Understanding Computer Usage Evolution

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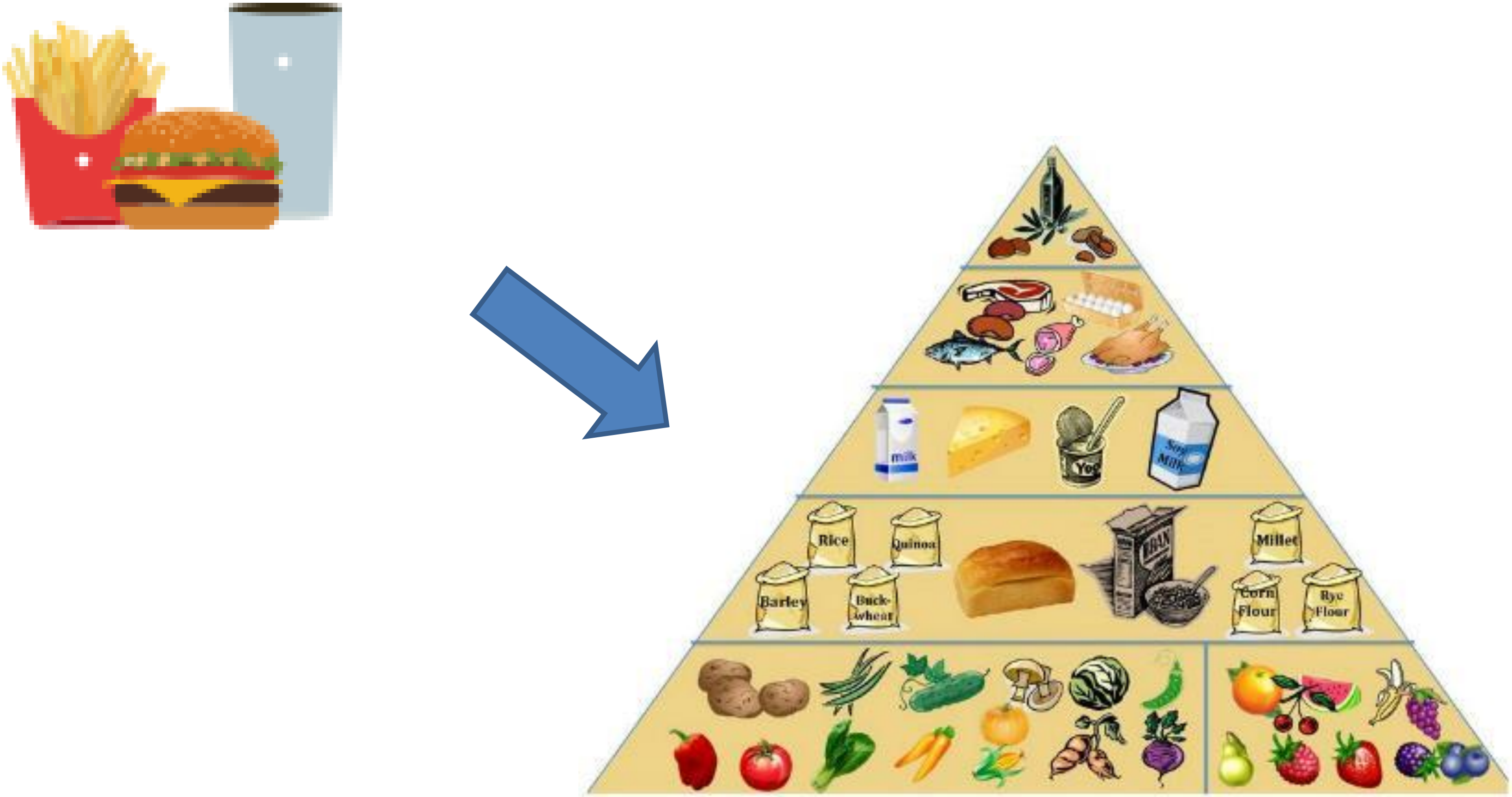
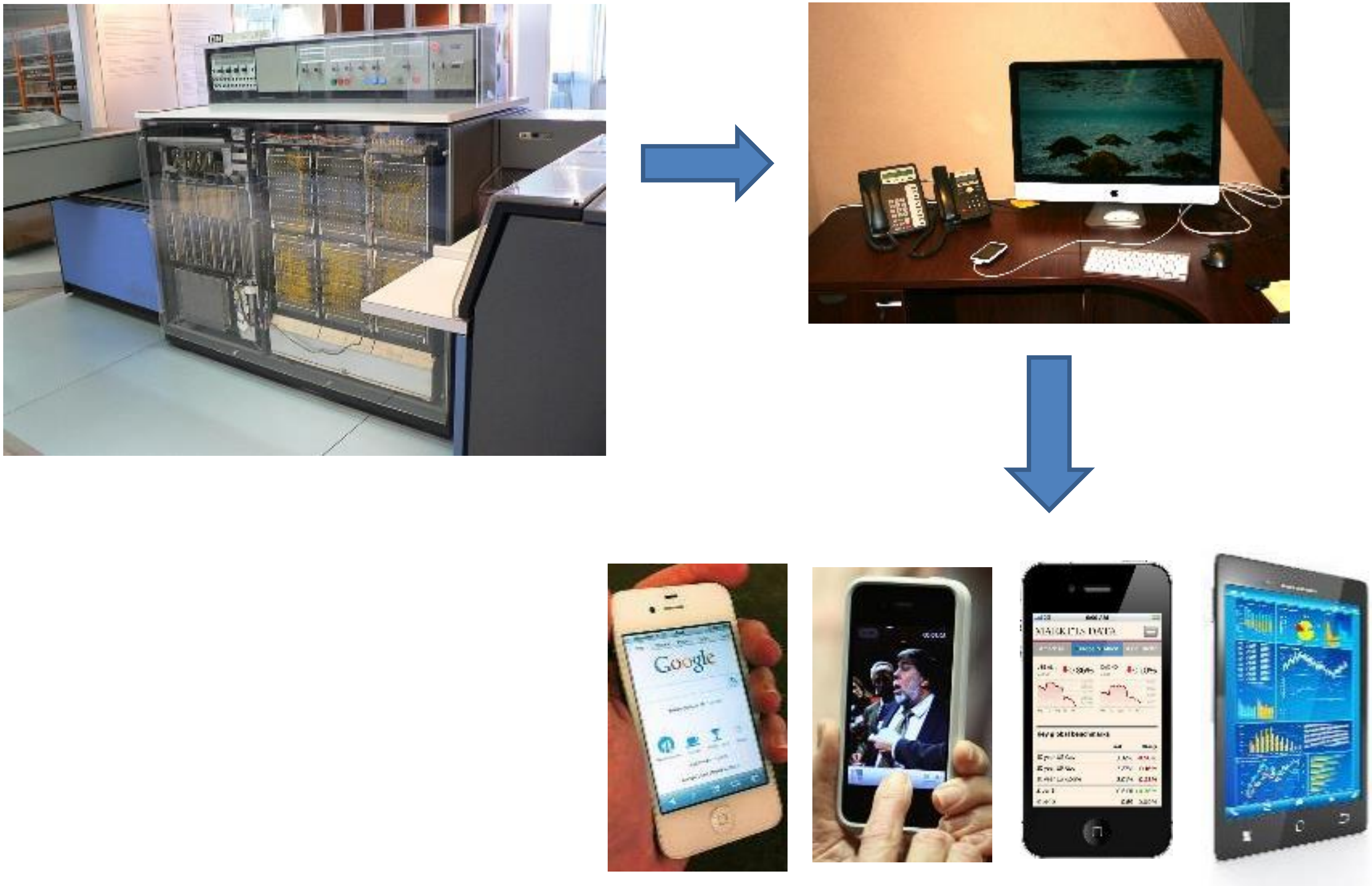
Behavior evolves!



Behavior evolves!



Context

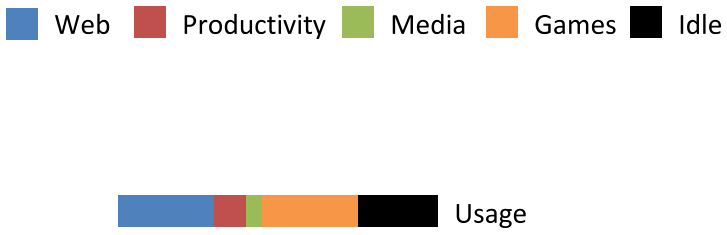
- Given various (summary) statistics related to how users use their PCs:
  - Activity information:
    - running applications, resource utilization, launch times, etc.
  - System status/configuration:
    - network type, CPU type and states, temperature, etc.
- Goal:
  - **model and characterize PC usage evolution.**
- Why?

Outline

- ~~Context of the work~~
- Modeling and characterizing the evolution of computer usage
- Orion: Cross-user usage segmentation
- Results on Intel’s usage data
- Next steps
- Recap

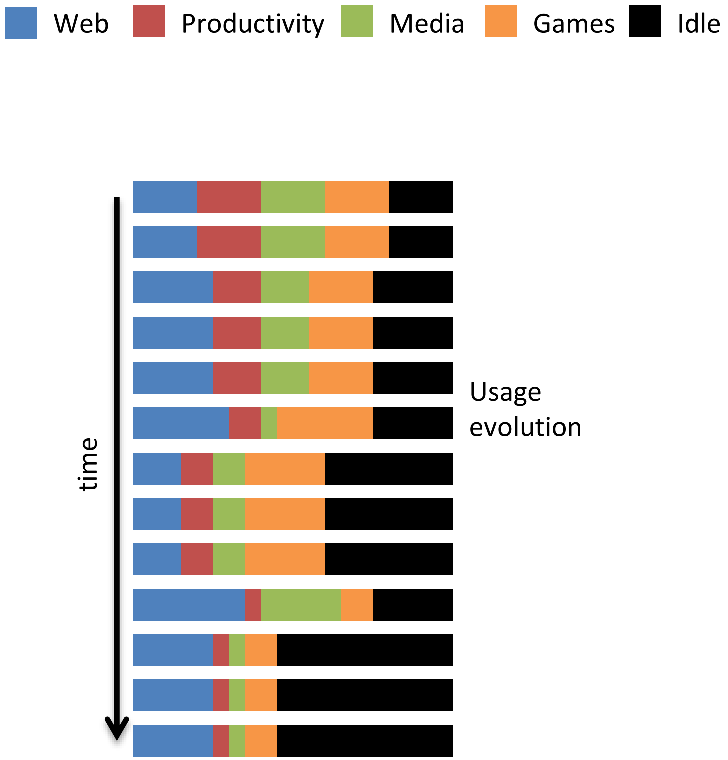
Computing usage evolution

- What is “usage”?



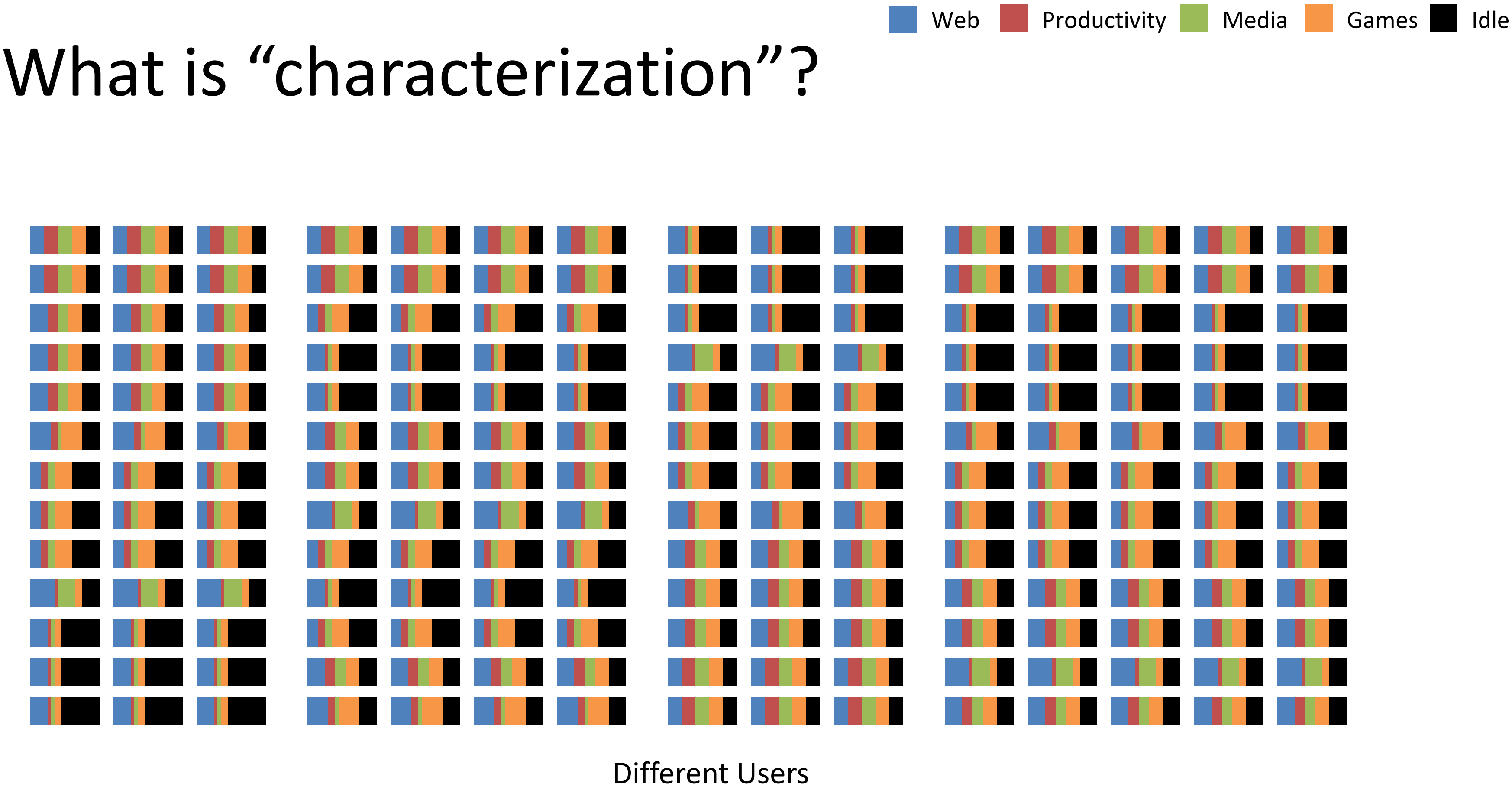
Computing usage evolution

- What is a “usage evolution”?



Usage evolution

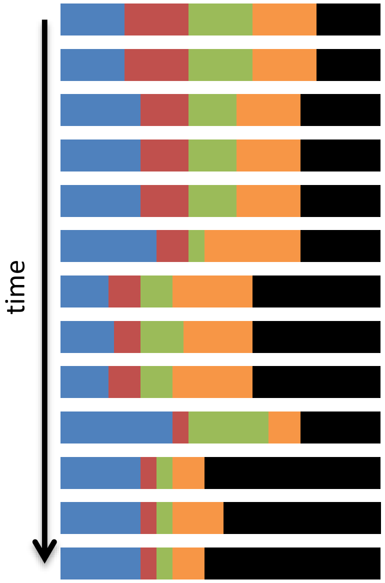
- What is “characterization”?



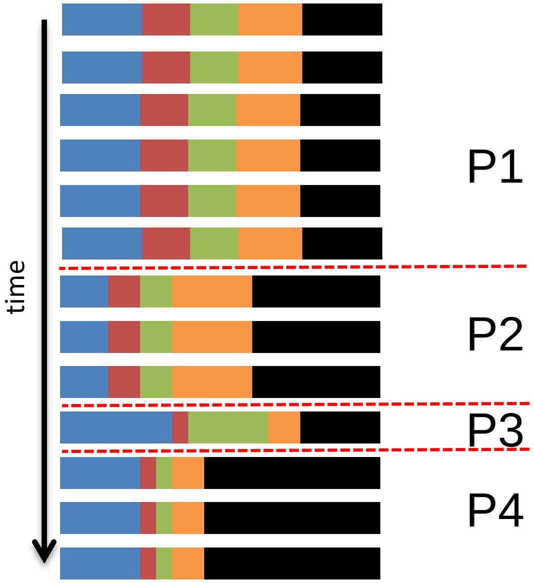
Key: common usage patterns

Characterize usage evolution

- We follow a segmentation based approach:
  - Partition a user’s usage sequence into disjoint consecutive sets of observations (segments) such that the usage in each segment remains fairly consistent.



Usage evolution



Proto evolution

Characterize usage evolution

- We follow a segmentation based approach:
  - Partition a user's usage sequence into disjoint consecutive sets of observations (segments) such that the usage in each segment remains fairly consistent.
  - Let $\langle \mathbf{w}_1, \ldots, \mathbf{w}_n \rangle$ be a sequence of usage vectors.
  - A segmentation into *m* segments optimizes a function of the form:

$$\min_{s_*, \mathbf{p}_l} \sum_{l=1}^{m} \sum_{j=s_{l-1}+1}^{s_l} ||\mathbf{w}_j - \mathbf{p}_l||^2.$$

  - The proto vector $\mathbf{p}_l$ captures the consistent usage during

$$\langle \mathbf{w}_{s_{l-1}+1}, \ldots, \mathbf{w}_{s_l} \rangle$$

- What if protos were shared among users?

Orion: Cross-user usage segmentation

- Input:
  - Sequences of usage vectors of a set of users.
  - A predefined number of protos.
- Output:
  - A segmentation of the sequences of all users such that the error associated with modeling each segment by one of the protos is minimized.

$$\min_{s_*, m_*, \mathbf{p}_*} \sum_{i=1}^{n} \sum_{l=1}^{m_i} \sum_{j=s_{i,l-1}+1}^{s_{i,l}} ||\mathbf{w}_{i,j} - \mathbf{p}_{i,l}||^2$$

Orion: Algorithmic details

- Iterative algorithm, whose iterations consists of two phases:
  - – Given the current set of protos, it identifies the segmentation that minimizes the total error.
  - – Given the segmentation, it identifies the protos that minimize the total error.

$$\min_{s_*, m_*, \mathbf{p}_*} \sum_{i=1}^{n} \sum_{l=1}^{m_i} \sum_{j=s_{i,l-1}+1}^{s_{i,l}} ||\mathbf{w}_{i,j} - \mathbf{p}_{i,l}||^2$$

Orion: Algorithmic details (3)

- Initialization:
  - The initial protos are determined by performing a *K*-means clustering of all usage vectors across all users.
- Robustness:
  - Minimum length constraints on each segment.
  - A penalty associated with the creation of each additional segment within a user’s sequence.
    - A segment is allowed to be created if it leads to a user-specified reduction in the approximation error.

Orion: Model assumptions

- The different users exhibit a rather small number of prototypical usage behaviors
  - that are captured by the protos.
- The usage behavior of users remains consistent over a certain period.
- The usage behavior of users can change from one prototypical behavior to another.

proto#:duration

$$
\begin{aligned}
&\text{User } 1\text{: } \langle p_1{:}15, p_5{:}11\rangle \\
&\text{User } 2\text{: } \langle p_2{:}5, p_3{:}10, p_2{:}7, p_5{:}22\rangle \\
&\text{User } 3\text{: } \langle p_1{:}11, p_4{:}15, p_5{:}40\rangle \\
&\text{User } 4\text{: } \langle p_1{:}13, p_5{:}25\rangle \\
&\vdots \\
&\text{User } n\ {:}\langle p_7{:}43\rangle
\end{aligned}
$$

DATA

Intel data

- Users' systems provide Intel servers with:
  - Daily summary application usage statistics
    - Execution start and end time
    - CPU time
    - Number of page faults
  - Geo-location (at the country level)
  - System type
  - CPU type
  - OS first start date
- 7.52 B initial records, aggregated to 2.13 B weekly
- Much noise, e.g. 1.49 B records with 0 utilization

Data filtering

- App filtering:
  - Removed unknown, system, and internet apps
  - Removed records with < 60s/week utilization
  - Removed apps with < 2K records
- User filtering:
  - Kept users with > 5/week utilizations in > 20 weeks

# users	28360
# apps	762
# records	11.05M

We only present results for analyzing the dataset using 15 protos.

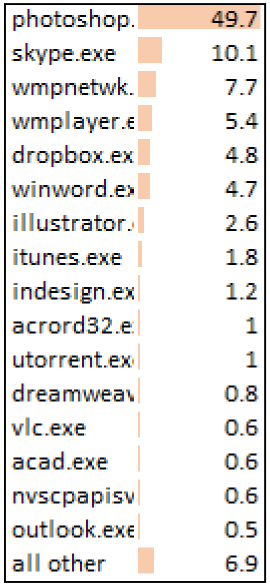
RESULTS

Prototypical behaviors (protos)

- Work/productivity related behaviors

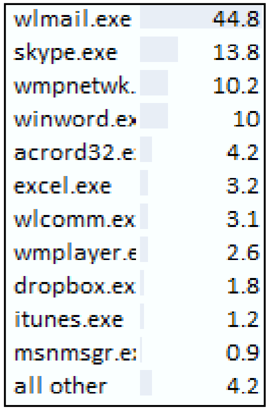
#usage vectors

P2 (32K)
Media creation



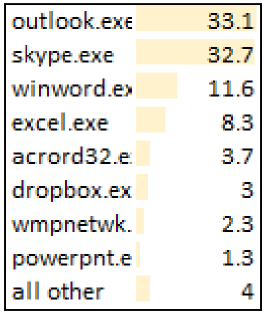
photoshop.	49.7
skype.exe	10.1
wmpnetwk.	7.7
wmplayer.e	5.4
dropbox.ex	4.8
winword.ex	4.7
illustrator.	2.6
itunes.exe	1.8
indesign.ex	1.2
acrord32.e	1
utorrent.ex	1
dreamweav	0.8
vlc.exe	0.6
acad.exe	0.6
nvscpapisv	0.6
outlook.exe	0.5
all other	6.9

P3 (31K)
Email & office



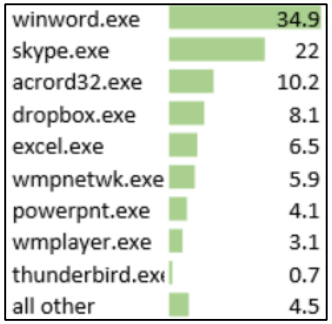
wlmail.exe	44.8
skype.exe	13.8
wmpnetwk.	10.2
winword.ex	10
acrord32.e	4.2
excel.exe	3.2
wlcomm.ex	3.1
wmplayer.e	2.6
dropbox.ex	1.8
itunes.exe	1.2
msnmsgr.e	0.9
all other	4.2

P4 (106K)
Business
communication



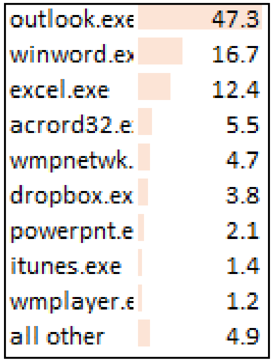
outlook.exe	33.1
skype.exe	32.7
winword.ex	11.6
excel.exe	8.3
acrord32.e	3.7
dropbox.ex	3
wmpnetwk.	2.3
powerpnt.e	1.3
all other	4

P9 (83K)
Writer



winword.exe	34.9
skype.exe	22
acrord32.exe	10.2
dropbox.exe	8.1
excel.exe	6.5
wmpnetwk.exe	5.9
powerpnt.exe	4.1
wmplayer.exe	3.1
thunderbird.exe	0.7
all other	4.5

P10 (105)
Office

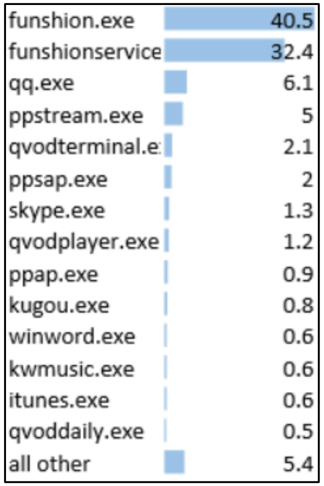


outlook.exe	47.3
winword.ex	16.7
excel.exe	12.4
acrord32.e	5.5
wmpnetwk.	4.7
dropbox.ex	3.8
powerpnt.e	2.1
itunes.exe	1.4
wmplayer.e	1.2
all other	4.9

Prototypical behaviors (protos)

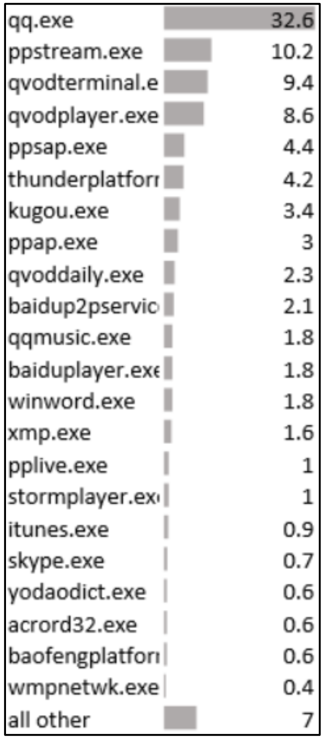
- Asian media & social related behaviors

P7 (22K)
Asian media
downloads

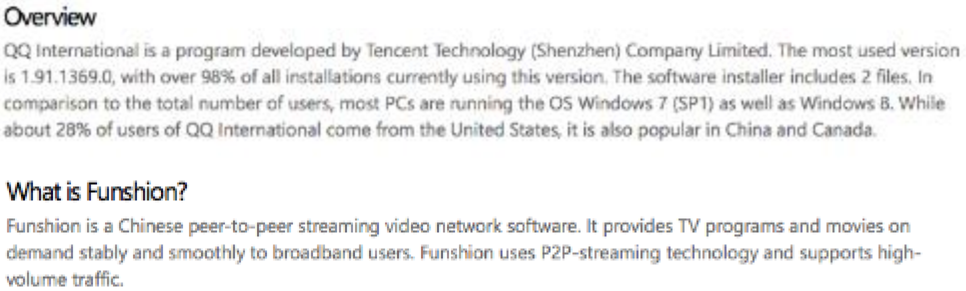


funshion.exe	40.5
funshionservice	32.4
qq.exe	6.1
ppstream.exe	5
qvodterminal.e	2.1
ppsap.exe	2
skype.exe	1.3
qvodplayer.exe	1.2
ppap.exe	0.9
kugou.exe	0.8
winword.exe	0.6
kwmusic.exe	0.6
itunes.exe	0.6
qvoddaily.exe	0.5
all other	5.4

P8 (31K)
Asian messenger



qq.exe	32.6
ppstream.exe	10.2
qvodterminal.e	9.4
qvodplayer.exe	8.6
ppsap.exe	4.4
thunderplatfor	4.2
kugou.exe	3.4
ppap.exe	3
qvoddaily.exe	2.3
baidup2pservic	2.1
qqmusic.exe	1.8
baiduplayer.exe	1.8
winword.exe	1.8
xmp.exe	1.6
pplive.exe	1
stormplayer.ex	1
itunes.exe	0.9
skype.exe	0.7
yodaodict.exe	0.6
acrord32.exe	0.6
baofengplatfor	0.6
wmpnetwk.exe	0.4
all other	7



Overview

QQ International is a program developed by Tencent Technology (Shenzhen) Company Limited. The most used version is 1.91.1369.0, with over 98% of all installations currently using this version. The software installer includes 2 files. In comparison to the total number of users, most PCs are running the OS Windows 7 (SP1) as well as Windows 8. While about 28% of users of QQ International come from the United States, it is also popular in China and Canada.

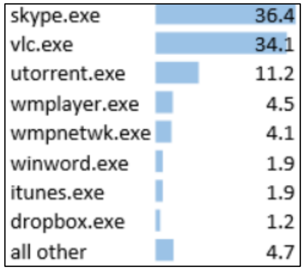
What is Funshion?

Funshion is a Chinese peer-to-peer streaming video network software. It provides TV programs and movies on demand stably and smoothly to broadband users. Funshion uses P2P-streaming technology and supports high-volume traffic.

Prototypical behaviors (protos)

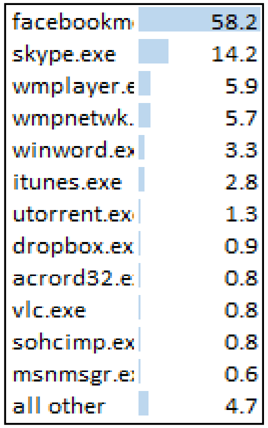
- Media & social related behaviors

P0 (37K)
Communicate & watch



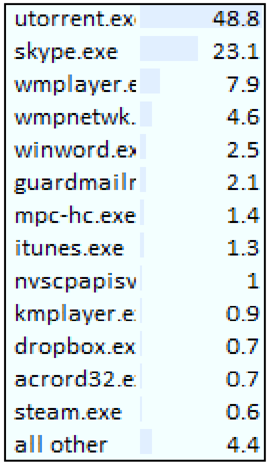
skype.exe	36.4
vlc.exe	34.1
utorrent.exe	11.2
wmplayer.exe	4.5
wmpnetwk.exe	4.1
winword.exe	1.9
itunes.exe	1.9
dropbox.exe	1.2
all other	4.7

P14 (71K)
Facebook Messenger



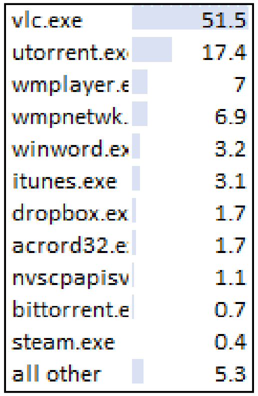
facebookm	58.2
skype.exe	14.2
wmplayer.e	5.9
wmpnetwk.	5.7
winword.ex	3.3
itunes.exe	2.8
utorrent.ex	1.3
dropbox.ex	0.9
acrord32.e	0.8
vlc.exe	0.8
sohcimp.ex	0.8
msnmsgr.e	0.6
all other	4.7

P1 (83K)
File transfers



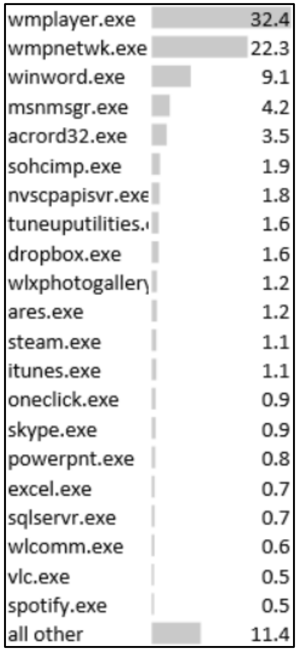
utorrent.ex	48.8
skype.exe	23.1
wmplayer.e	7.9
wmpnetwk.	4.6
winword.ex	2.5
guardmailr	2.1
mpc-hc.exe	1.4
itunes.exe	1.3
nvscpapisv	1
kmplayer.e	0.9
dropbox.ex	0.7
acrord32.e	0.7
steam.exe	0.6
all other	4.4

P5 (48K)
Media downloads



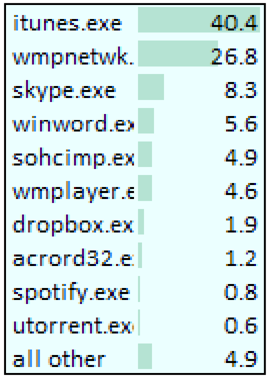
vlc.exe	51.5
utorrent.ex	17.4
wmplayer.e	7
wmpnetwk.	6.9
winword.ex	3.2
itunes.exe	3.1
dropbox.ex	1.7
acrord32.e	1.7
nvscpapisv	1.1
bittorrent.e	0.7
steam.exe	0.4
all other	5.3

P6 (105K)
Media player



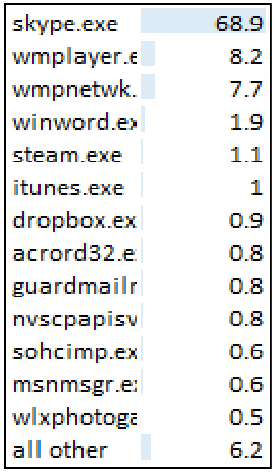
wmplayer.exe	32.4
wmpnetwk.exe	22.3
winword.exe	9.1
msnmsgr.exe	4.2
acrord32.exe	3.5
sohcimp.exe	1.9
nvscpapisvr.exe	1.8
tuneuputilities.	1.6
dropbox.exe	1.6
wlxphotogaller	1.2
ares.exe	1.2
steam.exe	1.1
itunes.exe	1.1
oneclick.exe	0.9
skype.exe	0.9
powerpnt.exe	0.8
excel.exe	0.7
sqlservr.exe	0.7
wlcomm.exe	0.6
vlc.exe	0.5
spotify.exe	0.5
all other	11.4

P11 (72K)
iTunes



itunes.exe	40.4
wmpnetwk.	26.8
skype.exe	8.3
winword.ex	5.6
sohcimp.ex	4.9
wmplayer.e	4.6
dropbox.ex	1.9
acrord32.e	1.2
spotify.exe	0.8
utorrent.ex	0.6
all other	4.9

P12 (115K)
Skype

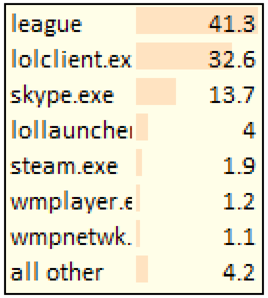


skype.exe	68.9
wmplayer.e	8.2
wmpnetwk.	7.7
winword.ex	1.9
steam.exe	1.1
itunes.exe	1
dropbox.ex	0.9
acrord32.e	0.8
guardmailr	0.8
nvscpapisv	0.8
sohcimp.ex	0.6
msnmsgr.e	0.6
wlxphotoga	0.5
all other	6.2

Prototypical behaviors (protos)

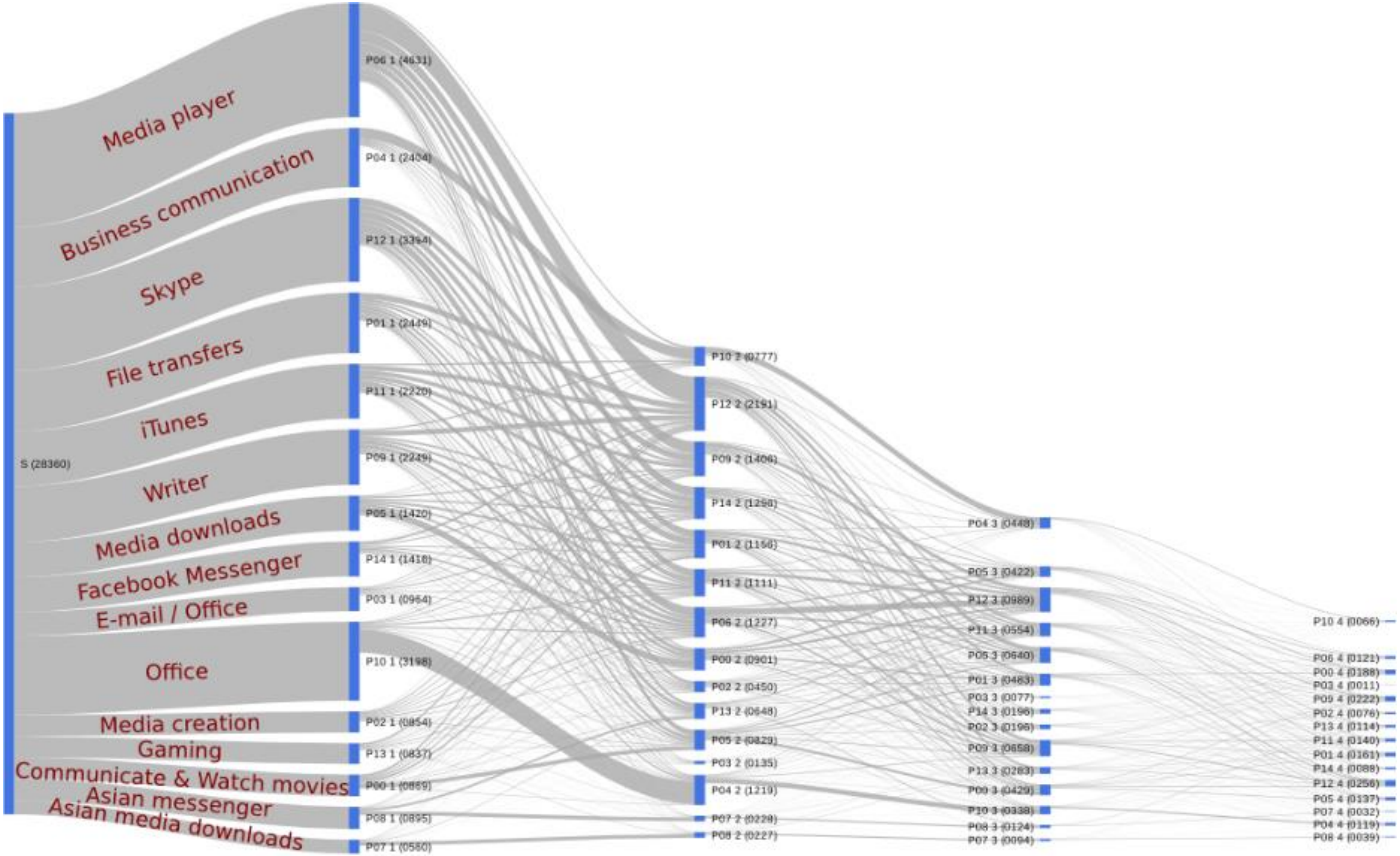
- Gaming

P13 (35K)
Gaming`

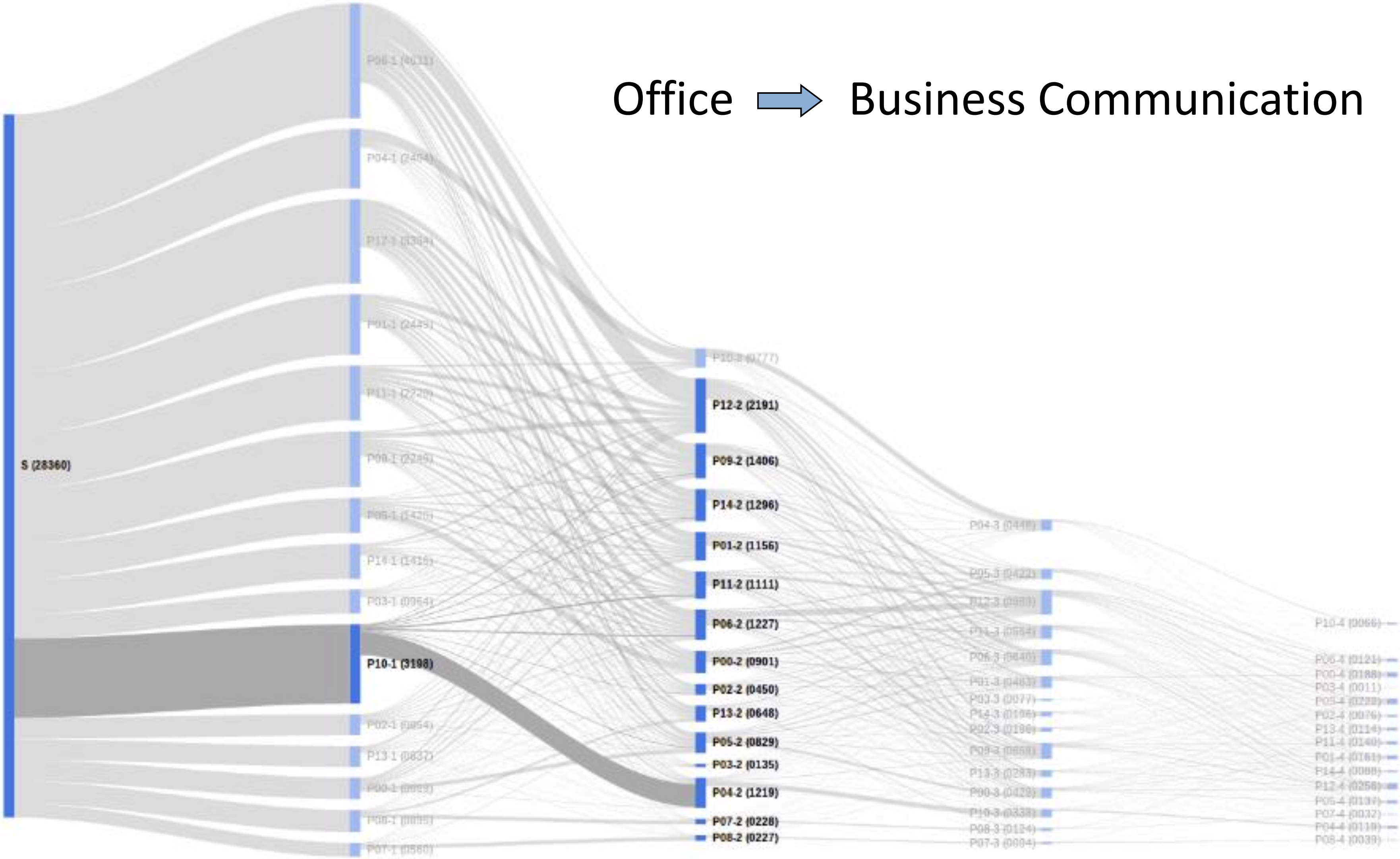


league	41.3
lolclient.ex	32.6
skype.exe	13.7
lollaunche	4
steam.exe	1.9
wmplayer.e	1.2
wmpnetwk.	1.1
all other	4.2

Proto evolution

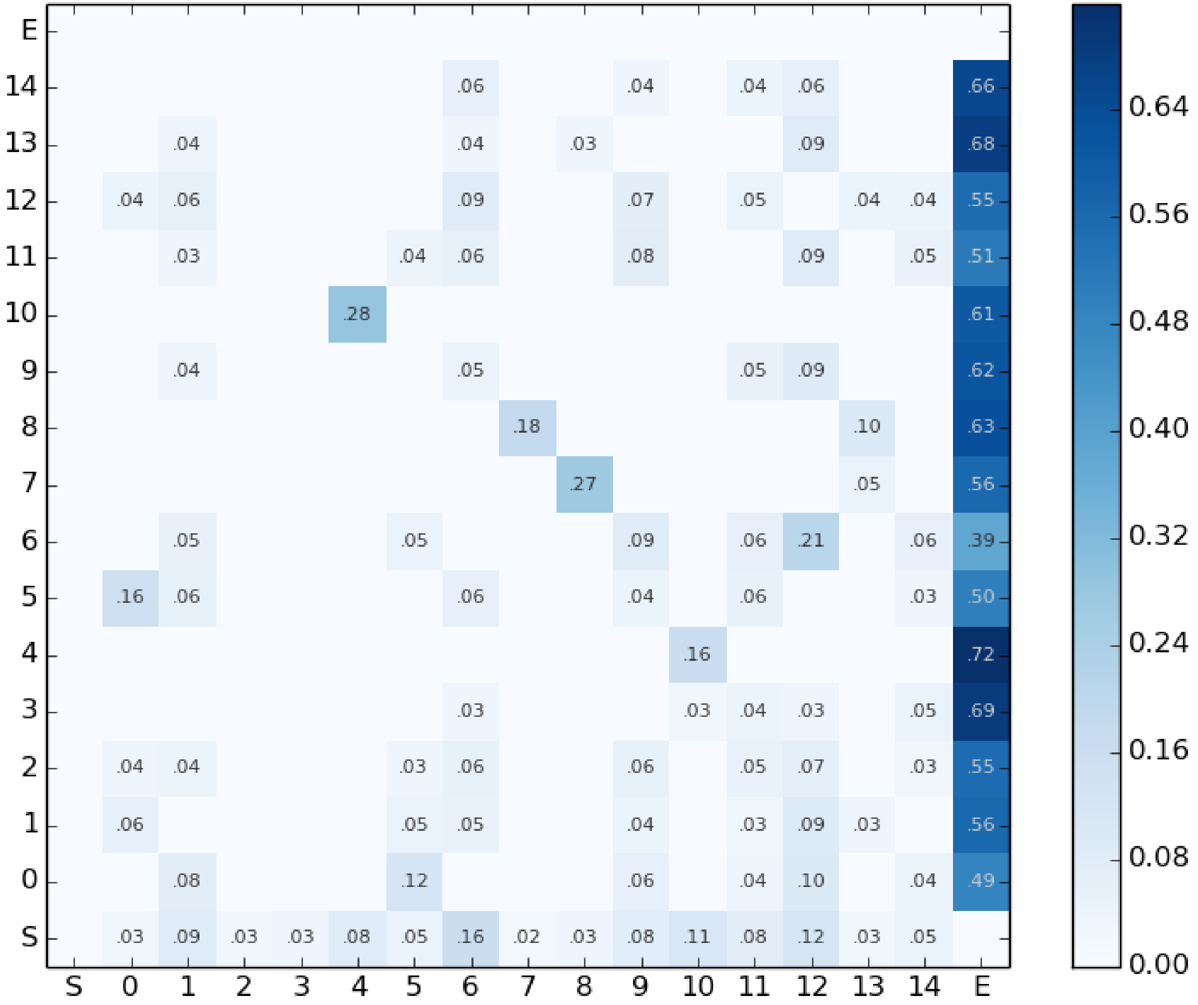


Proto transitions



Office → Business Communication

Proto evolution



	S	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	E
E																	
14								.06			.04		.04	.06			.66
13			.04					.04		.03				.09			.68
12		.04	.06					.09			.07		.05		.04	.04	.55
11			.03				.04	.06			.08			.09		.05	.51
10						.28											.61
9			.04					.05					.05	.09			.62
8									.18						.10		.63
7										.27					.05		.56
6			.05				.05				.09		.06	.21		.06	.39
5		.16	.06					.06			.04		.06			.03	.50
4												.16					.72
3								.03				.03	.04	.03		.05	.69
2		.04	.04				.03	.06			.06		.05	.07		.03	.55
1		.06					.05	.05			.04		.03	.09	.03		.56
0			.08				.12				.06		.04	.10		.04	.49
S		.03	.09	.03	.03	.08	.05	.16	.02	.03	.08	.11	.08	.12	.03	.05	

S **Start**

0 Communicate & watch movies

1 File transfers

2 Media creation

3 Email/Office

4 Business communication

5 Media downloads

6 Media player

7 Asian media downloads

8 Asian messenger

9 Writer

10 Office

11 iTunes

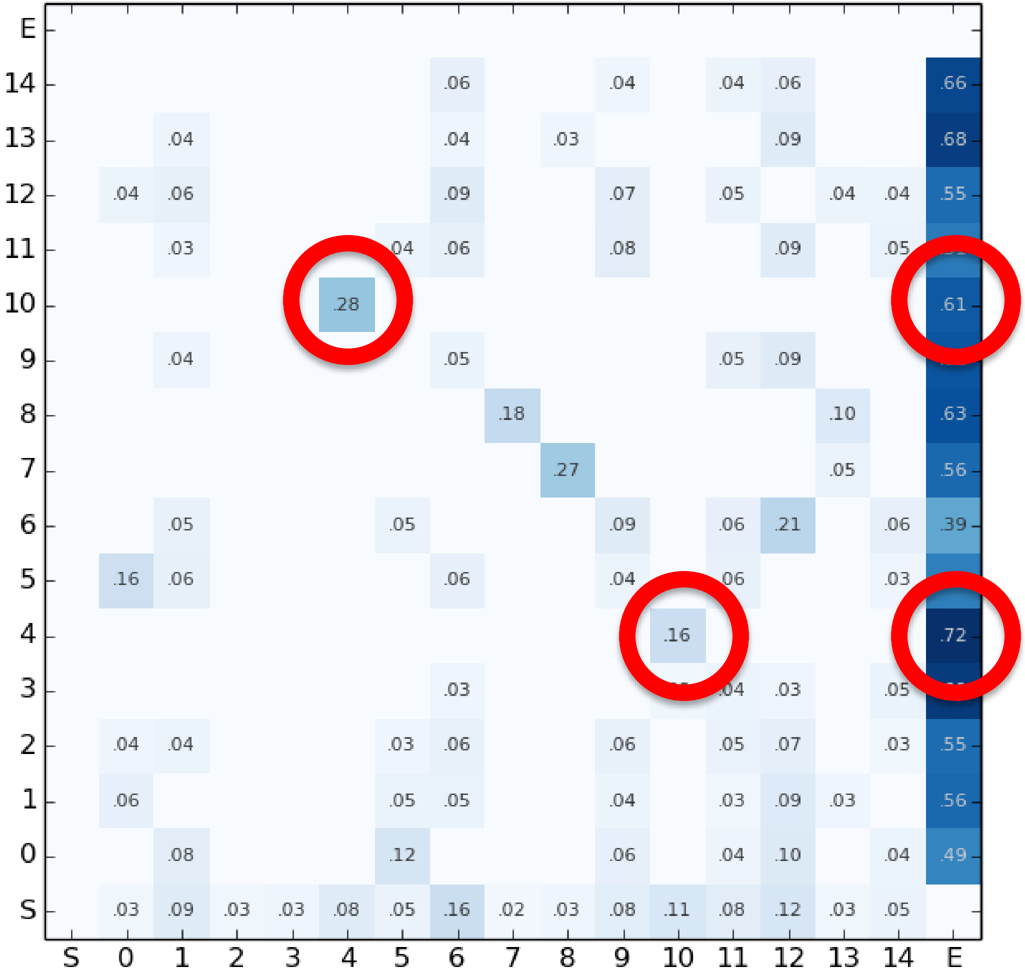
12 Skype

13 Gaming

14 Facebook Messenger

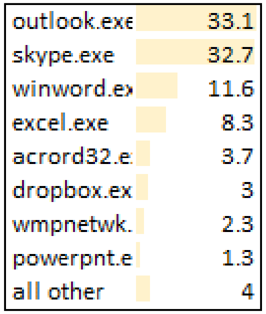
E **End**

Proto evolution



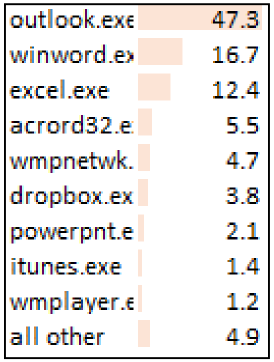
	S	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	E
E																	
14								.06			.04		.04	.06			.66
13			.04					.04		.03				.09			.68
12		.04	.06					.09			.07		.05		.04	.04	.55
11			.03				.04	.06			.08			.09		.05	[illegible]
10						.28											.61
9			.04					.05					.05	.09			[illegible]
8									.18						.10		.63
7										.27					.05		.56
6			.05				.05				.09		.06	.21		.06	.39
5		.16	.06					.06			.04		.06			.03	[illegible]
4												.16					.72
3								.03				[illegible]	.04	.03		.05	[illegible]
2		.04	.04				.03	.06			.06		.05	.07		.03	.55
1		.06					.05	.05			.04		.03	.09	.03		.56
0			.08				.12				.06		.04	.10		.04	.49
S		.03	.09	.03	.03	.08	.05	.16	.02	.03	.08	.11	.08	.12	.03	.05	

P4 (106K)
Business
communication



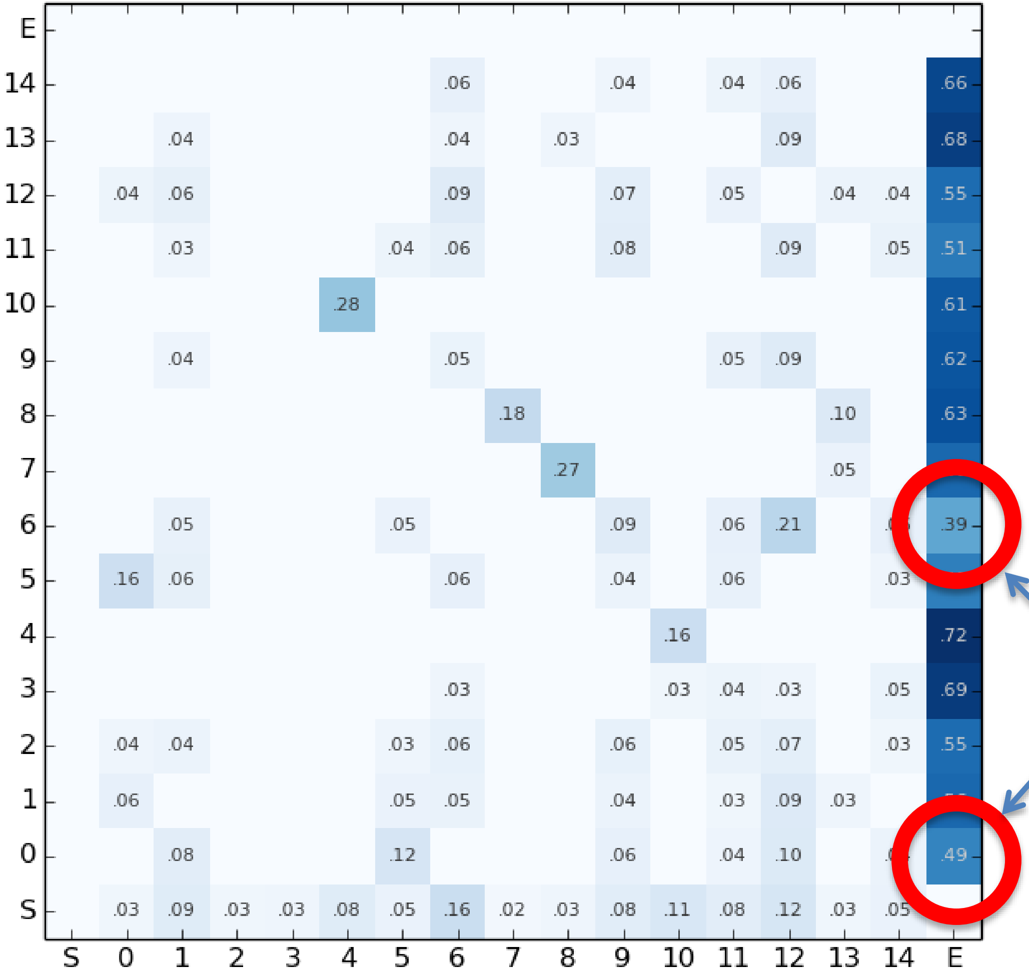
outlook.exe	33.1
skype.exe	32.7
winword.ex	11.6
excel.exe	8.3
acrord32.e:	3.7
dropbox.ex	3
wmpnetwk.	2.3
powerpnt.e	1.3
all other	4

P10 (105K)
Office



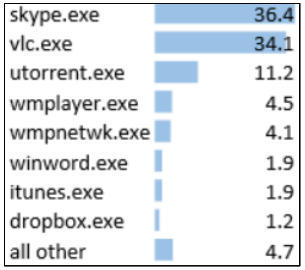
outlook.exe	47.3
winword.ex	16.7
excel.exe	12.4
acrord32.e:	5.5
wmpnetwk.	4.7
dropbox.ex	3.8
powerpnt.e	2.1
itunes.exe	1.4
wmplayer.e	1.2
all other	4.9

Proto evolution



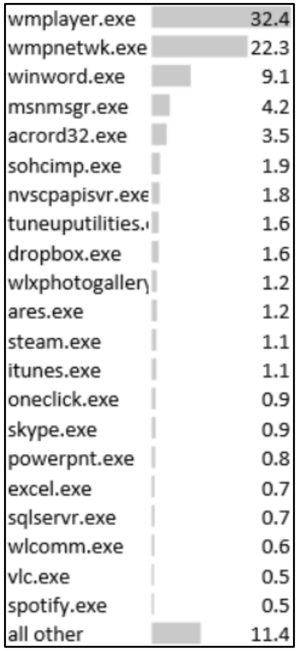
Tend to be “interior” protos

P0 (37K)
Communicate & watch



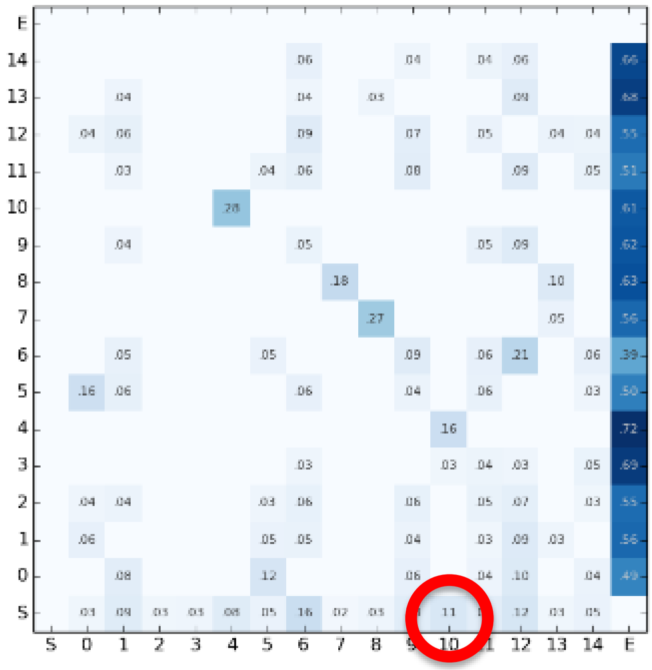
skype.exe	36.4
vlc.exe	34.1
utorrent.exe	11.2
wmplayer.exe	4.5
wmpnetwk.exe	4.1
winword.exe	1.9
itunes.exe	1.9
dropbox.exe	1.2
all other	4.7

P6 (105K)
Media player



wmplayer.exe	32.4
wmpnetwk.exe	22.3
winword.exe	9.1
msnmsgr.exe	4.2
acrord32.exe	3.5
sohcimp.exe	1.9
nvscpapisvr.exe	1.8
tuneuputilities.(	1.6
dropbox.exe	1.6
wlxphotogallery	1.2
ares.exe	1.2
steam.exe	1.1
itunes.exe	1.1
oneclick.exe	0.9
skype.exe	0.9
powerpnt.exe	0.8
excel.exe	0.7
sqlservr.exe	0.7
wlcomm.exe	0.6
vlc.exe	0.5
spotify.exe	0.5
all other	11.4

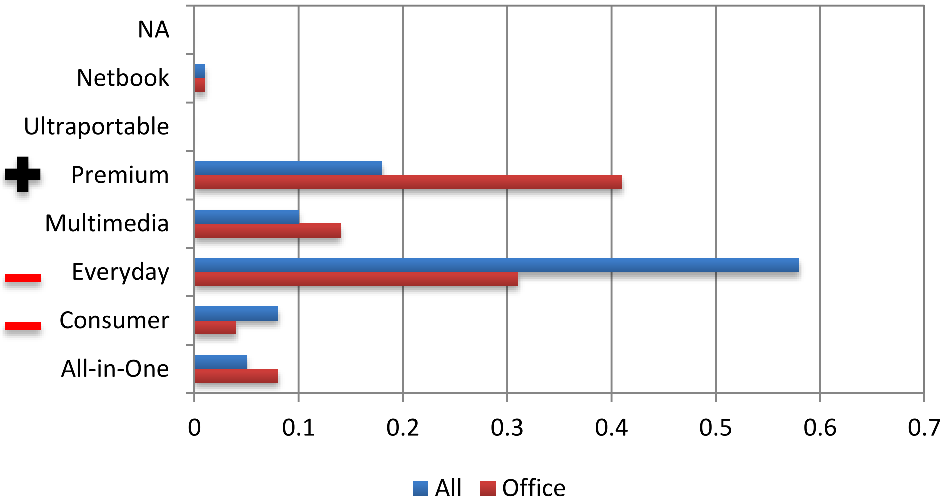
Side information correlation



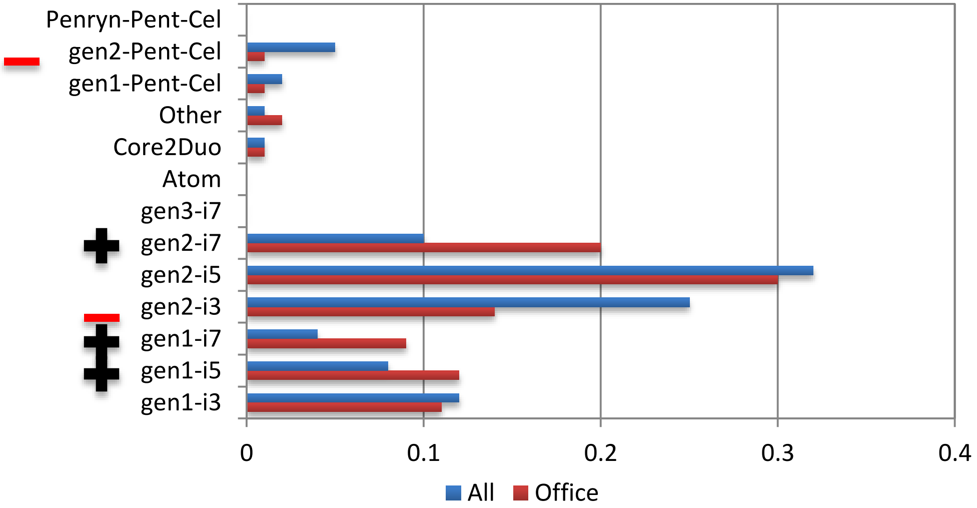
P10 (105K)
Office

outlook.exe	47.3
winword.ex	16.7
excel.exe	12.4
acrord32.e	5.5
wmpnetwk.	4.7
dropbox.ex	3.8
powerpnt.e	2.1
itunes.exe	1.4
wmplayer.e	1.2
all other	4.9

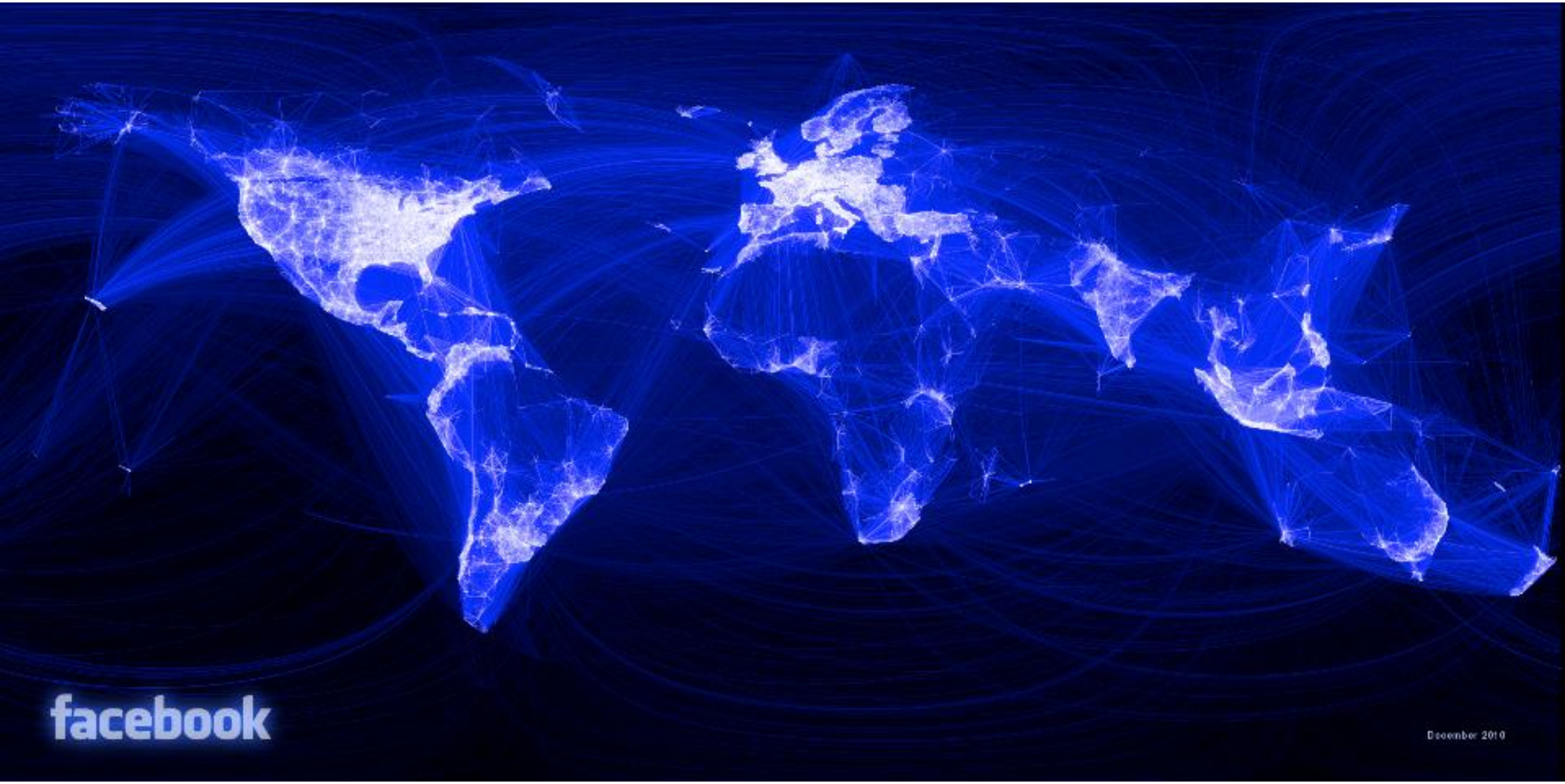
System Type



CPU Type



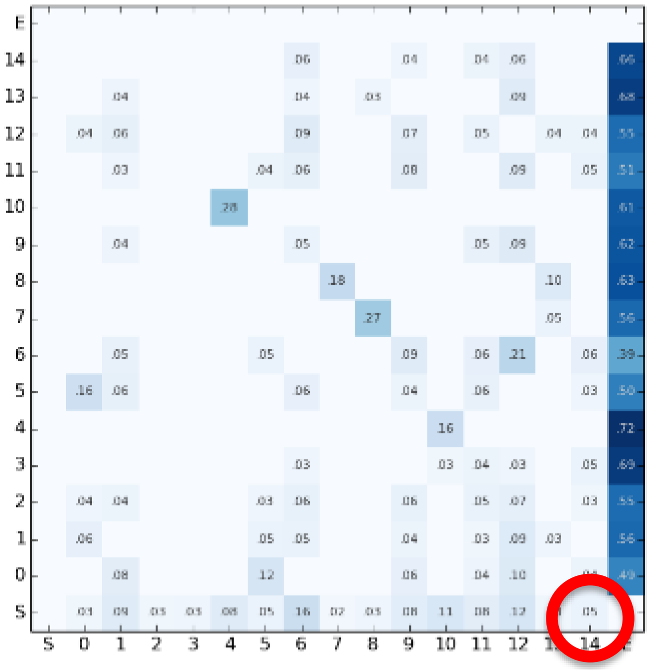
Side information correlation



December 2010

https://www.facebook.com/notes/facebook-engineering/visualizing-friendships/469716398919

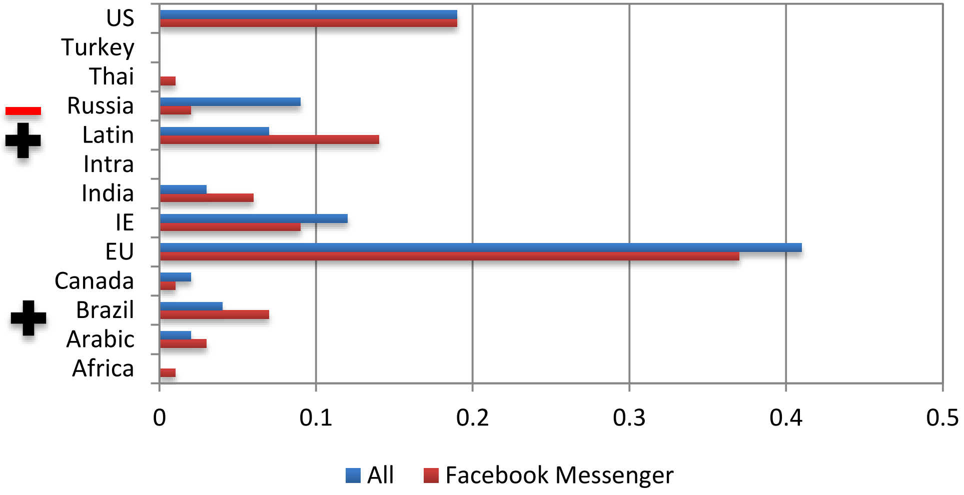
Side information correlation



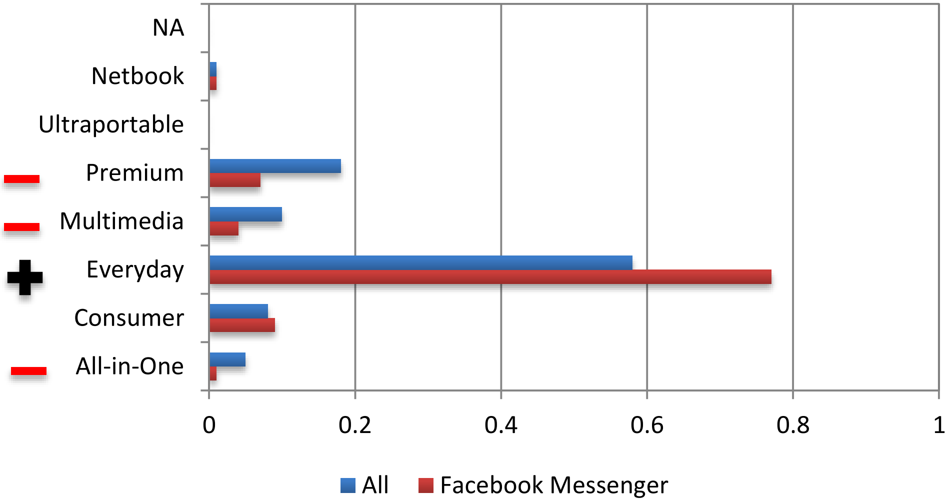
P14 (71K)
Facebook
Messenger

facebookm	58.2
skype.exe	14.2
wmplayer.e	5.9
wmpnetwk.	5.7
winword.ex	3.3
itunes.exe	2.8
utorrent.ex	1.3
dropbox.ex	0.9
acrord32.e	0.8
vlc.exe	0.8
sohcimp.ex	0.8
msnmsgr.e	0.6

Geolocation



System Type



Future directions

- Model sub-application classes:
  - Explore approaches based on dimensionality reduction.
    - This can be done within the context of Orion's cross-user segmentation
    - Lower-dimensional protos should still be interpretable.
- Generalize the segment's properties assumptions:
  - Instead of assuming that the usage in each segment is constant, what if we assume that the usage can be predicted based on previous within-segment behavior?

Recap

- Behavior evolves!
- Orion provides a way to analyze population behavior evolution
  - Identifies common patterns of behavior (protos)
  - Translates user behavior into sequences of protos
- Orion is versatile, applicable to diverse multivariate time-series domains

Orion source code @ http://users.cs.umn.edu/~dragos/orion

Q & A

Royalty-free Images from Wikimedia.org and morguefile.com.

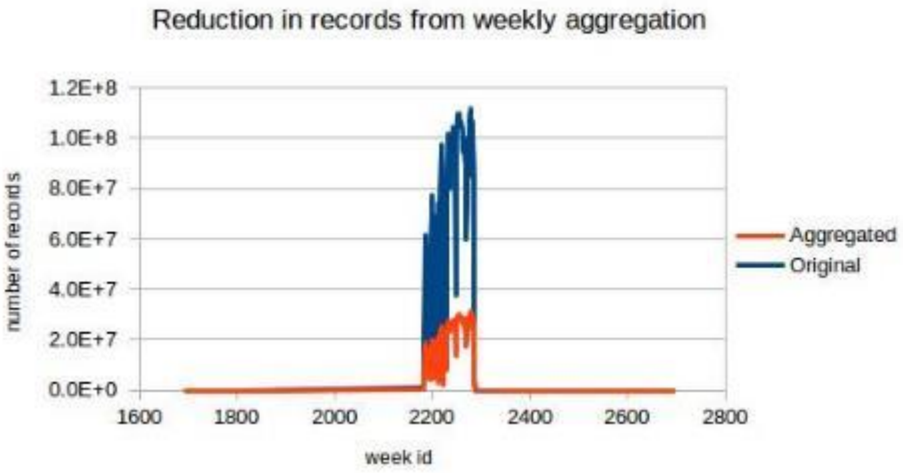
BACKUP SLIDES

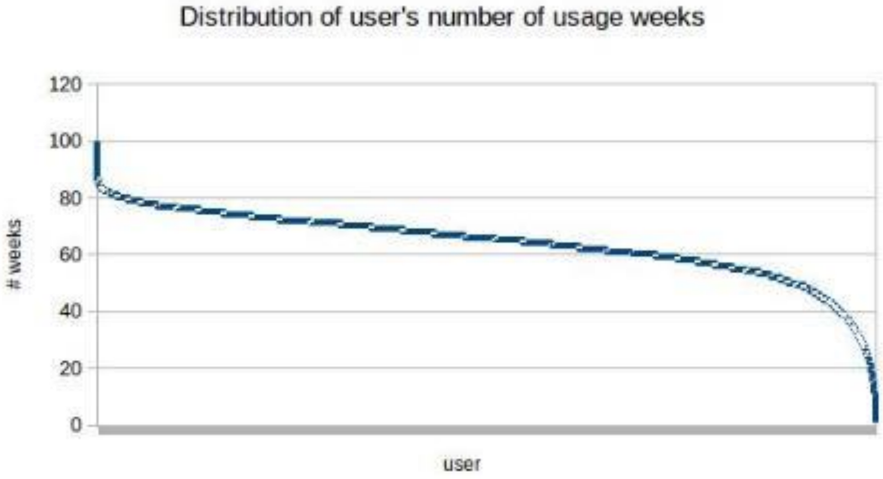
Orion: Algorithmic details (2)

- Segmentation identification:
  - Uses a dynamic-programming algorithm to find the optimal segmentation.
    - Complexity: O(*#users* x μ^2 x *#protos*).
- Optimal proto identification:
  - The mean of the usage vectors spanned by the proto.

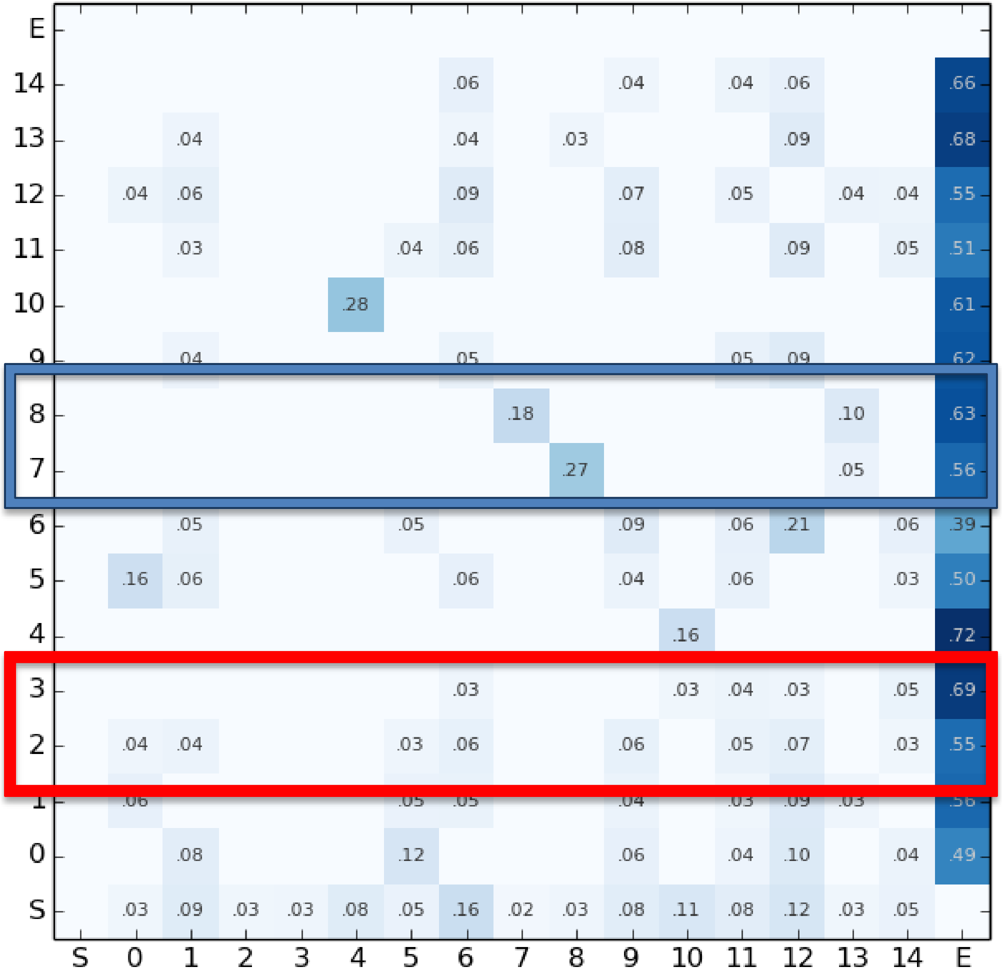
Data filtering

- 7.52 B initial records, aggregated to 2.13 B weekly
- Most records within 100 week time span
- Most users have records for at least 50 weeks
- Much noise, e.g. 1.49 B records with 0 utilization
- Focused analysis on subset of users/applications



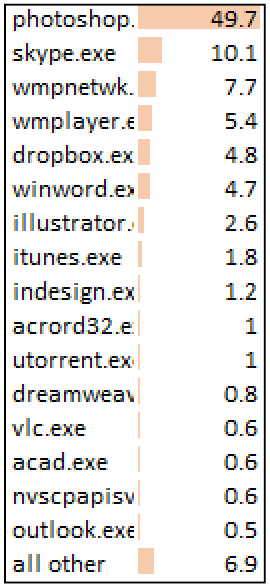


Proto evolution



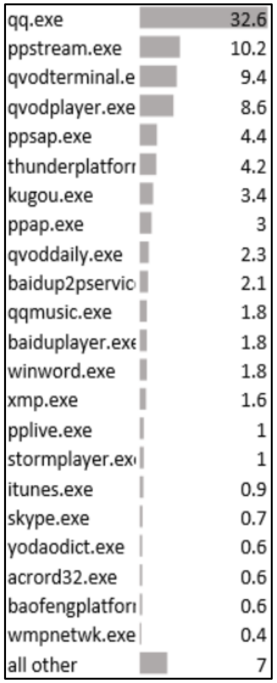
	S	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	E
E																	
14								.06			.04		.04	.06			.66
13			.04					.04		.03				.09			.68
12		.04	.06					.09			.07		.05		.04	.04	.55
11			.03				.04	.06			.08			.09		.05	.51
10						.28											.61
9			.04					.05					.05	.09			.62
8									.18						.10		.63
7										.27					.05		.56
6			.05				.05				.09		.06	.21		.06	.39
5		.16	.06					.06			.04		.06			.03	.50
4												.16					.72
3								.03				.03	.04	.03		.05	.69
2		.04	.04				.03	.06			.06		.05	.07		.03	.55
1		.06					.05	.05			.04		.03	.09	.03		.56
0			.08				.12				.06		.04	.10		.04	.49
S		.03	.09	.03	.03	.08	.05	.16	.02	.03	.08	.11	.08	.12	.03	.05	

P2 (32K)
Media creation



photoshop.	49.7
skype.exe	10.1
wmpnetwk.	7.7
wmplayer.e	5.4
dropbox.ex	4.8
winword.ex	4.7
illustrator.	2.6
itunes.exe	1.8
indesign.ex	1.2
acrord32.e	1
utorrent.ex	1
dreamweav	0.8
vlc.exe	0.6
acad.exe	0.6
nvscpapisv	0.6
outlook.exe	0.5
all other	6.9

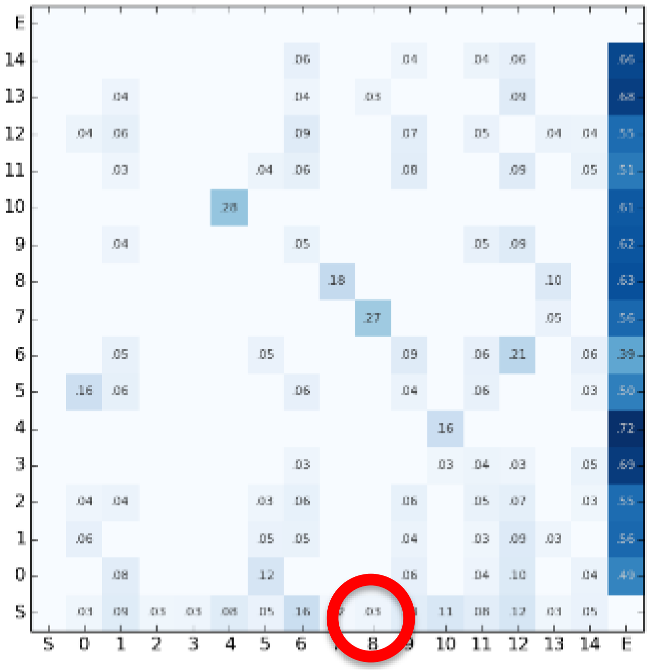
P8 (31K)
Asian messenger



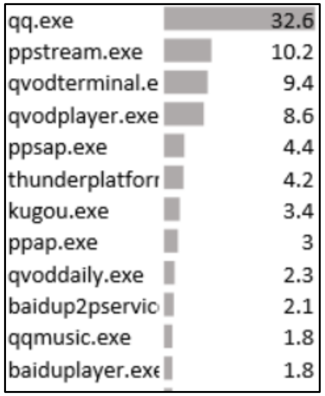
qq.exe	32.6
ppstream.exe	10.2
qvodterminal.e	9.4
qvodplayer.exe	8.6
ppsap.exe	4.4
thunderplatforr	4.2
kugou.exe	3.4
ppap.exe	3
qvoddaily.exe	2.3
baidup2pservic	2.1
qqmusic.exe	1.8
baiduplayer.exe	1.8
winword.exe	1.8
xmp.exe	1.6
pplive.exe	1
stormplayer.ex	1
itunes.exe	0.9
skype.exe	0.7
yodaodict.exe	0.6
acrord32.exe	0.6
baofengplatforı	0.6
wmpnetwk.exe	0.4
all other	7

Protos with low (blue box) and high (red box) fan-out

Side information correlation

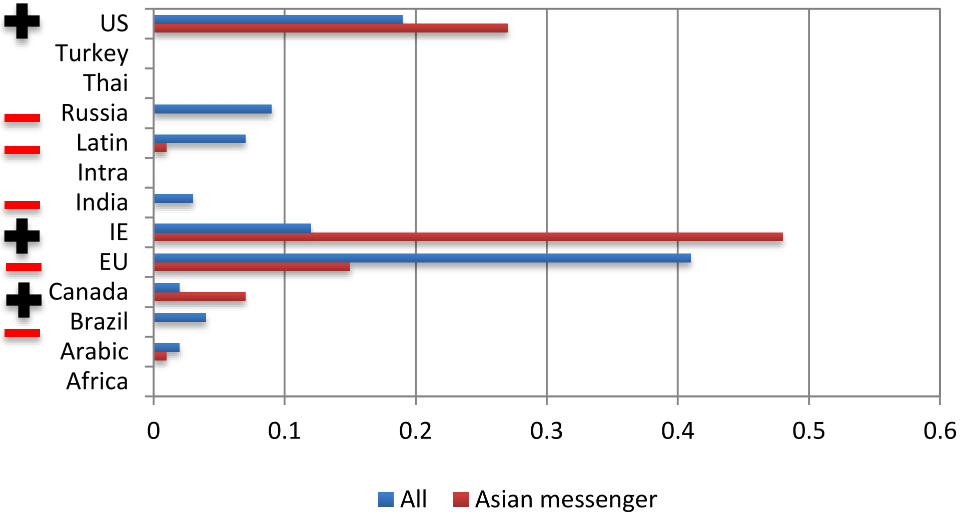


P8 (31K, 204)
Asian messenger

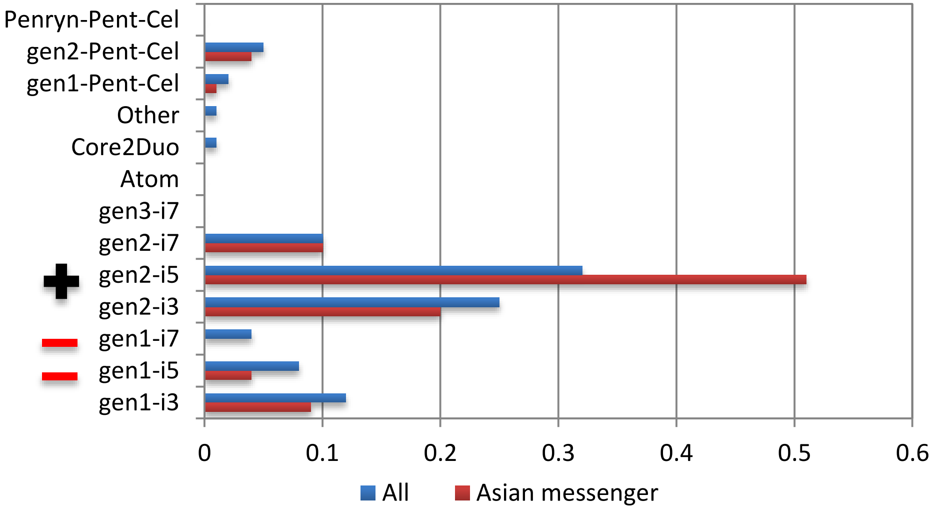


qq.exe	32.6
ppstream.exe	10.2
qvodterminal.e	9.4
qvodplayer.exe	8.6
ppsap.exe	4.4
thunderplatforr	4.2
kugou.exe	3.4
ppap.exe	3
qvoddaily.exe	2.3
baidup2pservic	2.1
qqmusic.exe	1.8
baiduplayer.exe	1.8

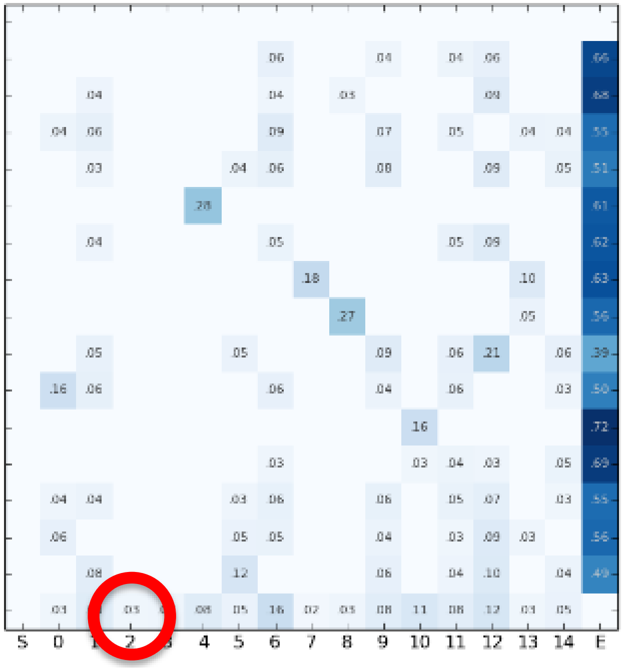
Geolocation



CPU Type

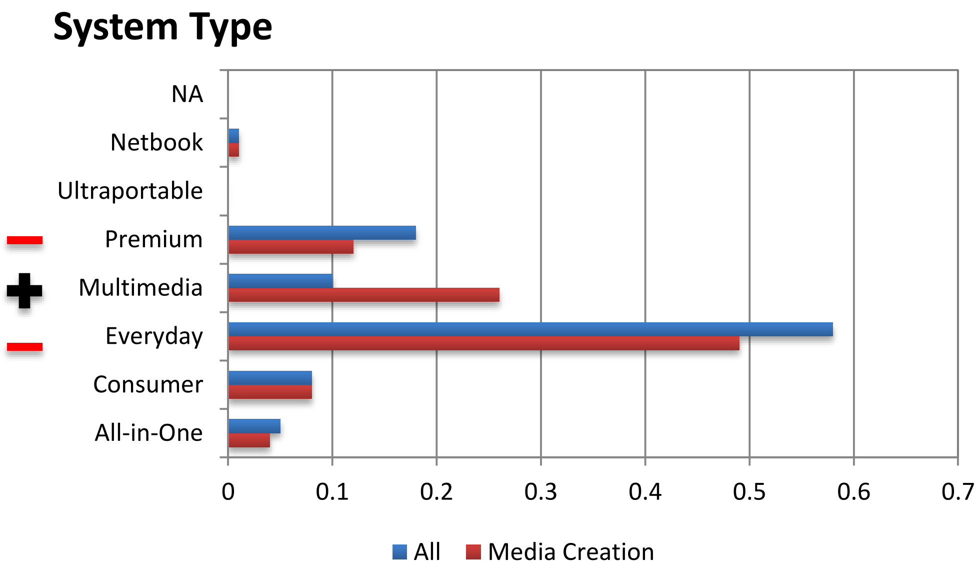


Side information correlation

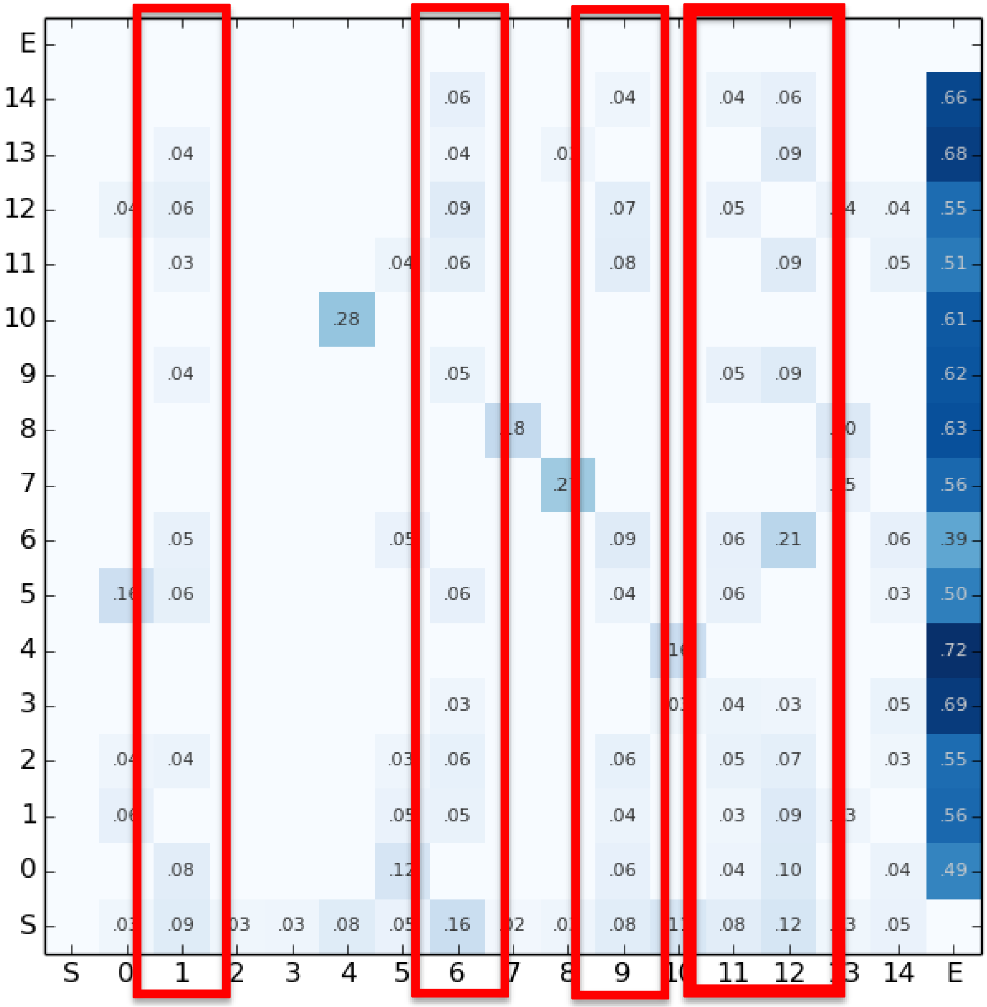


P2 (32K, 211)
Media creation

photoshop.	49.7
skype.exe	10.1
wmpnetwk.	7.7
wmplayer.e	5.4
dropbox.ex	4.8
winword.ex	4.7
illustrator.	2.6
itunes.exe	1.8
indesign.ex	1.2
acrord32.e	1
utorrent.ex	1
dreamweav	0.8

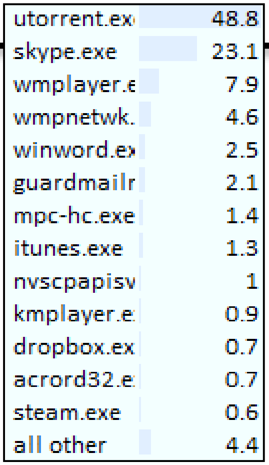


Proto evolution



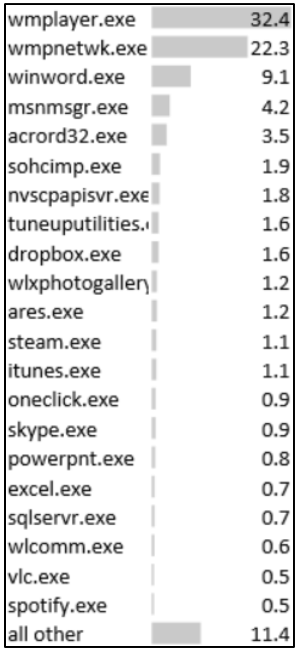
Protos with high fan-in

P1 (83K, 238)
File transfers



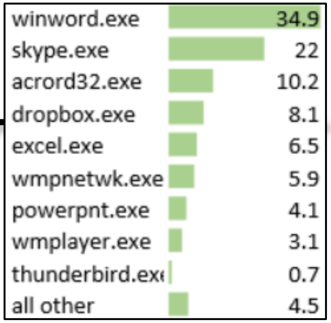
utorrent.ex	48.8
skype.exe	23.1
wmplayer.e	7.9
wmpnetwk.	4.6
winword.ex	2.5
guardmailr	2.1
mpc-hc.exe	1.4
itunes.exe	1.3
nvscpapisv	1
kmplayer.e	0.9
dropbox.ex	0.7
acrord32.e	0.7
steam.exe	0.6
all other	4.4

P6 (105K, 85)
Media player



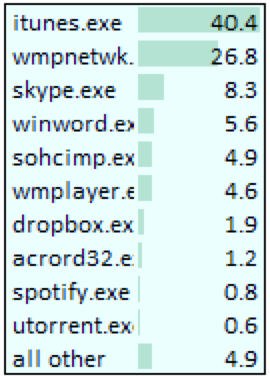
wmplayer.exe	32.4
wmpnetwk.exe	22.3
winword.exe	9.1
msnmsgr.exe	4.2
acrord32.exe	3.5
sohcimp.exe	1.9
nvscpapisvr.exe	1.8
tuneuputilities.	1.6
dropbox.exe	1.6
wlxphotogallery	1.2
ares.exe	1.2
steam.exe	1.1
itunes.exe	1.1
oneclick.exe	0.9
skype.exe	0.9
powerpnt.exe	0.8
excel.exe	0.7
sqlservr.exe	0.7
wlcomm.exe	0.6
vlc.exe	0.5
spotify.exe	0.5
all other	11.4

P9 (83K, 239)
Writer



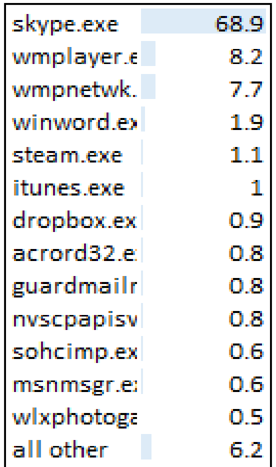
winword.exe	34.9
skype.exe	22
acrord32.exe	10.2
dropbox.exe	8.1
excel.exe	6.5
wmpnetwk.exe	5.9
powerpnt.exe	4.1
wmplayer.exe	3.1
thunderbird.exe	0.7
all other	4.5

P11 (72K, 243)
iTunes



itunes.exe	40.4
wmpnetwk.	26.8
skype.exe	8.3
winword.ex	5.6
sohcimp.ex	4.9
wmplayer.e	4.6
dropbox.ex	1.9
acrord32.e	1.2
spotify.exe	0.8
utorrent.ex	0.6
all other	4.9

P12 (115K, 195)
Skype



skype.exe	68.9
wmplayer.e	8.2
wmpnetwk.	7.7
winword.ex	1.9
steam.exe	1.1
itunes.exe	1
dropbox.ex	0.9
acrord32.e	0.8
guardmailr	0.8
nvscpapisv	0.8
sohcimp.ex	0.6
msnmsgr.e	0.6
wlxphotoga	0.5
all other	6.2

LESSONS LEARNED

Lessons learned (1)

- We had to eliminate all web-browsing related applications in order to get meaningful protos
  - With browsers in, the protos and their transitions were dominated by users switching between different browsers.
  - A large chunk of user activity is lost.
    - Need visibility into what the users are doing with their browsers to properly model/analyze this aspect of user behavior.

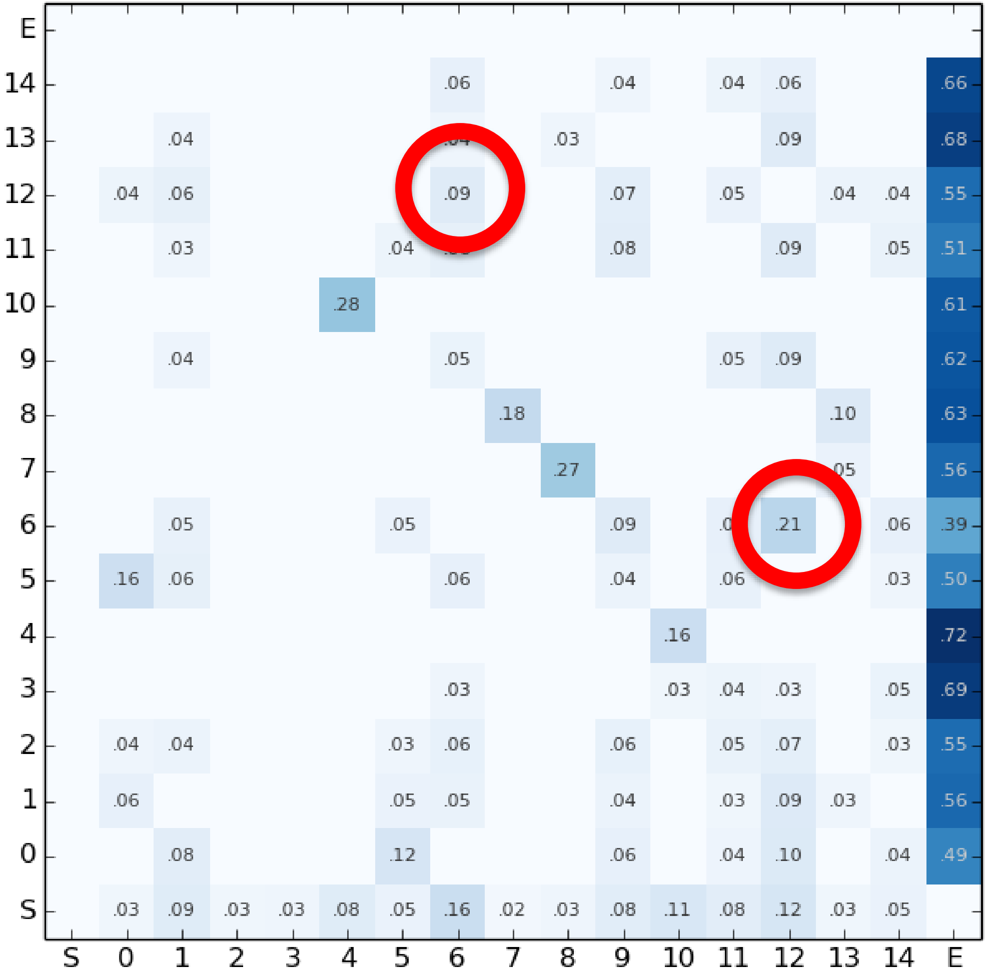
Lessons learned (2)

- Granularity of usage: Application vs. application class
- Each application was mapped by Intel to one of 11 application classes.
  - Our early attempts to represent a user's usage in terms of application classes did not produce very encouraging results.
    - We need to see how the Orion approach performs with that representation.
- Application-level representation fails to model usage of application subclasses for which there are not dominating applications.
  - Users use a large number of applications to perform essentially the same task.
  - Need to identify these scenarios and create sub-application classes to group them by.
    - A middle ground between the individual applications and the 11 top-level classes.

Lessons learned (3)

- Data cleaning
  - We ended up spending a large amount of time mapping across different versions of the same application:
    - Locale specific executable names
    - Executable names with embedded version numbers
- There is a need to map the different executables that are running in the context of a single application into a unique application ID:
  - background processes, daemons, auxiliary programs, installers, servers, clients, etc.
    - This is also related to the granularity issue discussed earlier.

Proto transitions



	S	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	E
E																	
14								.06			.04		.04	.06			.66
13			.04					.04		.03				.09			.68
12		.04	.06					.09			.07		.05		.04	.04	.55
11			.03				.04	[illegible]			.08			.09		.05	.51
10						.28											.61
9			.04					.05					.05	.09			.62
8									.18						.10		.63
7										.27					.05		.56
6			.05				.05				.09		.0	.21		.06	.39
5		.16	.06					.06			.04		.06			.03	.50
4												.16					.72
3								.03				.03	.04	.03		.05	.69
2		.04	.04				.03	.06			.06		.05	.07		.03	.55
1		.06					.05	.05			.04		.03	.09	.03		.56
0			.08				.12				.06		.04	.10		.04	.49
S		.03	.09	.03	.03	.08	.05	.16	.02	.03	.08	.11	.08	.12	.03	.05	

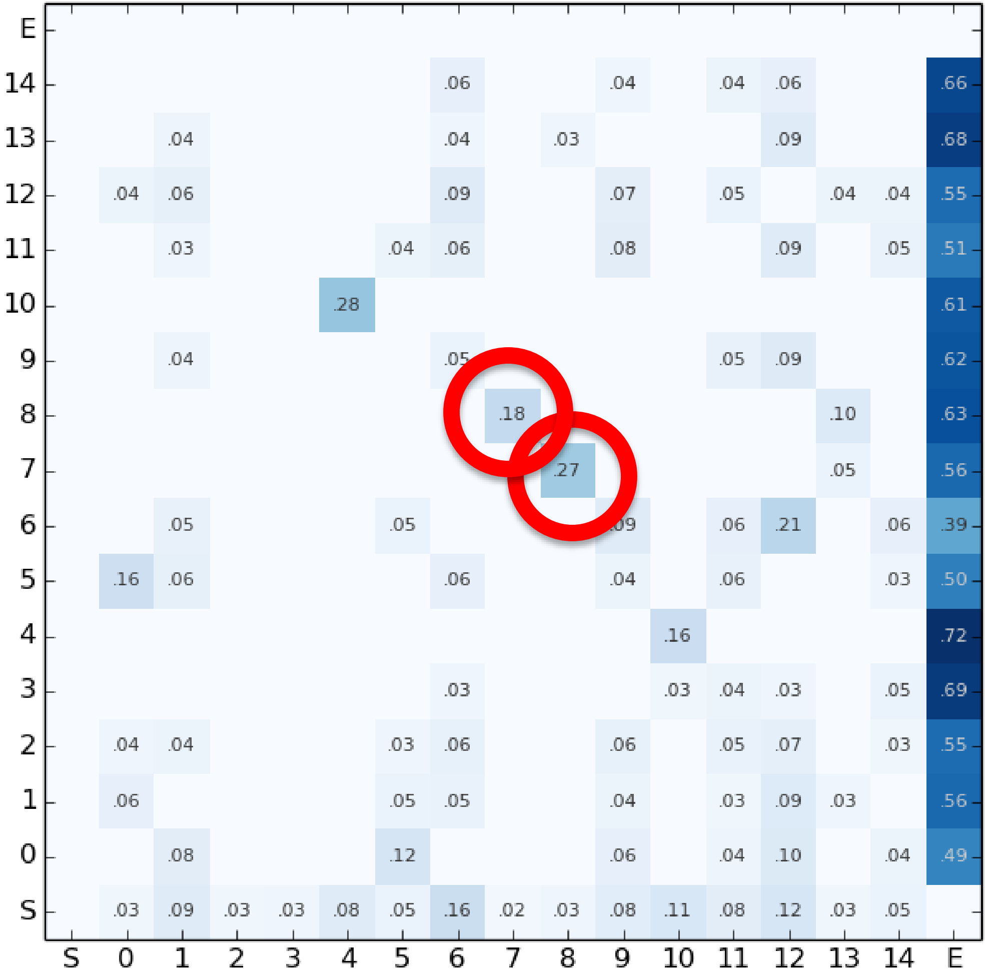
P6 (105K, 85)
Media player

wmplayer.exe	32.4
wmpnetwk.exe	22.3
winword.exe	9.1
msnmsgr.exe	4.2
acrord32.exe	3.5
sohcimp.exe	1.9
nvscpapisvr.exe	1.8
tuneuputilities.	1.6
dropbox.exe	1.6
wlxphotogaller	1.2
ares.exe	1.2
steam.exe	1.1
itunes.exe	1.1
oneclick.exe	0.9
skype.exe	0.9
powerpnt.exe	0.8
excel.exe	0.7
sqlservr.exe	0.7
wlcomm.exe	0.6
vlc.exe	0.5
spotify.exe	0.5
all other	11.4

P12 (115K, 195)
Skype

skype.exe	68.9
wmplayer.e	8.2
wmpnetwk.	7.7
winword.ex	1.9
steam.exe	1.1
itunes.exe	1
dropbox.ex	0.9
acrord32.e	0.8
guardmailr	0.8
nvscpapisv	0.8
sohcimp.ex	0.6
msnmsgr.e	0.6
wlxphotoga	0.5
all other	6.2

Proto transitions



	S	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	E
E																	
14								.06			.04		.04	.06			.66
13			.04					.04		.03				.09			.68
12		.04	.06					.09			.07		.05		.04	.04	.55
11			.03				.04	.06			.08			.09		.05	.51
10						.28											.61
9			.04					.05					.05	.09			.62
8									.18						.10		.63
7										.27					.05		.56
6			.05				.05				.09		.06	.21		.06	.39
5		.16	.06					.06			.04		.06			.03	.50
4												.16					.72
3								.03				.03	.04	.03		.05	.69
2		.04	.04				.03	.06			.06		.05	.07		.03	.55
1		.06					.05	.05			.04		.03	.09	.03		.56
0			.08				.12				.06		.04	.10		.04	.49
S		.03	.09	.03	.03	.08	.05	.16	.02	.03	.08	.11	.08	.12	.03	.05	

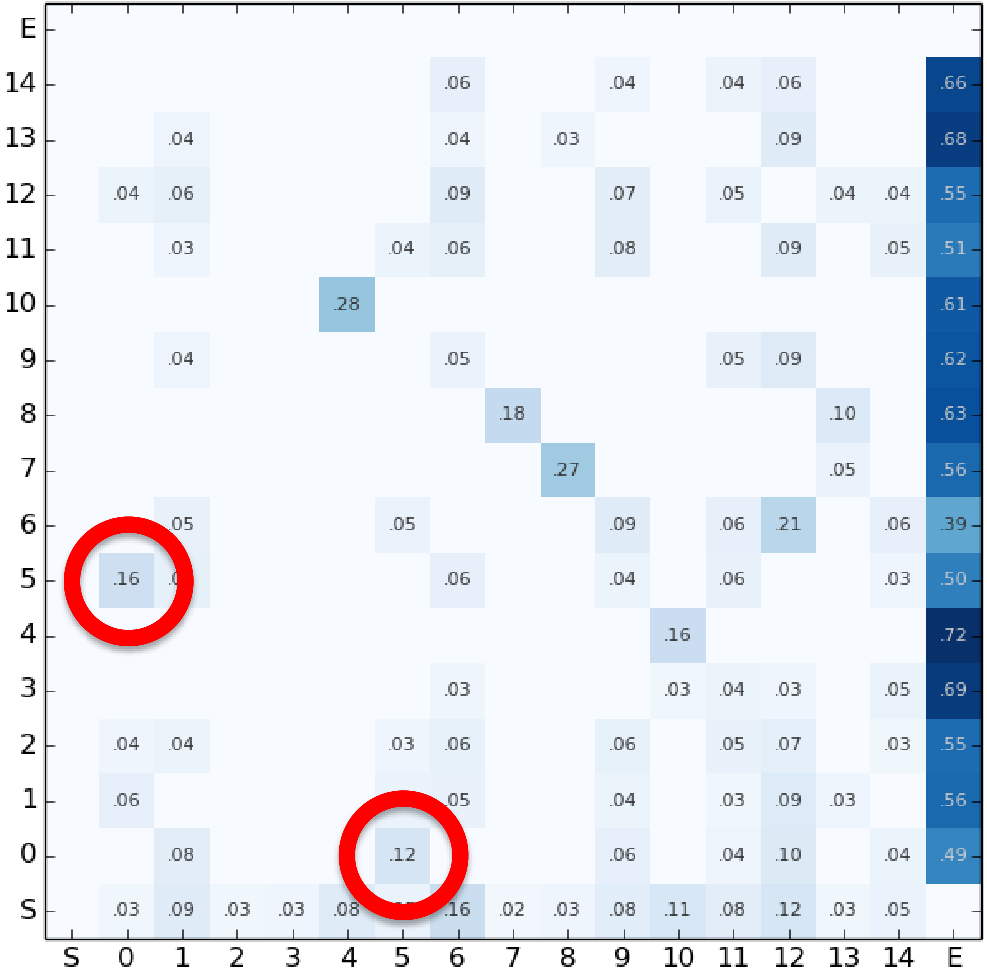
P7 (22K, 384)
Asian media
downloads

funshion.exe	40.5
funshionservice	32.4
qq.exe	6.1
ppstream.exe	5
qvodterminal.e	2.1
ppsap.exe	2
skype.exe	1.3
qvodplayer.exe	1.2
ppap.exe	0.9
kugou.exe	0.8
winword.exe	0.6
kwmusic.exe	0.6
itunes.exe	0.6
qvoddaily.exe	0.5
all other	5.4

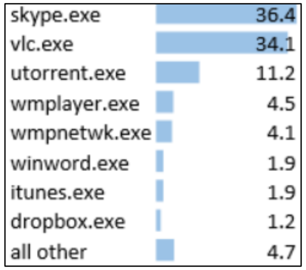
P8 (31K, 204)
Asian messenger

qq.exe	32.6
ppstream.exe	10.2
qvodterminal.e	9.4
qvodplayer.exe	8.6
ppsap.exe	4.4
thunderplatforı	4.2
kugou.exe	3.4
ppap.exe	3
qvoddaily.exe	2.3
baidup2pservic	2.1
qqmusic.exe	1.8
baiduplayer.exe	1.8
winword.exe	1.8
xmp.exe	1.6
pplive.exe	1
stormplayer.ex	1
itunes.exe	0.9
skype.exe	0.7
yodaodict.exe	0.6
acrord32.exe	0.6
baofengplatfor	0.6
wmpnetwk.exe	0.4
all other	7

Proto transitions

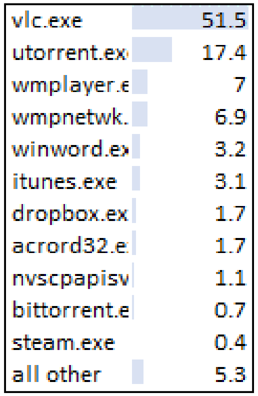


P0 (37K, 356)
Communicate & watch



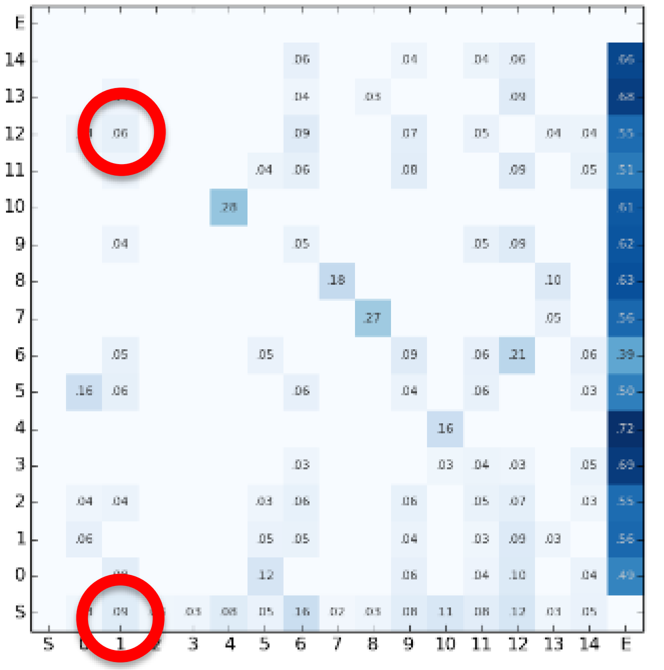
skype.exe	36.4
vlc.exe	34.1
utorrent.exe	11.2
wmplayer.exe	4.5
wmpnetwk.exe	4.1
winword.exe	1.9
itunes.exe	1.9
dropbox.exe	1.2
all other	4.7

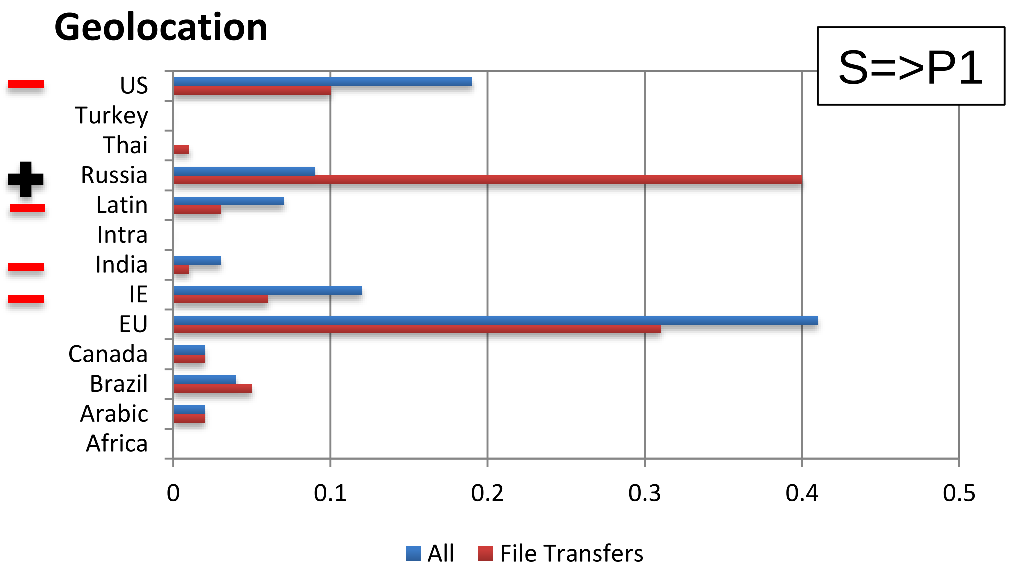
P5 (48K, 242)
Media downloads

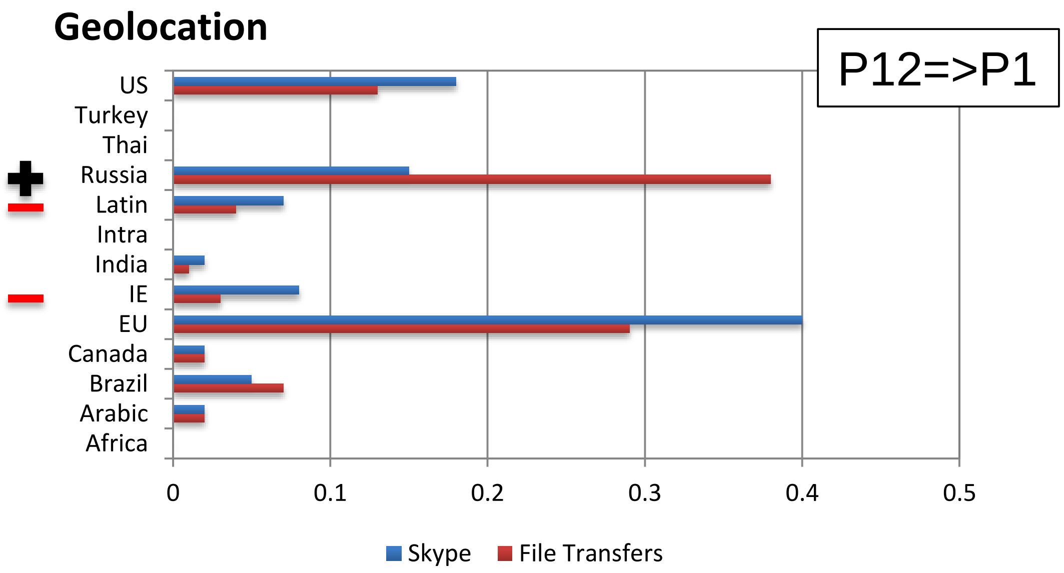


vlc.exe	51.5
utorrent.ex	17.4
wmplayer.e	7
wmpnetwk.	6.9
winword.ex	3.2
itunes.exe	3.1
dropbox.ex	1.7
acrord32.e	1.7
nvscpapisv	1.1
bittorrent.e	0.7
steam.exe	0.4
all other	5.3

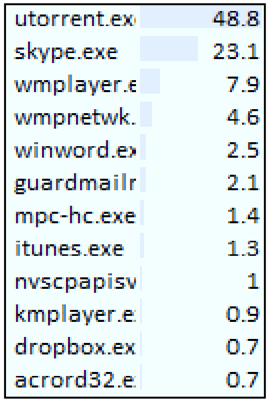
Side information correlation





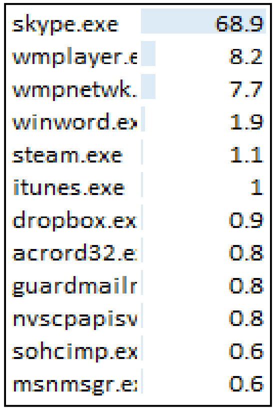


P1 (83K, 238)
File transfers



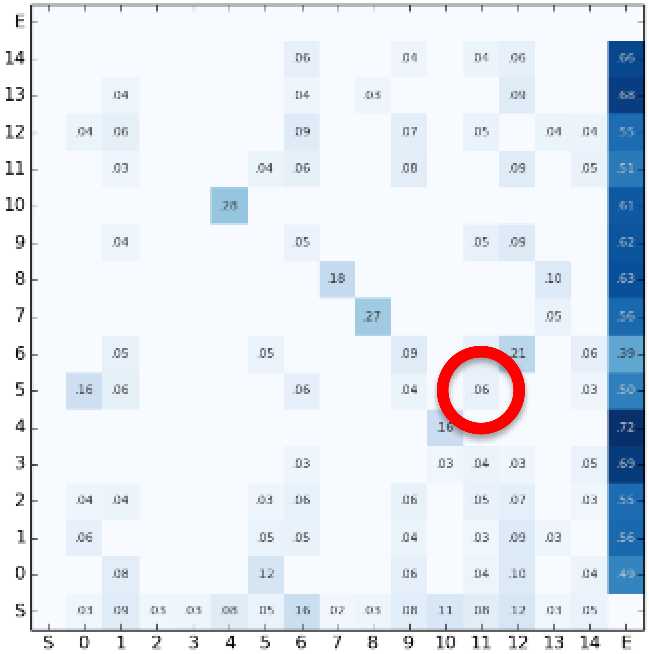
utorrent.ex	48.8
skype.exe	23.1
wmplayer.e	7.9
wmpnetwk.	4.6
winword.ex	2.5
guardmailr	2.1
mpc-hc.exe	1.4
itunes.exe	1.3
nvscpapisv	1
kmplayer.e	0.9
dropbox.ex	0.7
acrord32.e	0.7

P12 (115K, 195)
Skype

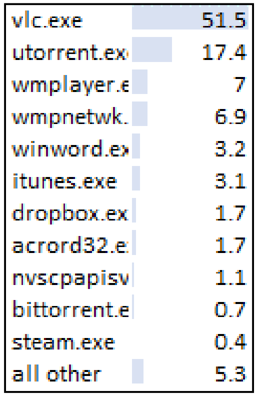


skype.exe	68.9
wmplayer.e	8.2
wmpnetwk.	7.7
winword.ex	1.9
steam.exe	1.1
itunes.exe	1
dropbox.ex	0.9
acrord32.e	0.8
guardmailr	0.8
nvscpapisv	0.8
sohcimp.ex	0.6
msnmsgr.e	0.6

Side information correlation

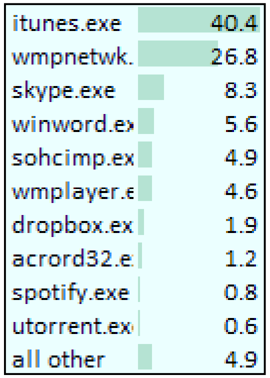


P5 (48K, 242)
Media downloads



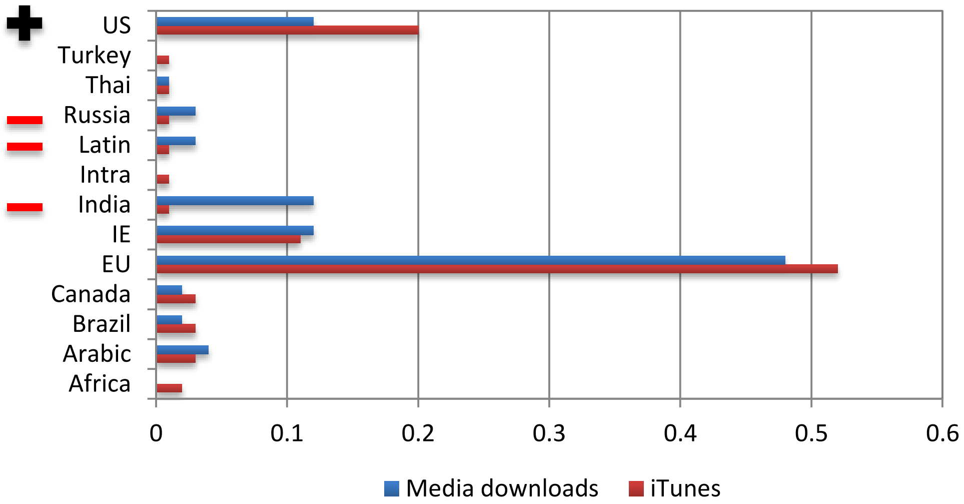
vlc.exe	51.5
utorrent.ex	17.4
wmplayer.e	7
wmpnetwk.	6.9
winword.ex	3.2
itunes.exe	3.1
dropbox.ex	1.7
acrord32.e	1.7
nvscpapisv	1.1
bittorrent.e	0.7
steam.exe	0.4
all other	5.3

P11 (72K, 243)
iTunes

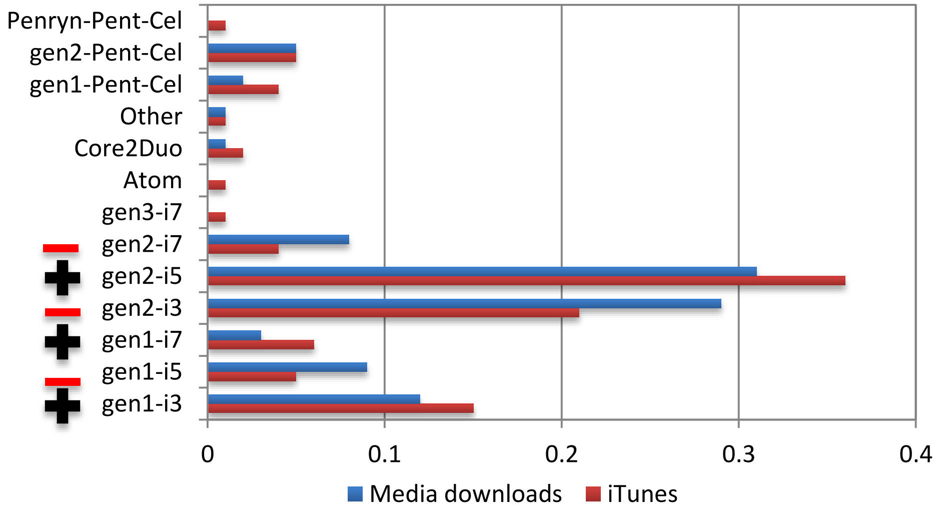


itunes.exe	40.4
wmpnetwk.	26.8
skype.exe	8.3
winword.ex	5.6
sohcimp.ex	4.9
wmplayer.e	4.6
dropbox.ex	1.9
acrord32.e	1.2
spotify.exe	0.8
utorrent.ex	0.6
all other	4.9

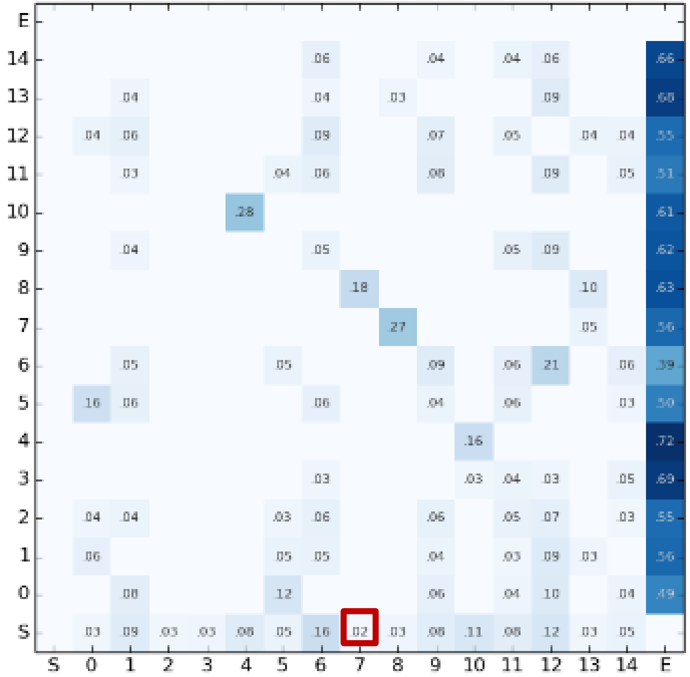
Geolocation



CPU Type



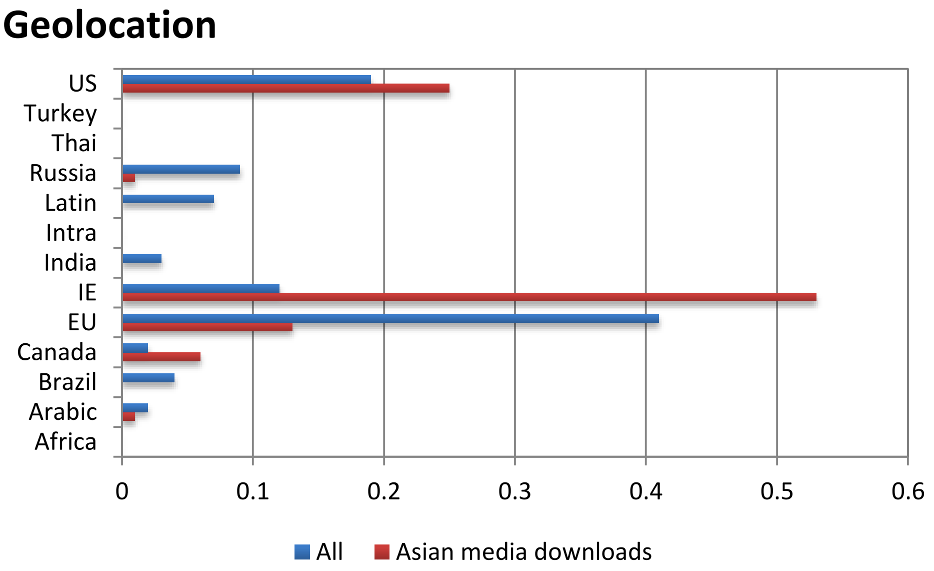
Side information correlation



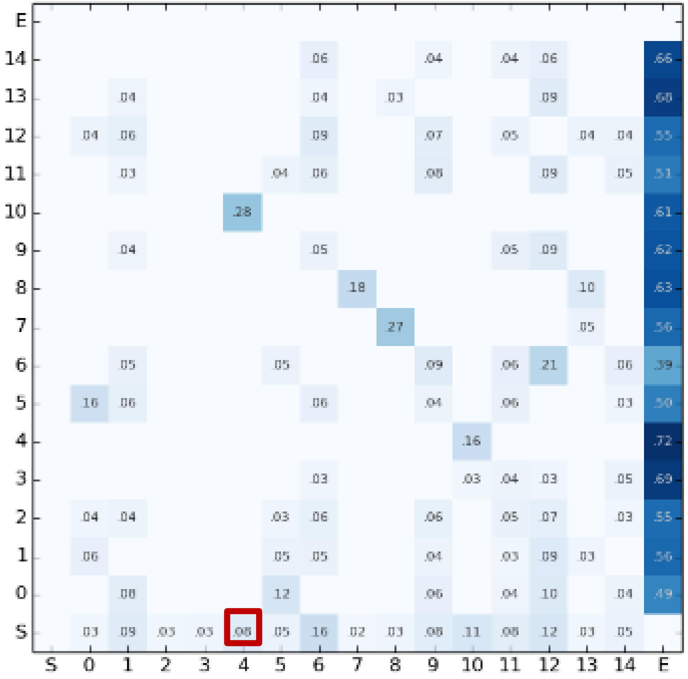
	S	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	E
E																	
14								.06			.04		.04	.06			.66
13			.04					.04		.03				.09			.68
12		.04	.06					.09			.07		.05		.04	.04	.55
11			.03				.04	.06			.08			.09		.05	.51
10						.28											.61
9			.04					.05					.05	.09			.62
8									.18						.10		.63
7										.27					.05		.56
6			.05				.05				.09		.06	.21		.06	.39
5		.16	.06					.06			.04		.06			.03	.50
4												.16					.72
3								.03				.03	.04	.03		.05	.69
2		.04	.04				.03	.06			.06		.05	.07		.03	.55
1		.06					.05	.05			.04		.03	.09	.03		.56
0			.08				.12				.06		.04	.10		.04	.49
S		.03	.09	.03	.03	.08	.05	.16	.02	.03	.08	.11	.08	.12	.03	.05	

P7: Asian media downloads

funshion.exe	40.5
funshionservice	32.4
qq.exe	6.1
ppstream.exe	5
qvodterminal.e:	2.1
ppsap.exe	2
skype.exe	1.3
qvodplayer.exe	1.2
ppap.exe	0.9
kugou.exe	0.8
winword.exe	0.6

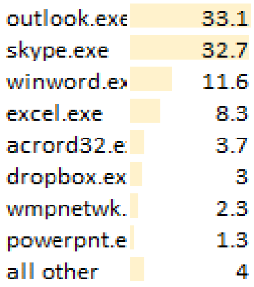


Side information correlation



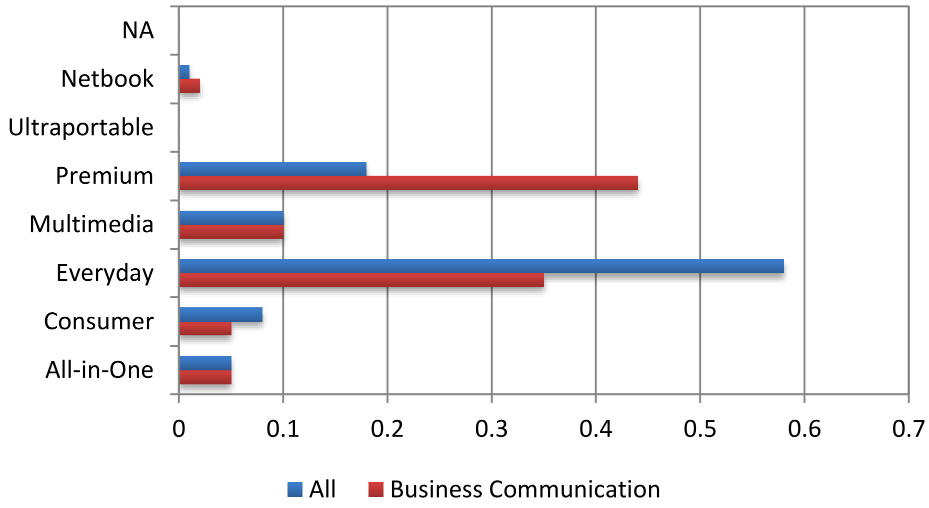
	S	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	E
E																	
14								.06			.04		.04	.06			.66
13			.04					.04		.03				.09			.68
12		.04	.06					.09			.07		.05		.04	.04	.55
11			.03				.04	.06			.08			.09		.05	.51
10						.28											.61
9			.04					.05					.05	.09			.62
8									.18						.10		.63
7										.27					.05		.56
6			.05				.05				.09		.06	.21		.06	.39
5		.16	.06					.06			.04		.06			.03	.50
4												.16					.72
3								.03				.03	.04	.03		.05	.69
2		.04	.04				.03	.06			.06		.05	.07		.03	.55
1		.06					.05	.05			.04		.03	.09	.03		.56
0			.08				.12				.06		.04	.10		.04	.49
S		.03	.09	.03	.03	.08	.05	.16	.02	.03	.08	.11	.08	.12	.03	.05	

P4: Business communication

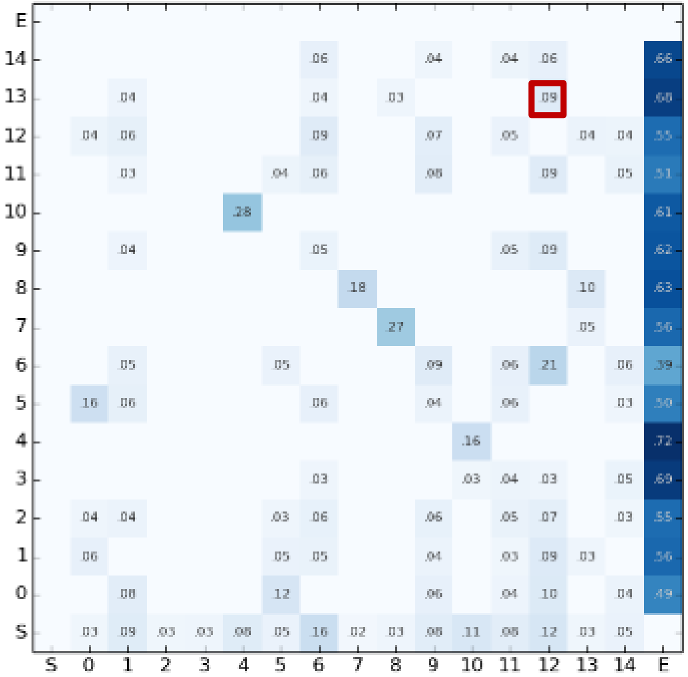


outlook.exe	33.1
skype.exe	32.7
winword.ex	11.6
excel.exe	8.3
acrord32.e	3.7
dropbox.ex	3
wmpnetwk.	2.3
powerpnt.e	1.3
all other	4

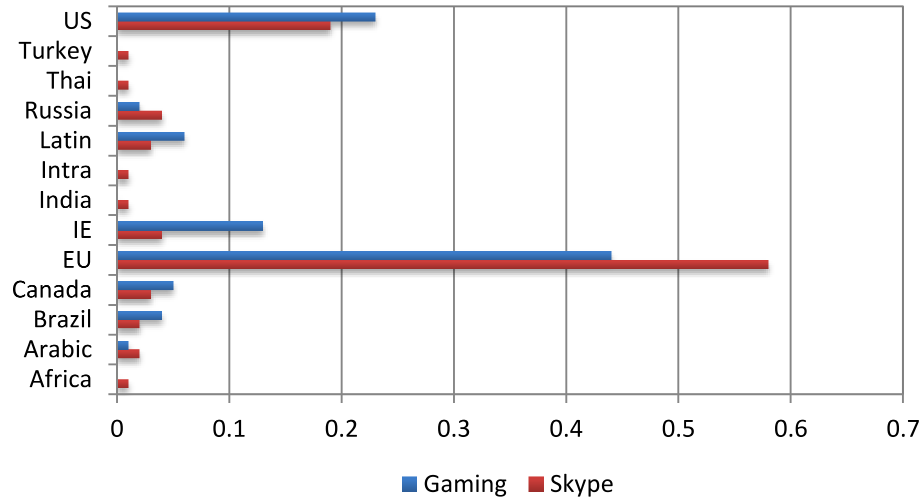
System Type



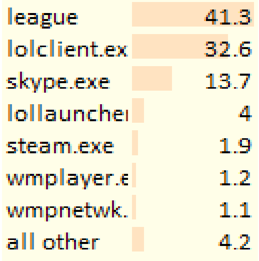
Side information correlation



Geolocation

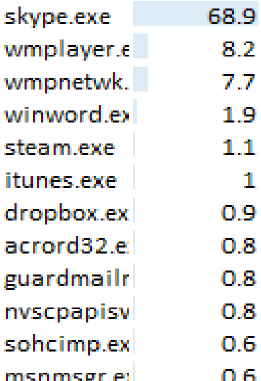


P13: Gaming



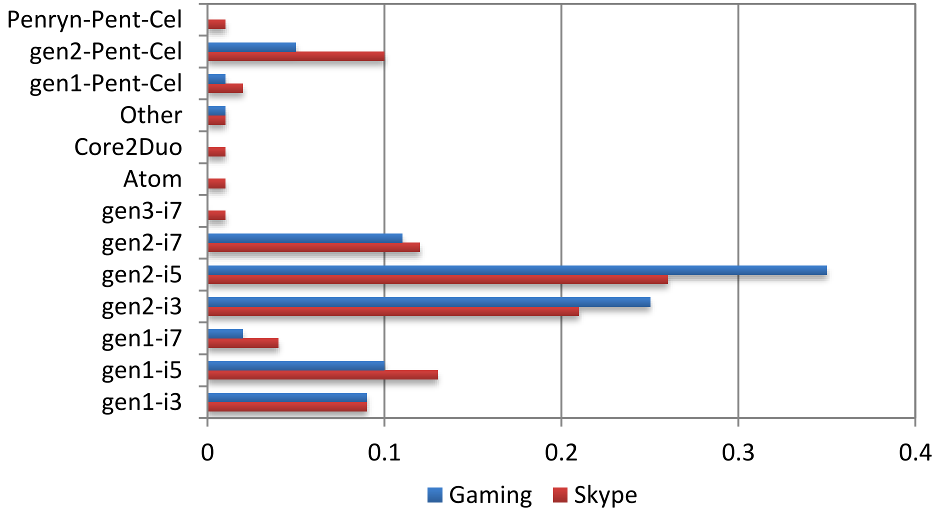
league	41.3
lolclient.ex	32.6
skype.exe	13.7
lollauncher	4
steam.exe	1.9
wmplayer.e	1.2
wmpnetwk.	1.1
all other	4.2

P12: Skype

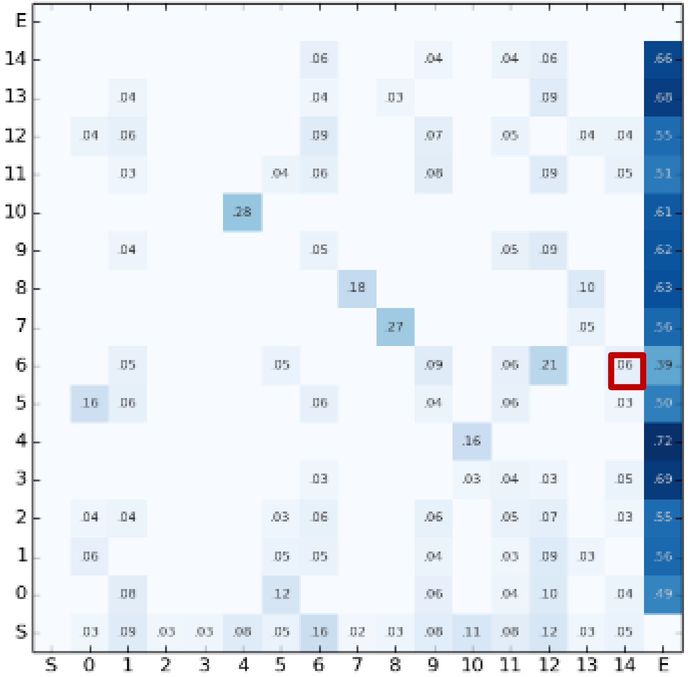


skype.exe	68.9
wmplayer.e	8.2
wmpnetwk.	7.7
winword.ex	1.9
steam.exe	1.1
itunes.exe	1
dropbox.ex	0.9
acrord32.e	0.8
guardmailr	0.8
nvscpapisv	0.8
sohcimp.ex	0.6
msnmsgr.e	0.6

CPU Type



Side information correlation



	S	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	E
E																	
14								.06			.04		.04	.06			.66
13			.04					.04		.03				.09			.68
12		.04	.06					.09			.07		.05		.04	.04	.55
11			.03				.04	.06			.08			.09		.05	.51
10						.28											.61
9			.04					.05					.05	.09			.62
8									.18						.10		.63
7										.27					.05		.56
6			.05				.05				.09		.06	.21		.06	.39
5		.16	.06					.06			.04		.06			.03	.50
4												.16					.72
3								.03				.03	.04	.03		.05	.69
2		.04	.04				.03	.06			.06		.05	.07		.03	.55
1		.06					.05	.05			.04		.03	.09	.03		.56
0			.08				.12				.06		.04	.10		.04	.49
S		.03	.09	.03	.03	.08	.05	.16	.02	.03	.08	.11	.08	.12	.03	.05	

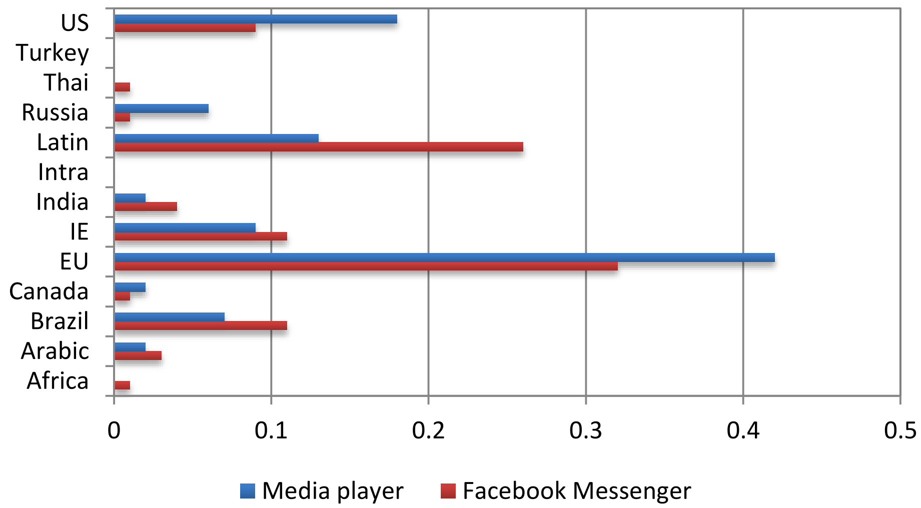
P6: Media player

wmplayer.exe	32.4
wmpnetwk.exe	22.3
winword.exe	9.1
msnmsgr.exe	4.2
acrord32.exe	3.5
sohcimp.exe	1.9
nvscpapisvr.exe	1.8
tuneuputilities.(	1.6
dropbox.exe	1.6
wlxphotogaller	1.2
ares.exe	1.2
steam.exe	1.1

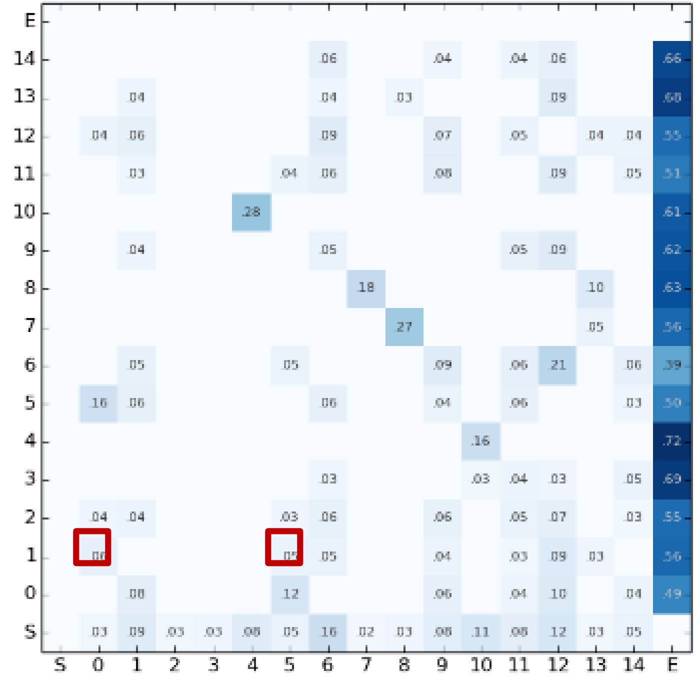
P14: Facebook Messenger

facebookm	58.2
skype.exe	14.2
wmplayer.e	5.9
wmpnetwk.	5.7
winword.ex	3.3
itunes.exe	2.8
utorrent.ex	1.3
dropbox.ex	0.9
acrord32.e	0.8
vlc.exe	0.8
sohcimp.ex	0.8

Geolocation

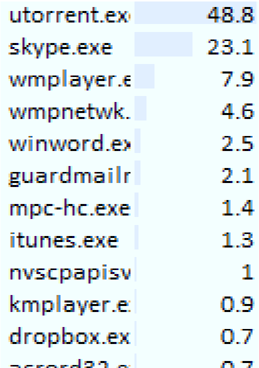


Side information correlation



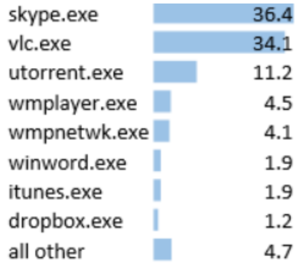
	S	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	E
E																	
14								.06			.04		.04	.06			.66
13			.04					.04		.03				.09			.68
12		.04	.06					.09			.07		.05		.04	.04	.55
11			.03				.04	.06			.08			.09		.05	.51
10						.28											.61
9			.04					.05					.05	.09			.62
8									.18						.10		.63
7										.27					.05		.56
6			.05				.05				.09		.06	.21		.06	.39
5		.16	.06					.06			.04		.06			.03	.50
4												.16					.72
3								.03				.03	.04	.03		.05	.69
2		.04	.04				.03	.06			.06		.05	.07		.03	.55
1		.06					.05	.05			.04		.03	.09	.03		.56
0			.08				.12				.06		.04	.10		.04	.49
S		.03	.09	.03	.03	.08	.05	.16	.02	.03	.08	.11	.08	.12	.03	.05	

P1: File transfers



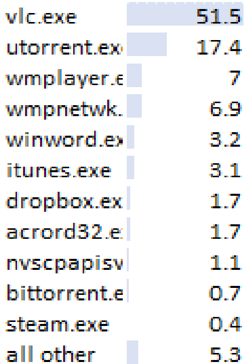
utorrent.ex	48.8
skype.exe	23.1
wmplayer.e	7.9
wmpnetwk.	4.6
winword.ex	2.5
guardmailr	2.1
mpc-hc.exe	1.4
itunes.exe	1.3
nvscpapisv	1
kmplayer.e	0.9
dropbox.ex	0.7
acrord32.e	0.7

P0: Communicate/ watch



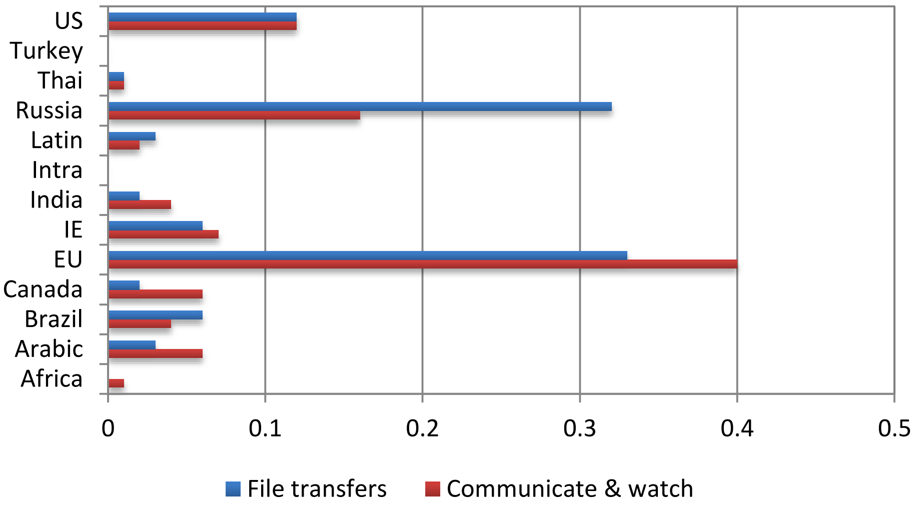
skype.exe	36.4
vlc.exe	34.1
utorrent.exe	11.2
wmplayer.exe	4.5
wmpnetwk.exe	4.1
winword.exe	1.9
itunes.exe	1.9
dropbox.exe	1.2
all other	4.7

P5: Media downloads

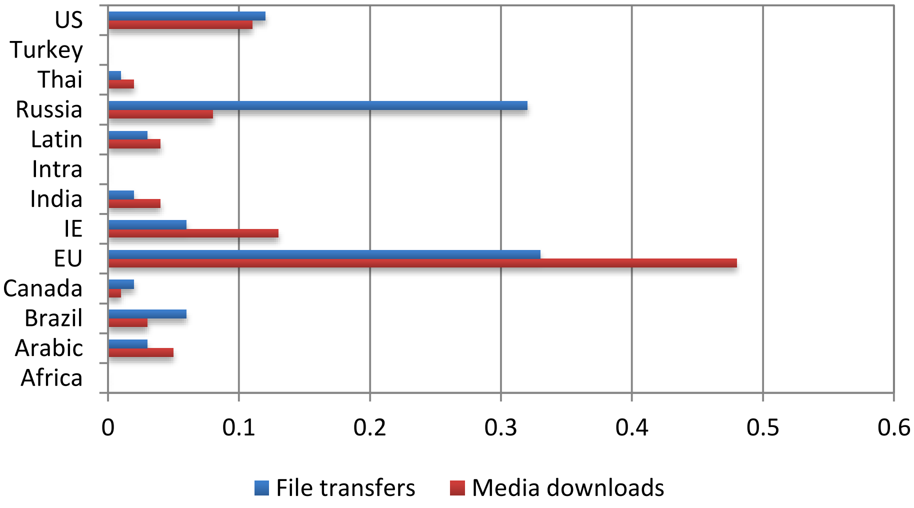


vlc.exe	51.5
utorrent.ex	17.4
wmplayer.e	7
wmpnetwk.	6.9
winword.ex	3.2
itunes.exe	3.1
dropbox.ex	1.7
acrord32.e	1.7
nvscpapisv	1.1
bittorrent.e	0.7
steam.exe	0.4
all other	5.3

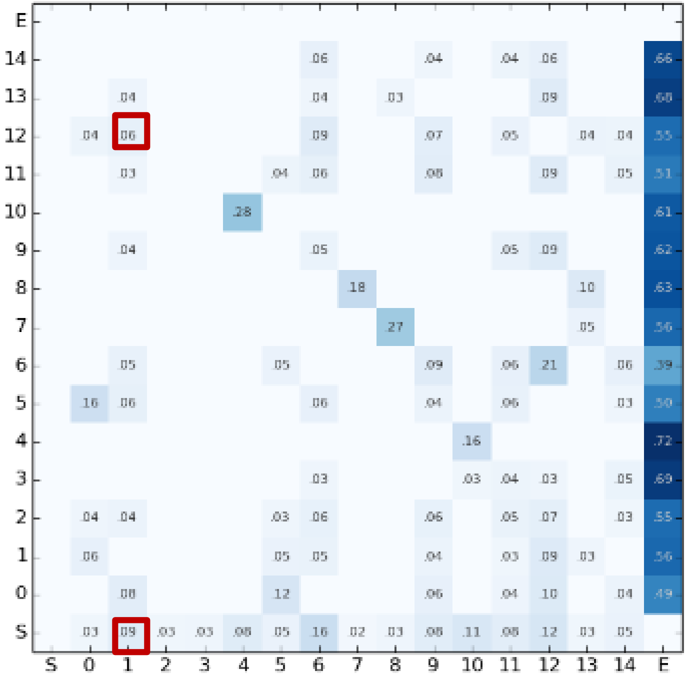
Geolocation



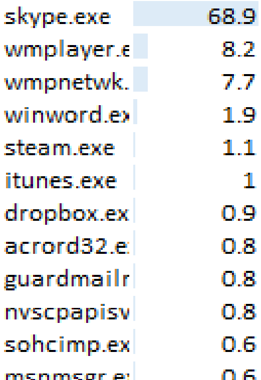
Geolocation



Side information correlation

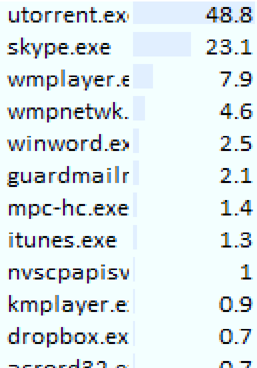


P12: Skype



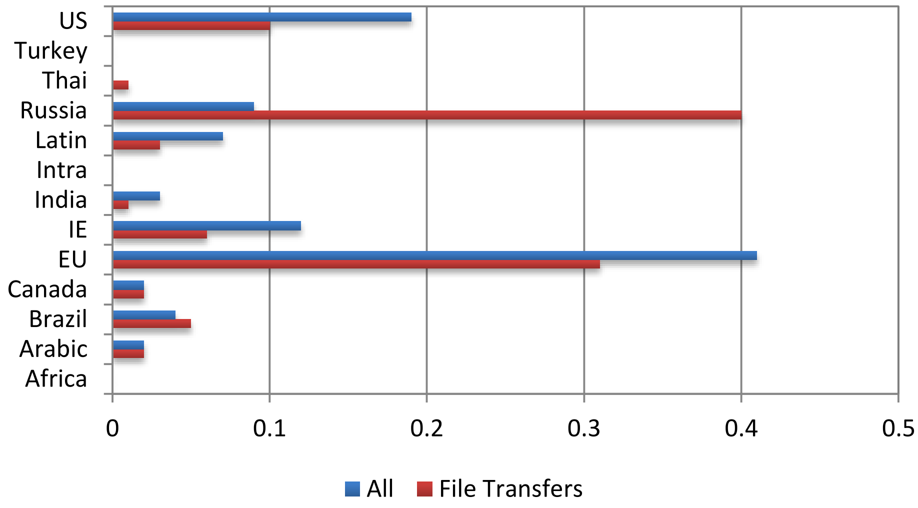
skype.exe	68.9
wmplayer.e	8.2
wmpnetwk.	7.7
winword.ex	1.9
steam.exe	1.1
itunes.exe	1
dropbox.ex	0.9
acrord32.e	0.8
guardmailr	0.8
nvscpapisv	0.8
sohcimp.ex	0.6
msnmsgr.e	0.6

P1: File transfers

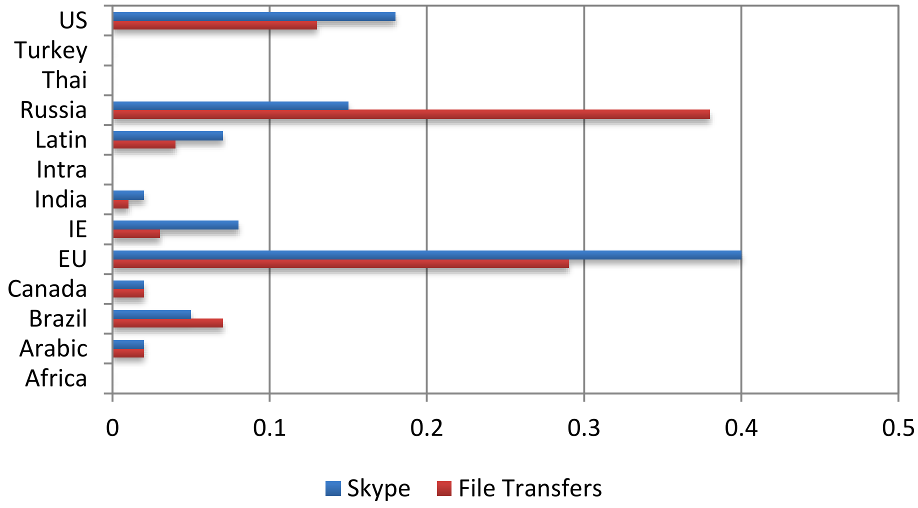


utorrent.ex	48.8
skype.exe	23.1
wmplayer.e	7.9
wmpnetwk.	4.6
winword.ex	2.5
guardmailr	2.1
mpc-hc.exe	1.4
itunes.exe	1.3
nvscpapisv	1
kmplayer.e	0.9
dropbox.ex	0.7
acrord32.e	0.7

Geolocation

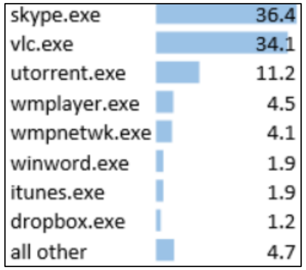


Geolocation



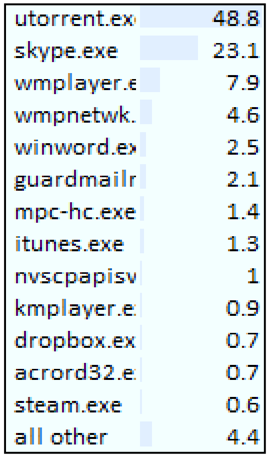
Prototypical behaviors (protos)

P0 (37K, 356)
Communicate & watch



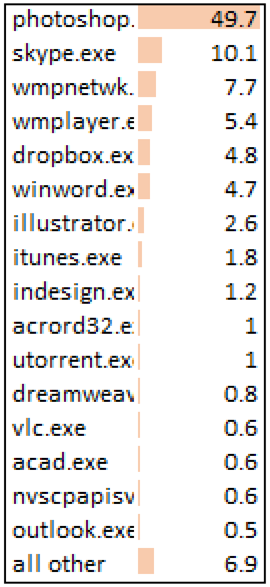
skype.exe	36.4
vlc.exe	34.1
utorrent.exe	11.2
wmplayer.exe	4.5
wmpnetwk.exe	4.1
winword.exe	1.9
itunes.exe	1.9
dropbox.exe	1.2
all other	4.7

P1 (83K, 238)
File transfers



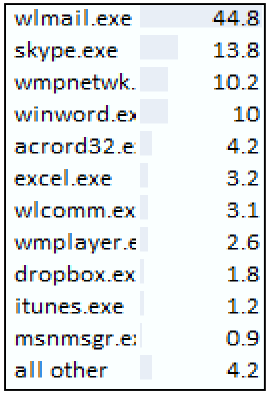
utorrent.ex	48.8
skype.exe	23.1
wmplayer.e	7.9
wmpnetwk.	4.6
winword.ex	2.5
guardmailr	2.1
mpc-hc.exe	1.4
itunes.exe	1.3
nvscpapisv	1
kmplayer.e	0.9
dropbox.ex	0.7
acrord32.e	0.7
steam.exe	0.6
all other	4.4

P2 (32K, 211)
Media creation



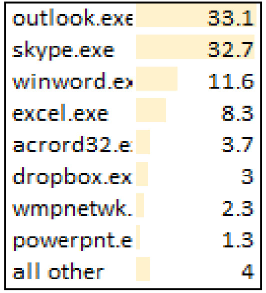
photoshop.	49.7
skype.exe	10.1
wmpnetwk.	7.7
wmplayer.e	5.4
dropbox.ex	4.8
winword.ex	4.7
illustrator.	2.6
itunes.exe	1.8
indesign.ex	1.2
acrord32.e	1
utorrent.ex	1
dreamweav	0.8
vlc.exe	0.6
acad.exe	0.6
nvscpapisv	0.6
outlook.exe	0.5
all other	6.9

P3 (31K, 231)
Email & office



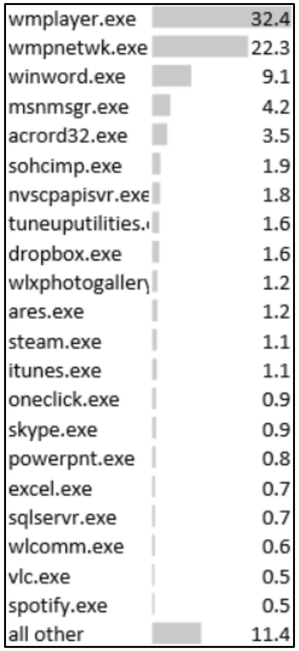
wlmail.exe	44.8
skype.exe	13.8
wmpnetwk.	10.2
winword.ex	10
acrord32.e	4.2
excel.exe	3.2
wlcomm.ex	3.1
wmplayer.e	2.6
dropbox.ex	1.8
itunes.exe	1.2
msnmsgr.e	0.9
all other	4.2

P4 (106K, 364)
Business communication



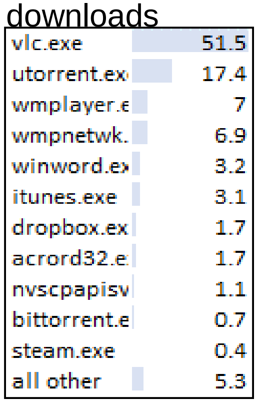
outlook.exe	33.1
skype.exe	32.7
winword.ex	11.6
excel.exe	8.3
acrord32.e	3.7
dropbox.ex	3
wmpnetwk.	2.3
powerpnt.e	1.3
all other	4

P6 (105K, 85)
Media player



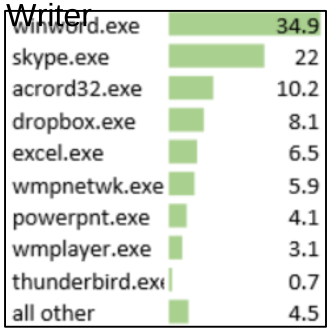
wmplayer.exe	32.4
wmpnetwk.exe	22.3
winword.exe	9.1
msnmsgr.exe	4.2
acrord32.exe	3.5
sohcimp.exe	1.9
nvscpapisvr.exe	1.8
tuneuputilities.	1.6
dropbox.exe	1.6
wlxphotogallery	1.2
ares.exe	1.2
steam.exe	1.1
itunes.exe	1.1
oneclick.exe	0.9
skype.exe	0.9
powerpnt.exe	0.8
excel.exe	0.7
sqlservr.exe	0.7
wlcomm.exe	0.6
vlc.exe	0.5
spotify.exe	0.5
all other	11.4

P5 (48K, 242)
Media downloads



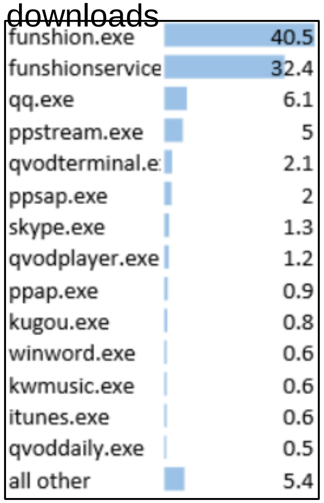
vlc.exe	51.5
utorrent.ex	17.4
wmplayer.e	7
wmpnetwk.	6.9
winword.ex	3.2
itunes.exe	3.1
dropbox.ex	1.7
acrord32.e	1.7
nvscpapisv	1.1
bittorrent.e	0.7
steam.exe	0.4
all other	5.3

P9 (83K, 239)
Writer



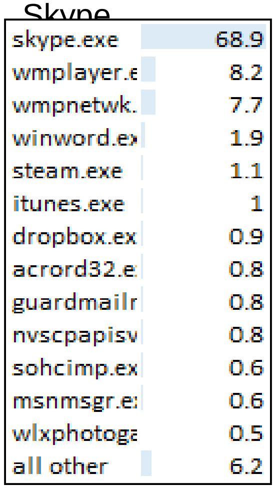
winword.exe	34.9
skype.exe	22
acrord32.exe	10.2
dropbox.exe	8.1
excel.exe	6.5
wmpnetwk.exe	5.9
powerpnt.exe	4.1
wmplayer.exe	3.1
thunderbird.exe	0.7
all other	4.5

P7 (22K, 384)
Asian media downloads



funshion.exe	40.5
funshionservice	32.4
qq.exe	6.1
ppstream.exe	5
qvodterminal.e	2.1
ppsap.exe	2
skype.exe	1.3
qvodplayer.exe	1.2
ppap.exe	0.9
kugou.exe	0.8
winword.exe	0.6
kwmusic.exe	0.6
itunes.exe	0.6
qvoddaily.exe	0.5
all other	5.4

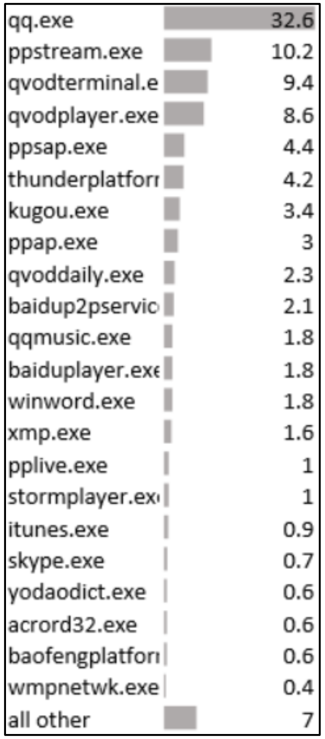
P12 (115K, 195)
Skype



skype.exe	68.9
wmplayer.e	8.2
wmpnetwk.	7.7
winword.ex	1.9
steam.exe	1.1
itunes.exe	1
dropbox.ex	0.9
acrord32.e	0.8
guardmailr	0.8
nvscpapisv	0.8
sohcimp.ex	0.6
msnmsgr.e	0.6
wlxphotoga	0.5
all other	6.2

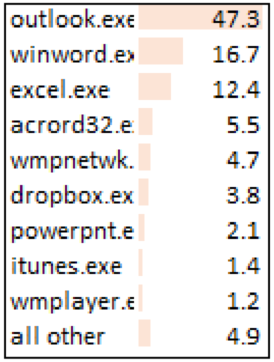
Prototypical behaviors (protos)

P8 (31K, 204)
Asian messenger



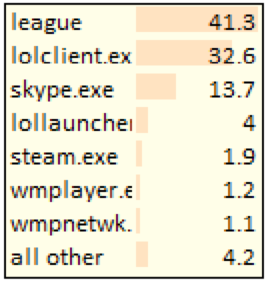
qq.exe	32.6
ppstream.exe	10.2
qvodterminal.e	9.4
qvodplayer.exe	8.6
ppsap.exe	4.4
thunderplatfor	4.2
kugou.exe	3.4
ppap.exe	3
qvoddaily.exe	2.3
baidup2pservic	2.1
qqmusic.exe	1.8
baiduplayer.exe	1.8
winword.exe	1.8
xmp.exe	1.6
pplive.exe	1
stormplayer.ex	1
itunes.exe	0.9
skype.exe	0.7
yodaodict.exe	0.6
acrord32.exe	0.6
baofengplatfor	0.6
wmpnetwk.exe	0.4
all other	7

P10 (105K, 249)
Office



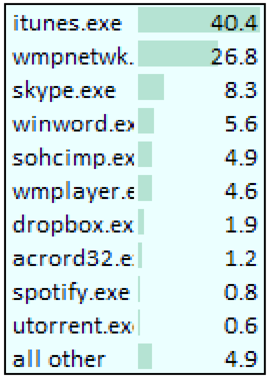
outlook.exe	47.3
winword.ex	16.7
excel.exe	12.4
acrord32.e	5.5
wmpnetwk.	4.7
dropbox.ex	3.8
powerpnt.e	2.1
itunes.exe	1.4
wmplayer.e	1.2
all other	4.9

P13 (35K, 557)
Gaming



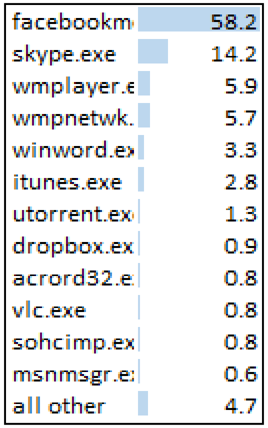
league	41.3
lolclient.ex	32.6
skype.exe	13.7
lollaunche	4
steam.exe	1.9
wmplayer.e	1.2
wmpnetwk.	1.1
all other	4.2

P11 (72K, 243)
iTunes



itunes.exe	40.4
wmpnetwk.	26.8
skype.exe	8.3
winword.ex	5.6
sohcimp.ex	4.9
wmplayer.e	4.6
dropbox.ex	1.9
acrord32.e	1.2
spotify.exe	0.8
utorrent.ex	0.6
all other	4.9

P14 (71K, 296)
Facebook
Messenger



facebookm	58.2
skype.exe	14.2
wmplayer.e	5.9
wmpnetwk.	5.7
winword.ex	3.3
itunes.exe	2.8
utorrent.ex	1.3
dropbox.ex	0.9
acrord32.e	0.8
vlc.exe	0.8
sohcimp.ex	0.8
msnmsgr.e	0.6
all other	4.7