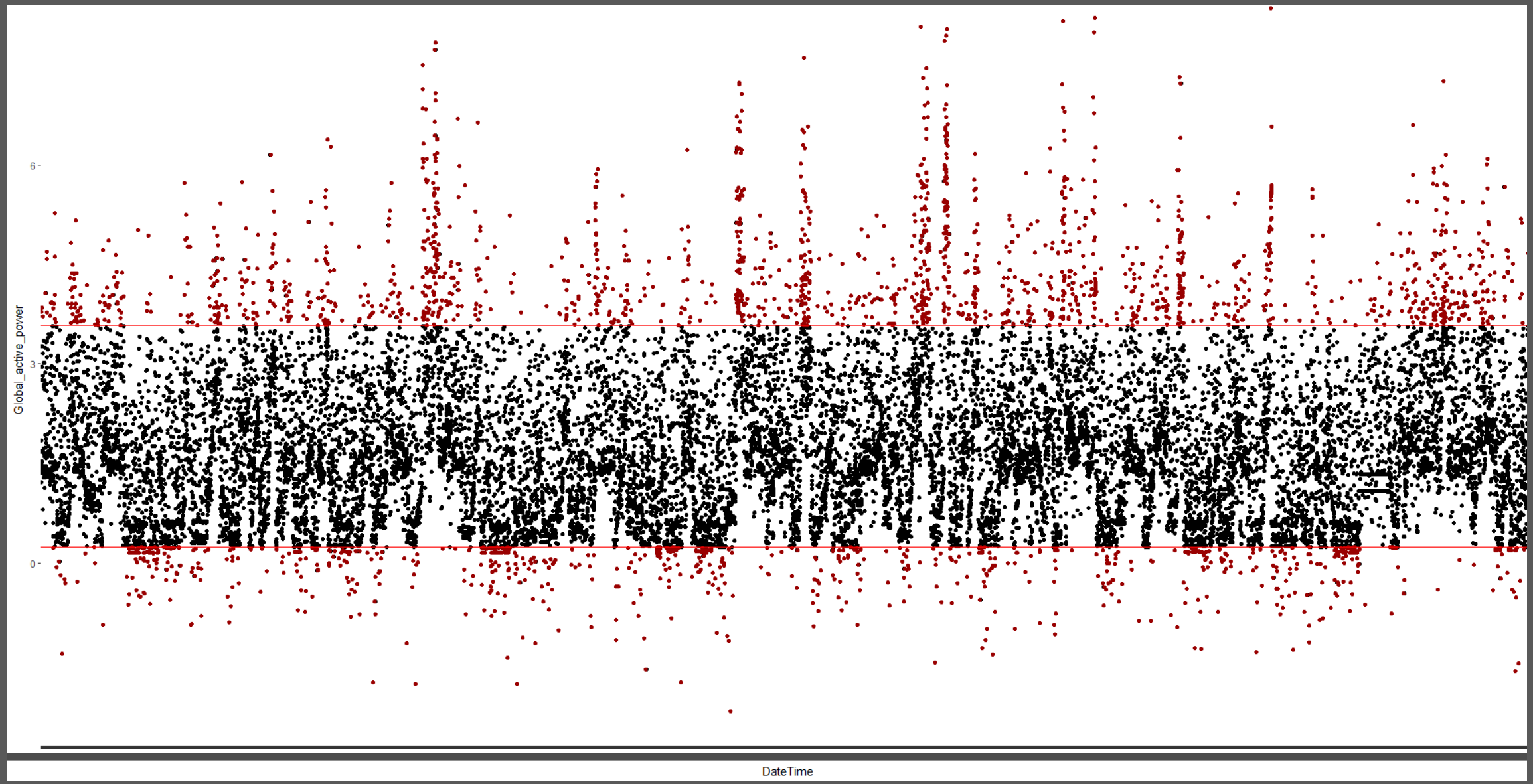

6
3
0
Global_active_power
DateTime

Out of Range

- I. Find minimum / maximum global active power for each Monday (training)
- II. Average out the total minimum / maximum across all Mondays

- Average Min: 0.2411429

- Average Max: 3.580115

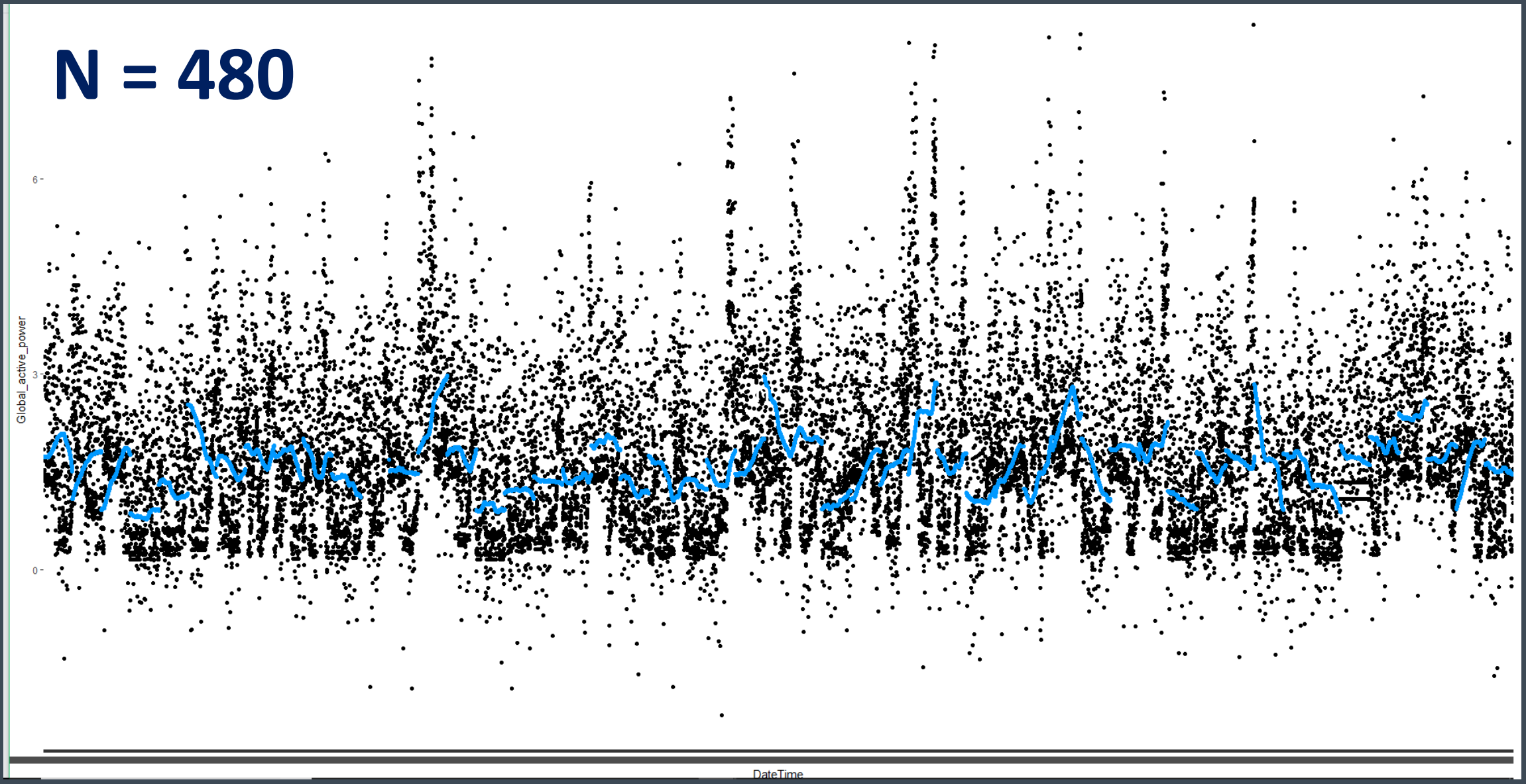

6
3
0
Global_active_power
DateTime

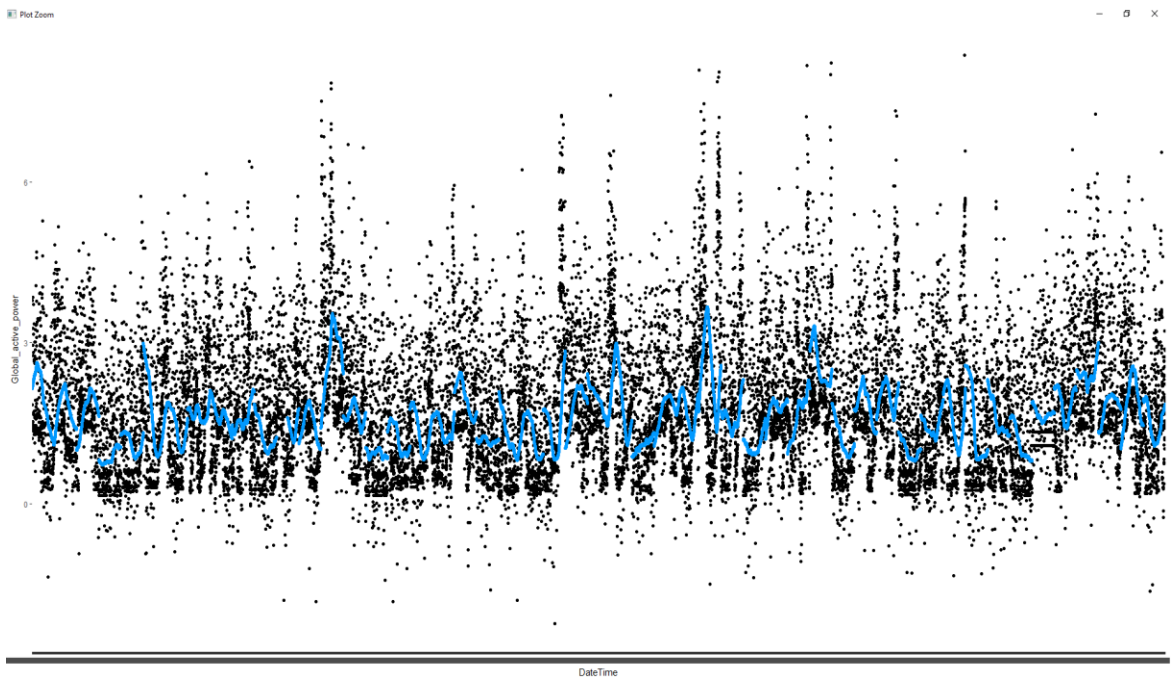
Moving Average

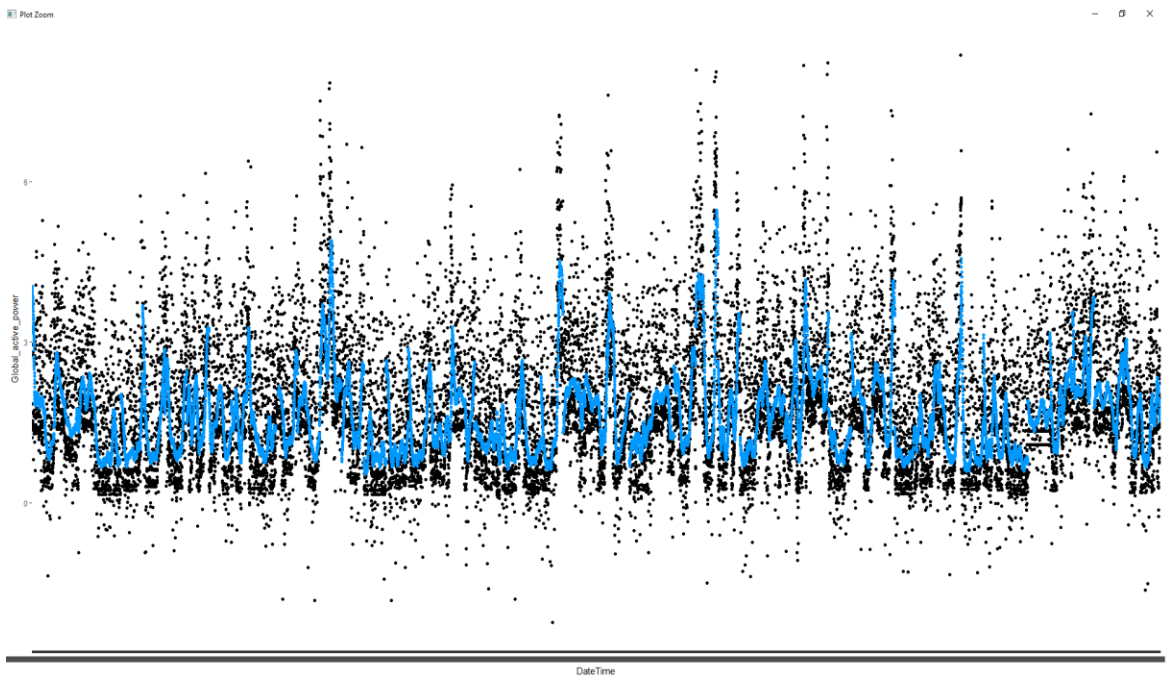
- Specify a time window of N observations
- Define a threshold from the moving average
- Points outside of this threshold is considered anomalous

'sma' function from R package 'TTR'

N = 480

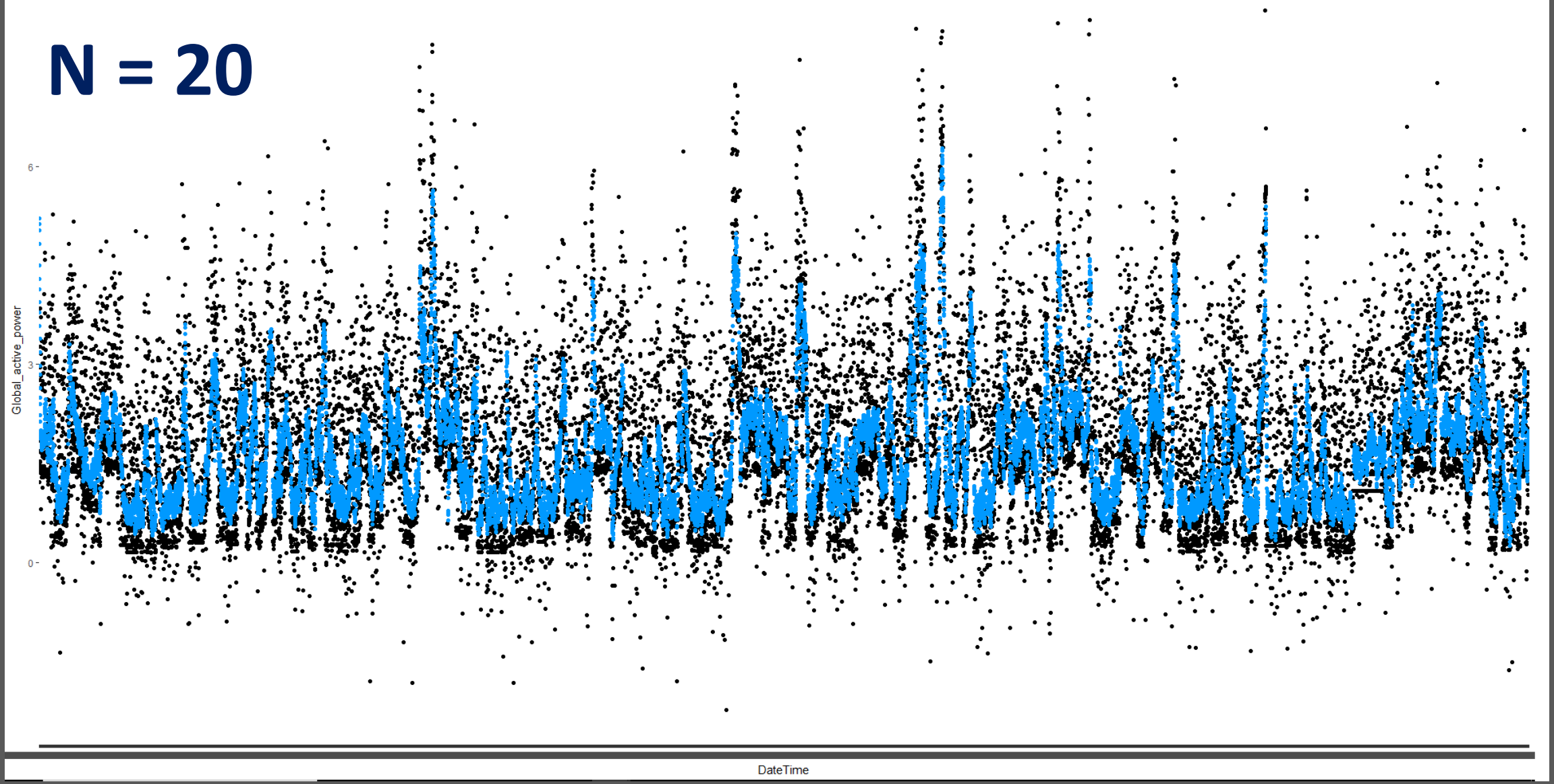


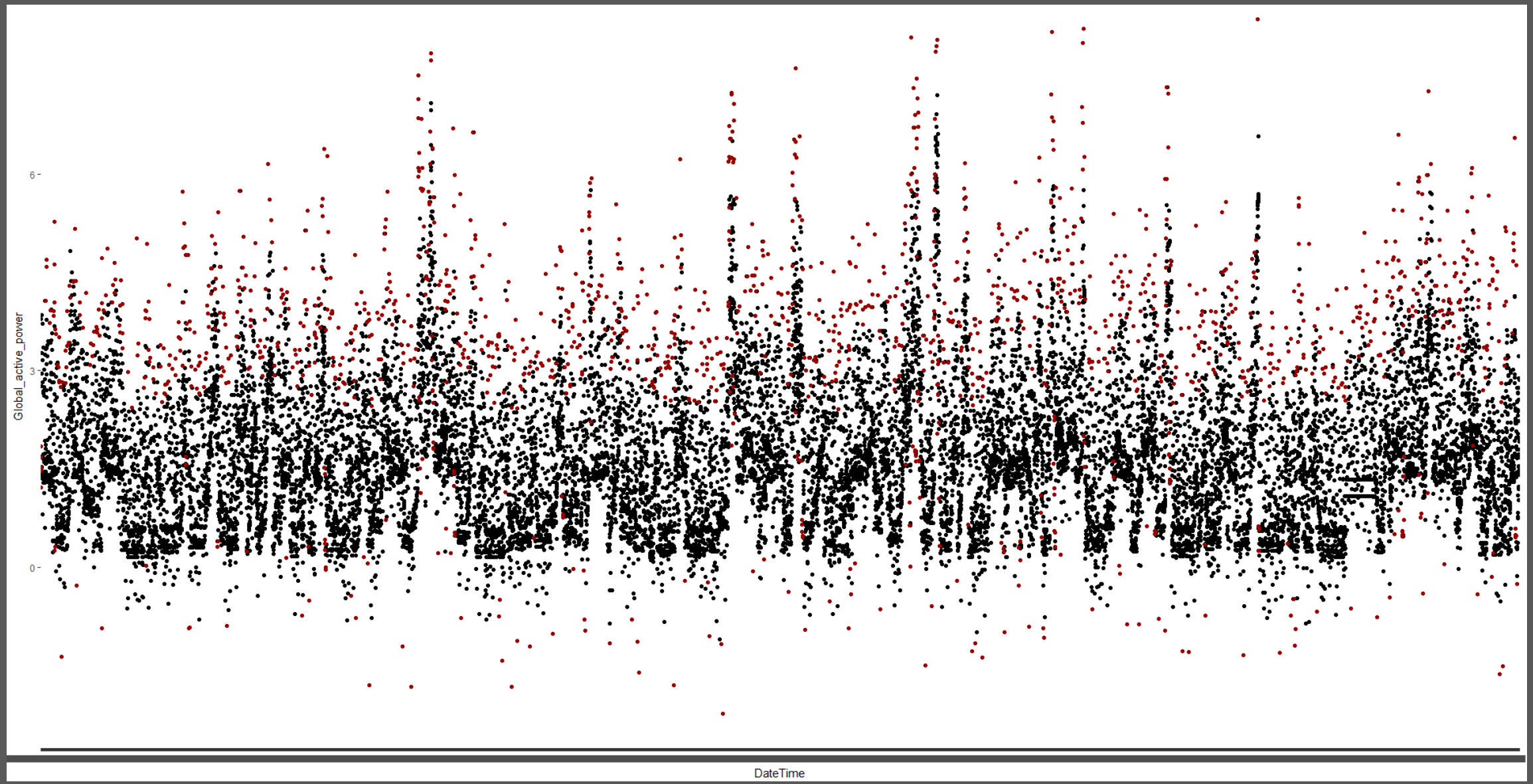

Plot Zoom
6
0
Global_active_power
DateTime


Plot Zoom
6
3
0
Global_active_power
DateTime

N = 240 & N = 60

N = 20




6
3
0
Global_active_power
DateTime

Approach 2: Hidden Markov Models

Hidden Markov Model

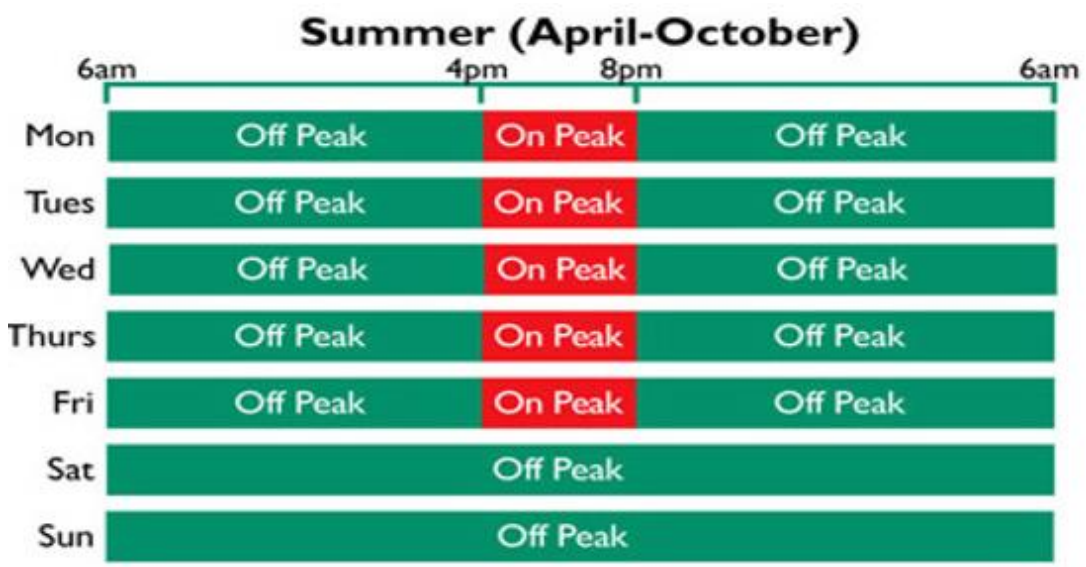
A hidden Markov model (HMM) is a Markov model in which the system being modeled is assumed to be a Markov process with unobserved (hidden) states. (Source: Rabiner, 1989)

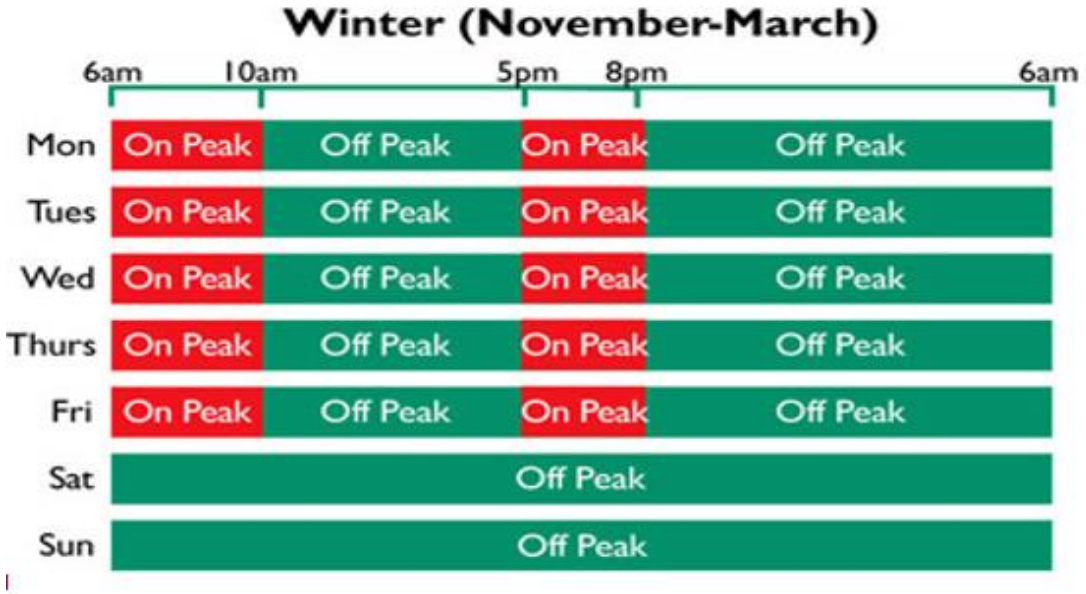
Training HMM

Values to look out for…

- Log-likelihood 
- BIC Value 
- Log-likelihood ratio 
  - training(80%) vs. validation(20%)
  - ranges between 0 and 1

Early models were based on intuition as well as statistics…





From Pacific Power

Weekday 4pm-8pm

Wed 16:00-19:59 08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
3	-3539.423	-84.27197619	7207.22	-1916.57	-174.2336364	3940.63	0.483672257
4	-2795.2	-66.55238095	5801	-1547.535	-140.685	3271.66	0.473059537
5	-2330.897	-55.49754762	4973.557	-1384.092	-125.8265455	3029.232	0.441063906
8	-1001.864	-23.85390476	2728.121	-980.0264	-89.09330909	2566.604	0.267740698
9	-428.547	-10.2035	1755.707	-885.6255	-80.51140909	2523.682	0.126733591

Weekday 4pm-8pm

Wed 16:00-19:59 08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
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5	-2330.897	-55.49754762	4973.557	-1384.092	-125.8265455	3029.232	0.441063906
8	-1001.864	-23.85390476	2728.121	-980.0264	-89.09330909	2566.604	0.267740698
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Wed 16:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
12	-685.9017	-8.263875904	3025.016	-505.4596	-22.97543636	2442.39	0.359683088
13	-117.517	-1.41586747	2155.533	-636.5176	-28.93261818	2935.941	0.048936721
14	positive						

Weekday 4pm-8pm

Wed 16:00-19:59 08'

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8	-1001.864	-23.85390476	2728.121	-980.0264	-89.09330909	2566.604	0.267740698
9	-428.547	-10.2035	1755.707	-885.6255	-80.51140909	2523.692	0.126733591

Wed 16:00-19:59 07-08'

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13	-117.517	-1.41586747	2155.533	-636.5176	-28.93261818	2935.941	0.048936721
14	positive						

…poor ratios

Mon, Wed, Fri 10am-2pm

MWF 10:00-13:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
7	-4623.019	-18.64120565	9370.039	-576.8778	-8.740572727	1753.314	0.468884518
8	-3954.22	-15.94443548	8776.971	-1723.065	-26.10704545	4210.082	0.610733049
9	-11.00976	-0.044394194	1099.438	106.6644	1.616127273	734.36	-0.027469491

Mon, Wed, Fri 10am-2pm

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7	-4623.019	-18.64120565	9370.039	-576.8778	-8.740572727	1753.314	0.468884518
8	-3954.22	-15.94443548	8776.971	-1723.065	-26.10704545	4210.082	0.610733049
9	-11.00976	-0.044394194	1099.438	106.6644	1.616127273	734.36	-0.027469491

…inconsistent numbers

All Days 10am-2pm

ALL DAYS 10:00-13:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
9	-13374.24	-23.13882353	27908.81	-3097.357	-20.2441634	7224.799	0.874900289
10	-12898.98	-22.31657439	27206.94	-3553.303	-23.22420261	8357.425	0.960918864
13	-4345.402	-7.51799654	9078.804	-3410.649	-22.29182353	8860.446	0.337253546
14	-1322.774	-2.288536332	3091.549	-104.3524	-0.68204183	2552.675	0.298025345
15	1650.873	2.856181661	-294.3312	671.2543	4.387283007	1327.305	0.651013772

All Days 10am-2pm

ALL DAYS 10:00-13:59 07-08'

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10	-12898.98	-22.31657439	27206.94	-3553.303	-23.22420261	8357.425	0.960918864
13	-4345.402	-7.51799654	9078.804	-3410.649	-22.29182353	8860.446	0.337253546
14	-1322.774	-2.288536332	3091.549	-104.3524	-0.68204183	2552.675	0.298025345
15	1650.873	2.856181661	-294.3312	671.2543	4.387283007	1327.305	0.651013772

…ratio still not that good

Finally…

We wanted to try a time that encompassed both “mid-peak” and “on-peak” hours

…12pm-8pm

Trial and error on all 7 days of the week…

Mon 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-19678	-237.0843373	39430.15	-4340.496	-197.2952727	8745.846	0.832173373
5	-2919.447	-35.17406024	6199.043	-339.0766	-15.41257273	993.1575	0.438180086
6	-319.0362	-3.843809639	1135.926	-114.9913	-5.226877273	665.4296	0.73539313
7	1589.869	19.15504819	-2522.995	456.81	20.76409091	-339.2006	0.922508396

Tues 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-32773.64	-394.8631325	65621.42	-6821.28	-310.0581818	13707.4	0.785229504
6	-12533.65	-151.0078313	25565.15	-2210	-100.4545455	4855	0.66522739
8	-7483.172	-90.1586988	15803.16	-1278.711	-58.12322727	3289.34	0.644676865
12	-3838.78	-46.25036145	9446.529	-24.2274	-1.101245455	1595.68	0.023810526
14	-4862.457	-58.58381928	12087.07	-39.45315	-1.793325	2144.96	0.030611268
15	positive						

Wed 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-26089	-314.3253012	52252.14	-8673.365	-394.2438636	17411.58	0.797286477
6	-8319.358	-100.2332289	17136.57	-3442.964	-156.4983636	7321.376	0.640474613
10	-1999.841	-24.09446988	5260.205	-2482.161	-112.8255	6066.837	0.213555179
11	-654.7305	-7.888319277	2813.614	-3074.441	-139.7473182	7464.487	0.056447017
12	positive						

Thu 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-16099.9	-193.9746988	32273.94	-3823.409	-182.0670952	7711.35	0.938612594
4	-3739.995	-45.06018072	7723.621	-677.1251	-32.24405238	1566.27	0.71557752
5	-1534.507	-18.48803614	3429.163	-207.9034	-9.900161905	729.229	0.535490186
6	1187.508	14.3073253	-1877.163	241.5677	11.50322381	-49.875	0.804009385

Fri 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
6	-3308.664	-40.34956098	7067.353	-1078.645	-49.02931818	2592.737	0.822968021
8	-3073.006	-37.47568293	6902.436	-1296.645	-58.93840909	3325.212	0.635844834
10	-1796.535	-21.90896341	4732.128	-322.8599	-14.67545	1748.234	0.669837715
11	-1766.154	-21.53846341	4891.956	-396.7697	-18.03498636	2109.145	0.83733858

Sat 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
5	-21963.71	-267.850122	44287.15	-4252.27	-193.285	8819.55	0.721616248
10	-15730.21	-191.8318293	32719.51	-2890.063	-131.3665	6882.64	0.68480033
12	-14075.2	-171.6487805	29917.35	-2576.033	-117.0924091	6699.29	0.682162779
15	-11386.68	-138.8619512	25460.82	-2484.556	-112.9343636	7322.38	0.813285156
20	-9025.868	-110.071561	22696.58	-1448.214	-65.82790909	6963.69	0.598046475

Sun 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-46291.68	-557.7310843	92657.42	-11968.69	-544.0313636	24002.23	0.975436691
6	-24049.38	-289.7515663	48596.05	-4353.747	-197.8975909	9142.941	0.682990582
23	-12355.6	-148.8626506	30784.4	-1600.867	-72.76668182	8519.745	0.488817588

Trial and error on all 7 days of the week…

Mon 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-19678	-237.0843373	39430.15	-4340.496	-197.2952727	8745.846	0.832173373
5	-2919.447	-35.17406024	6199.043	-339.0766	-15.41257273	993.1575	0.438180086
6	-319.0362	-3.843809639	1135.926	-114.9913	-5.226877273	665.4296	0.73539313
7	1589.869	19.15504819	-2522.995	456.81	20.76409091	-339.2006	0.922508396

Tues 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-32773.64	-394.8631325	65621.42	-6821.28	-310.0581818	13707.4	0.785229504
6	-12533.65	-151.0078313	25565.15	-2210	-100.4545455	4855	0.66522739
8	-7483.172	-90.1586988	15803.16	-1278.711	-58.12322727	3289.34	0.644676865
12	-3838.78	-46.25036145	9446.529	-24.2274	-1.101245455	1595.68	0.023810526
14	-4862.457	-58.58381928	12087.07	-39.45315	-1.793325	2144.96	0.030611268
15	positive						

Wed 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-26089	-314.3253012	52252.14	-8673.365	-394.2438636	17411.58	0.797286477
6	-8319.358	-100.2332289	17136.57	-3442.964	-156.4983636	7321.376	0.640474613
10	-1999.841	-24.09446988	5260.205	-2482.161	-112.8255	6066.837	0.213555179
11	-654.7305	-7.888319277	2813.614	-3074.441	-139.7473182	7464.487	0.056447017
12	positive						

Thu 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-16099.9	-193.9746988	32273.94	-3823.409	-182.0670952	7711.35	0.938612594
4	-3739.995	-45.06018072	7723.621	-677.1251	-32.24405238	1566.27	0.71557752
5	-1534.507	-18.48803614	3429.163	-207.9034	-9.900161905	729.229	0.535490186
6	1187.508	14.3073253	-1877.163	241.5677	11.50322381	-49.875	0.804009385

Fri 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
6	-3308.664	-40.34956098	7067.353	-1078.645	-49.02931818	2592.737	0.822968021
8	-3073.006	-37.47568293	6902.436	-1296.645	-58.93840909	3325.212	0.635844834
10	-1796.535	-21.90896341	4732.128	-322.8599	-14.67545	1748.234	0.669837715
11	-1766.154	-21.53846341	4891.956	-396.7697	-18.03498636	2109.145	0.83733858

Sat 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
5	-21963.71	-267.850122	44287.15	-4252.27	-193.285	8819.55	0.721616248
10	-15730.21	-191.8318293	32719.51	-2890.063	-131.3665	6882.64	0.68480033
12	-14075.2	-171.6487805	29917.35	-2576.033	-117.0924091	6699.29	0.682162779
15	-11386.68	-138.8619512	25460.82	-2484.556	-112.9343636	7322.38	0.813285156
20	-9025.868	-110.071561	22696.58	-1448.214	-65.82790909	6963.69	0.598046475

Sun 12:00-19:59 07-08'

States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-46291.68	-557.7310843	92657.42	-11968.69	-544.0313636	24002.23	0.975436691
6	-24049.38	-289.7515663	48596.05	-4353.747	-197.8975909	9142.941	0.682990582
23	-12355.6	-148.8626506	30784.4	-1600.867	-72.76668182	8519.745	0.488817588

…Monday 12pm-8pm was the best!

Mon 12:00-19:59 07-08'							
States	Train LogLike	Norm. Train LogLike	BIC Train	Val LogLike	Norm. Val LogLike	BIC Val	Norm. LogLikelihood Ratio
2	-19678	-237.0843373	39430.15	-4340.496	-197.2952727	8745.85	0.832173373
5	-2919.447	-35.17406024	6199.043	-339.0766	-15.41257273	993.158	0.438180086
6	-319.0362	-3.843809639	1135.926	-114.9913	-5.226877273	665.43	0.73539313
7	1589.869	19.15504819	-2522.995	456.81	20.76409091	-339.201	0.922508396

Good balance of all 3 values

Testing

Ran the test data on the model…

Monday 12:00-19:59 2007-2008 Model					
Month	Train LogLike	Norm. Train LogLike	Test LogLike	Norm. Test LogLike	Norm. LogLike Ratio
Dec 09'	-319.0362	-3.843809639	-2976.96	-744.24	0.005164745
Jan 09'	-319.0362	-3.843809639	-2844.231	-711.05775	0.005405763
Feb 10'	-319.0362	-3.843809639	-2822.686	-705.6715	0.005447024
Mar 10'	-319.0362	-3.843809639	-3530.595	-706.119	0.005443572
Apr 10'	-319.0362	-3.843809639	-2847.655	-711.91375	0.005399263
May 10'	-319.0362	-3.843809639	-3607.563	-721.5126	0.005327432
Jun 10'	-319.0362	-3.843809639	-3215.242	-803.8105	0.004781985
Jul 10'	-319.0362	-3.843809639	-3141.011	-785.25275	0.004894997
Aug 10'	-319.0362	-3.843809639	-3854.993	-770.9986	0.004985495
Sep 10'	-319.0362	-3.843809639	-2900.847	-725.21175	0.005300258
Oct 10'	-319.0362	-3.843809639	-3391.731	-847.93275	0.004533154
Nov 10'	-319.0362	-3.843809639	-2943.52	-735.88	0.005223419
ALL	-319.0362	-3.843809639	-38077.04	-746.6086275	0.00514836

Ran the test data on the model…

Monday 12:00-19:59 2007-2008 Model					
Month	Train LogLike	Norm. Train LogLike	Test LogLike	Norm. Test LogLike	Norm. LogLike Ratio
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ALL	-319.0362	-3.843809639	-38077.04	-746.6086275	0.0051483

…ratios significantly lower which was expected

Conclusion

Conclusion

- Applications

- Anomaly Detection is a challenge
  - Time and Effort
  - Trial and Error
  - Attention to Detail
  - Multiple approaches/solutions to a problem

- The Importance of the Industry

Thank you for listening!

Any Questions?

- *Leon (Trung) Trieu*
- *Antonio Leung*
- *Amanda (Fang Chi) Chang*
- *Johny Kuang*

CMPT 318

Cybersecurity