

Characterizing and Supporting **Cross-Device** Search Tasks

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Motivation

- Multi-device usage is becoming common
- People can search anytime, anywhere

Desktop



Smartphone

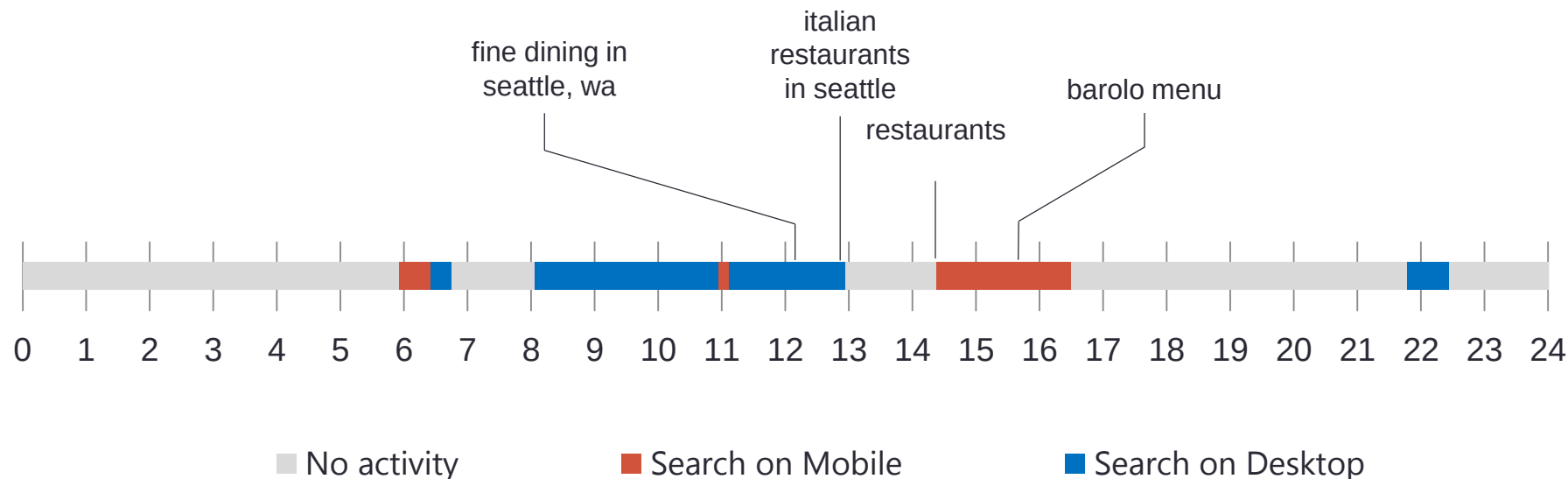


Slate



- We usually study one device at a time (primarily desktop)
- Here we examine ***cross-device*** searching ...

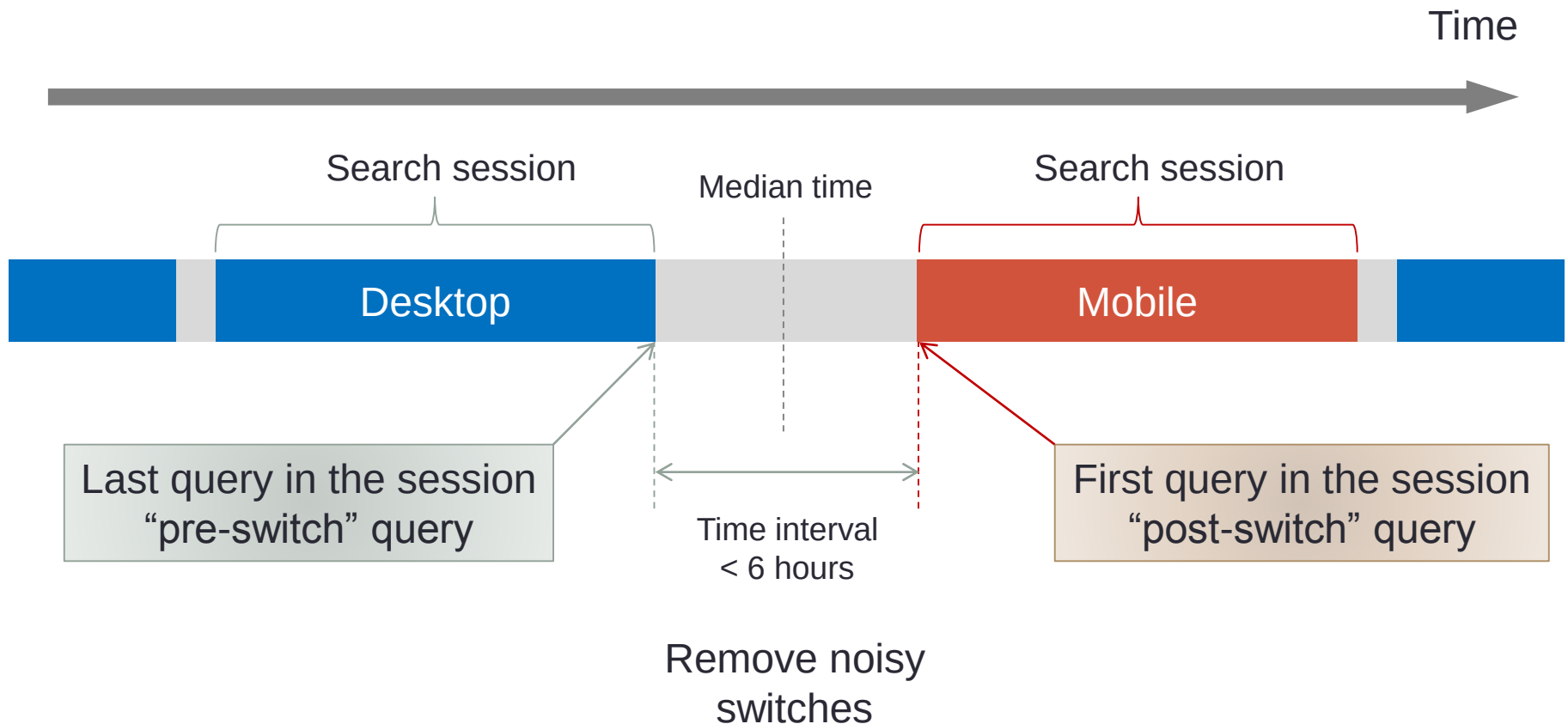
Search Activity over a Single Day



- Analyzing **desktop-only** one could observe **some events**
- Richer picture of behavior by considering multi-device use
- Focus on **switches** (transitions) between devices
- **Our belief:** Engine can help on post-switch device if it can anticipate post-switch task resumption

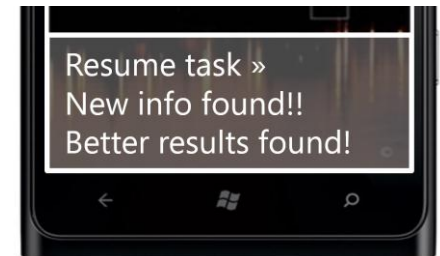
Our Definition of Device Switching

- Search sessions with 30 minute inactivity timeout



Challenges and Opportunities

- Challenges:
 - Switching is expensive for a user
 - User has to remember what has been searched on task
 - Re-typing is time consuming, sometimes very difficult if in motion
- Opportunities:
 - How a search engine could help with switching
 - Predict cross-device task continuation
 - Use prediction to capitalize on between device downtime
 - Why not just ***always*** use downtime?
 - Additional actions (e.g., run queries, crowdsourced answers) **expensive**
 - Only want to do it when confident that user will resume



Analyzing Cross-Device Search

- Subset of users who are **signed in** to Microsoft Bing
- Users who used both devices during one month period

Number of Days		31
Number of Users		39,081
Number of Sessions	Desktop	709,610
	Mobile	301,028
	Total	1,010,638
Number of Queries	Desktop	3,023,582
	Mobile	667,091
	Total	3,690,673
Number of Switches		158,324

Transitions (within 6 hours)

	Desktop-to-Mobile	Mobile-to-Desktop
Same-query switch	10,480 (6.6%)	5,282 (3.3%)
Different-query switch	69,441 (43.9%)	73,121 (46.2%)

- Volume of Desktop-to-Mobile $\approx$ Mobile-to-Desktop
- Different query switches $\gg$ Same query switches
- 2x same-query D-to-M as M-to-D
 - Many desktop search tasks will be carried over to mobile.
 - More support for D-to-M is needed.

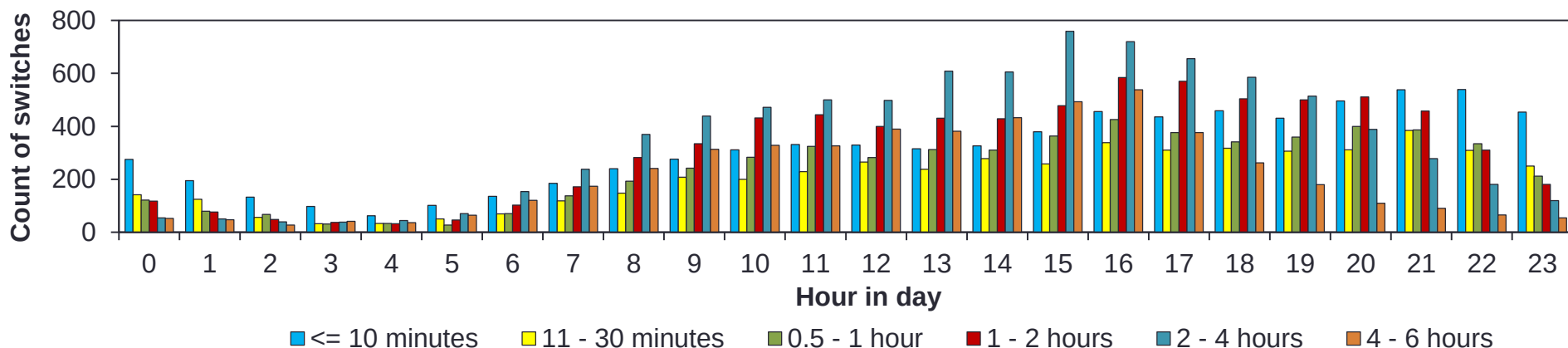
What do cross-device tasks look like?

Characterizing Cross-Device Search

- Focus on Desktop-to-Mobile
- Temporal:
 - When do users switch
 - How long elapses between pre- and post-switch
- Topical:
 - Topic shifts during switches
- Geospatial:
 - Physical location before and after device switch

Temporal

- Time between pre- and post-switch queries as a function of hour in the day, of *pre-switch query*



- Most switches initiated late afternoon, end early evening
- Gap between pre- and post-switch queries varies with time:
 - Short gaps are more likely late evening and early morning
 - Long gaps are more likely during work hours (9-6)
- Engine can use temporal features to predict task resumption

Topical

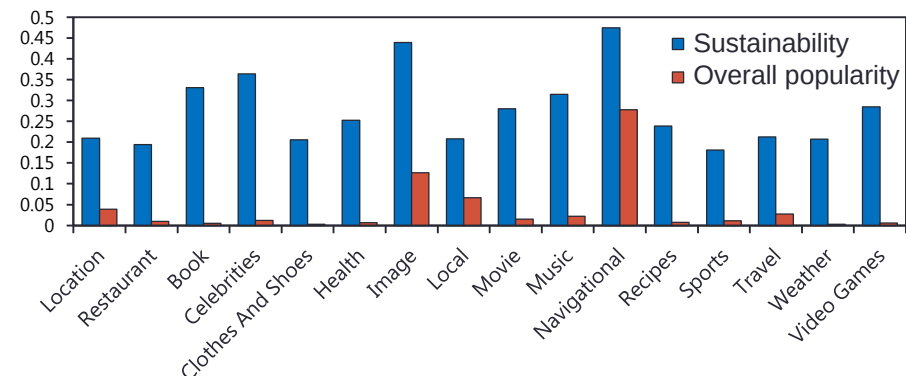
- Query topics estimated from Bing runtime classifiers
- Sustainability = $\Pr(\text{topic post-switch} \mid \text{topic pre-switch})$
- Lift over background (sustainability / overall topic popularity):

Most likely to
be resumed
post-switch,
if pre-switch

Category	Lift
Clothes and Shoes	82.240
Weather	77.528
Books	66.180
Video Games	42.478
Health	39.608
Recipes	31.827
Celebrities	30.342
Restaurant	19.576
Movie	18.305
Sports	15.595
Music	14.429
Travel	7.805
Location	5.364
Image	3.467
Local	3.117
Navigational	1.710

Least likely to
be resumed
post-switch,
if pre-switch

Purchasing (need to try on clothes/shoes)
Weather forecasts
Entertainment while mobile



General interest on mobile, popular
irrespective of pre-switch topic

Geospatial

- Examine physical location before and after switch
- **Caveat:** Uses RevIP and cellphone provider geocoding
 - At town/city level, not GPS based
- 67% stay within same city, 33% move to different city
- Movement during post-switch session:

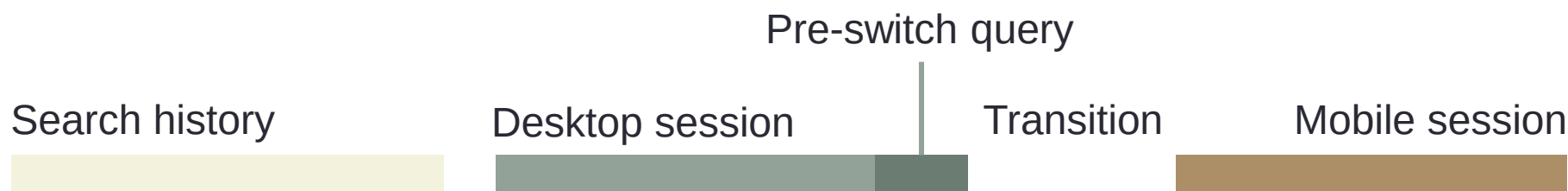
Single query session	Multiple query session	
	Moving session	Stationary session
60.6%	5.3%	34.2%

Must be moving quickly given
how location is estimated

Can we predict cross-device tasks?

Predicting Cross-Device Search Tasks

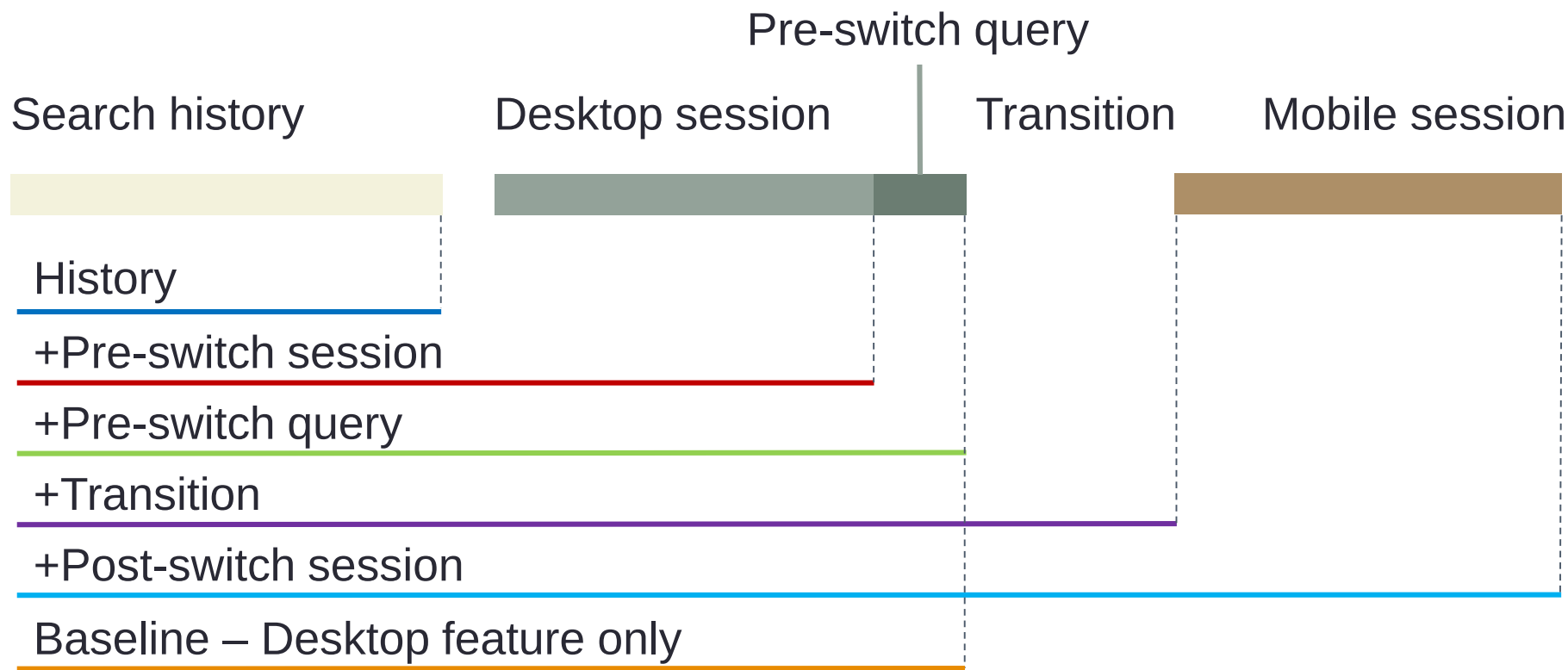
- Predict whether the user will resume the task in the pre-switch session on another device



- Two main points of interest:
 - Once you leave the pre-switch engine
 - Once you reach post-switch engine (homepage)
- Different types of support offered at each (more later)

Prediction Experiment

- Different features to predict cross-device task resumption



Prediction Experiment

- MART classifier
- Features
 - Behavioral, Topical, Temporal, Geospatial
- Cross-validation at the user level
- Training data
 - **Automatic:** Machine learned model using query similarity features
 - 17k judgments, **9.5%** of the labeled switches were on same task
 - **Human labeled:** 5 judges reviewing pre- and post-switch behavior
 - 800 judgments, **15%** of the labeled switches were on same task
- Dropped nav. queries (personal freq > 5, global freq > 10)
 - Represent long-term ***interests***, not search tasks

Feature Dictionary

Name	Description
Features from Search History	
NumOfDesktopQuery ^B	Number of queries issued on desktop
NumOfMobileQuery	Number of queries issued on mobile
PercentageDesktopQuery ^B	Percentage of queries issued on desktop
PercentageMobileQuery	Percentage of queries issued on mobile
PercentageDesktopTime ^B	Percentage of searching time on desktop
PercentageMobileTime	Percentage of searching time on mobile
NumOfSession ^B	Number of search sessions
NumOfContiguousSwitch	Number of contiguous cross-device search tasks
NumOfRelevantCrossDevice	Number of search tasks appearing on both devices
EntropyAvg	Average device entropy of same-task queries
EntropySum	Total device entropy of same-task queries
EntropyWeighted	Weighted device entropy of same-task queries
Features from Pre-switch Sessions	
NumOfQuery ^B	Number of queries within session s_i
TimeSpanPreSess ^B	Temporal length of session s_i (in minutes)
NumOfLocationQuery ^B	Number of location-related queries in session s_i
AvgDistancePreSess ^B	Average distance from current location to locations mentioned in session s_i

Note: No cross-device *query similarity* features were included in the model
→ Also part of the automatic labeling

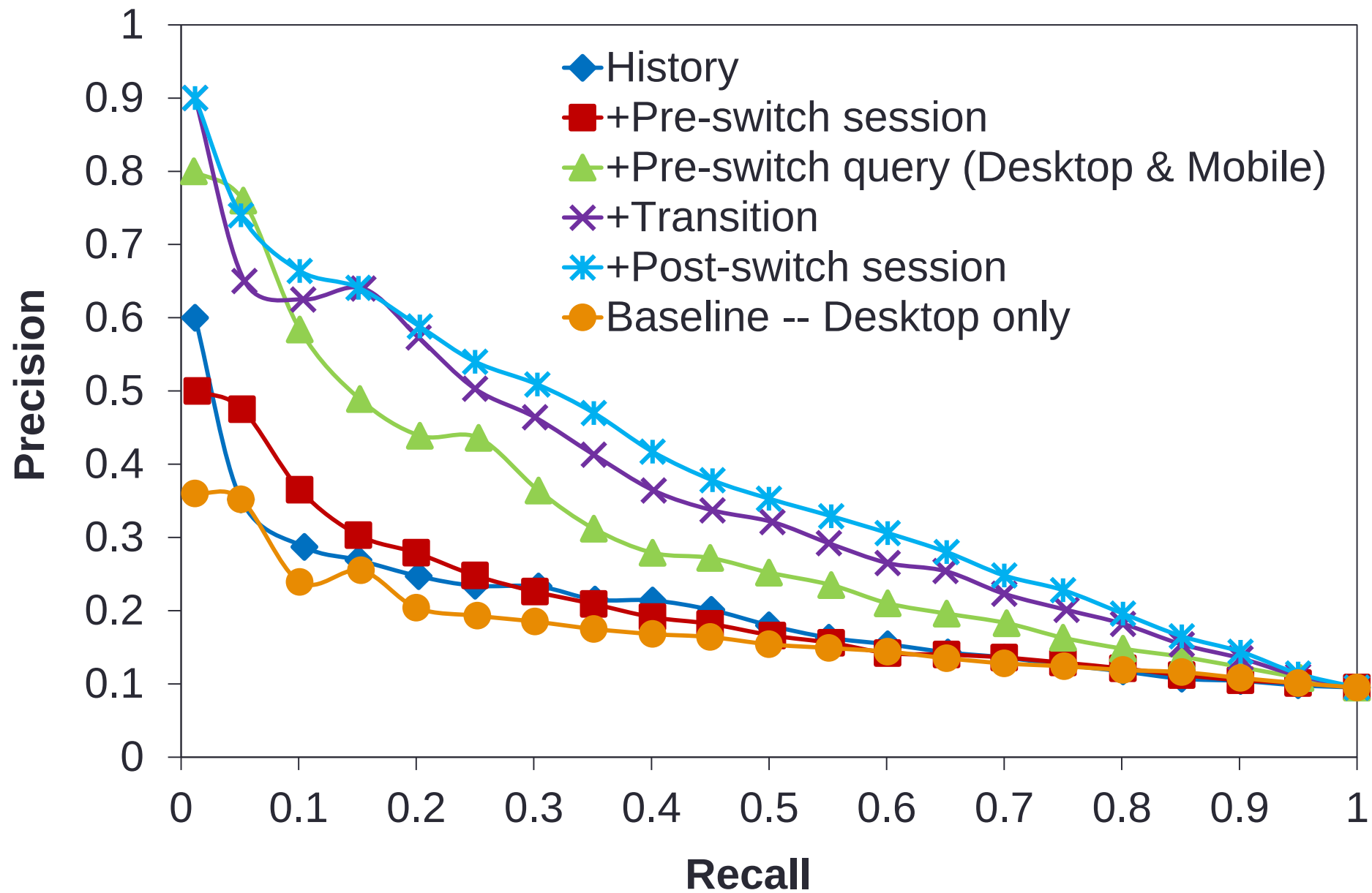
Features from Pre-switch Query	
GlobalFrequency	The historical frequency of q_i in the entire dataset
PersonalFrequency	The frequency of q_i in personal search history $\mathcal{S}$
NumExactQueryDesktop ^B	Number of same queries as q_i on desktop in $\mathcal{S}$
NumExactQueryMobile	Number of same queries as q_i on mobile
NumRelatedQueryDesktop ^B	Number of related queries as q_i on desktop
NumRelatedQueryMobile	Number of related queries as q_i on mobile
NumExactQuerySwitch	Number of switches that pre-switch query and post-switch query are the same as q_i
NumRelatedQuerySwitch	Number of switches that pre-switch query and post-switch query are both relevant to q_i
PreQueryContiguousSwitch	Number of contiguous cross-device tasks of q_i
NumOfRelatedQueryInSess ^B	Number of queries relevant to q_i in session s_i
NumOfTerm ^B	Number of terms in query q_i
PreQueryCategory ^B	The search topic of query q_i
PreQueryHour ^B	The hour component of t_i
PreQueryDayOfWeek ^B	The day of week of t_i
IsWeekday ^B	Boolean, indicates t_i is weekday or weekend
HasLocation ^B	Boolean, true if q_i contains location
PreQueryDistance ^B	The distance from current location to location in q_i
HasLocalService ^B	Boolean, true if q_i contains local service
Features from the Transition	
TimeIntervalSwitch	The timespan between t_i and t_{i+1}
GeoDistanceSwitch	The distance between where q_i and q_{i+1} are issued
IsSameLocationSwitch	Boolean, true if q_i and q_{i+1} occur at the same place
AvgSpeedSwitch	Average travelling speed during the switch
Features from Post-switch Session	
TimeSpanPostSess	The temporal length of session s_{i+1}
PostQueryCategory	The search topic of query q_{i+1}
PostQueryHour	The hour component of t_{i+1}
GeoDistancePostSess	The distance travelled within session s_{i+1}
AvgSpeedPostSess	Average travelling speed within session s_{i+1}

^B = baseline features

Findings (Automatic Labeling)

Feature Grouping	Accuracy	Positive Precision	Positive Recall	AUC
Baseline - Desktop Only	0.903	0.337	0.037	0.646
History	0.880	0.250	0.142	0.661
+ Pre-switch Session	0.899	0.381	0.130	0.679
+ Pre-switch Query	0.907**	0.504**	0.145**	0.757**
+ Transition	0.910**	0.544**	0.184**	0.781**
+ Post-switch Session	0.910	0.568	0.169	0.806

Note: Similar findings for human labeling and when navigational queries retained (although smaller gains)



Feature Analysis

Top 10 features for predicting contiguous search tasks

Features	χ^2	Info Gain
Number of related queries on mobile	491.23	0.0317
Time span of the switch	378.00	0.0240
Number of contiguous switch lead by the query (as pre-switch query)	342.97	0.0204
Number of related queries appear as pre-switch queries	315.35	0.0208
Average mobile moving speed during switch	295.77	0.0227
Distance travelled during switch	270.39	0.0201
Number of contiguous switches in user's history	235.27	0.0201
Average device use entropy for all tasks in user's history	221.83	0.0154
Number of related queries on desktop	172.74	0.0151
If the pre-switch query and post-switch query are issued in the same city	95.81	0.0091



Pre-switch query



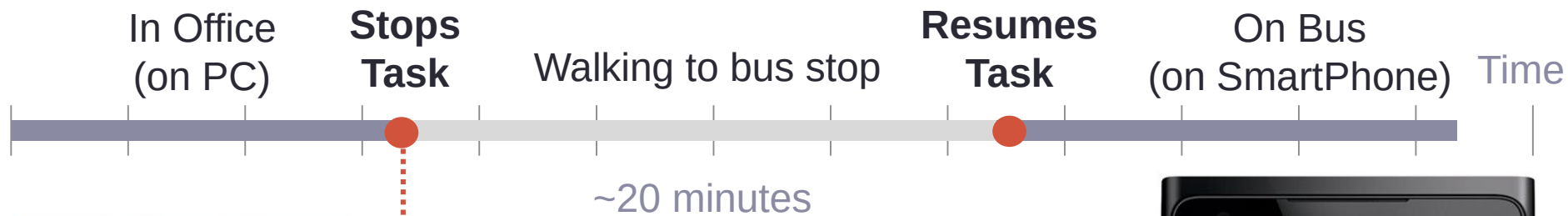
Transition



History

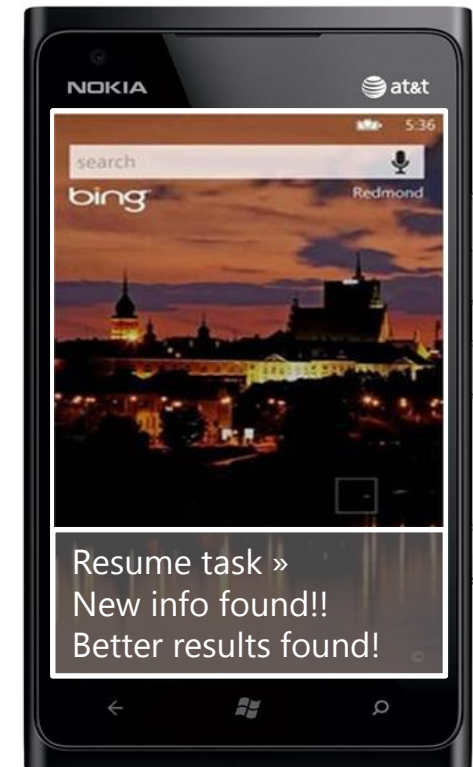
Enabled Scenario: Exploit Downtime

Being able to predict task resumption enables scenarios such as



Will user resume task immediately on mobile?

If Yes, then the search engine can help ...



What Can Engine do to Help?

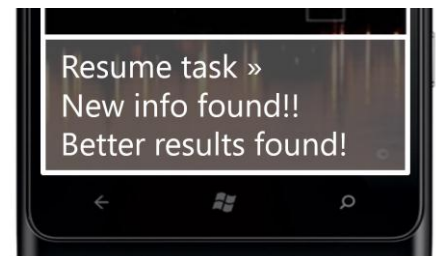
- Search engine can perform actions on the users' behalf to ***capitalize on the downtime*** during the switch, e.g.,

Predict resumption at end of **pre-switch** session:

- Proactively save recent session state
- Try different ranking algorithms
- Pose the query to a question answering site
- Alert the user if better results found

Predict at start of **post-switch** session:

- Provide the user with the option to explicitly resume task on homepage



Summary and Takeaways

- Multi-device usage increasingly popular
- Cross-device search is prevalent
 - 15% of (non-navigational) switches are on same task
- Characterized some aspects of cross-device tasks
- Built predictive models of cross-device task resumption
- Provides a search engine with opportunity to help searchers by using between-device downtime