# Mining Apps to Learn Normal Behavior

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Joint work with Alessandra Gorla, Ilaria Tavecchia, Vitalii Avdiienko, Konstantin Kuznetsov, and Florian Gross


Saarbrücken

# Saarbrücken

**1700**
BSc + MSc students

**375**
PhD students

**200**
Researchers (post PhD)

**8**
New buildings since 2001

**7**
ERC Grant holders

**6**
Leibniz Awardees

**4**
ACM Fellows

**1**
Software Engineer

UNIVERSITÄT DES SAARLANDES | max planck institut informatik | Max Planck Institute for Software Systems | DFKI | intel Visual Computing Institute | CISPA Center for Information Security, Privacy and Accountability

# Specifications

$$
\begin{array}{l}
\textbf{Schema } \mathit{removeChild} \\
\hline
\Delta \mathit{XMLElement} \\
\mathit{child?} : \mathit{XML\_ELEMENT} \\
\hline
\mathit{child?} \in \mathit{enumerateChildren} \\
\mathit{child?} \neq \mathit{null} \\
\mathit{enumerateChildren}' = \mathit{enumerateChildren} \setminus \mathit{child?} \\
\mathit{getChildrenCount}' = \mathit{getChildrenCount} - 1 \\
\hline
\end{array}
$$

# Specifications

*removeChild*

$\Delta XMLElement$
$child? : XML\_ELEMENT$

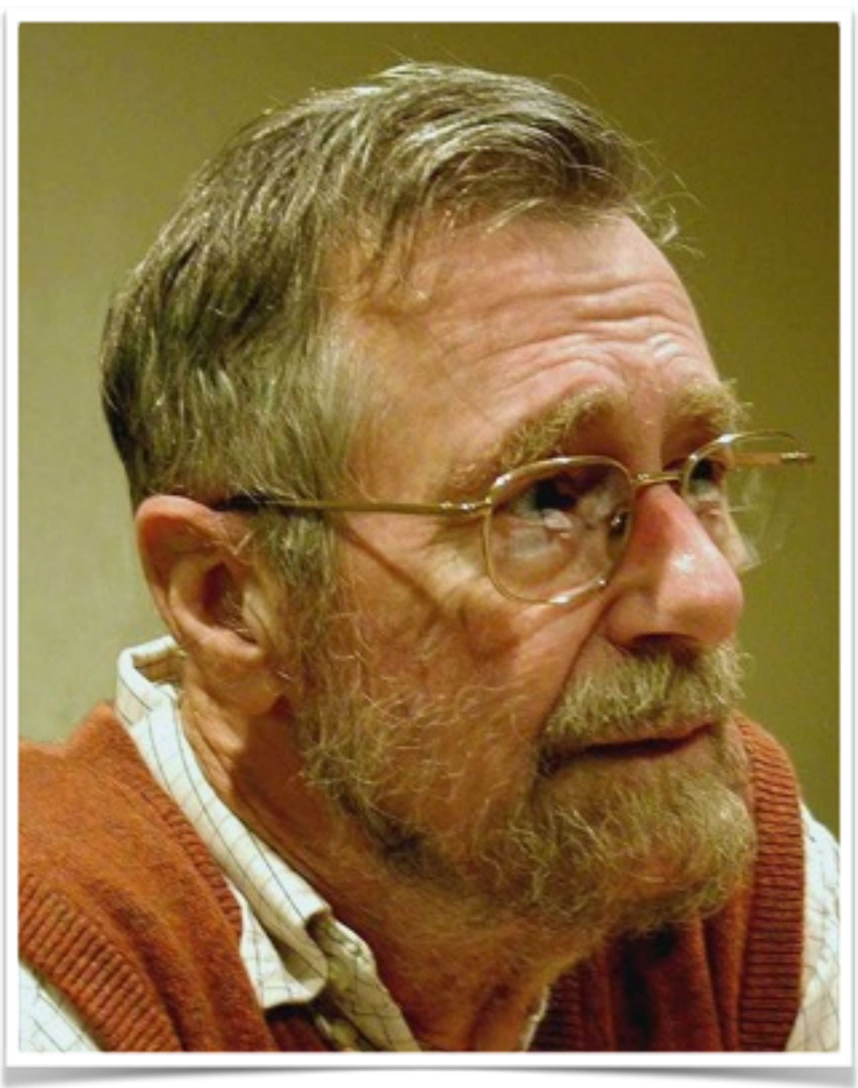
$child? \in enumerateChildren$
$child? \neq null$
$enumerateChildren' = enumerateChildren \setminus child?$
$getChildrenCount' = getChildrenCount - 1$

**fully automated testing**

**fully automated debugging**

**widely automated verification**

# Specifying Correctness



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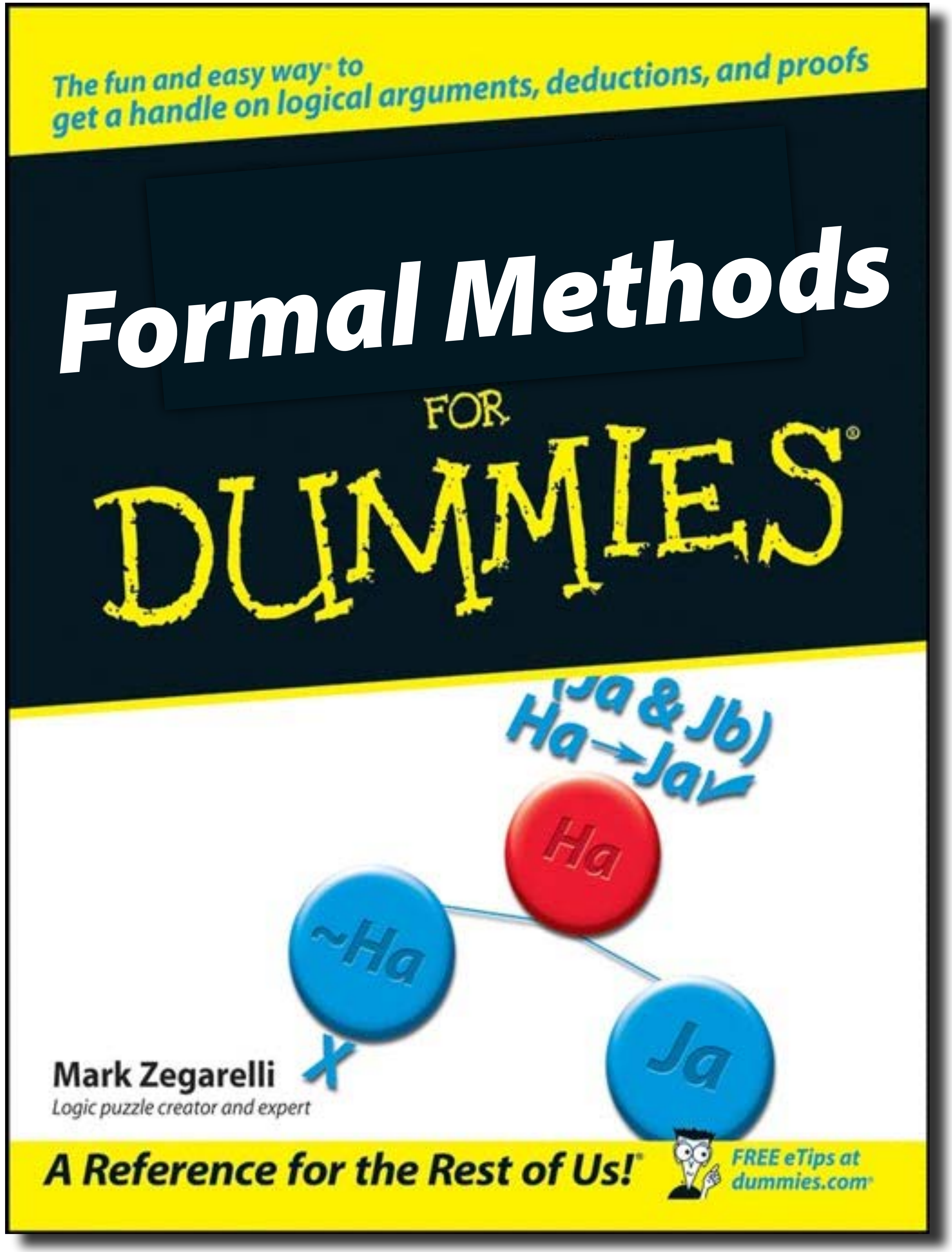

The fun and easy way to get a handle on logical arguments, deductions, and proofs
Formal Methods
FOR
DUMMIES
(Ja & Jb)
Ha→Ja
Ha
~Ha
Ja
Mark Zegarelli
Logic puzzle creator and expert
A Reference for the Rest of Us!
FREE eTips at dummies.com


Microsoft Outlook
Unknown error
OK
Was this information helpful?

# Normality

# Mining Normality


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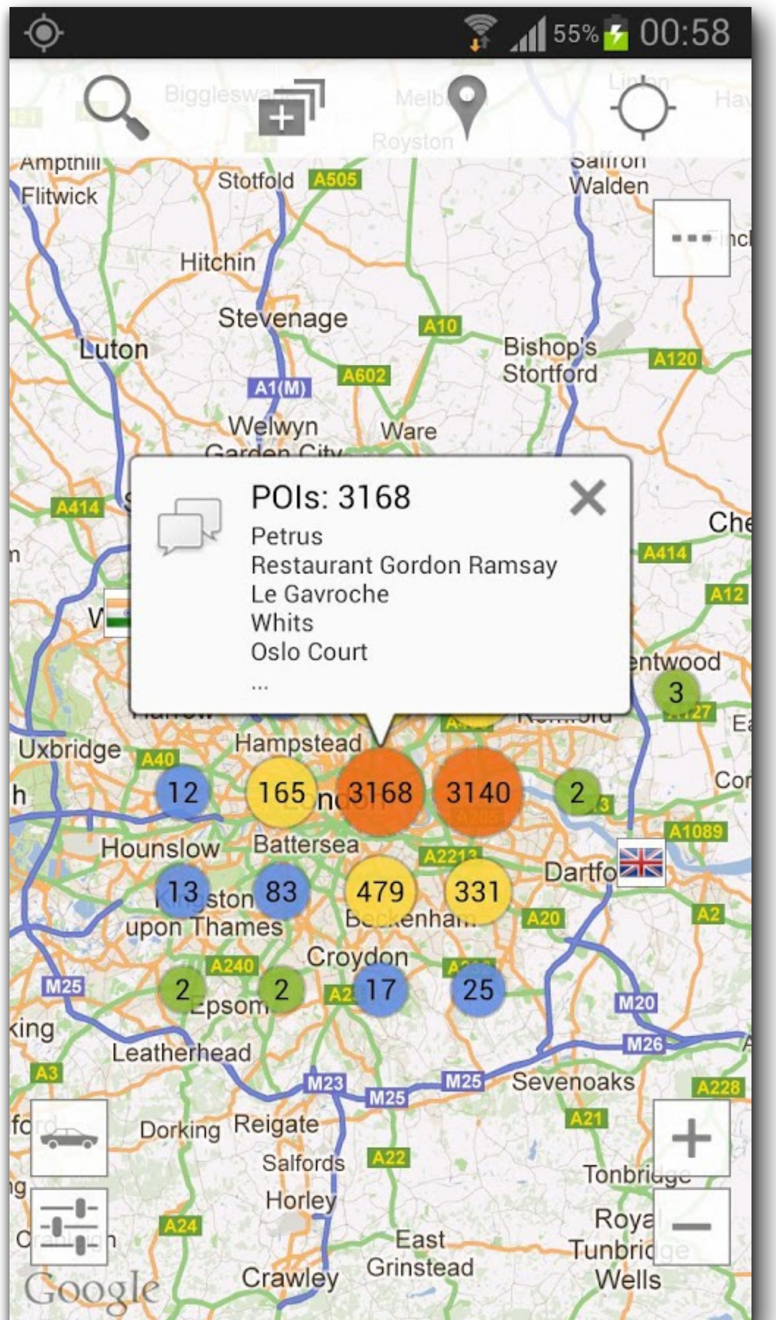
# Outliers


# London Restaurants



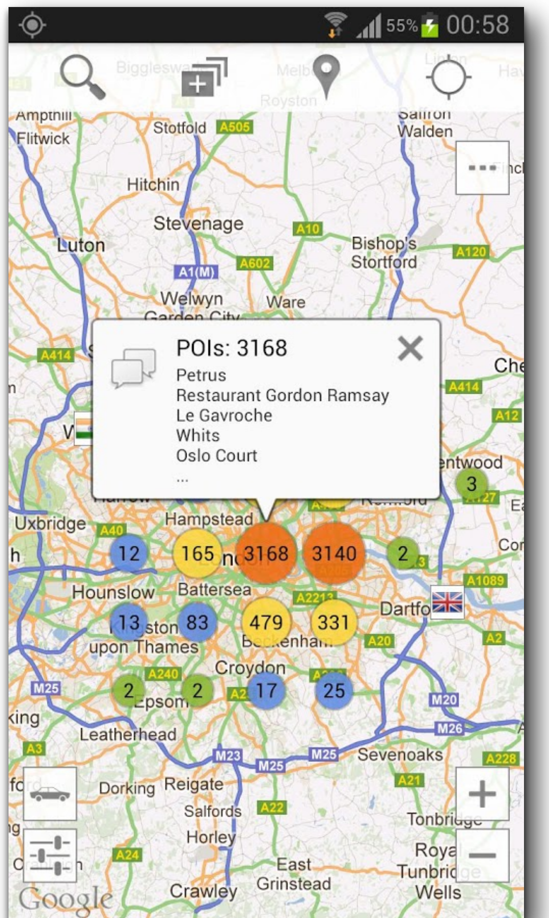

Looking for a restaurant, a bar, a pub or just to have fun in London? Search no more! This application has all the information you need:

• You can search for every type of food you want: french, british, chinese, indian etc.
• You can use it if you are in a car, on a bicycle or walking
• You can view all objectives on the map
• You can search objectives
• You can view objectives near you
• You can view directions (visual route, distance and duration)
• You can use it with Street View
• You can use it with Navigation

Keywords: london, restaurants, bars, pubs, food, breakfast, lunch, dinner, meal, eat, supper, street view, navigation

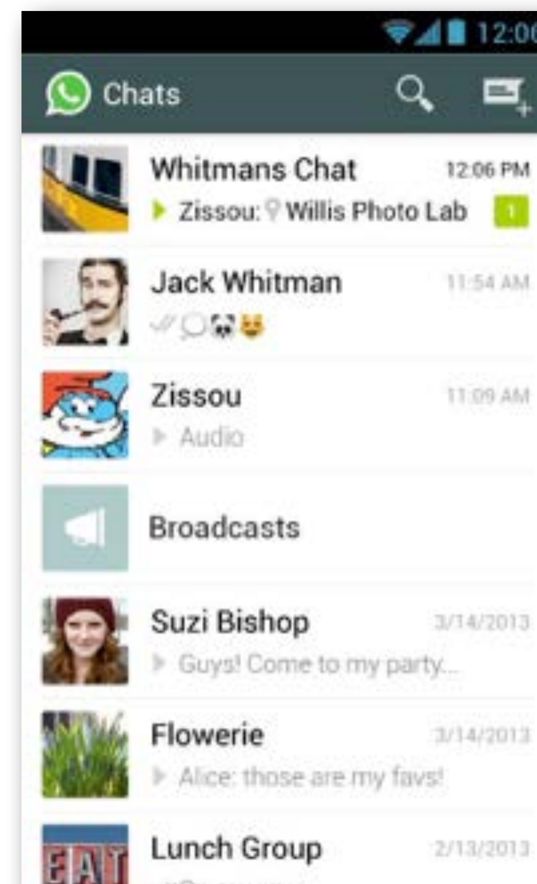
**Also sends out *account info***
**Also sends out *mobile phone number***
**Also sends out *your device ID***

# What is malicious?




London Restaurants

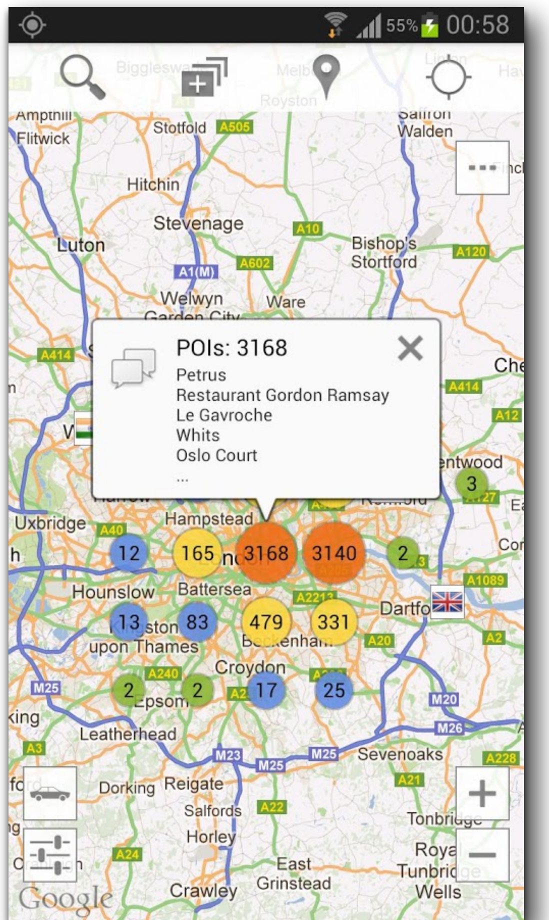
Also sends out *account info*
Also sends out *mobile phone number*
Also sends out *your device ID*




Also sends out account info
Also sends out mobile phone number
Also sends out your device ID

WhatsApp messenger

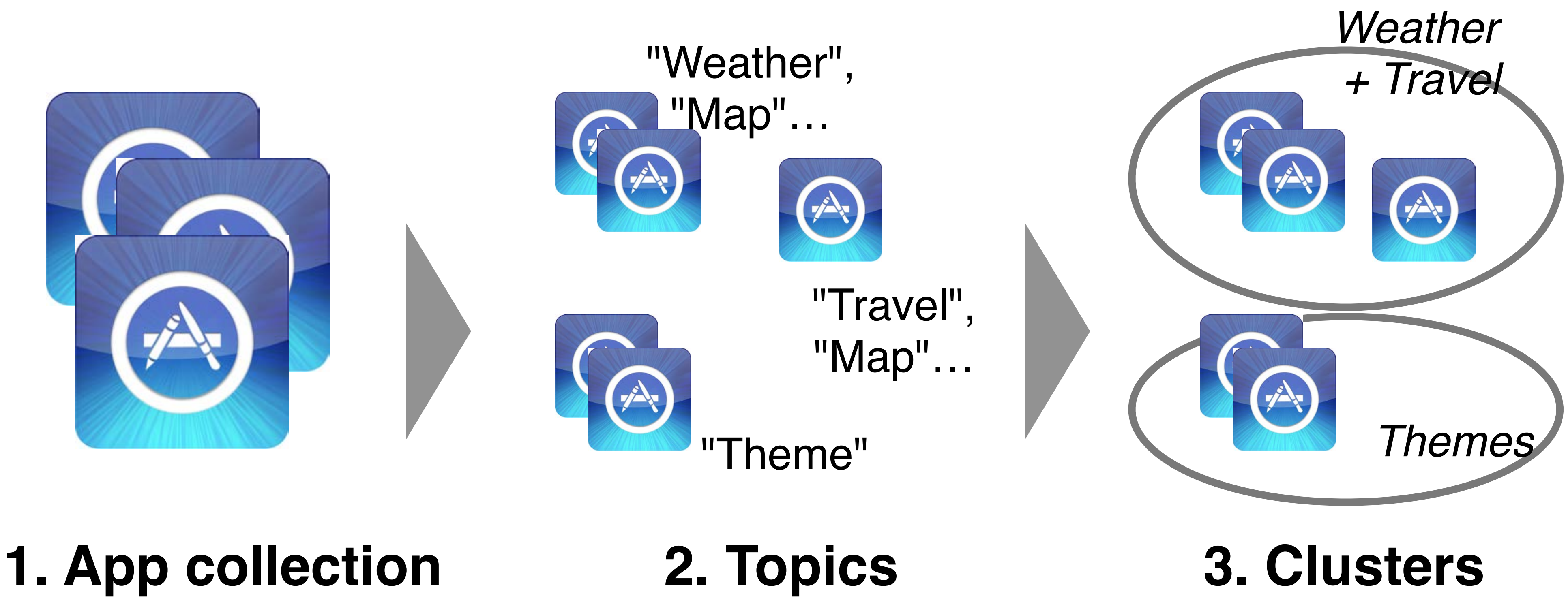
# What is normal?



London Restaurants

- “London Restaurants” is a “travel” app
- For “travel” apps, sending account infos is *abnormal*
- For “messaging” apps, this is far more likely

# CHABADA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"Theme"
Weather
+ Travel
Themes
1. App collection
2. Topics
3. Clusters

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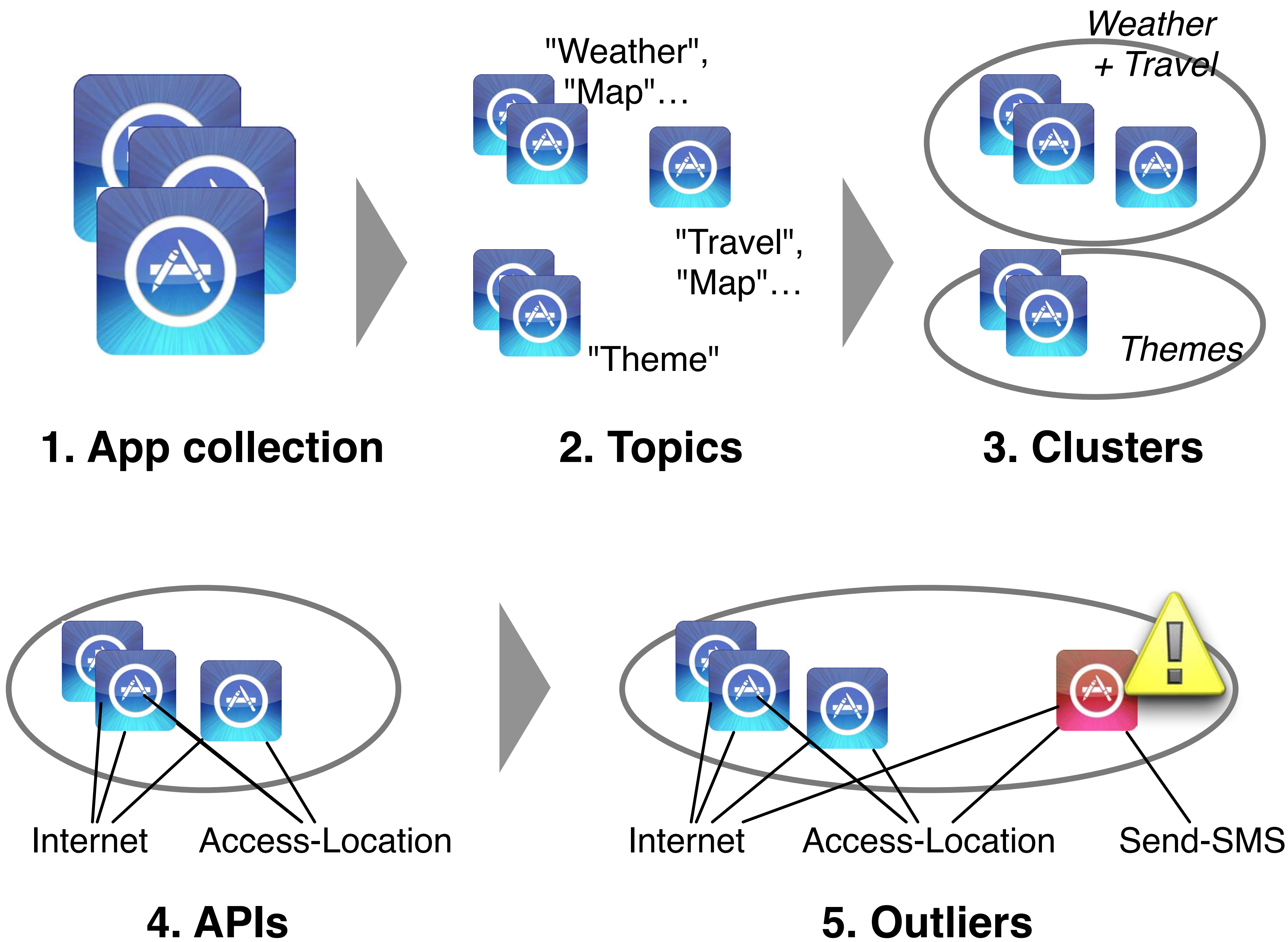
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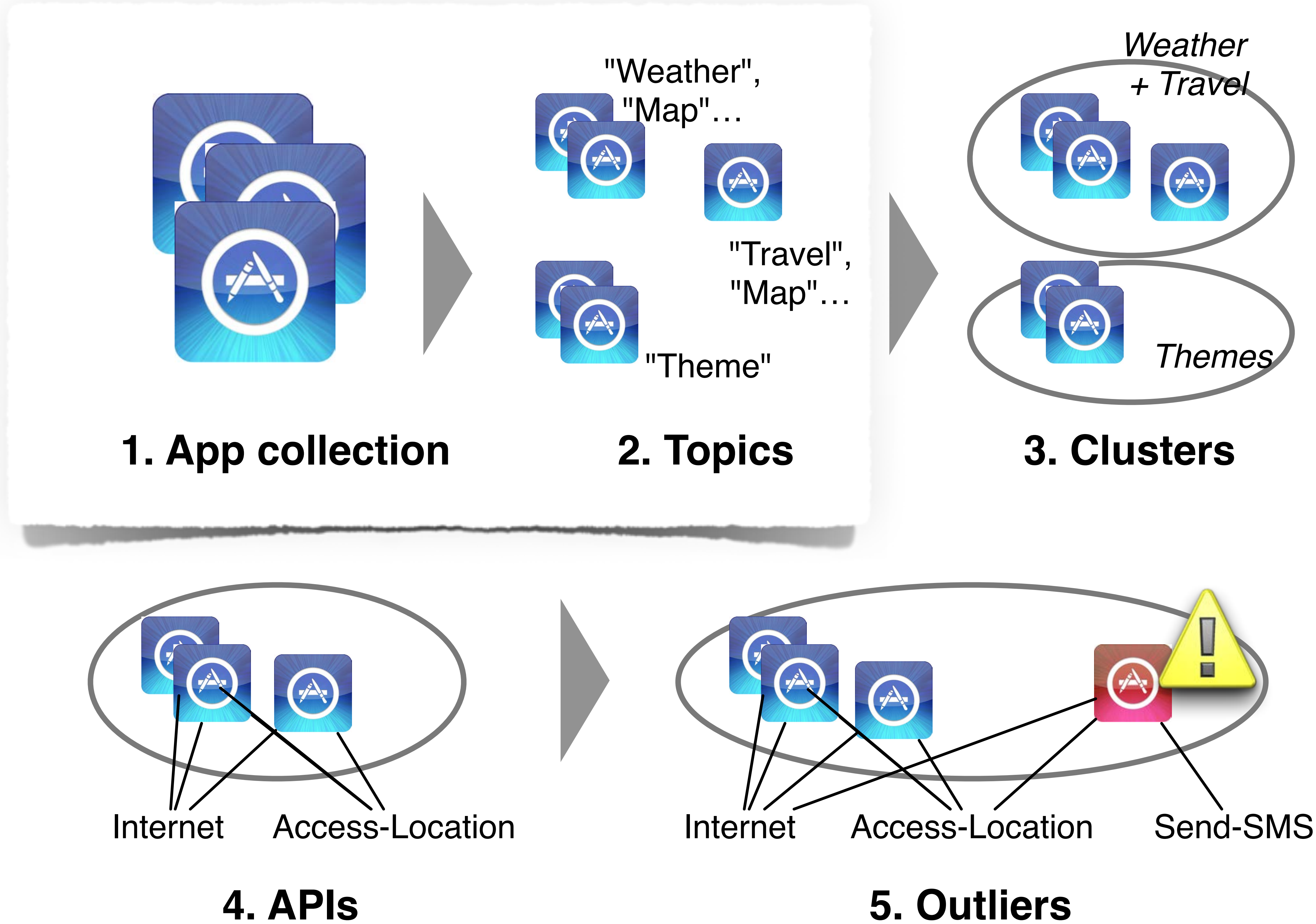

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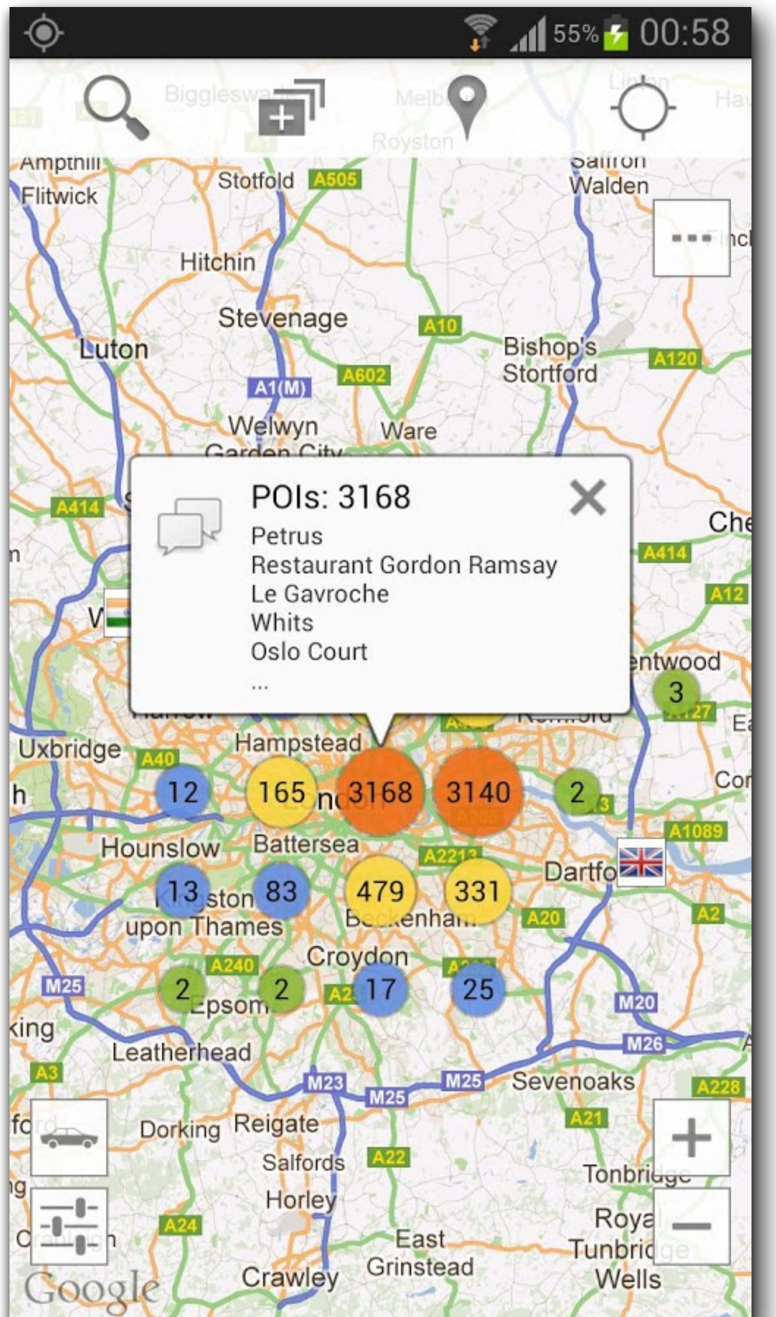
# App Collection

- Source: Google Play Store
- Downloaded top 150 apps + metadata from each of the 30 categories
- Time frame: Winter to Spring 2013
- Total: 32,136 apps
- Data package available on Web site

# Stemming

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keywords: london, restaurants, bars, pubs, food, breakfast, lunch, dinner, meal, eat, supper, street view, navigation

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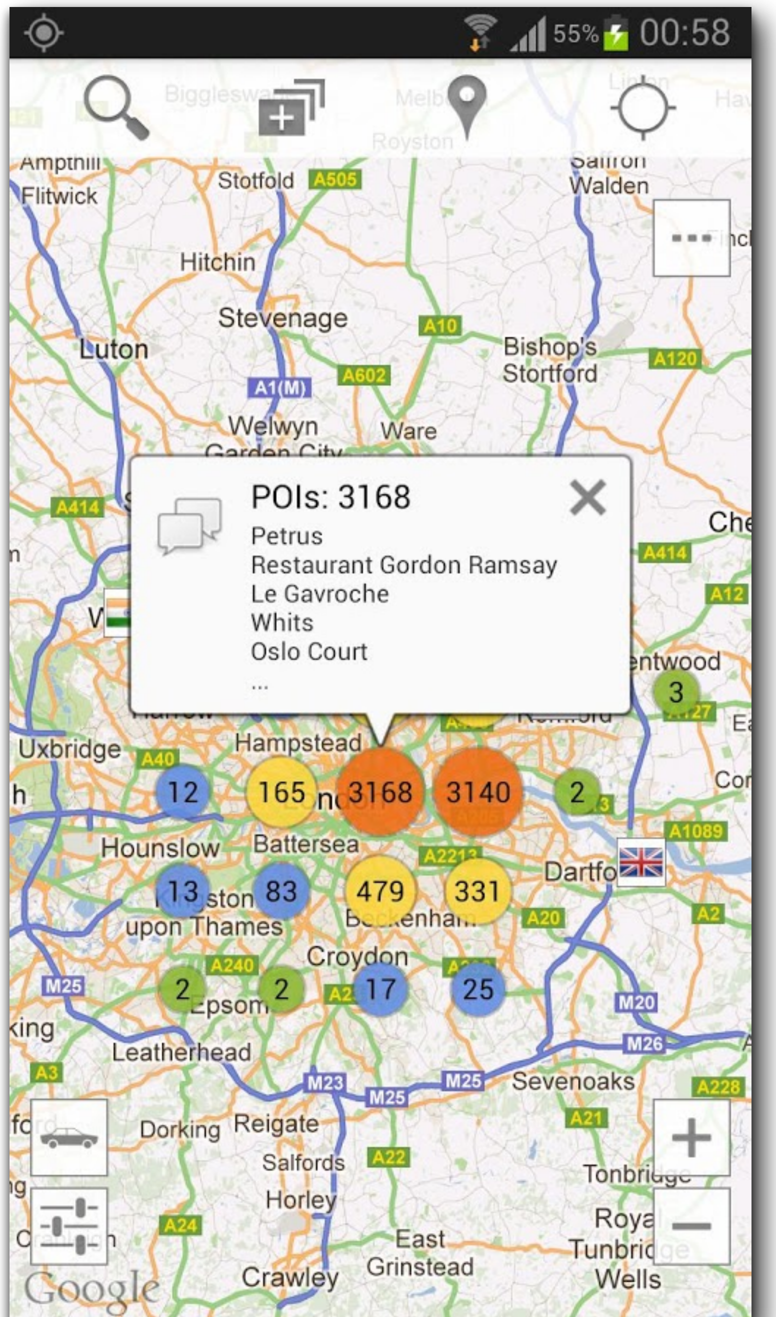


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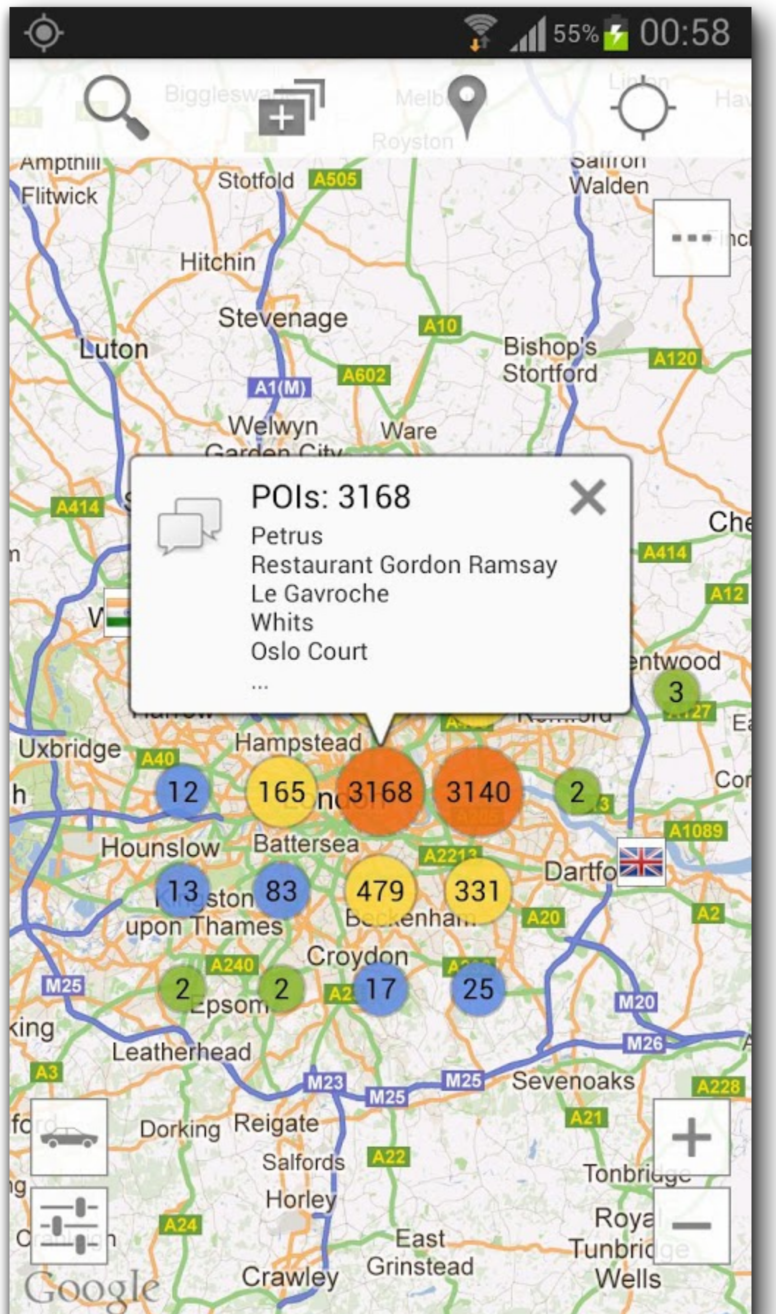


look london restaur search bar pub just applic fun

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british chines indian etc car bicycl walk

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durat can view direct object near

can us street view can us navig

keyword london restaur bar pub food view

breakfast lunch dinner meal eat supper street navig

# Topic Analysis

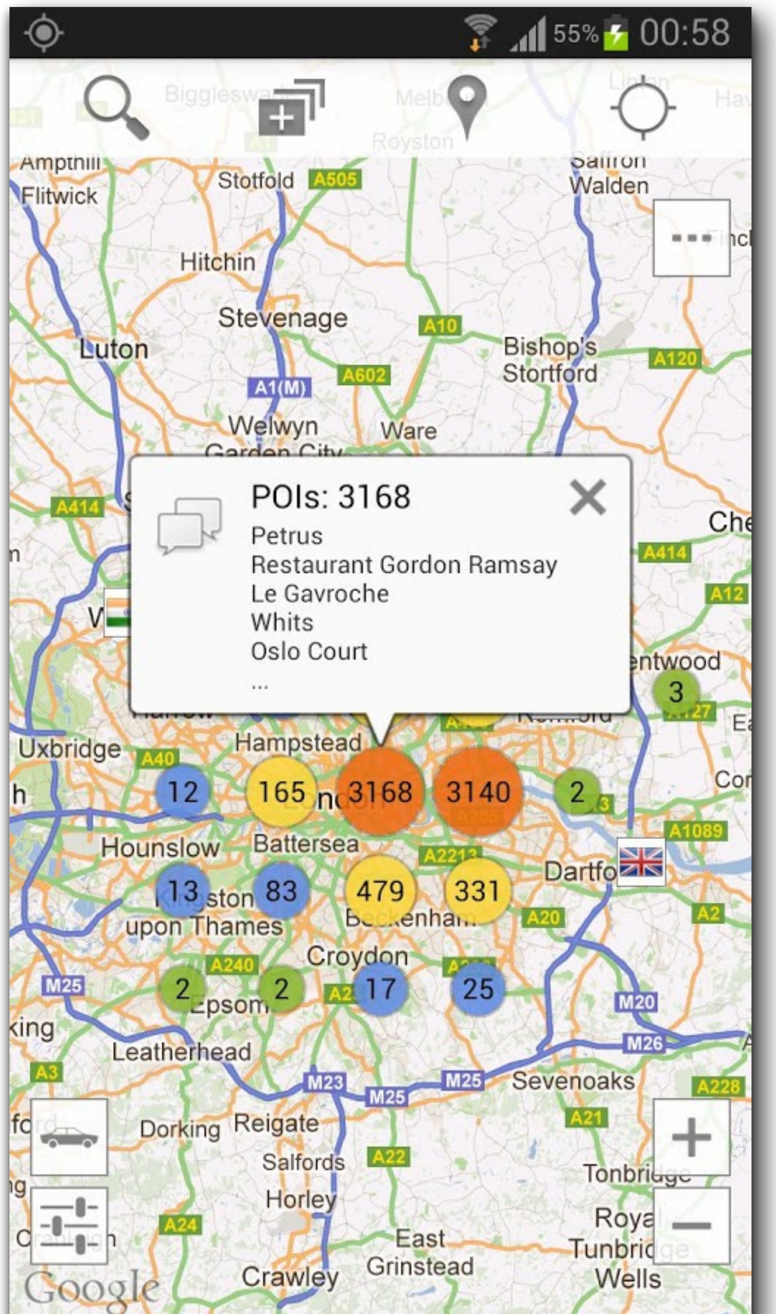
- Eliminated all apps with $\leq$10 words,
  now 22,521 apps
- Want to discover the *topics* that occur in a collection of unlabeled text
- A *topic* consists of a cluster of words that frequently occur together
- Used *Latent Dirichlet Allocation* (LDA)
  to identify 30 topics

# Topics

| Id | Assigned Name | Most Representative Words (stemmed) |
|---|---|---|
| 0 | “personalize” | galaxi, nexu, device, screen, effect, instal, customis |
| 1 | “game and cheat sheets” | game, video, page, cheat, link, tip, trick |
| 2 | “money” | slot, machine, money, poker, currenc, market, trade, stock, casino coin, finance |
| 3 | “tv” | tv, channel, countri, live, watch, germani, nation, bbc, newspap |
| 4 | “music” | music, song, radio, play, player, listen |
| 5 | “holidays” and religion | christmas, halloween, santa, year, holiday, islam, god |
| 6 | “navigation and travel” | map, inform, track, gps, navig, travel |
| 7 | “language” | language, word, english, learn, german, translat |
| 8 | “share” | email, ad, support, facebook, share, twitter, rate, suggest |
| 9 | “weather and stars” | weather, forecast, locate, temperatur, map, city, light |
| 10 | “files and video” | file, download, video, media, support, manage, share, view, search |

| | | |
|---|---|---|
| 13 | "design and art" | life, peopl, natur, form, feel, learn, art, design, uniqu, effect, modern |
| 14 | "food and recipes" | recip, cake, chicken, cook, food |
| 15 | "personalize" | theme, launcher, download, install, icon, menu |
| 16 | "health" | weight, bodi, exercise, diet, workout, medic |
| 17 | "travel" | citi, guid, map, travel, flag, countri, attract |
| 18 | "kids and bodies" | kid, anim, color, girl, babi, pictur, fun, draw, design, learn |
| 19 | "ringtones and sound" | sound, rington, alarm, notif, music |
| 20 | "game" | game, plai, graphic, fun, jump, level, ball, 3d, score |
| 21 | "search and browse" | search, icon, delet, bookmark, link, homepag, shortcut, browser |
| 22 | "battle games" | story, game, monster, zombi, war, battle |
| 23 | "settings and utils" | screen, set, widget, phone, batteri |
| 24 | "sports" | team, football, leagu, player, sport, basketbal |
| 25 | "wallpapers" | wallpap, live, home, screen, background, menu |
| 26 | "connection" | device, connect, network, wifi, blootooth, internet, remot, server |
| 27 | "policies and ads" | live, ad, home, applovin, notif, data, polici, privacy, share, airpush, advertis |
| 28 | "popular media" | seri, video, film, album, movi, music, award, star, fan, show, gangnam, top, bieber |
| 29 | "puzzle and card games" | game, plai, level, puzzl, player, score, challeng, card |

# London Restaurant Topics

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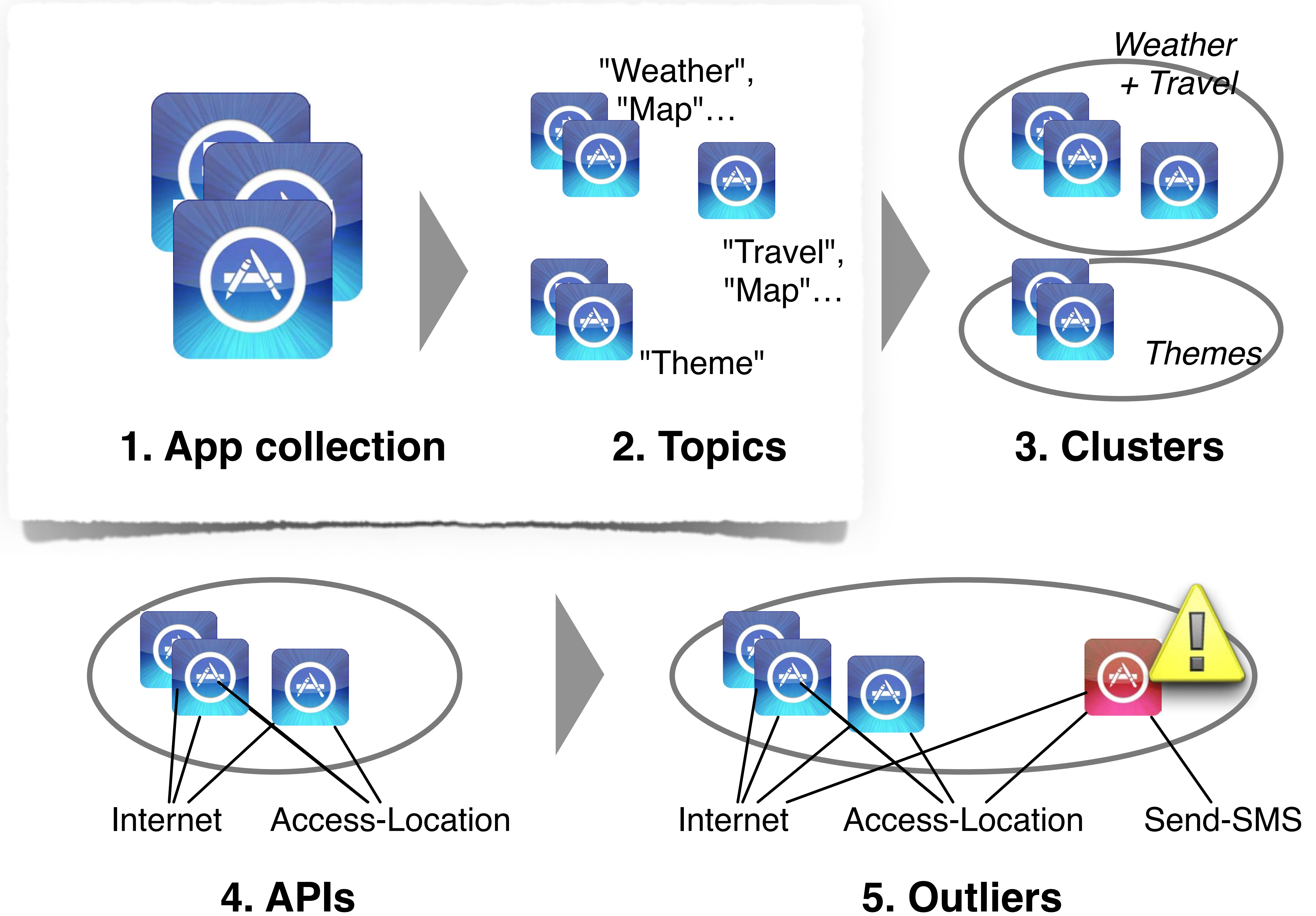
can us street view can us navig

keyword london restaur bar pub food view

breakfast lunch dinner meal eat supper street navig

"navigation and travel" (59.8%)
"food and recipes" (19.9%)
"travel" (14.0%)

# CHABADA



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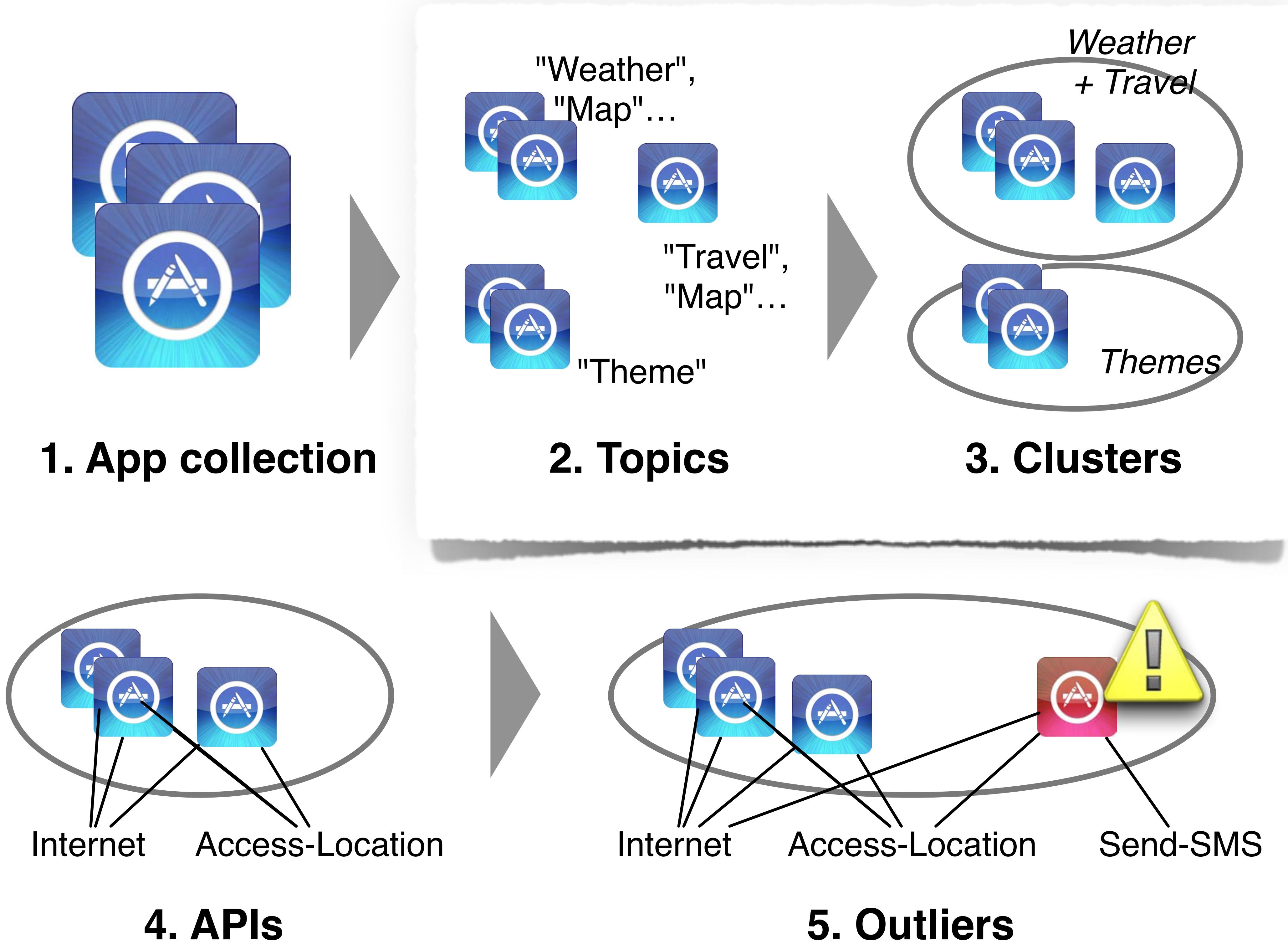
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# Clustering

- Want to identify *groups of applications* that are similar according to their descriptions.
- Used *K-Means* to identify such clusters
- Used *elements silhouette*
  to identify best number K of clusters

# Clusters

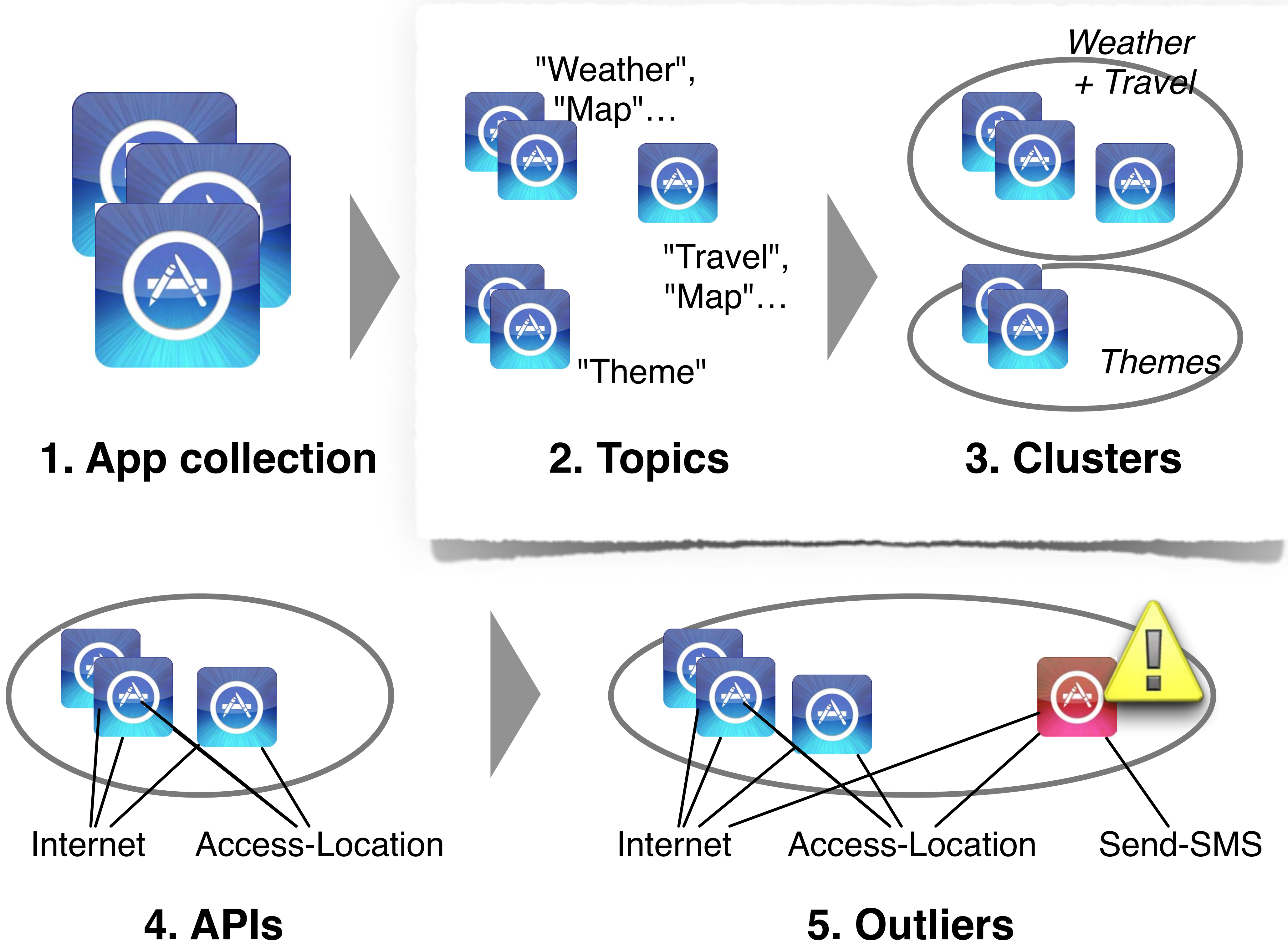
| Id | Assigned Name | Size | Most Important Topics |
|---|---|---|---|
| 1 | “sharing” | 1,453 | **share** (53%), settings and utils, navigation and travel |
| 2 | “puzzle and card games” | 953 | **puzzle and card games** (78%), share, game |
| 3 | “memory puzzles” | 1,069 | **puzzle and card games** (40%), game (12%), share |
| 4 | “music” | 714 | **music** (58%), share, settings and utils |
| 5 | “music videos” | 773 | **popular media** (44%), **holidays and religion** (20%), share |
| 6 | “religious wallpapers” | 367 | **holidays and religion** (56%), design and art, wallpapers |
| 7 | “language” | 602 | **language** (67%), share, settings and utils |
| 8 | “cheat sheets” | 785 | **game and cheat sheets** (76%), share, popular media |
| 9 | “utils” | 1,300 | **settings and utils** (62%), share, connection |
| 10 | “sports game” | 1,306 | **game** (63%), battle games, puzzle and card games |
| 11 | “battle games” | 953 | **battle games** (60%), **game** |

| | | | |
|---|---|---|---|
| | | | and travel |
| 19 | “sports” | 580 | **sports** (62%), share, popular media |
| 20 | “files and videos” | 679 | **files and videos** (63%), share, settings and utils |
| 21 | “search and browse” | 363 | **search and browse** (64%), game, puzzle and card games |
| 22 | “advertisements” | 380 | **policies and ads** (97%) |
| 23 | “design and art” | 978 | **design and art** (48%), share, game |
| 24 | “car games” | 449 | **cars** (51%), game, puzzle and card games |
| 25 | “tv live” | 500 | **tv** (57%), share, navigation and travel |
| 26 | “adult photo” | 828 | **photo and social** (59%), share, settings and utils |
| 27 | “adult wallpapers” | 543 | **wallpapers** (51%), share, kids and bodies |
| 28 | “ad wallpapers” | 180 | **policies and ads** (46%), wallpapers, settings and utils |
| 29 | “ringtones and sound” | 662 | **ringtones and sound** (68%), share, settings and utils |
| 30 | “theme wallpapers” | 593 | **wallpapers** (90%), holidays and religion, share |
| 31 | “personalize” | 402 | **personalize** (86%), share, settings and utils |
| 32 | “settings and wallpapers” | 251 | **settings and utils** (37%), **wallpapers** (37%), personalize |

# "Personalize" Cluster

# “Travel” Cluster

# CHABADA



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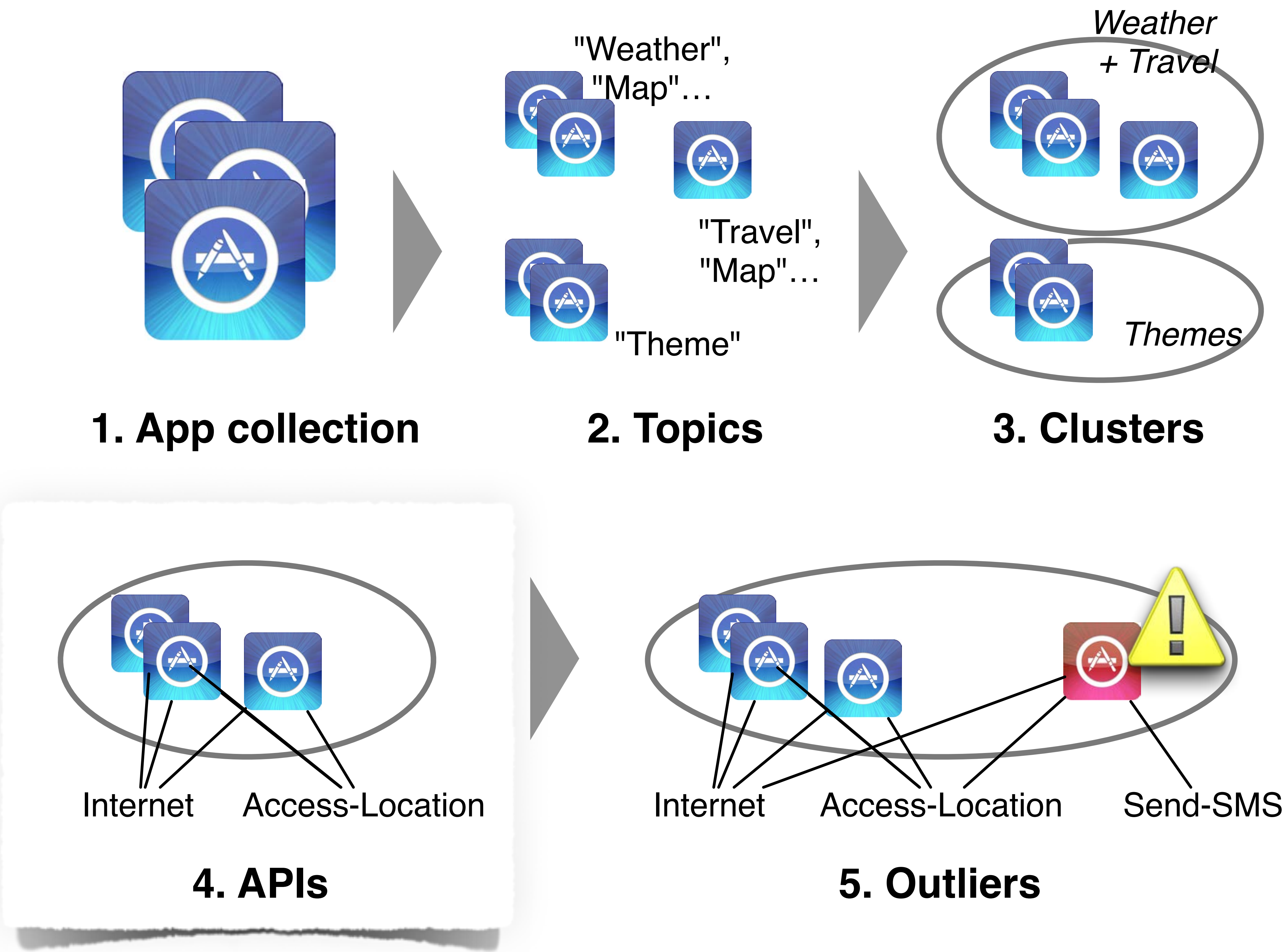

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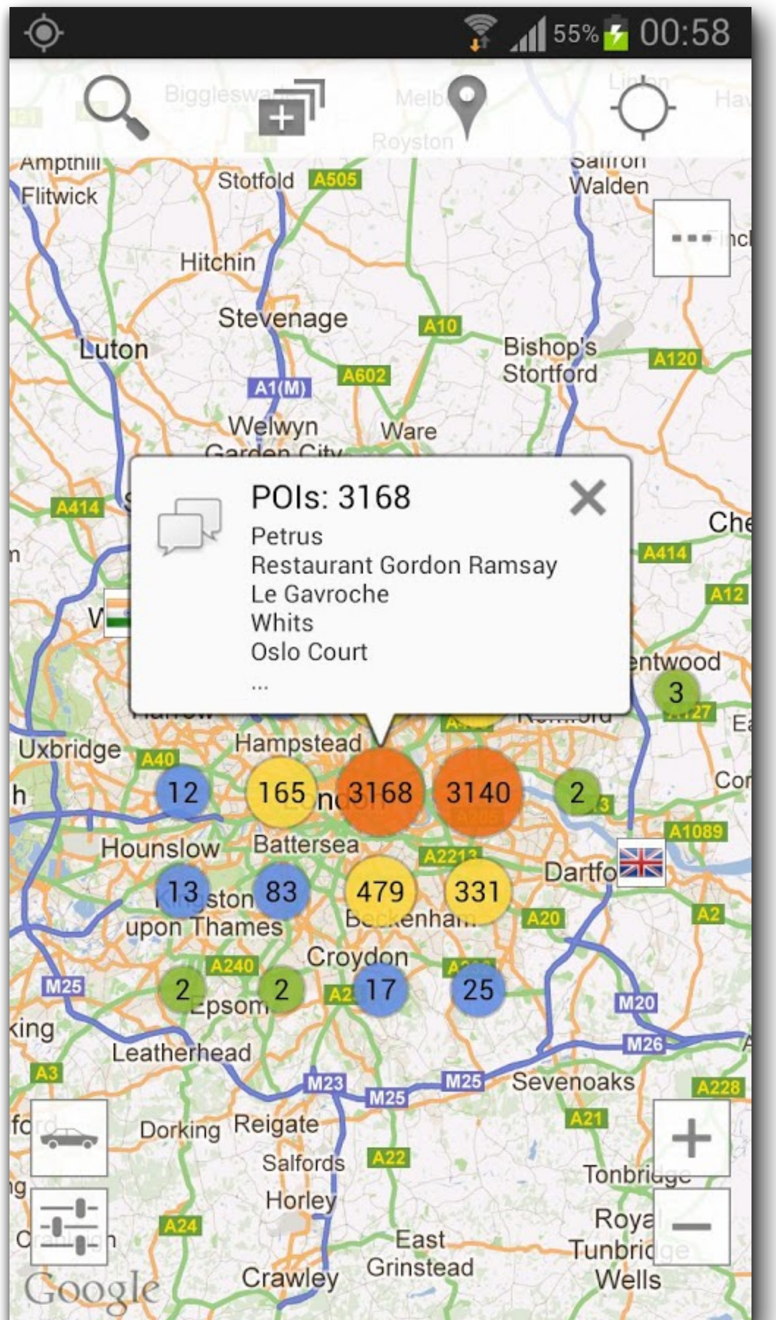
# API Analysis

- For each APK, we identified the APIs used
- Used simple static analysis
- Only considered *sensitive APIs* which would be governed by *permissions*

# London Restaurants




android.net.ConnectivityManager.getActiveNetworkInfo()
android.webkit.WebView()

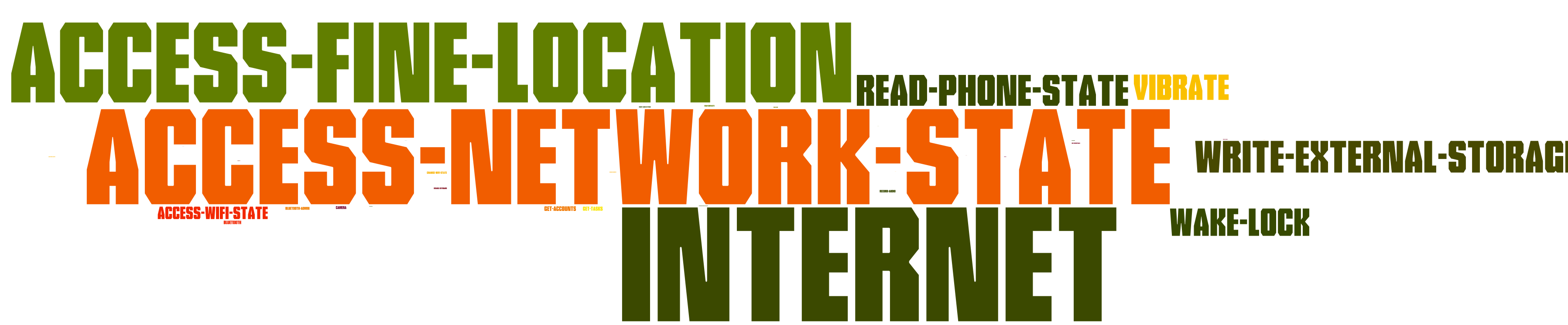
INTERNET
GET-ACCOUNTS
ACCESS-WIFI-STATE
ACCESS-NETWORK-STATE
ACCESS-FINE-LOCATION
READ-PHONE-STATE
VIBRATE

android.net.NetworkInfo.isConnectedOrConnecting()
android.net.ConnectivityManager.getAllNetworkInfo()

# “Travel” Cluster

Description


Permissions of APIs used



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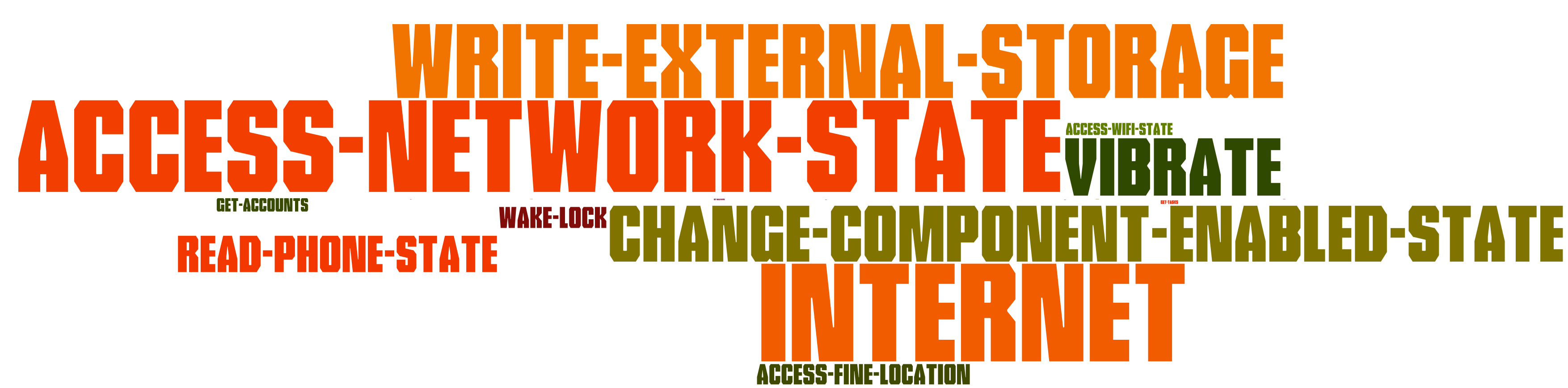

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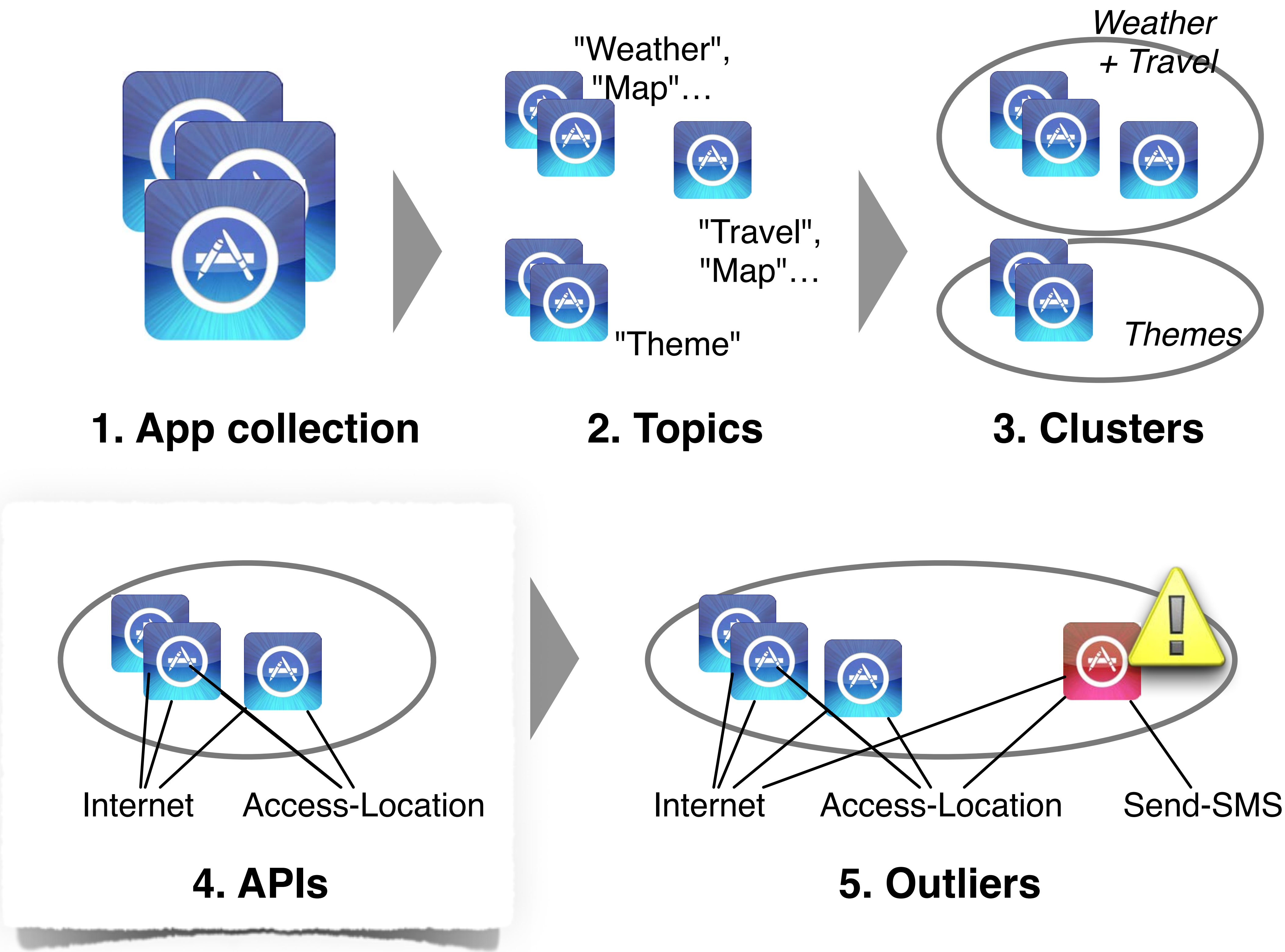
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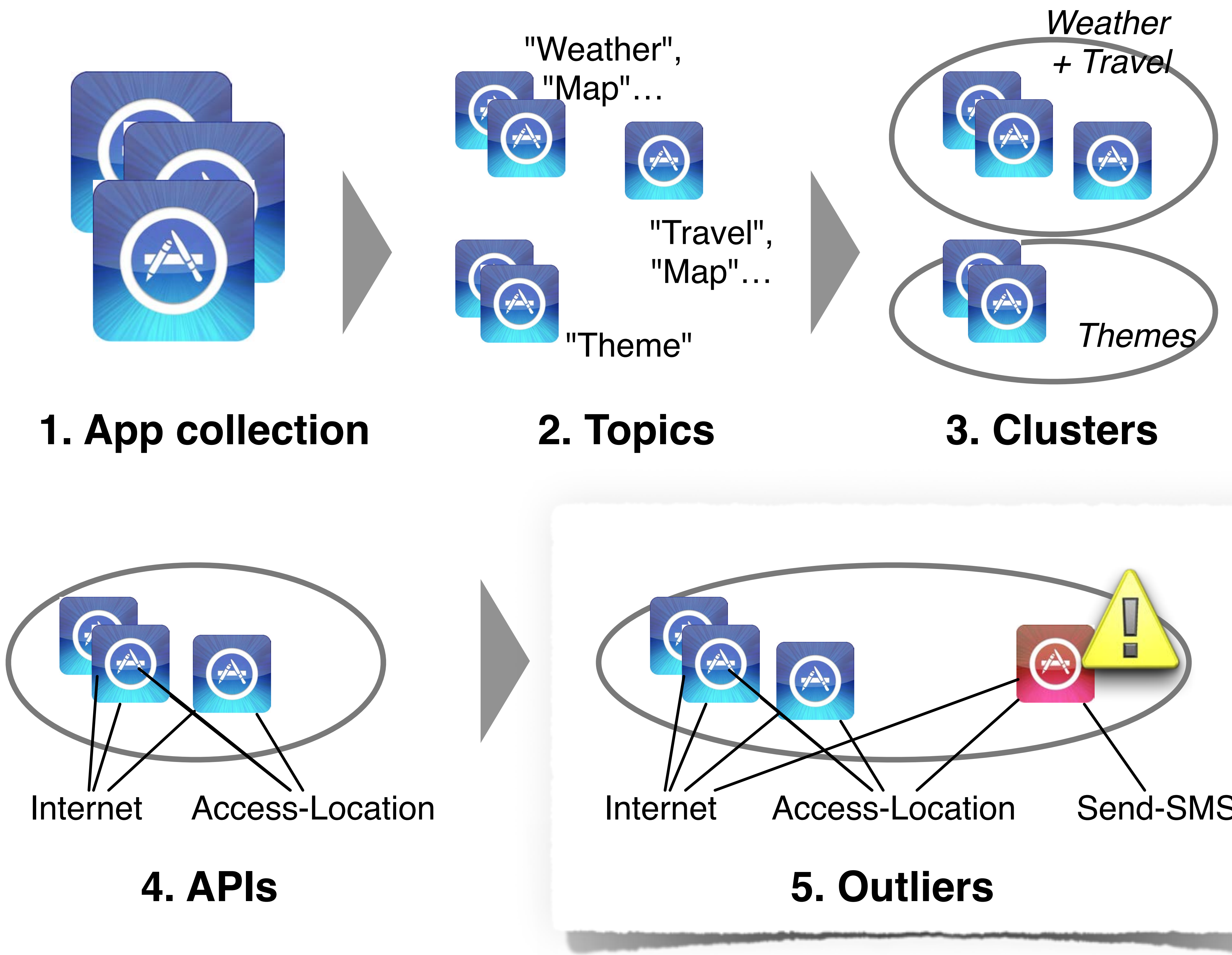

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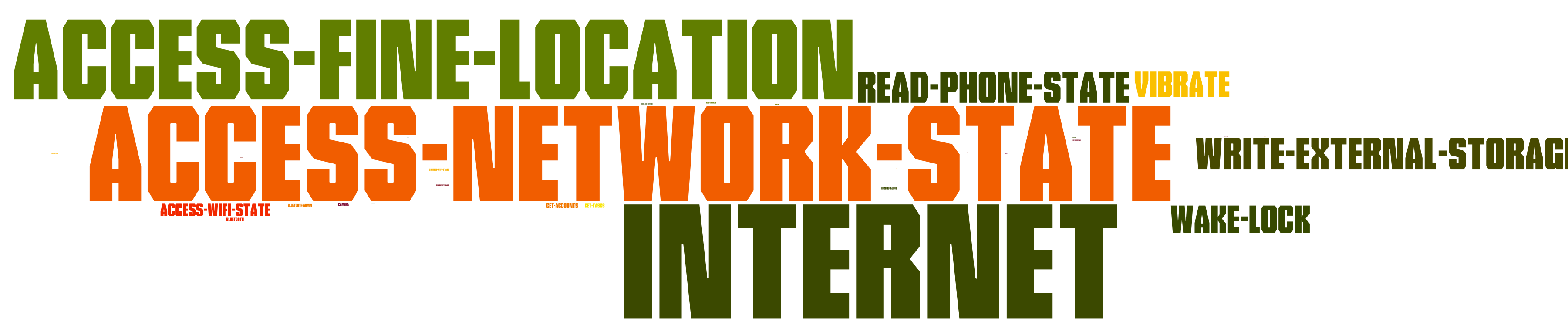

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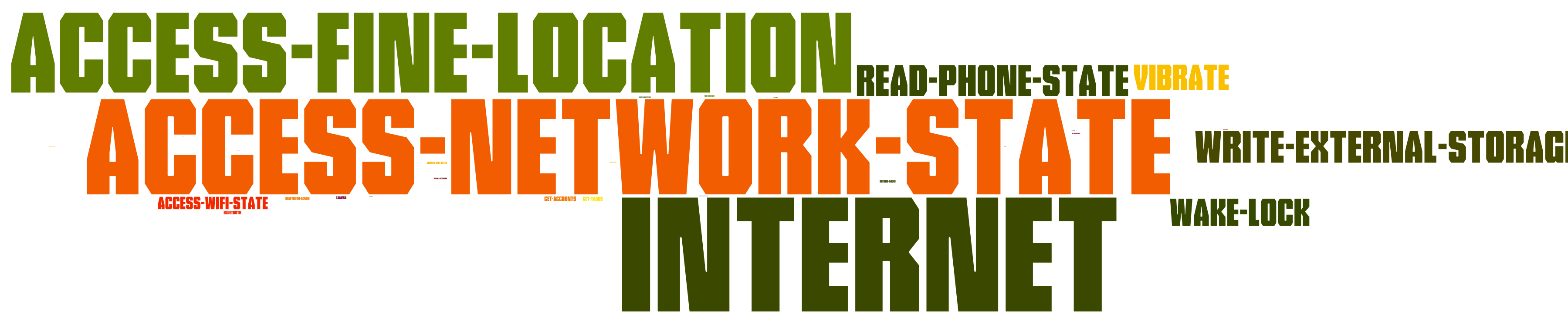
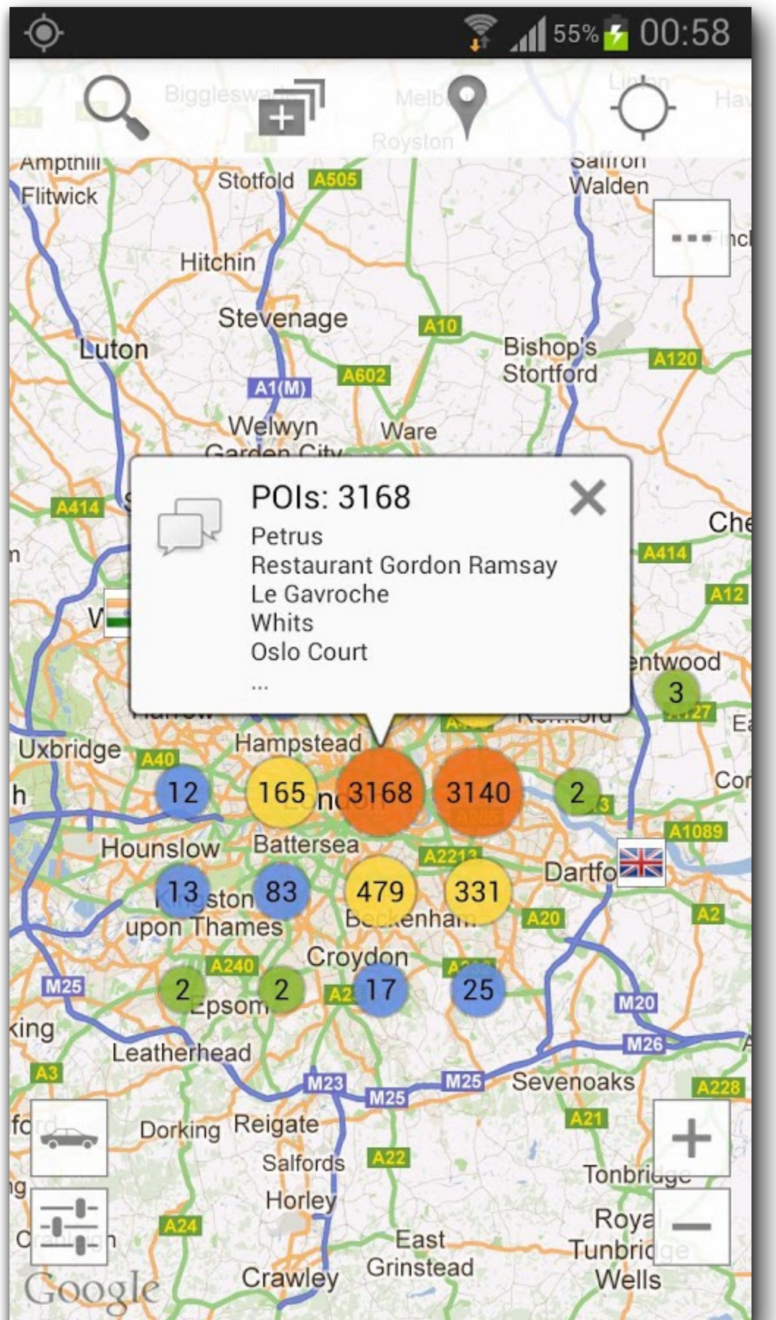



# London Restaurants

Permissions of APIs used

# London Restaurants

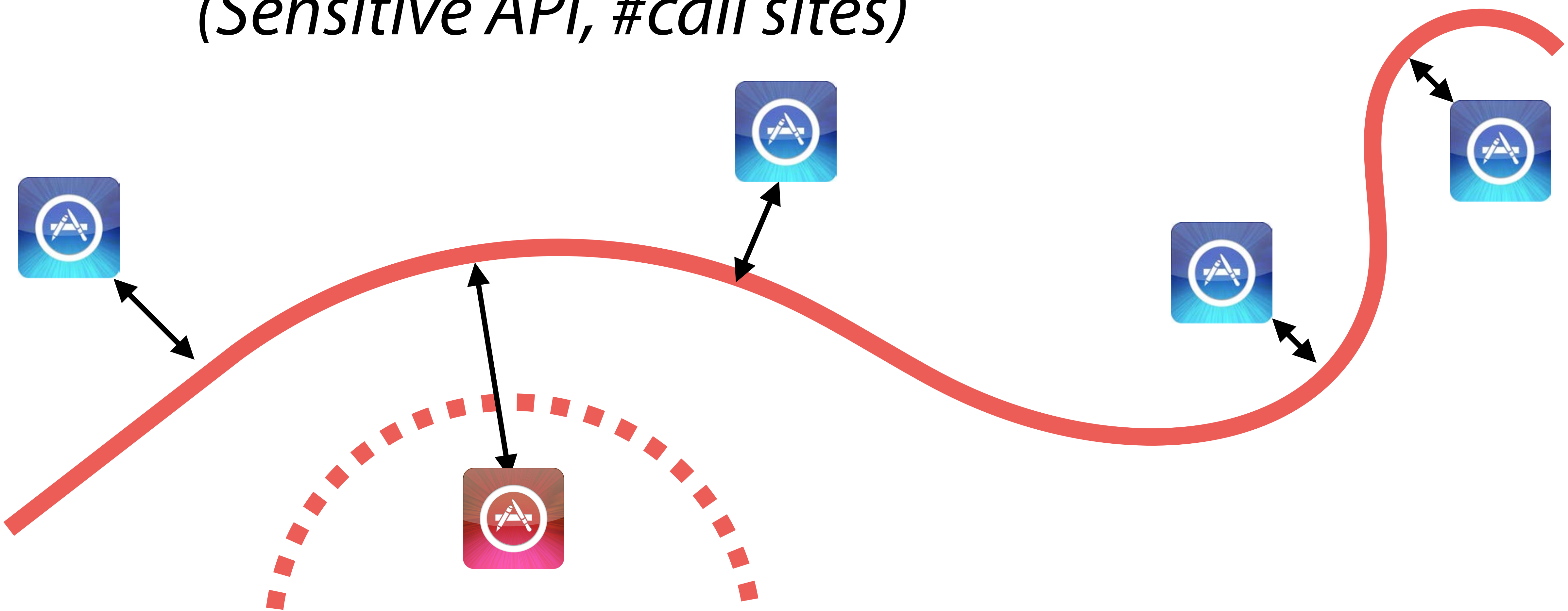



android.net.ConnectivityManager.getActiveNetworkInfo()
android.webkit.WebView()
java.net.HttpURLConnection.connect()
android.app.NotificationManager.notify()
java.net.URL.openConnection()
**android.telephony.TelephonyManager.getDeviceId()**
org.apache.http.impl.client.DefaultHttpClient()
org.apache.http.impl.client.DefaultHttpClient.execute()
android.location.LocationManager.getBestProvider()
**android.telephony.TelephonyManager.getLine1Number()**
android.net.wifi.WifiManager.isWifiEnabled()
**android.accounts.AccountManager.getAccountsByType()**
android.net.wifi.WifiManager.getConnectionInfo()
android.location.LocationManager.getLastKnownLocation()
android.location.LocationManager.isProviderEnabled()
android.location.LocationManager.requestLocationUpdates()
android.net.NetworkInfo.isConnectedOrConnecting()
android.net.ConnectivityManager.getAllNetworkInfo()

**→ An *Outlier* in the “Travel” Cluster**

# Outlier Analysis

- In each cluster, identified outliers through *one-class support vector machine* (OC-SVM)
- Features of each APK: a vector of *(Sensitive API, #call sites)*



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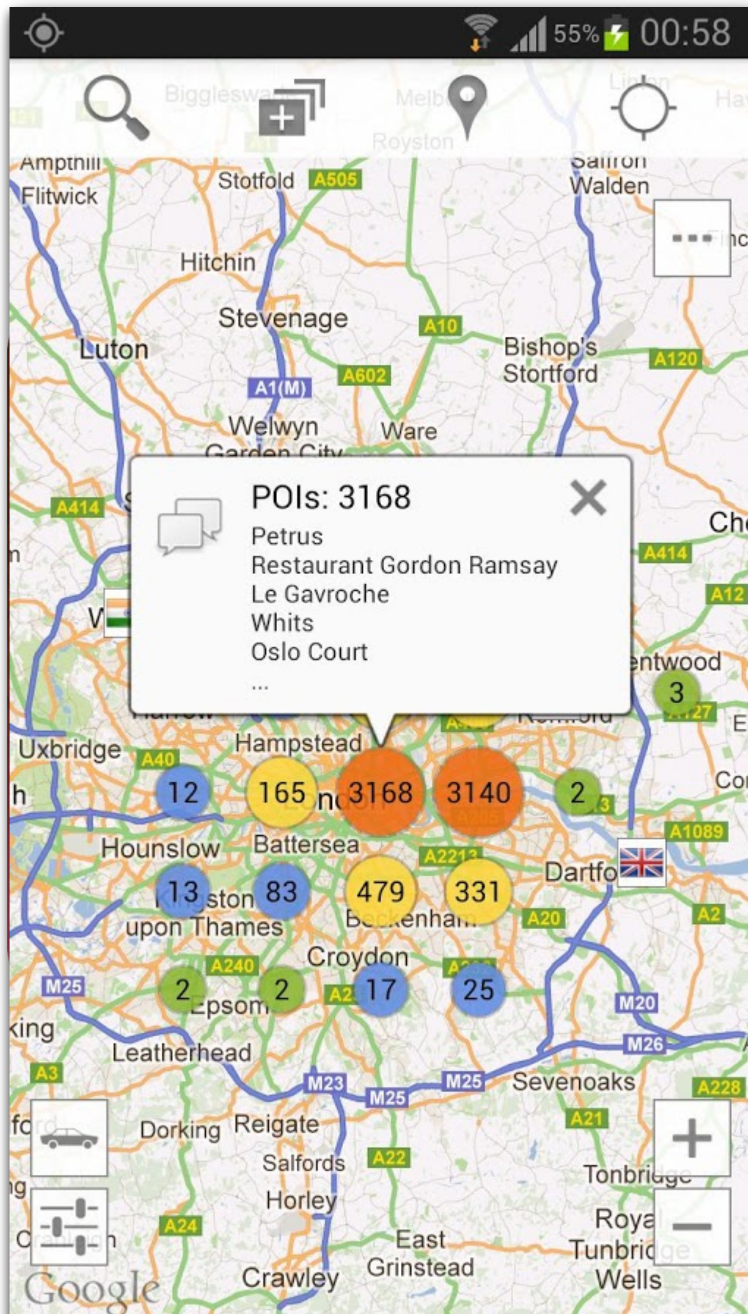


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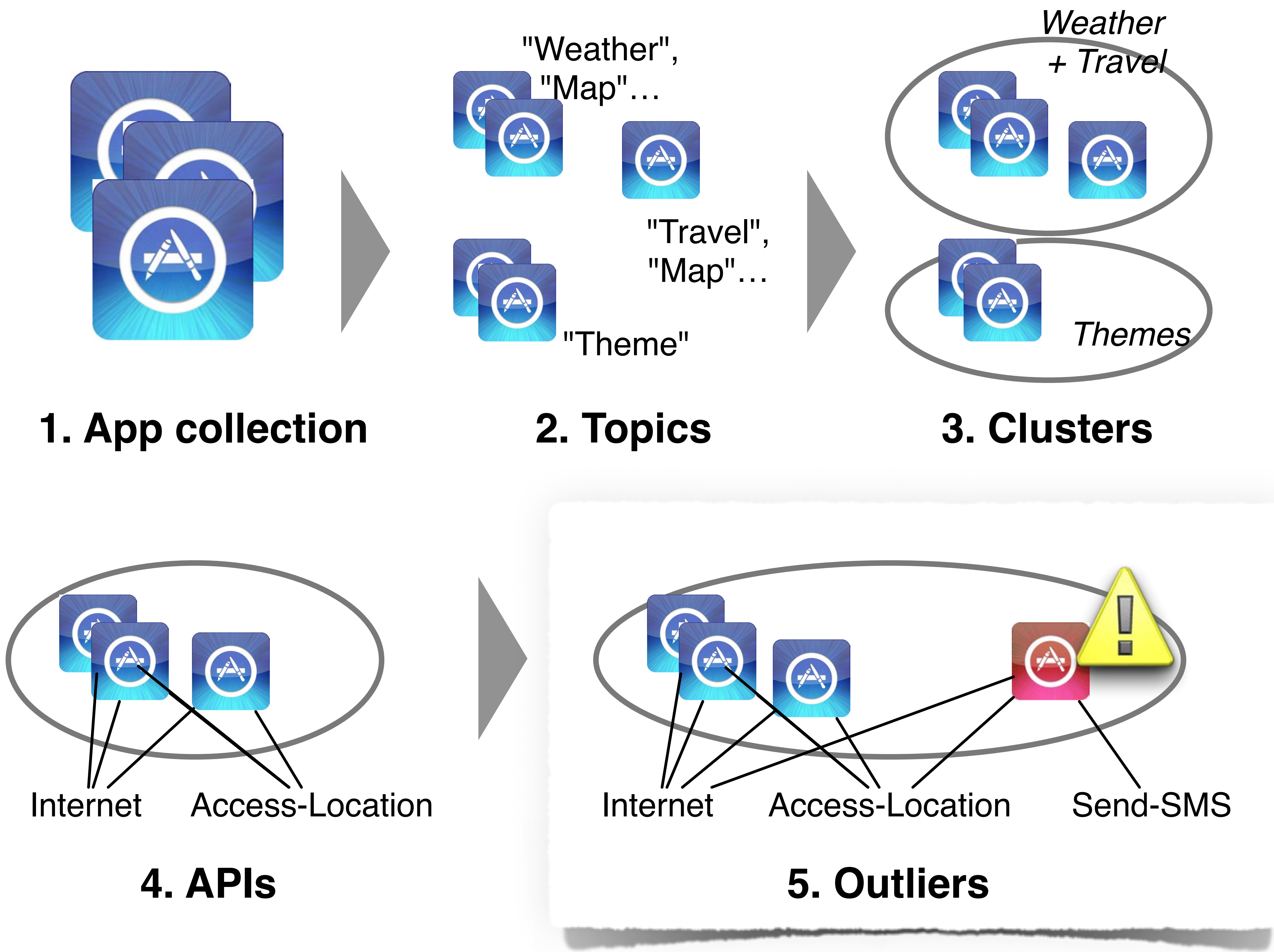
→ **Identified as Outlier**

# CHABADA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"Map"…
"Travel",
"Map"…
"Theme"
Weather
+ Travel
Themes
1. App collection
2. Topics
3. Clusters
Internet
Access-Location
Internet
Access-Location
Send-SMS
4. APIs
5. Outliers

# Evaluation: Outliers

- *Can our technique effectively identify anomalies (i.e., mismatches between description and behavior) in Android apps?*
- Manually checked
  top 5 outliers in each cluster (160 total)
- 26% showed *covert behavior using sensitive APIs that acts against the interest of its users.*

# What makes an outlier?

- Ad frameworks (apploving, airpush)
- Dubious behavior (UNO, WICKED, Yahoo!)
- Uncommon behavior (SoundCloud)
- Benign outliers (Mr. Will's Stud Poker)

# Evaluation: Malware

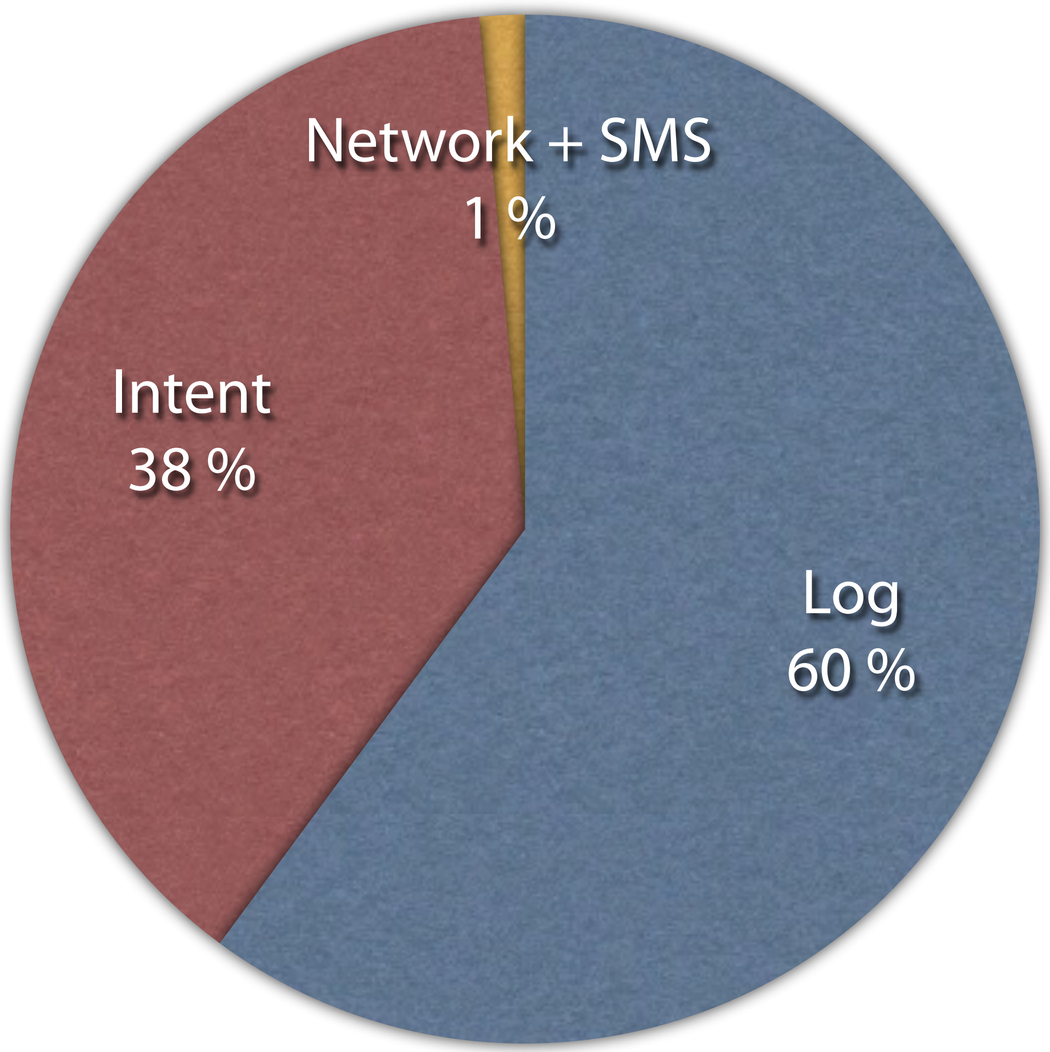
- *Can our technique be used to identify malicious Android applications?*
- In each cluster, trained OC-SVM on 90% of "benign" apps
- Used TF-IDF as classifier on sets with remaining "benign" apps and 173 known malware apps

**Malware recognition rate >80%**

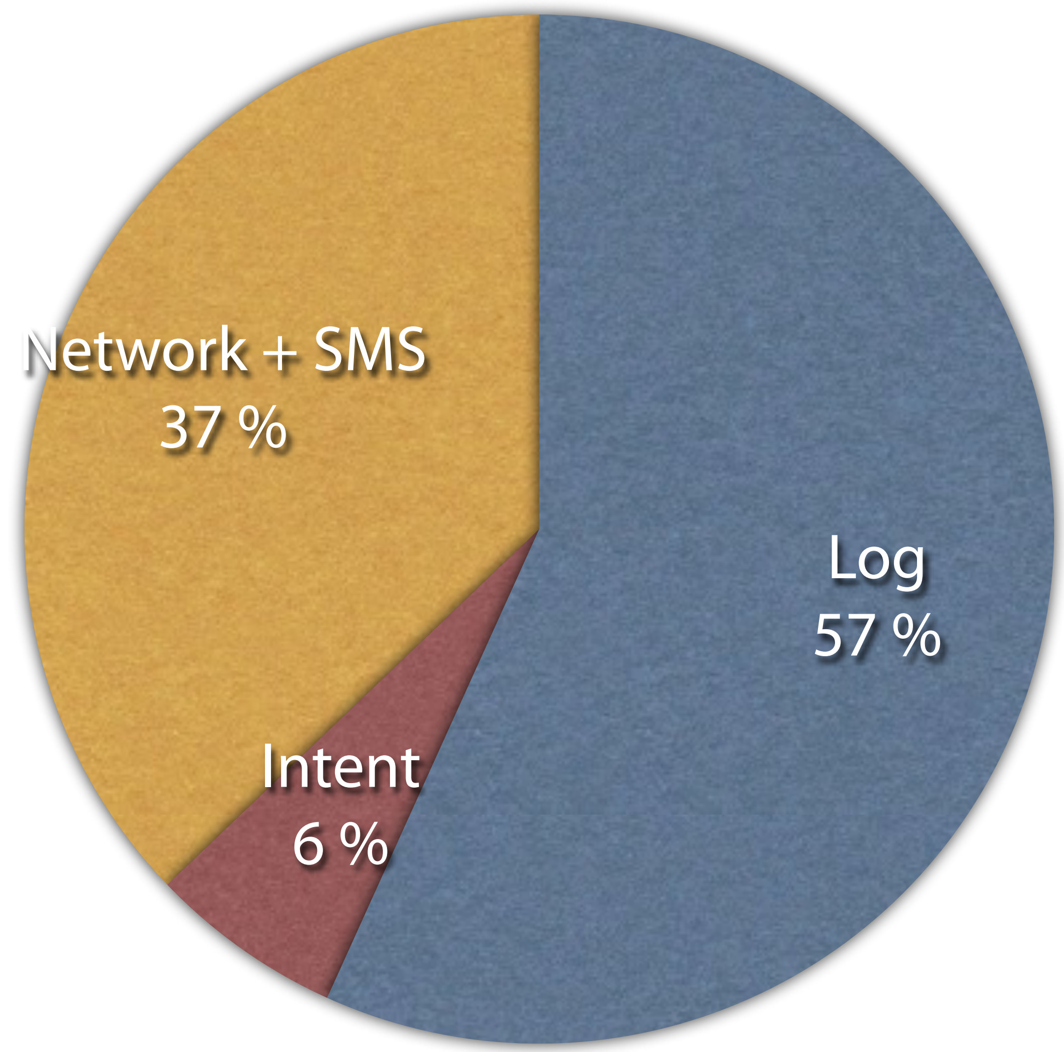
# Information Flow

- Which sensitive APIs does the *device ID* flow to?

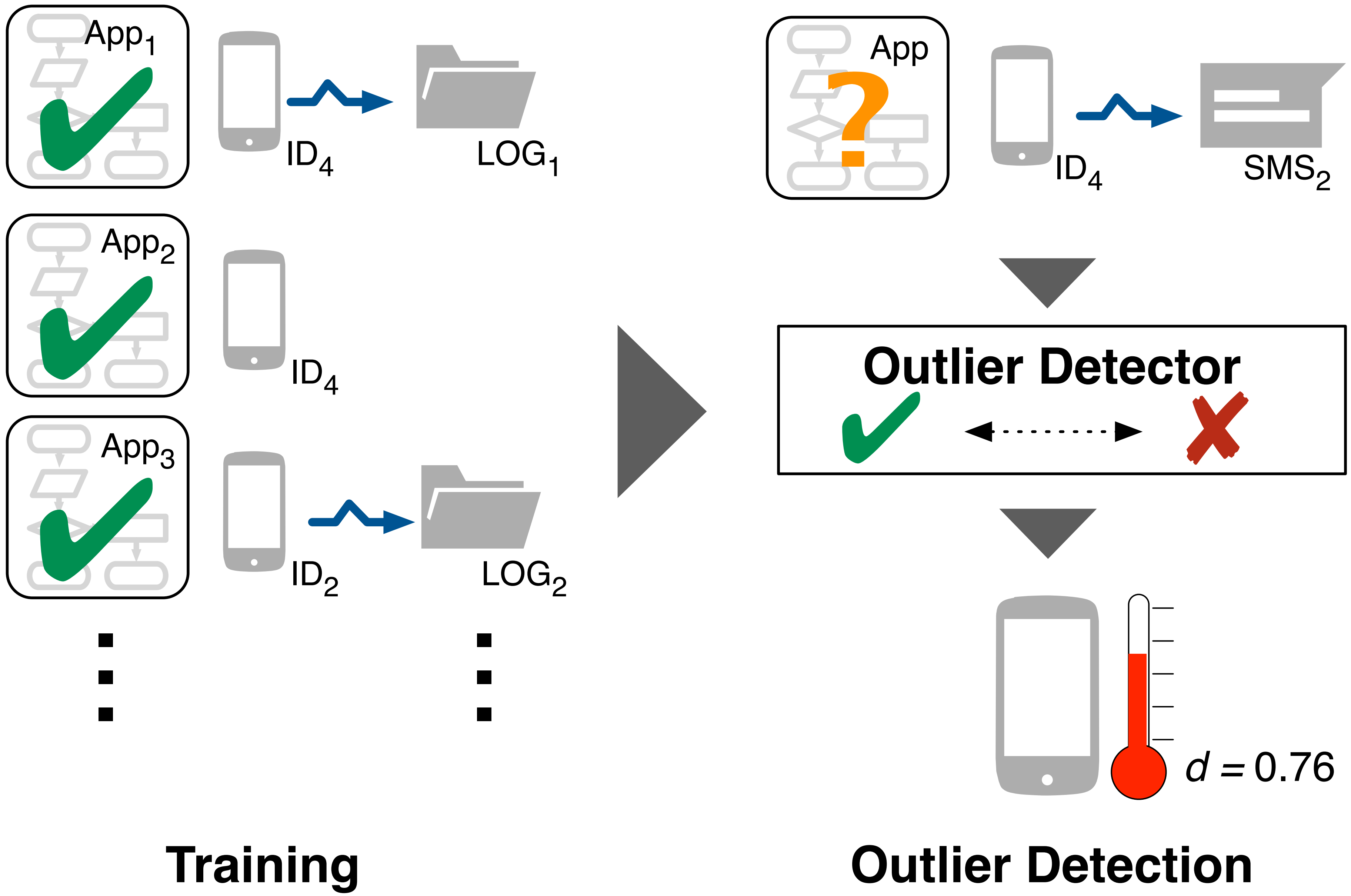
**Benign Apps**




**Malicious Apps**



# MUDFLOW



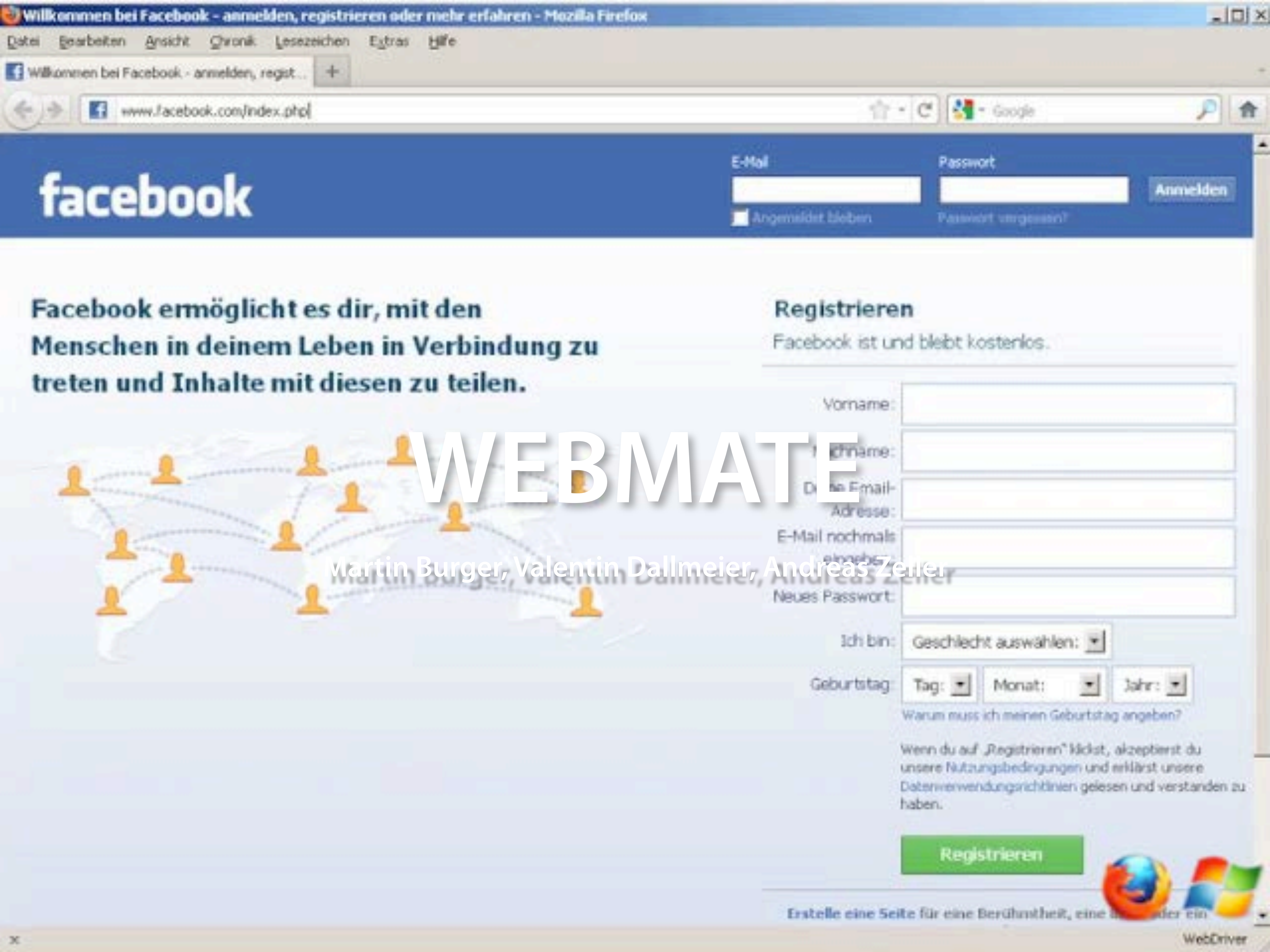

**Malware recognition rate >86%**

# Úlfar Erlingsson

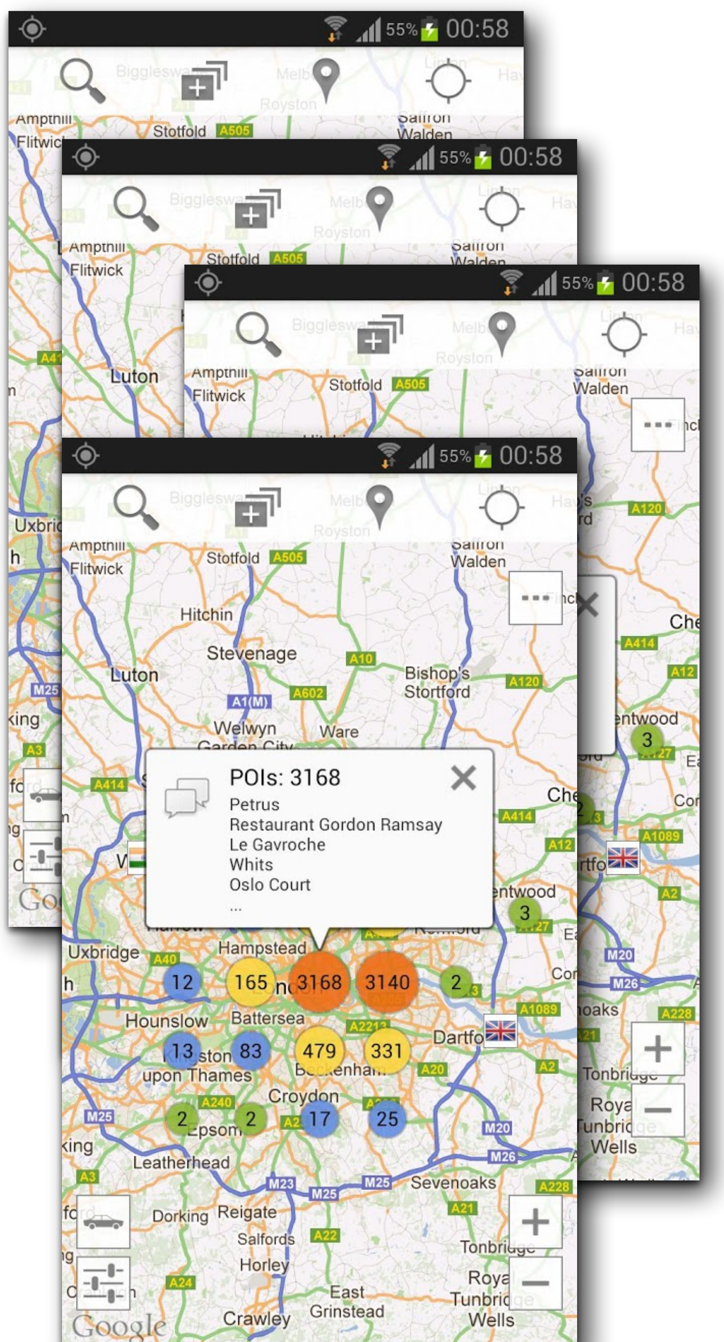

Error.
RAD
SHIFT
DRG
FSE
MR
MS
M+
hyp
sin
cos
tan
ln
log
%
7
9
DEL
AC

# WEBMATE

Martin Burger, Valentin Dallmeier, Andreas Zeller

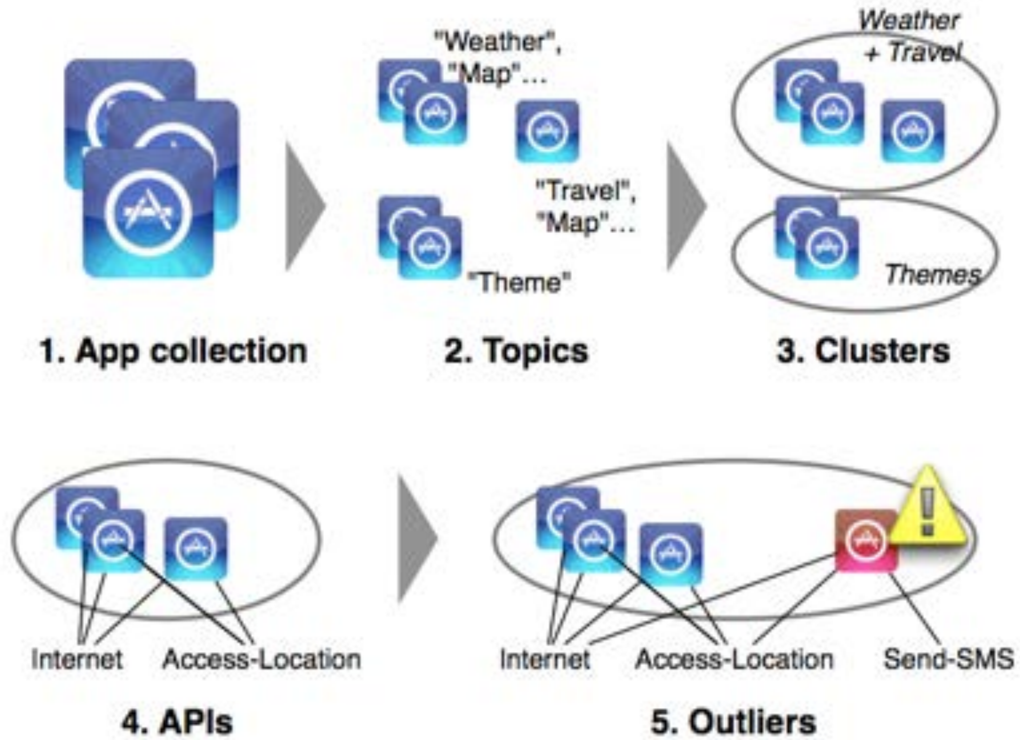


# App Mining




- For 100,000s of apps:
- Gather *descriptions*
- Gather *metadata*
- Gather *execution features*
- Find what is *common* and what is *uncommon*

# CHABADA




# Travel Cluster

Description


APIs used


# London Restaurants

android.net.ConnectivityManager.getActiveNetworkInfo()
android.webkit.WebView()
java.net.HttpURLConnection.connect()
android.app.NotificationManager.notify()
java.net.URL.openConnection()
**android.telephony.TelephonyManager.getDeviceId()**
org.apache.http.impl.client.DefaultHttpClient()
org.apache.http.impl.client.DefaultHttpClient.execute()
android.location.LocationManager.getBestProvider()
**android.telephony.TelephonyManager.getLine1Number()**
android.net.wifi.WifiManager.isWifiEnabled()
**android.accounts.AccountManager.getAccountsByType()**
android.net.wifi.WifiManager.getConnectionInfo()
android.location.LocationManager.getLastKnownLocation()
android.location.LocationManager.isProviderEnabled()
android.location.LocationManager.requestLocationUpdates()
android.net.NetworkInfo.isConnectedOrConnecting()
android.net.ConnectivityManager.getAllNetworkInfo()

**→ An *Outlier* in the "Travel" Cluster**

# Key Findings

- Of the top five API outliers per cluster,
  26% show unadvertised (covert) behavior
  - Typically *ad frameworks* (apploving, airpush)
  - Several anomalies (UNO, WICKED, Yahoo! Mail…)
- Using TF-IDF to classify API outliers per cluster,
  we could flag >80% of novel malware as such
- Current work: Dynamic API usage, information
  flow, user authorization

http://www.st.cs.uni-saarland.de/chabada/

erc Google