Chonnam National University
Advanced Network Lab

Modeling and Discovering Human Behavior from Smartphone Sensing Life-Log Data

Rischan Mafrur

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Outline

- **Introduction**
  - Background and Problem Statements
- **Methods**
  - Data Preprocessing and Features Extraction
  - Our approach
- **Goal**
  - Modeling and discovering user behavior based on their smartphone life-log
  - Modeling human behavior for user identification

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Human Behavior

- Alice is research's student in one of university in Korea.
- Almost every day, he wakes up, takes a shower, breakfast, and goes to his campus at 8:40 AM.
- He is living in dormitory, he walks from dormitory to his lab (campus) takes 10 minutes.
- Usually, he arrives in his lab at 9 AM and then sits on his chair and starts working.

This example is one of the human daily routine in working day. Based on this story, we can used Alice's smartphone sensor data to define and build Alice's behavior model.

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Thesis Background and Problem Statements

- Common approach which is using one feature is good to know that feature is reliable or not. The problem when we use only one feature is the lack of sensor accuracy, data loss, and we have to think about realistic data.
- User has different types and brand of smartphone and each smartphone has different types of sensors and hardware specification and capabilities.
- We could not expect the human actions and their activities, they will do actions and activities as they want.
- There is no ideal data collection that can record user personal data for every day 24 hour non-stop, it will drain the battery and spend smartphone resource.
- There is no ideal data collection that can record all of data without any data loss.
- We decide to use many of sensors rather than focus only one sensor, we have to realize that the data from smartphone are heterogeneous data because the data came from multiple sensors and multiple source information.
- Our proposed method tried to deal with those situations.

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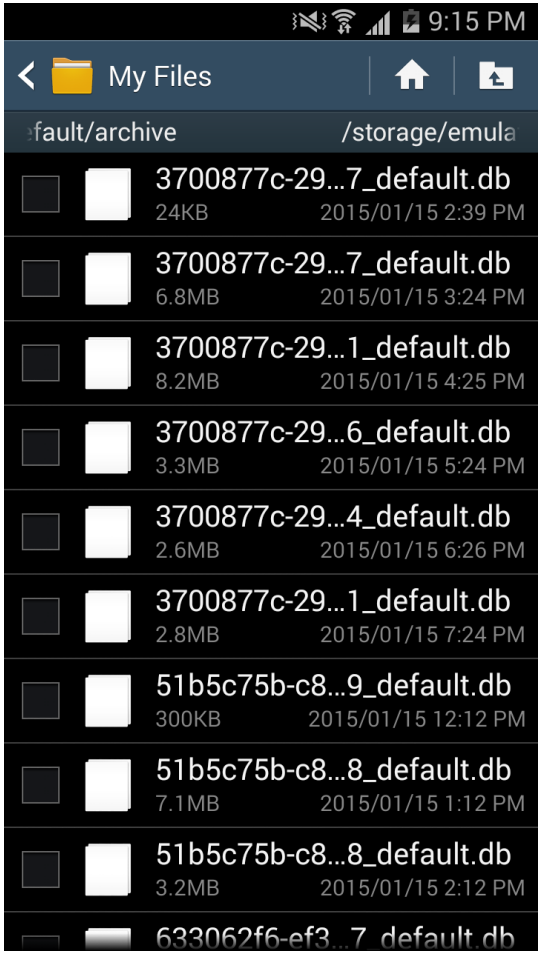
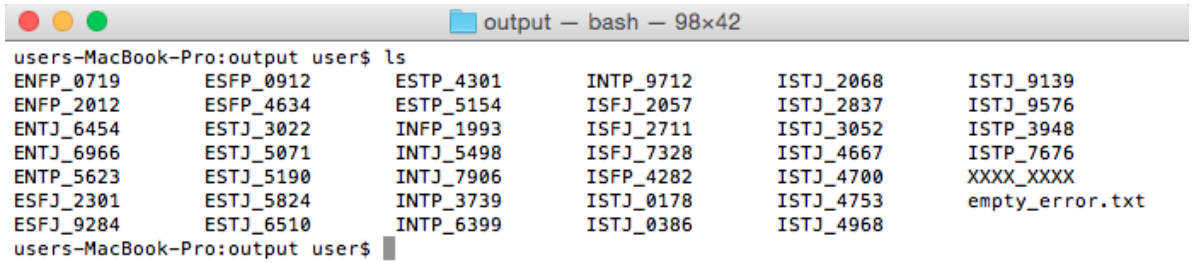
Raw Data looks like





_id	name	timestamp	value
Filter	Filter	Filter	Filter
1	HardwareInfoProbe	1404116791.153	{"androidId":"df03d9eae60fecb3","bluetoothMac":"88:9...
2	SmsProbe	1403883215.0	{"address":"15444302","body":"{\"ONE_WAY_HASH\":\"...
3	SmsProbe	1403883087.0	{"address":"15444302","body":"{\"ONE_WAY_HASH\":\"...
4	CallLogProbe	1404112293.842	{"_id":4108,"date":1404112293842,"duration":29,"name":...
5	SmsProbe	1403772474.744	{"address":"01066296348","body":"{\"ONE_WAY_HASH\...
6	SmsProbe	1403697660.0	{"address":"0220338500","body":"{\"ONE_WAY_HASH\"...
7	CallLogProbe	1404111655.487	{"_id":4107,"date":1404111655487,"duration":75,"name":...
8	SmsProbe	1403697242.0	{"address":"0625101111","body":"{\"ONE_WAY_HASH\"...
9	CallLogProbe	1404111605.734	{"_id":4106,"date":1404111605734,"duration":0,"name":"...
10	SmsProbe	1403609220.0	{"address":"0622395000","body":"{\"ONE_WAY_HASH\"...
11	SmsProbe	1403540566.46	{"address":"01029738808","body":"{\"ONE_WAY_HASH\...
12	CallLogProbe	1404111295.005	{"_id":4105,"date":1404111295005,"duration":0,"name":"...
13	SmsProbe	1403540204.981	{"address":"01086198051","body":"{\"ONE_WAY_HASH\...

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In terms of human behavior

- What is the human behavior in case of smartphone sensing?.
  - Human daily activities which carried out continuously
- In terms of human daily activities, we have to consider about four things:
  - What kind of activity (e.g meeting, study, exercise)
  - When (e.g around 9 AM)
  - Location (e.g Lab)
  - Human Interaction (e.g all lab's members)
- Possibilities : same activity in different time and location, different activity in same time and location, etc.

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Features

Proposed Features *(every single data has timestamp)*

- What kind of Human Activity
  - Activity [none, low, high]
- Human Location
  - GPS [longitude, latitude]
  - Bluetooth [list of nearby Bluetooth]
  - Wi-Fi [lists of nearby AP]
- Human Interaction (Human->Human)
  - Call [incoming, outgoing, missed]
  - SMS [sent, received]
  - Run apps [social network apps]
- Human Interaction (Human -> Smartphone)
  - Battery [time charging]
  - Run apps [name of apps]
  - Screen [screen ON, screen OFF]

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Dataset Description

1. We store the data from all of students in archive file.
2. The size of all of data after extracted is around 28.7 GB. Extracted data contain 47 directories in different name for each student's data.
3. We used 37 students data.

Table 2-2. List of probes and types

No.	Name of Probes	Explanation	Used
On Request Data			
1.	SimpleLocationProbe	GPS data (user location)	X
2.	WifiProbe	Nearby Wi-Fi signals	X
3.	BluetoothProbe	Nearby Bluetooth signals	X
4.	BatteryProbe	Battery status	X
Historical Data			
1.	CallLogProbe	User call log	X
2.	SmsProbe	User SMS log	X
3.	ApplicationsProbe	List of application installed	
4.	HardwareInfoProbe	User's smartphone hardware info	
5.	BrowserBookmarksProbe	User Bookmarks	
6.	BrowserSearchesProbe	User Browser log	
7.	ContactProbe	User contact (phonebook)	
Continuous Data			
1.	LightSensorProbe	Measures the ambient light level (illumination) in lx	
2.	ProximitySensorProbe	Measures the proximity of an object in cm relative to the view screen of a device.	
3.	TemperatureSensorProbe	Measures the temperature of the device in degrees Celsius (°C).	
4.	MagneticFieldSensorProbe	Measures the ambient geomagnetic field (x, y, z) in µT	
5.	PressureSensorProbe	Measures the ambient air pressure in hPa or mbar.	
6.	ScreenProbe	Screen phone (on and off)	X
7.	RunningApplicationsProbe	List of running applications	X
8.	ActivityProbe	User activity log based on accelerometer sensor (none, low, and high activity)	X

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Technical Explanation

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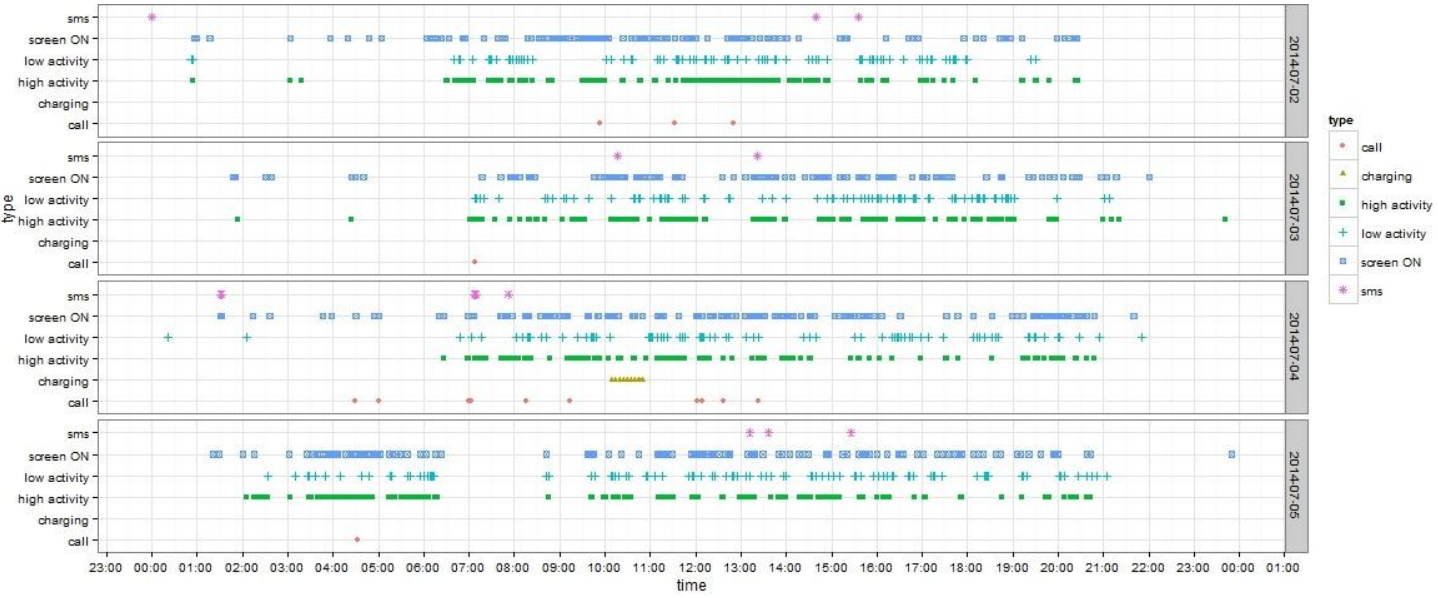
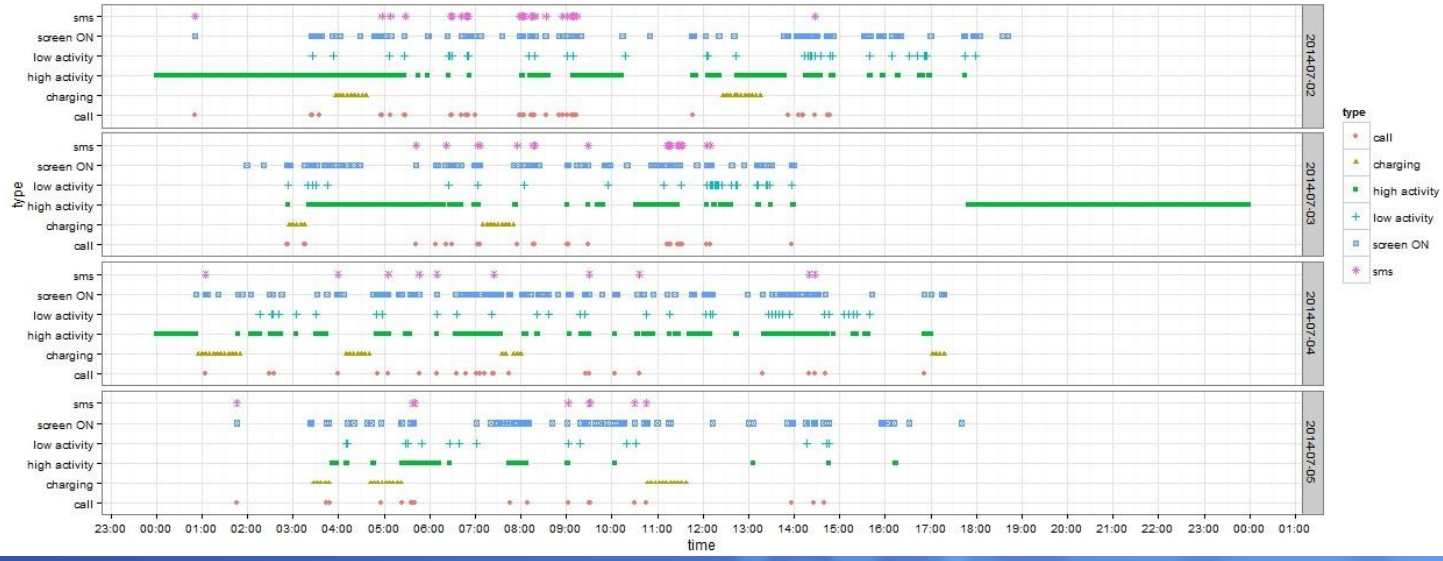
Example data plot from two of students





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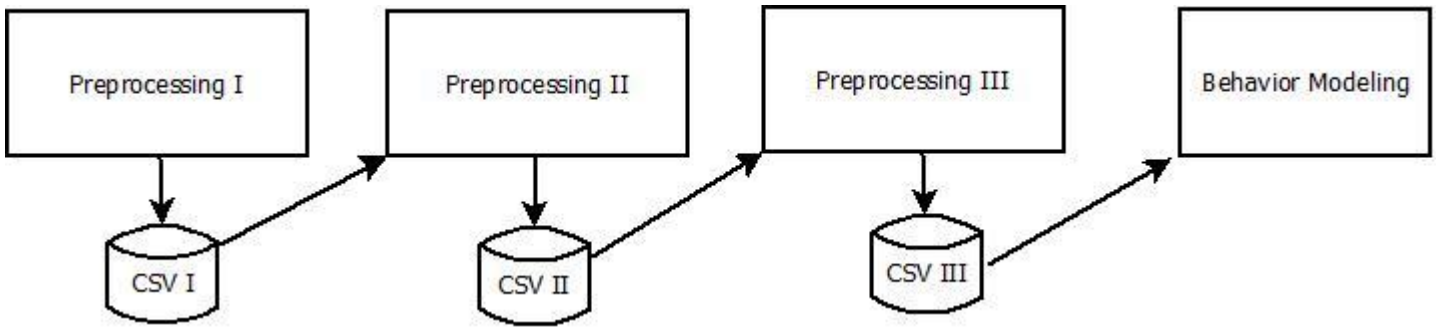
Pre-Processing Summarization



- Preprocessing I
  - Data cleansing
  - Removing duplication and noisy data
  - Select the most important data
- Preprocessing II
  - Features Extraction applied in here
- Preprocessing III
  - Features Aggregation
  - Adding new values based on features
  - Fitting the dataset before modeling behavior applied

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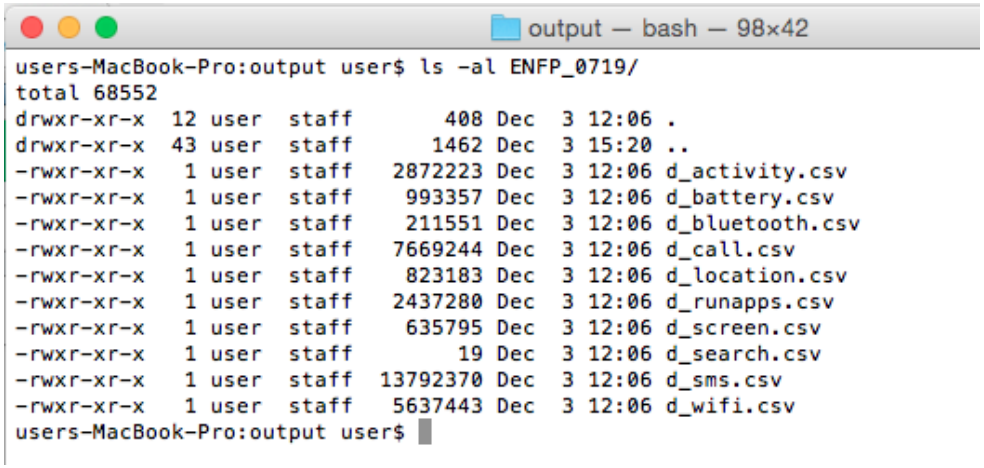
Preprocessing I



1. Funf lib has problem in historical data such as SMS and call log.
2. We use 86400 second interval, means the application copy those data from android database system to our application database once every day.
3. It makes duplication in our database.
4. The function of this module are:
    1. Removing duplication
    2. Data cleansing
    3. Features separation

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Preprocessing I output data looks like

ENFP_0719 — more — 98×42

```
"","when","latitude","longitude"
"1","2014-06-30 08:26:36","35.1754255","126.9130674"
"2","2014-06-30 08:31:30","35.1754281","126.9130184"
"3","2014-06-30 08:36:30","35.1754225","126.9130536"
"4","2014-06-30 08:41:30","35.1753982","126.9130597"
"5","2014-06-30 08:46:30","35.1753991","126.9130549"
"6","2014-06-30 08:51:30","35.1753997","126.9130598"
"7","2014-06-30 08:56:31","35.1754333","126.9130484"
"8","2014-06-30 09:01:30","35.1754143","126.9130638"
"9","2014-06-30 09:06:30","35.1754126","126.9130687"
"10","2014-06-30 09:11:30","35.1754142","126.9130553"
"11","2014-06-30 09:16:30","35.1753987","126.913074"
"12","2014-06-30 09:21:30","35.1754178","126.9130686"
"13","2014-06-30 09:26:30","35.1754176","126.9130779"
"14","2014-06-30 09:31:30","35.1753914","126.9130496"
"15","2014-06-30 09:36:30","35.1754066","126.9130196"
"16","2014-06-30 09:41:30","35.1753833","126.9130507"
"17","2014-06-30 09:46:30","35.1753883","126.9130474"
"18","2014-06-30 09:51:52","35.174465","126.9135807"
"19","2014-06-30 09:56:30","35.174465","126.9135807"
"20","2014-06-30 10:01:30","35.1735813","126.9119189"
"21","2014-06-30 10:06:53","35.1744781","126.9137426"
"22","2014-06-30 10:11:30","35.1735813","126.9119189"
"23","2014-06-30 10:16:52","35.174502","126.9137499"
"24","2014-06-30 10:21:30","35.1749091","126.9124954"
"25","2014-06-30 10:26:30","35.1749091","126.9124954"
"26","2014-06-30 10:31:30","35.1749091","126.9124954"
```

ENFP_0719 — more — 98×42

```
"","timestamp","duration","package"
"1","2014-06-30 08:26:31","12.401","edu.mit.media.funf.wifiscanner"
"2","2014-06-30 08:26:43","2.055","com.nhn.android.search"
"3","2014-06-30 08:26:45","9.183","com.buzzpia.aqua.launcher"
"4","2014-06-30 08:26:54","15.32","edu.mit.media.funf.wifiscanner"
"5","2014-06-30 08:27:10","38.126","com.rechild.advancedtaskkiller"
"6","2014-06-30 08:27:48","3.015","edu.mit.media.funf.wifiscanner"
"7","2014-06-30 08:27:51","6.015","com.buzzpia.aqua.launcher"
"8","2014-06-30 08:27:57","2.005","edu.mit.media.funf.wifiscanner"
"9","2014-06-30 08:27:59","2.006","com.buzzpia.aqua.launcher"
"10","2014-06-30 08:28:01","2.044","com.kakao.talk"
"11","2014-06-30 08:28:03","6.042","com.buzzpia.aqua.launcher"
"12","2014-06-30 08:28:09","63.362","com.nhn.android.search"
"13","2014-06-30 08:29:12","0.841","com.buzzpia.aqua.launcher"
"14","2014-06-30 08:30:02","55.247","com.buzzpia.aqua.launcher"
"15","2014-06-30 08:33:35","9.898","com.buzzpia.aqua.launcher"
"16","2014-06-30 08:33:46","4.015","com.buzzpia.aqua.launcher"
"17","2014-06-30 08:33:50","68.308","com.kakao.talk"
"18","2014-06-30 08:34:58","9.017","com.kakao.talk"
"19","2014-06-30 08:35:07","3.006","com.buzzpia.aqua.launcher"
"20","2014-06-30 08:35:10","205.598","com.facebook.katana"
"21","2014-06-30 08:38:36","1.245","com.buzzpia.aqua.launcher"
"22","2014-06-30 08:40:27","5.011","com.buzzpia.aqua.launcher"
"23","2014-06-30 08:40:32","61.606","com.joeware.android.gpulumera"
"24","2014-06-30 08:41:34","13.806","com.buzzpia.aqua.launcher"
```


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Pre-processing II (Features Extraction)

Table 2-4. List of features and the values

No	Name of Probes	Value1	Value2	Value3
1.	ActivityProbe	Status (“*none*”,”*low*”, and ”*high*”)		
2.	SimpleLocationProbe	Latitude	Longitude	
3.	WifiProbe	List of nearby SSID	MAC	Signal strength (dB)
4.	BluetoothProbe	List of nearby Bluetooth devices		
5.	BatteryProbe	Status (“*discharging*”,”*full*”, and ”*charging*”)		
6.	ScreenProbe	ON/OFF		
7.	RunningApplicationsProbe	Apps name	Duration	
8.	CallLogProbe	Number	Types	Duration
9.	SmsProbe	Number	Types	Text length

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Preprocessing II output data looks like

output2 — more — 98×42

```
"","time","type","value1","value2","value3"
"5135","2014-07-01 00:01:55","activity","none","",""
"5136","2014-07-01 00:01:56","activity","none","",""
"96154","2014-07-01 00:02:54","battery","full","",""
"166061","2014-07-01 00:02:54","location","37.53724098","126.96960174",""
"487488","2014-07-01 00:02:58","wifi","2-607","44:ed:57:01:f9:ac","-55"
"5137","2014-07-01 00:03:56","activity","none","",""
"5138","2014-07-01 00:03:57","activity","none","",""
"5139","2014-07-01 00:05:56","activity","none","",""
"96155","2014-07-01 00:07:55","battery","full","",""
"166062","2014-07-01 00:07:55","location","37.53724098","126.96960174",""
"5140","2014-07-01 00:07:56","activity","none","",""
"5141","2014-07-01 00:07:57","activity","none","",""
"487489","2014-07-01 00:07:58","wifi","2-607","44:ed:57:01:f9:ac","-54"
"487490","2014-07-01 00:07:58","wifi","2-507","44:ed:57:01:55:ca","-86"
"5142","2014-07-01 00:09:55","activity","none","",""
"5143","2014-07-01 00:09:56","activity","none","",""
"5144","2014-07-01 00:11:55","activity","none","",""
"5145","2014-07-01 00:11:56","activity","none","",""
"96156","2014-07-01 00:12:55","battery","full","",""
"166063","2014-07-01 00:12:55","location","37.53724098","126.96960174",""
"487491","2014-07-01 00:12:58","wifi","2-607","44:ed:57:01:f9:ac","-61"
"487492","2014-07-01 00:12:58","wifi","2-507","44:ed:57:01:55:ca","-87"
"487493","2014-07-01 00:12:58","wifi","sparrow","64:e5:99:c8:06:d2","-92"
"5146","2014-07-01 00:13:57","activity","none","",""
"5147","2014-07-01 00:13:58","activity","none","",""
"5148","2014-07-01 00:15:56","activity","none","",""
"5149","2014-07-01 00:15:57","activity","none","",""
"96157","2014-07-01 00:17:55","battery","full","",""
"166064","2014-07-01 00:17:55","location","37.53724098","126.96960174",""
"5150","2014-07-01 00:17:56","activity","none","",""
"5151","2014-07-01 00:17:57","activity","none","",""
"487494","2014-07-01 00:17:58","wifi","2-607","44:ed:57:01:f9:ac","-54"
"487495","2014-07-01 00:17:58","wifi","2-507","44:ed:57:01:55:ca","-87"
"5152","2014-07-01 00:19:55","activity","none","",""
"5153","2014-07-01 00:19:57","activity","none","",""
"5154","2014-07-01 00:21:55","activity","none","",""
"5155","2014-07-01 00:21:56","activity","none","",""
"96158","2014-07-01 00:22:55","battery","full","",""
"166065","2014-07-01 00:22:55","location","37.53724098","126.96960174",""
"487496","2014-07-01 00:22:58","wifi","2-607","44:ed:57:01:f9:ac","-52"
ENFP_2012.csv
```


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Preprocessing III

- Temporal Granularity (round time value)
  - < :30 -> round down
  - > :30 -> round up
- Changing Location value to *(“same”,”little”,”long”)*
  - 0.0001 degree = 11.1132 m (“little”: “between 0.0001 ~ 0.0005”)
- Battery : shows != discharging
- Screen Status : screen OFF only
- Aggregate values of Wi-Fi and Bluetooth
- Removing values such as text length and duration from SMS log and call log, duration from running application probe, MAC and signal strength from nearby Wi-Fi probe.

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Output of Preprocessing III

output3 — more — 108×42

```
Timestamp,Weekday,HP,Sensor Name,Sensor Value
07/01/2014  0:01,Tuesday,00:00,location,long
07/01/2014  0:01,Tuesday,00:00,wifi,KT_WLAN_C1BF, iptime
07/01/2014  0:02,Tuesday,00:00,activity,low
07/01/2014  0:02,Tuesday,00:00,activity,low
07/01/2014  0:04,Tuesday,00:00,runapps,com.buzzpia.aqua.launcher
07/01/2014  0:04,Tuesday,00:00,runapps,com.facebook.katana
07/01/2014  0:04,Tuesday,00:00,runapps,com.buzzpia.aqua.launcher
07/01/2014  0:04,Tuesday,00:00,runapps,net.daum.android.cafe
07/01/2014  0:06,Tuesday,00:00,location,long
07/01/2014  0:06,Tuesday,00:00,wifi,KT_WLAN_C1BF, iptime
07/01/2014  0:11,Tuesday,00:00,location,long
07/01/2014  0:11,Tuesday,00:00,wifi,KT_WLAN_C1BF, iptime
07/01/2014  0:14,Tuesday,00:00,activity,low
07/01/2014  0:14,Tuesday,00:00,activity,low
07/01/2014  0:15,Tuesday,00:00,runapps,com.buzzpia.aqua.launcher
07/01/2014  0:15,Tuesday,00:00,runapps,com.nhn.android.search
07/01/2014  0:16,Tuesday,00:00,runapps,net.daum.android.cafe
07/01/2014  0:16,Tuesday,00:00,location,long
07/01/2014  0:16,Tuesday,00:00,wifi,KT_WLAN_C1BF, iptime
07/01/2014  0:19,Tuesday,00:00,runapps,com.nhn.android.search
07/01/2014  0:20,Tuesday,00:00,runapps,net.daum.android.cafe
07/01/2014  0:21,Tuesday,00:00,location,long
07/01/2014  0:21,Tuesday,00:00,wifi,KT_WLAN_C1BF
07/01/2014  0:26,Tuesday,00:00,location,long
07/01/2014  0:26,Tuesday,00:00,wifi,KT_WLAN_C1BF
07/01/2014  0:31,Tuesday,01:00,location,long
07/01/2014  0:31,Tuesday,01:00,wifi,KT_WLAN_C1BF, iptime
07/01/2014  0:36,Tuesday,01:00,activity,high
07/01/2014  0:36,Tuesday,01:00,location,long
07/01/2014  0:36,Tuesday,01:00,activity,high
07/01/2014  0:36,Tuesday,01:00,wifi,KT_WLAN_C1BF
07/01/2014  0:37,Tuesday,01:00,runapps,com.facebook.katana
07/01/2014  0:37,Tuesday,01:00,runapps,net.daum.android.cafe
07/01/2014  0:40,Tuesday,01:00,activity,high
07/01/2014  0:41,Tuesday,01:00,location,long
07/01/2014  0:41,Tuesday,01:00,wifi,KT_WLAN_C1BF, iptime
07/01/2014  0:46,Tuesday,01:00,location,long
07/01/2014  0:46,Tuesday,01:00,activity,low
07/01/2014  0:46,Tuesday,01:00,wifi,KT_WLAN_C1BF
07/01/2014  0:51,Tuesday,01:00,location,long
INTJ_5498_HP.csv
```


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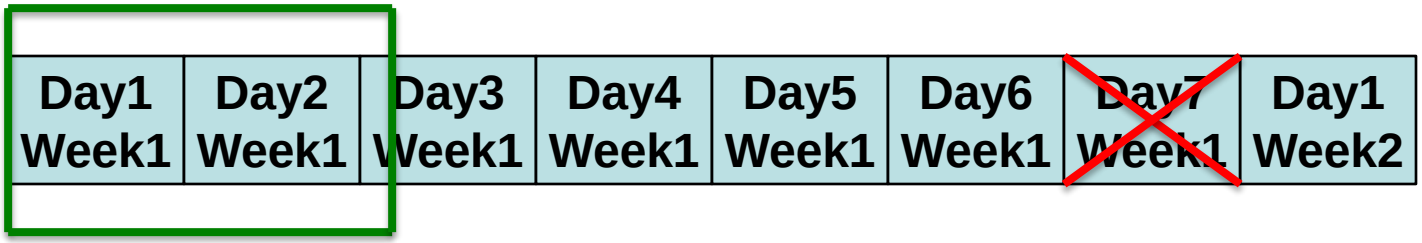
Discovering Human Behaviors

1. The data that we have are set of activities.
2. Behavior means activities which is carried out continuously.
3. Behavior means set of group activities which has (* similar time and similar activity).



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Finding Similar Patterns

Time	Sensor Name	Sensor Value
13:00	location	same
13:00	wifi	1-AP, iptime
14:00	runapps	kakao
14:00	location	long
15:00	runapps	kakao
15:00	location	little

Time	Sensor Name	Sensor Value
13:00	location	same
13:00	wifi	1-AP, iptime
14:00	battery	charging
14:00	wifi	D-link
15:00	runapps	kakao
15:00	location	little

Group-1 = 13:00,location,same | 13:00,wifi,1-AP,iptime

Group-1 = 13:00,location,same | 13:00,wifi,1-AP,iptime

Group-2 = 15:00,runapps,kakao | 15:00, location, little

Group-2 = 15:00,runapps,kakao | 15:00, location, little

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Algorithm (Similarity Detection)

```
Data : D, w
Result : All Detected Group in a Window
grpAll, grpTemp, grpPrevious<- NULL
dataValue, dataValueNext <- NULL
while (D in w) for all of D do
    dataValue <- D.current.day
    dataValueNext <- D.next.day
    grpTemp <- findingSimilarPatterns(dataValue, dataValueNext)

    if (grpTemp in grpPrevious)then
         grpNew <- merge(grpPrevious, grpTemp)
         grpAll <- add(grpNew)
    else
         grpAll <- add(grpTemp)
```

Behavior Profiling/Modeling

We collect all of intersection data between Groups, and mark those data as the user behaviors.

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Grouping Result

```
G2,"19:00,location,same|19:00,bluetooth,DTVBluetooth|"
G2,"19:00,location,same|19:00,bluetooth,DTVBluetooth|"
G2,"19:00,location,same|19:00,bluetooth,DTVBluetooth|"
G2,"19:00,location,same|19:00,bluetooth,DTVBluetooth|"
G2,"19:00,location,same|19:00,bluetooth,DTVBluetooth|"
G3,"20:00,location,same|20:00,bluetooth,DTVBluetooth|"
G3,"20:00,location,same|20:00,bluetooth,DTVBluetooth|"
G3,"20:00,location,same|20:00,bluetooth,DTVBluetooth|"
G3,"20:00,location,same|20:00,bluetooth,DTVBluetooth|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G7,"06:00,screen,OFF|06:00,location,same|"
G9,"12:00,battery,charging|12:00,bluetooth,ESVH-PC|12:00,location,same|12:00,runapps,com.lge.launcher2|"
G9,"12:00,battery,charging|12:00,bluetooth,ESVH-PC|12:00,location,same|12:00,runapps,com.lge.launcher2|"
G9,"12:00,battery,charging|12:00,bluetooth,ESVH-PC|12:00,location,same|12:00,runapps,com.lge.launcher2|"
G9,"12:00,battery,charging|12:00,bluetooth,ESVH-PC|12:00,location,same|12:00,runapps,com.lge.launcher2|"
G9,"12:00,battery,charging|12:00,bluetooth,ESVH-PC|12:00,location,same|12:00,runapps,com.lge.launcher2|"
G9,"12:00,battery,charging|12:00,bluetooth,ESVH-PC|12:00,location,same|12:00,runapps,com.lge.launcher2|"
G9,"12:00,battery,charging|12:00,bluetooth,ESVH-PC|12:00,location,same|12:00,runapps,com.lge.launcher2|"
INTJ_8928_groups.csv
```


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Performance Evaluation

- Total of dataset around 1 month 20 days
- We Divide all of dataset to two parts
  - First month for creating model (first dataset)
  - Remaining dataset for testing performance (second dataset)
- Modeling user behavior based on first data,
  - B1: Behavior model/profile.
- Extract and Process the second dataset.
- Apply similarity detection to second dataset with same setting.
  - B2: Set of behavior group result from second dataset.
- Is the all of B2 identified by Behavior model/profile (B1).
- Calculate group detection, The percentage of data identified.
- Implement this approach for Identification

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Confusion matrix (Only 10 students)

model	P_0719_HP._	P_2012_HP._	P_1993_HP._g	J_5498_HP._	J_3052_HP._g	J_2301_HP._	P_4634_HP._	J_3022_HP._g	P_5154_HP._	P_4301_HP
P_0719_HP._g	67.922	0	0	0.4	2.187	0	1.943	0	2.011	0
P_2012_HP._g	0	83.582	0	0	0	0	0	0	0	0
P_1993_HP._g	0.221	0	75.966	0	0.099	0	0.112	0	1.121	1.793
J_5498_HP._gı	2.178	0	0	75.977	2.087	0	3.401	0	0.891	0
J_3052_HP._gı	2.289	0	0	0.4	93.439	8.232	1.943	4.144	2.586	2.288
J_2301_HP._gı	0	0	0	0	0.099	23.171	0	9.116	0.776	7.05
P_4634_HP._g	2.289	0	0	0.977	2.087	0	89.686	0	0.316	0
J_3022_HP._gı	0	0	0	0	0.099	17.378	0	66.851	1.063	5.69
P_5154_HP._g	3.285	0	0	0.488	1.789	7.317	2.018	3.315	55.144	2.474
P_4301_HP._g	0	0	0	0	0.099	17.378	0	16.851	5.23	30.736

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