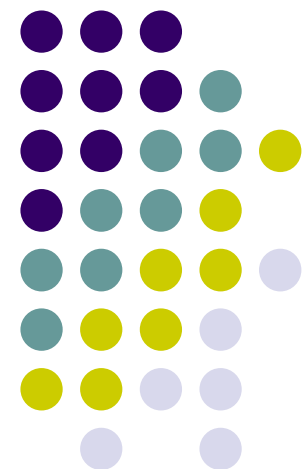


Ubiquitous and Mobile Computing

CS 528: *Falling asleep with Angry Birds, Facebook and Kindle: a large scale study on mobile application usage*

Di Yu

*Electrical and Computer Engineering Dept.
Worcester Polytechnic Institute (WPI)*



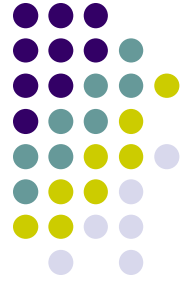
What's the problem?



Little public information exists on mobile application usage behavior:

- How long does each interaction with an app last?
- Does this vary by application category?
- How does the user's context (location and time) affect her app choices?
- What type of app is opened first?

... ..



Related Works

- Framework which is capable of tracking the high-level functionality => ***limited in number of users, length of study, and number of apps***
- Using app store to gather feedback to improve an app => ***is limited to single application***
- AppAware, which aggregating world-wide occurrences of app installation => ***only focus on installation, update and deinstallation***

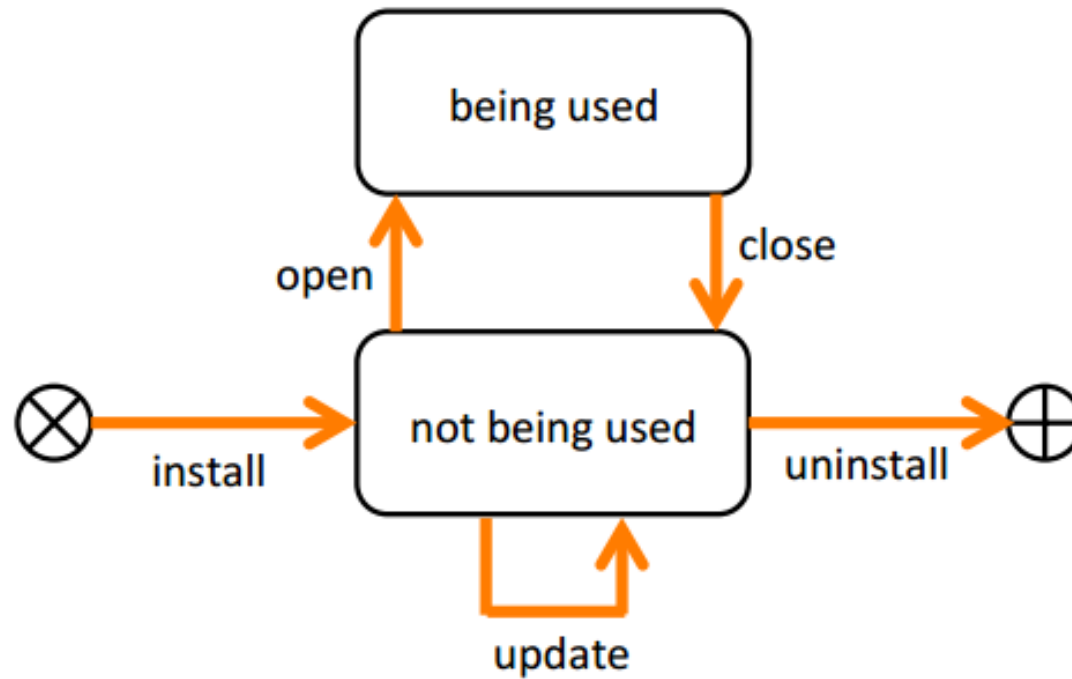
Solution: AppSensor



	Users	Apps	Days	Comment
Verkasalo [18]	324	~14	67	Investigation of contextual pattern of mobile device usage.
Froehlich et al. [10]	4-16	-	7-28	System for collecting in-situ data (pre-installed).
Demieux and Losguin [8]	11	-	2	A study with a strong focus on device usage (distributed via SMS).
Girardello & Michahellis [11]	19,000	-	-	Measuring popularity instead of usage (released to Android Market).
McMillan et al. [16]	8,674	1	154	Exploring world-wide field trials (released to iPhone App Store).
Henze et al. [12]	3,934	1	72	Evaluation of off-screen visualization (released to Android Market).
<i>AppSensor</i> (this paper)	4,125	22,626	127	Large scale study on app usage (released to Android Market).

- an approach of large-scale, in-the-wild user studies with the fine-grained measuring of app usage.

Lifecycle of a Mobile App





AppSensor features

- **focus on two app states**

 - being used

 - not being used

- **based on Android platform**

 - Android os can report the most recently started application

 - as part of [appazaar](#) application, runs background

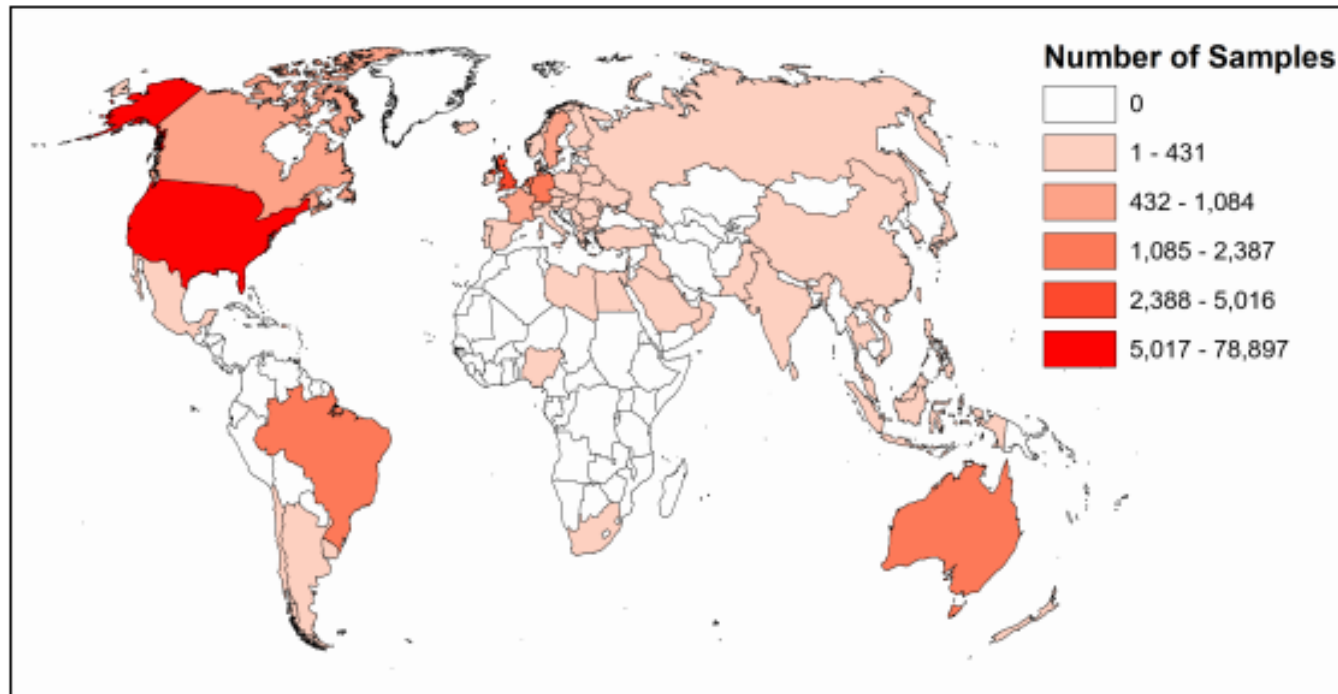


Formal Description of AppSensor

- $A = \{a_1, \dots, a_n\}$: set of apps that are available
 - ε : user is currently not using an app
 - $as(t) = \begin{cases} a_i & \text{if app } a_i \text{ is used} \\ \varepsilon & \text{if no app is used} \end{cases}$
- \Rightarrow $as(t_1) = as(t_2)$ the user is running the same app
 $as(t_1) \neq as(t_2)$ the user changes an app



Characteristics of Final Dataset



4,125 users, between 08/16/2010 to 01/25/2011



Category	Apps	Avg. usage	Exemplary Apps
unknown	4,823	36.37 sec	-
Finance	307	37.01 sec	Mint.com Personal Finance, Bank of America, Google Finance, iStockManager
Travel	782	44.72 sec	Google Maps, Yelp, Waze
Communication	881	46.92 sec	Google Mail, Handcent SMS, K-9 Mail
Productivity	1,062	61.49 sec	Calendar, Evernote, GTasks
Shopping	326	61.71 sec	Market, Barcode Scanner, Craigslist
Social	538	62.69 sec	Facebook for Android, Twitter, TweetDeck
Sports	385	65.98 sec	Yahoo! Fantasy Football '10, ESPN ScoreCenter, NFL Mobile
News	784	68.11 sec	NewsRob, reddit is fun, BBC News
Settings	1	68.71 sec	Default Settings App
Browser	10	74.01 sec	Default Browser, Skyfire Browser, Dolphin Browser
Entertainment	84	76.90 sec	IMDb Movies & TV, TV Guide Mobile, PhotoFunia
Multimedia	130	82.79 sec	Pandora Radio, Music, Camera
Comics	3,242	91.33 sec	DailyStrip, XkcdViewer, Dilbert Mobile
Games	2,822	114.25 sec	Angry Birds, Wordfeud FREE, Solitaire
Health	424	153.80 sec	CardioTrainer, Sleep Bot Tracker Log, Baby ESP
Lifestyle	956	167.77 sec	DailyHoroscope, Gentle Alarm, Epicurious Recipe
Reference	764	176.28 sec	Kindle for Android, Aldiko Book Reader, Audible
Tools	3,004	206.26 sec	AppBrain App Market, Apps Organizer, Google Goggles
Themes	1,061	258.28 sec	Zune Home, Fingerprint Screensaver, HomeChange
Libraries & Demos	240	274.23 sec	Google Services Framework, default Updater, Motorola Updater, Bubbles Demo, Ride Logger Demo, ES Task Manager

average usage time of every categories's apps

Descriptive Statistics

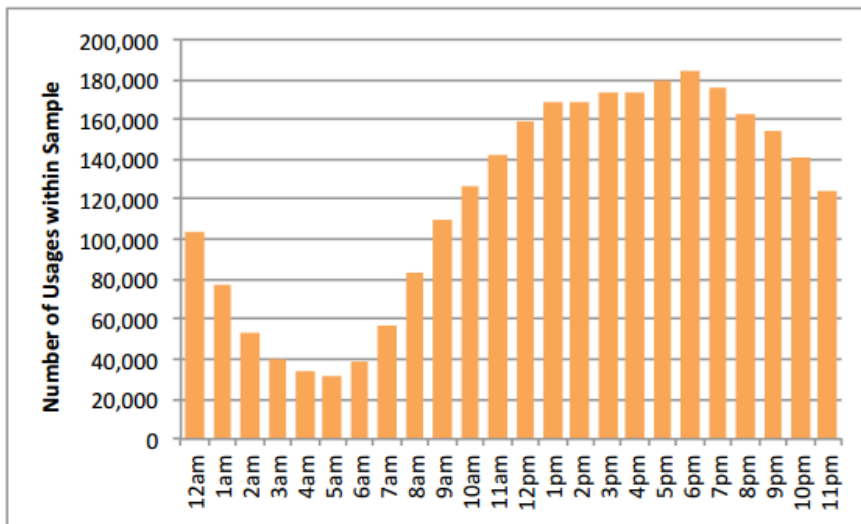
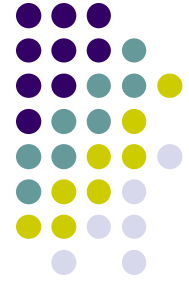


Figure 3. Total number of recorded app utilizations during a day.

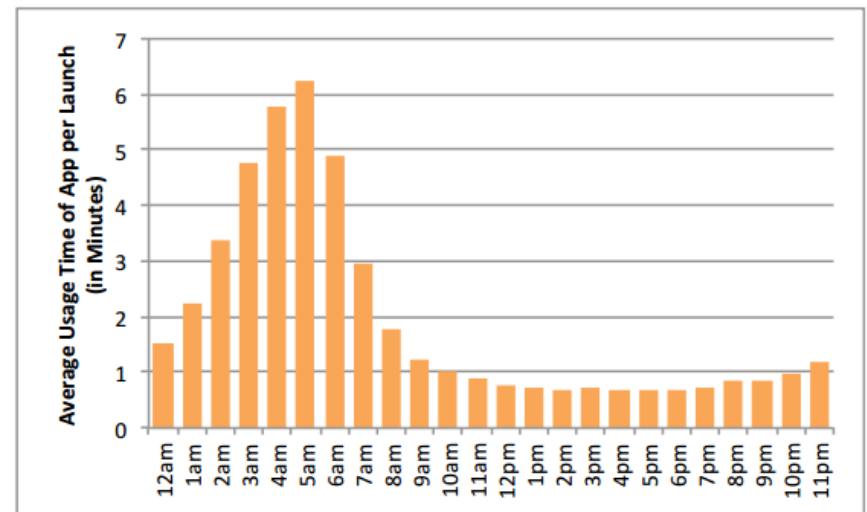


Figure 4. Daily average usage duration of opened apps per launch in minutes.



Application Usage over Time

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	% of Total Launches Users Apps		
Browser	7.9%	7.7%	7.8%	7.6%	7.3%	7.4%	7.0%	7.9%	8.1%	8.0%	7.7%	7.3%	7.0%	6.9%	6.8%	6.4%	6.6%	6.6%	6.4%	6.6%	7.0%	7.4%	7.5%	7.4%	6.83%	2,398	9
Comics	4.5%	5.2%	5.4%	5.8%	5.8%	5.6%	5.5%	5.2%	5.4%	5.1%	4.7%	4.3%	4.3%	4.2%	4.2%	4.3%	4.4%	4.0%	4.4%	4.2%	4.1%	4.1%	4.1%	4.4%	4.31%	2,151	1,810
Communication	44.9%	41.1%	38.3%	35.4%	31.6%	31.8%	32.7%	34.7%	39.4%	44.8%	49.0%	52.6%	54.8%	55.2%	55.2%	56.1%	55.7%	56.8%	57.1%	56.1%	54.8%	53.3%	52.0%	49.0%	49.50%	2,769	550
Entertainment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.02%	126	43
Finance	0.2%	0.3%	0.3%	0.2%	0.1%	0.1%	0.1%	0.2%	0.3%	0.3%	0.4%	0.5%	0.3%	0.3%	0.4%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.25%	604	164
Games	3.2%	3.0%	3.0%	2.7%	2.5%	2.3%	2.2%	1.7%	1.9%	1.9%	2.0%	2.1%	2.2%	2.2%	2.2%	2.3%	2.3%	2.2%	2.2%	2.4%	2.7%	3.0%	3.0%	3.2%	2.30%	1,716	1,702
Health	0.3%	0.4%	0.4%	0.4%	0.6%	0.6%	0.7%	0.6%	0.4%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.2%	0.3%	0.2%	0.3%	0.26%	540	227
Libraries & Demo	0.4%	0.5%	0.6%	0.7%	0.9%	0.8%	0.7%	0.6%	0.5%	0.4%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%	0.3%	0.30%	1,267	117
Lifestyle	0.8%	0.9%	1.0%	1.4%	1.3%	1.5%	1.4%	1.4%	1.1%	0.9%	0.6%	0.6%	0.5%	0.5%	0.5%	0.5%	0.6%	0.5%	0.3%	0.4%	0.4%	0.5%	0.5%	0.5%	0.60%	2,132	451
Multimedia	2.1%	2.1%	2.4%	2.4%	2.7%	2.4%	1.8%	1.8%	1.9%	1.7%	1.8%	2.0%	2.0%	2.0%	2.2%	2.1%	2.2%	2.4%	2.3%	2.3%	2.2%	2.1%	1.9%	2.0%	2.03%	1,713	76
News	2.6%	2.5%	2.6%	2.5%	2.5%	2.7%	3.3%	3.7%	4.1%	3.6%	3.0%	2.6%	2.5%	2.7%	2.5%	2.4%	2.2%	2.1%	2.3%	2.2%	2.3%	2.2%	2.3%	2.3%	2.46%	1,777	440
Productivity	3.6%	5.0%	5.0%	5.8%	6.3%	6.5%	6.0%	5.4%	4.8%	5.1%	4.9%	4.3%	4.2%	4.0%	4.0%	3.7%	3.4%	3.4%	3.0%	3.1%	3.1%	3.0%	2.9%	3.2%	3.76%	2,190	648
Reference	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.6%	0.6%	0.7%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.3%	0.4%	0.4%	0.4%	0.5%	0.5%	0.5%	0.6%	0.47%	903	346
Settings	1.3%	1.6%	1.5%	1.3%	1.6%	1.2%	1.2%	1.1%	1.3%	1.4%	1.4%	1.4%	1.2%	1.3%	1.2%	1.2%	1.3%	1.1%	1.1%	1.2%	1.2%	1.3%	1.3%	1.4%	1.23%	2,178	1
Shopping	3.9%	4.5%	3.7%	3.4%	3.2%	3.2%	3.1%	3.0%	3.1%	3.3%	3.2%	3.2%	3.2%	2.8%	2.9%	2.9%	2.7%	2.7%	2.7%	2.7%	2.8%	3.1%	3.6%	3.5%	2.96%	2,556	198
Social	5.7%	5.0%	4.9%	4.3%	4.2%	4.0%	4.4%	5.1%	5.3%	5.4%	5.2%	5.0%	4.7%	4.8%	4.9%	4.5%	4.5%	4.6%	4.6%	4.9%	5.2%	5.4%	5.8%	5.7%	4.77%	1,902	342
Sports	0.5%	0.3%	0.3%	0.2%	0.3%	0.3%	0.2%	0.3%	0.3%	0.3%	0.3%	0.4%	0.4%	0.6%	0.7%	0.8%	0.9%	0.8%	0.6%	0.6%	0.7%	0.8%	0.7%	0.7%	0.56%	571	215
Themes	0.2%	0.1%	0.2%	0.3%	0.4%	0.4%	0.4%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.14%	249	231
Tools	10.9%	12.2%	14.6%	17.6%	20.3%	21.5%	21.4%	18.6%	14.7%	10.4%	8.4%	6.8%	6.1%	5.9%	5.9%	5.9%	6.0%	6.1%	5.8%	6.0%	6.3%	6.8%	7.4%	9.1%	7.89%	2,512	1,688
Travel	1.4%	1.6%	2.1%	2.2%	2.4%	2.6%	2.2%	1.9%	2.0%	2.1%	2.0%	1.8%	1.9%	1.9%	1.9%	1.8%	2.0%	1.9%	2.2%	2.2%	1.9%	1.7%	1.6%	1.4%	1.86%	1,752	407
Unknown	4.7%	5.3%	5.1%	5.0%	5.3%	4.4%	5.0%	5.9%	4.6%	4.4%	4.1%	3.8%	3.5%	3.8%	3.7%	3.7%	4.0%	3.6%	3.7%	3.7%	3.7%	3.9%	4.1%	4.5%	3.88%	2,284	1,796
Total Launches per Hour	103,604	77,053	53,633	40,332	33,438	30,949	38,161	56,895	83,488	109,550	127,069	142,642	158,876	168,082	169,018	172,935	173,963	179,801	184,012	176,050	163,080	153,835	141,303	123,639			

hourly relative app usage by category in terms of launches

Chains of App Usage

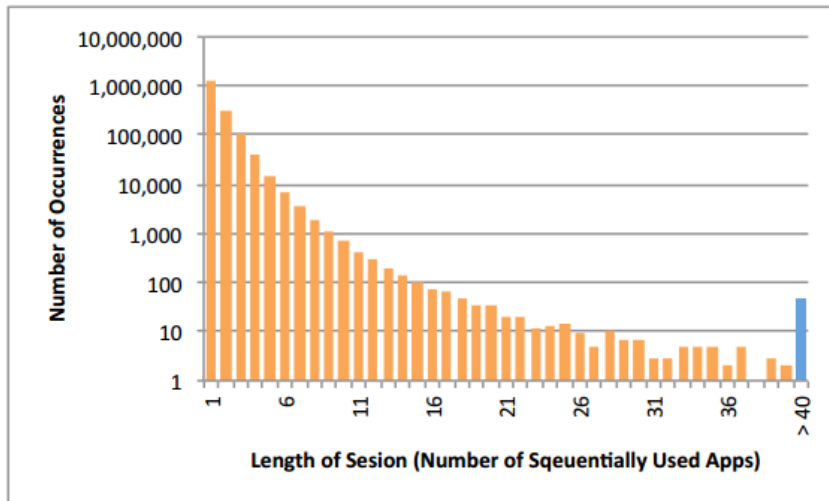


Figure 6. Number of apps used in a session. We aggregated sessions longer than 40 apps since the graph flattens out and scarcity increases. Maximum length is 237.

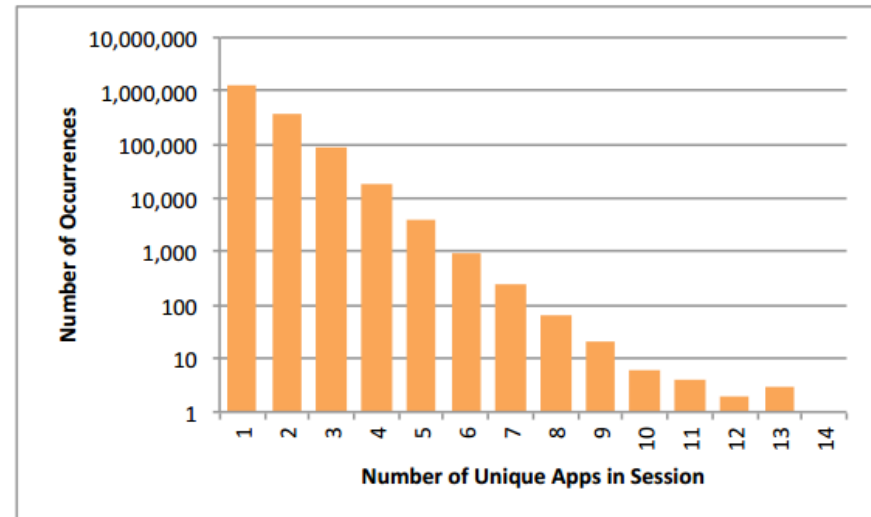


Figure 7. Occurrences of sessions according to number of unique apps used within a session.



Chains of App Usage

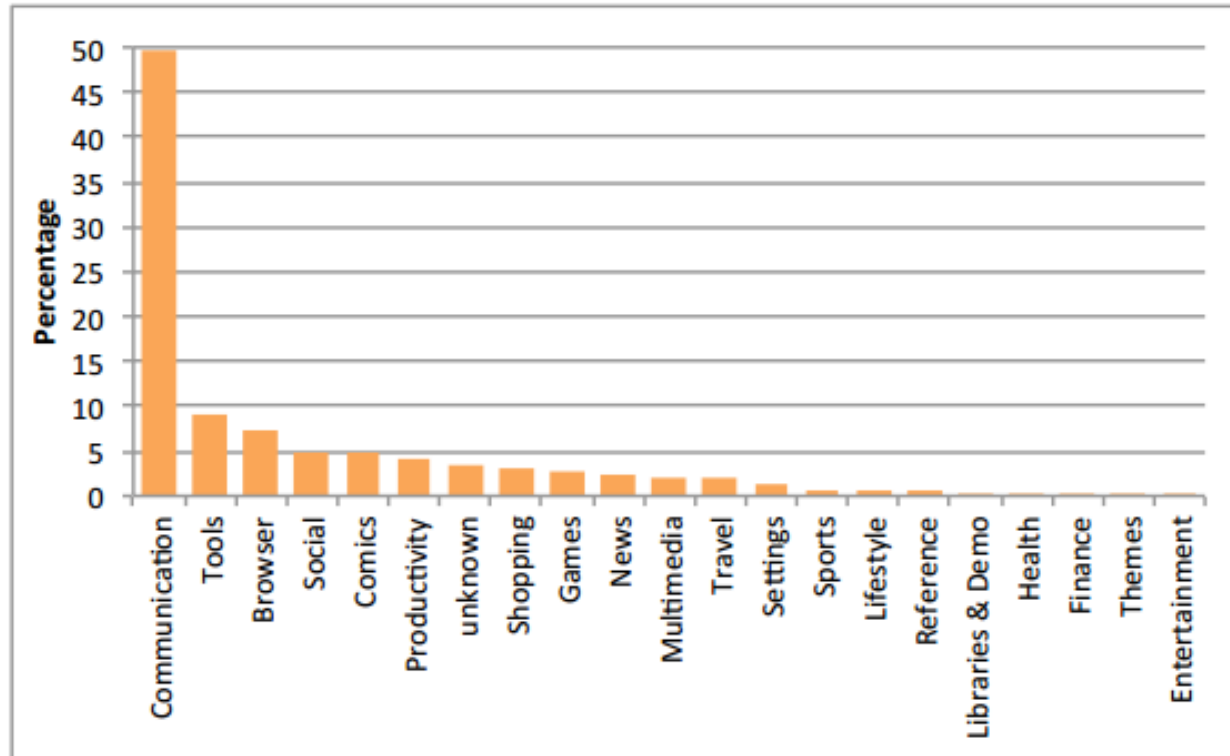


Figure 8. Categories of first used app within a session.

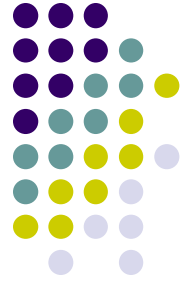
Chains of App Usage



	Browser	Comics	Communication	Entertainment	Finance	Games	Health	Libraries & Demo	Lifestyle	Multimedia	News	Productivity	Reference	Settings	Shopping	Social	Sports	Themes	Tools	Travel	Unknown	Samples	Users	Apps
Browser	2.4%	3.6%	33.8%	0.0%	0.3%	3.5%	0.2%	0.2%	0.4%	1.5%	11.8%	3.8%	0.6%	1.7%	3.6%	15.6%	0.5%	0.3%	8.1%	2.2%	6.1%	48,379	2,193	9
Comics	6.5%	9.4%	36.1%	0.0%	0.2%	4.8%	0.6%	0.2%	0.6%	5.2%	2.7%	4.1%	0.6%	2.2%	5.2%	4.3%	0.6%	0.4%	8.4%	2.7%	5.0%	31,258	1,754	1,220
Communication	5.7%	2.7%	65.5%	0.0%	0.2%	1.5%	0.1%	0.1%	0.2%	1.3%	2.1%	2.5%	0.3%	1.0%	1.7%	4.8%	0.4%	0.1%	5.0%	1.4%	3.2%	434,974	2,839	449
Entertainment	6.7%	6.1%	26.1%	0.0%	0.0%	3.3%	0.6%	0.0%	0.6%	5.6%	0.6%	2.8%	0.0%	3.3%	7.2%	3.3%	3.3%	0.0%	8.3%	5.6%	16.7%	180	65	28
Finance	10.3%	3.7%	37.3%	0.0%	1.8%	2.9%	0.2%	0.3%	0.2%	1.5%	8.6%	3.5%	0.1%	1.5%	5.5%	6.1%	0.7%	0.1%	10.6%	1.9%	3.1%	1,496	347	117
Games	11.8%	5.9%	30.4%	0.0%	0.3%	15.1%	0.3%	0.4%	0.7%	1.0%	2.1%	4.2%	0.7%	1.5%	6.5%	4.0%	0.8%	0.1%	8.3%	1.7%	4.2%	8,620	1,077	995
Health	3.8%	4.8%	34.3%	0.0%	0.3%	2.5%	6.1%	0.6%	1.2%	6.1%	2.9%	3.1%	1.6%	2.3%	6.0%	4.9%	0.8%	0.0%	12.4%	2.3%	3.9%	1,466	328	130
Libraries & Demo	6.0%	3.7%	23.3%	0.0%	0.2%	2.3%	0.3%	2.6%	0.8%	1.3%	1.7%	3.2%	0.3%	16.2%	11.9%	3.7%	0.3%	0.1%	13.4%	3.2%	5.5%	3,936	1,082	90
Lifestyle	8.2%	5.3%	17.3%	0.0%	0.1%	4.0%	0.5%	0.6%	3.0%	0.9%	2.3%	4.3%	0.7%	2.3%	28.7%	3.1%	0.2%	0.4%	10.2%	2.2%	5.5%	4,673	1,383	303
Multimedia	6.2%	10.5%	38.2%	0.0%	0.2%	1.4%	0.6%	0.2%	0.4%	2.5%	2.5%	6.2%	0.3%	2.0%	1.8%	4.4%	0.3%	0.4%	9.5%	3.2%	9.1%	12,451	1,376	53
News	33.6%	3.3%	33.3%	0.0%	0.5%	1.6%	0.2%	0.1%	0.2%	1.4%	3.9%	2.9%	0.4%	1.4%	3.0%	3.7%	0.4%	0.0%	6.5%	1.0%	2.4%	25,131	1,440	312
Productivity	7.4%	5.0%	38.5%	0.0%	0.4%	2.6%	0.4%	0.2%	0.6%	2.8%	2.8%	7.2%	1.1%	3.8%	4.8%	5.1%	0.6%	0.3%	9.7%	2.4%	4.4%	31,113	1,954	498
Reference	13.1%	4.5%	34.3%	0.0%	0.2%	7.5%	0.6%	0.3%	1.0%	1.0%	2.5%	4.6%	2.9%	1.7%	5.2%	4.1%	0.4%	0.2%	9.8%	1.7%	4.4%	2,611	552	199
Settings	8.9%	5.6%	26.3%	0.1%	0.2%	1.8%	0.4%	5.2%	0.7%	2.0%	2.6%	6.9%	0.5%	0.0%	5.6%	4.7%	0.6%	0.5%	11.6%	4.8%	11.1%	13,576	1,863	1
Shopping	8.5%	7.8%	23.2%	0.0%	0.4%	4.8%	0.4%	0.9%	9.6%	0.9%	2.8%	5.2%	0.7%	3.0%	4.7%	4.3%	0.5%	0.5%	16.6%	1.6%	3.8%	21,788	2,207	132
Social	24.1%	3.0%	35.3%	0.0%	0.3%	2.3%	0.2%	0.2%	0.3%	1.2%	2.9%	2.8%	0.3%	1.5%	2.7%	12.4%	0.7%	0.1%	5.3%	1.2%	3.3%	35,086	1,593	239
Sports	7.4%	4.3%	43.3%	0.1%	0.4%	2.5%	0.4%	0.2%	0.3%	1.3%	3.0%	4.8%	0.5%	2.4%	3.8%	5.4%	7.6%	0.0%	7.0%	1.5%	3.9%	2,793	387	135
Themes	8.5%	10.2%	37.2%	0.0%	0.2%	2.4%	0.1%	0.2%	1.4%	3.2%	0.4%	4.7%	0.4%	3.3%	6.5%	3.6%	0.1%	1.2%	8.6%	3.3%	4.6%	1,929	175	175
Tools	11.0%	5.1%	36.1%	0.0%	0.2%	2.7%	0.3%	0.4%	0.6%	2.1%	2.4%	4.2%	0.6%	2.1%	5.5%	4.1%	0.4%	0.2%	15.7%	2.8%	3.5%	88,911	2,384	1,310
Travel	6.7%	9.1%	36.2%	0.1%	0.2%	2.3%	0.3%	0.5%	0.7%	1.9%	1.6%	6.7%	0.4%	5.0%	2.9%	4.4%	0.3%	0.2%	10.2%	6.6%	3.6%	12,556	1,403	281
Unknown	10.7%	4.4%	40.8%	0.1%	0.2%	2.1%	0.2%	0.3%	0.6%	3.9%	1.8%	3.2%	0.3%	3.9%	2.9%	4.7%	0.3%	0.2%	6.4%	1.5%	11.6%	48,379	1,972	1,277

transition probabilities in app chains, from categories in a row to categories in a column

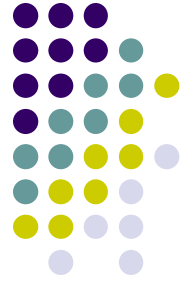
Application Usage by Location



When In an airport ...

- Users were 2.78 times more likely to be using a browser.
- Users were less likely to be using games, tool applications.
- During flight, users were more than 2.26 more likely to be using an app of Multimedia.
- Less likely(0.83) to be using apps about Travel.

Specific Application Usage



	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	% of Total Usage Time	Users
Facebook	4.8%	3.9%	4.0%	3.4%	3.2%	3.3%	3.8%	4.1%	4.1%	4.1%	3.9%	4.7%	4.0%	4.2%	4.1%	3.5%	4.1%	4.0%	4.3%	4.5%	4.7%	4.8%	5.6%	4.8%	1.91%	1,467
Google Maps	2.9%	1.7%	2.0%	1.8%	1.8%	1.8%	1.9%	2.2%	3.2%	4.0%	4.0%	5.0%	5.7%	5.6%	5.7%	5.8%	6.8%	6.4%	7.3%	6.6%	5.0%	4.8%	4.6%	3.4%	0.81%	1,584
Alarmclock 1	6.6%	8.2%	8.8%	10.0%	10.4%	9.7%	8.7%	6.8%	4.8%	3.3%	2.2%	1.4%	1.0%	1.0%	1.0%	1.0%	0.9%	0.6%	1.0%	1.2%	1.4%	2.0%	3.0%	5.0%	4.55%	341
Alarmclock 2	3.9%	4.3%	7.5%	9.2%	10.8%	10.7%	9.7%	9.2%	8.2%	7.7%	5.3%	3.3%	1.8%	0.5%	0.4%	0.3%	0.5%	0.6%	0.7%	0.4%	1.0%	0.6%	1.1%	2.0%	0.32%	169
Weather App	2.1%	0.9%	0.6%	0.3%	0.5%	2.0%	3.8%	2.2%	4.0%	10.1%	11.2%	9.8%	8.1%	3.2%	2.9%	5.9%	6.5%	4.3%	2.0%	4.9%	3.3%	4.0%	4.7%	2.5%	0.06%	309
Twitter	3.6%	3.3%	3.6%	4.4%	3.3%	3.0%	3.8%	4.0%	4.3%	4.3%	4.8%	4.7%	4.3%	4.4%	4.7%	4.6%	4.0%	4.1%	4.0%	4.6%	4.9%	4.8%	4.3%	4.1%	0.56%	457
Phone	2.6%	2.2%	1.9%	1.9%	1.8%	1.9%	1.9%	1.7%	2.4%	3.3%	4.1%	4.8%	5.2%	5.8%	5.7%	6.5%	6.4%	7.4%	7.6%	6.8%	5.8%	4.8%	4.1%	3.5%	1.94%	2,409
Angry Birds	5.3%	4.3%	3.2%	2.4%	1.6%	1.8%	1.5%	2.0%	1.8%	2.8%	3.5%	3.5%	4.6%	5.6%	4.9%	6.5%	4.7%	6.2%	5.6%	6.0%	5.1%	6.0%	5.4%	5.7%	0.64%	727
Kindle	9.1%	7.7%	6.9%	5.5%	4.0%	3.2%	2.9%	2.3%	1.7%	2.0%	2.3%	1.9%	2.8%	3.6%	2.6%	4.3%	2.5%	3.8%	3.1%	2.5%	4.9%	5.3%	7.3%	7.7%	0.47%	209
Calculator	2.6%	2.3%	2.0%	0.8%	0.7%	0.8%	1.1%	1.7%	2.8%	1.6%	6.6%	6.8%	7.1%	6.2%	5.6%	7.6%	7.7%	6.9%	5.8%	5.3%	6.8%	6.2%	3.3%	1.8%	0.19%	650
Calendar	5.1%	3.6%	0.7%	0.4%	0.2%	0.4%	3.8%	2.2%	3.9%	6.1%	7.6%	7.8%	6.3%	5.3%	3.5%	5.5%	5.8%	5.3%	3.8%	4.4%	5.6%	4.3%	3.1%	5.1%	0.14%	615
Camera	4.2%	4.3%	2.7%	3.5%	2.7%	2.0%	3.0%	2.2%	1.3%	2.6%	3.6%	3.2%	4.4%	5.7%	5.0%	5.1%	6.2%	6.7%	6.0%	4.7%	5.0%	5.8%	4.5%	5.7%	0.19%	781
Music	2.0%	3.6%	4.5%	5.1%	5.3%	5.4%	6.2%	6.1%	5.8%	4.5%	5.3%	3.7%	4.2%	3.8%	3.6%	3.6%	3.4%	3.6%	3.1%	4.1%	3.6%	3.8%	2.9%	2.8%	0.41%	483

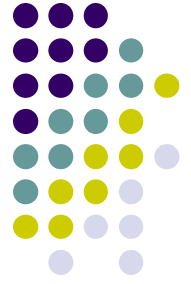
Top apps usage within a day based on hours



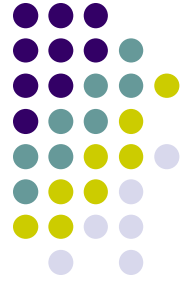
General Conclusion

- Users spend more than an hour a day using apps while spend less than 72 seconds with an app at a time.
- Mobile phones are still used mostly for communication.
- Some apps have spikes while others are broadly employed throughout the day.
- When actively using devices, users spend less time on a single app.
- People are less likely to use travel apps when travelling.

Vision: Making use of the AppSensor



- For inferring a user's context based on his actually used apps.
- Using the 'chains of app usage' to determine the users's current activity.
- Push useful informations based on the user's app usage history.



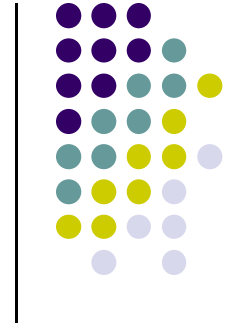
Limitations and tradeoff

- Some apps have a general purpose (browser)
- not capable of tracking multitasking
- currently dataset may not represent a general population
- Higher sampling rates results in both higher accuracy and higher power consumption

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Questions