Search User Behavior Modeling

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About The Speaker

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Outlines

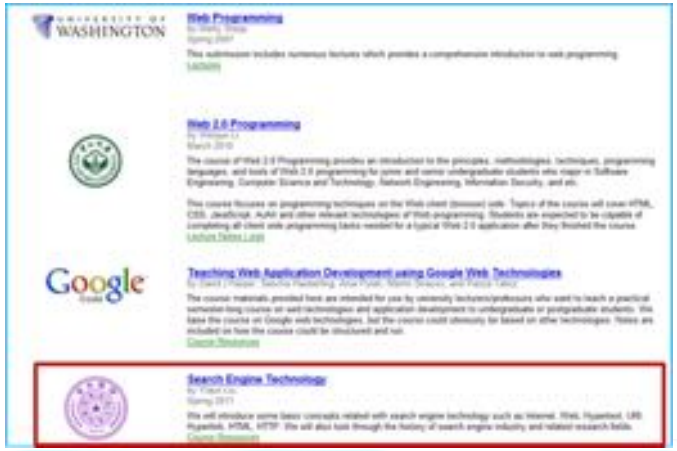
1. **Introduction and Background**
2. **Click and Examination during Web Search**
3. **Constructing Click Models**

1. Introduction: The THUIR Group

- Research Interests
  - Information retrieval models and algorithms
  - Web search technologies
  - Cognitive behavior of Web search users
- Members
  - Leader: Prof. Shaoping Ma
  - Professors: Min Zhang, Yijiang Jin, Yiqun Liu;
  - Students: 10 Ph. D. students, 8 M.S. students, ...

1. Introduction: The THUIR Group

- **Cooperation with industries**
  - **Tsinghua-Sogou** joint lab on Web search technology (since 2006)
  - **Tsinghua-Baidu** joint course: Fundamentals of search engine technology (since 2008), Computational advertising (since 2013)
  - **Tsinghua-Google** joint course: Search Engine Product Design and Implementation (since 2009), Google Code University Project
  - Research projects from Yahoo!, Samsung, Toshiba, etc.

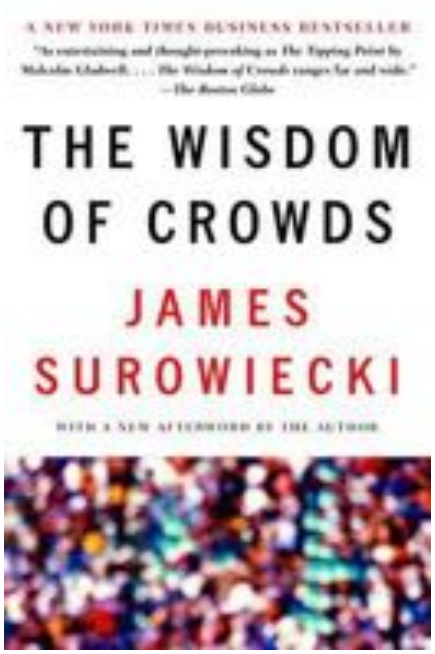


1. Introduction: The THUIR Group

- **When Cognitive Psychology meets Web search**
  - **Users' information perceiving process on SERPs**
    - E.g. Result Examination Behavior
    - E.g. Decision Making Behavior (Click-through/query reformulation/abandonment/search engine switch)
  - **Applications**
    - Search ranking algorithm: click models, LTR training, …
    - Search evaluation methodology: evaluation metrics, A/B test, interleaving, …
    - Search satisfaction prediction: satisfaction, frustration, …

1. Introduction: User Behavior

- **How do Search Engines Rank Results**
  - **Yahoo LTR task: 700+ ranking signals:** Hyperlink, Content relevance, **User behavior**, Page structure, Freshness, Service stability, ……
- **Crowd behavior helps**
  - A certain user may make mistakes
  - User crowds usually make much wiser decisions
  - E.g. the most clicked results



1. Introduction: User Behavior

- **User behavior may be biased: position bias**
  - **Users' behaviors may be affected by ranking positions**
  - **How to model this effect is essential for the utility of user behaviors**

Outlines

1. Introduction and Background
2. **Click and Examination during Web Search**
3. **Constructing Click Models**

2. Clicking/Examination Behavior

- **2.1 Data Collecting: Clicking behavior**
  - Search click-through logs (e.g. WSCD, SogouQ)
    - User info: user ID & IP, search device
    - Query info: query text, time stamp, location, …
    - Click info: URL, time stamp, …
    - Search results
      - Organic results: algorithmic results
      - Ads results: advertisement results
      - Query suggestions, Vertical links, …

2. Clicking/Examination Behavior

- **2.1 Data Collecting: Clicking behavior**
  - Data sample from SogouQ

Time	Query	Rank	Page Clicked
20:58:58	丰田(*Toyota*)	6	www.autohome.com.cn/526/
21:02:34	丰田(*Toyota*)	5	www.autohome.com.cn/110/
21:03:23	丰田(*Toyota*)	6	www.autohome.com.cn/526/
21:04:11	上海大众(*Shanghai Volkswagen*)	5	www.che168.com/che168/cardb/brand/brand_58.html
21:06:14	广州本田(*Guangzhou Honda*)	3	car.autohome.com.cn/brand/32/
21:09:23	丰田(*Toyota*)	2	car.autohome.com.cn/brand/63/
21:10:20	丰田(*Toyota*)	4	price.pcauto.com.cn/brand.jsp?bid=31
21:11:20	丰田(*Toyota*)	10	www.che168.com/che168/cardb/brand/brand_24.html
21:12:43	丰田卡罗拉(Toyota Corolla)	1	www.autohome.com.cn/526/
21:19:12	丰田卡罗拉(Toyota Corolla)	11	www.autohome.com.cn/526/options.html

2. Clicking/Examination Behavior

- **2.1 Data Collecting: Examining behavior**
  - Eye-tracking behavior of search users
  - Strong eye-mind hypothesis: There is no appreciable lag between what is fixated on and what is processed (Just et al., 1980).

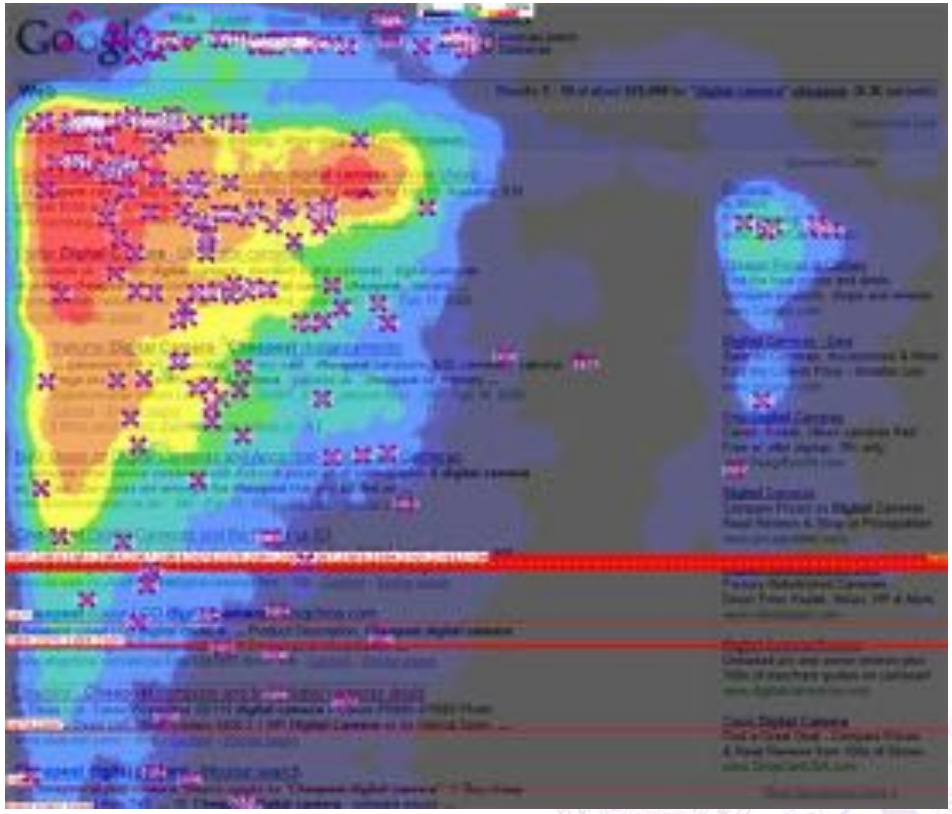
http://aeg.knmurthy.netdna-cdn.com/wp-content/uploads/2013/01/tobii.jpg

2. Clicking/Examination Behavior

- **2.1 Data Collecting: Examining behavior**
  - Human reading behavior: fixation v.s. saccade
  - Fixation: spatially stable gazes each lasting for approximately 200–500 milliseconds
  - Saccade: rapid eye movements that occur between fixations lasting 40–50 milliseconds
  - Most existing studies infer examination behavior with eye fixation sequences

2. Clicking/Examination Behavior

- **2.2 Position bias in clicking/examination**
  - A user study organized by Nielson Group with over 230 participants on search user behavior
  - Golden Triangle: F-shape heat map in eye fixation sequence
  - Northwestern: Hot
  - Southeastern: Cold



2. Clicking/Examination Behavior

- **2.2 Position bias in clicking/examination**
  - Users have a larger chance to examine top-ranked results and then click them

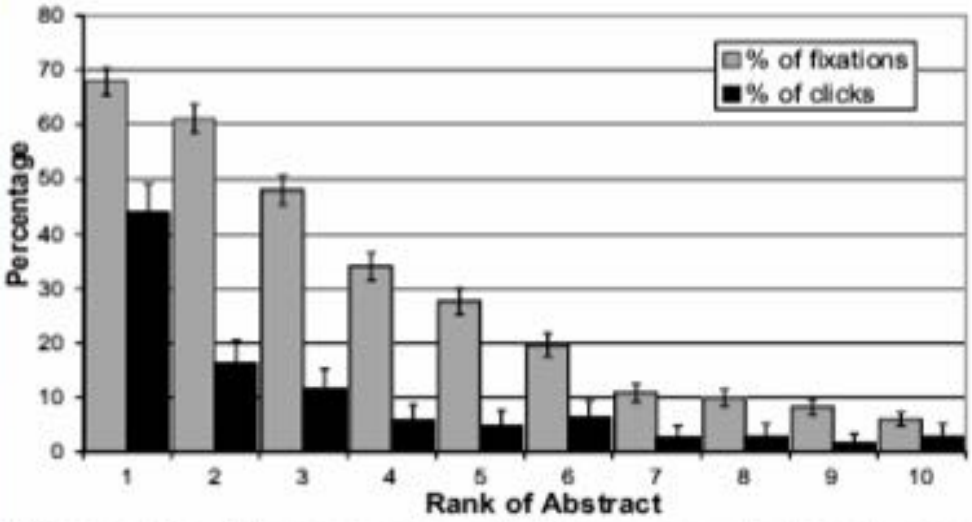


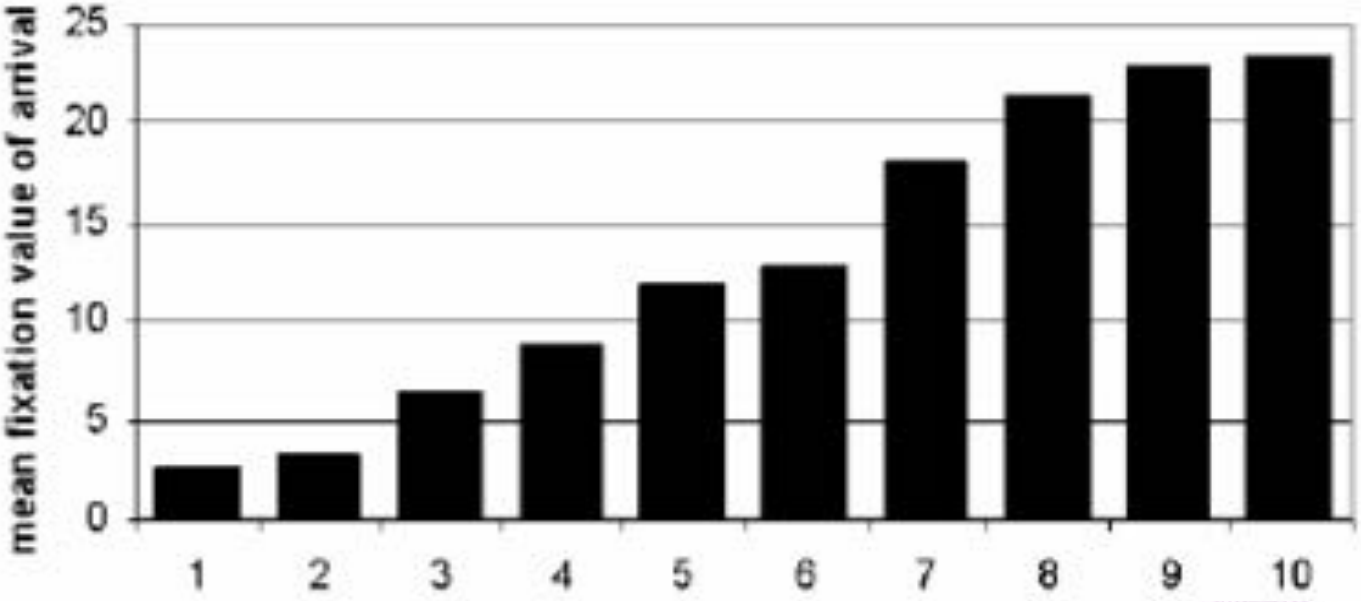
Figure 1: Percentage of times an abstract was viewed/clicked depending on the rank of the result.

- Title: 17.4%
- Snippet: 42.1%
- Category: 1.9%
- URL: 30.4%
- Other: 8.2% (includes, cached, similar pages, description)

Joachims et.al, Eye-tracking analysis of user behavior in www search. SIGIR 2005

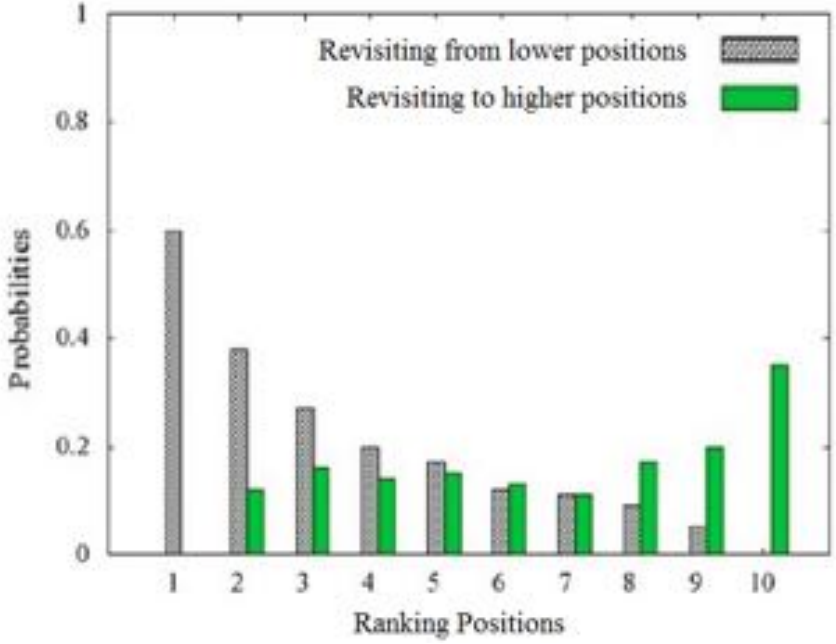
2. Clicking/Examination Behavior

- **2.3 Examination sequence of search users**
  - Cascade assumption: Users tend to examine results from top to bottom
  - Mean time of arrival v.s. result ranking position



2. Clicking/Examination Behavior

- **2.3 Examination sequence of search users**
  - Revisiting behaviors also happen a lot
    - Chinese search engine (Sogou): 27.9% sessions
    - Non-Chinese search engine (Yandex): 30.4% sessions



Query Frequency	Chinese	Yandex
[1,9]	0.239	0.597
[10,30]	0.235	0.593
[31,99]	0.228	0.592
[100,499]	0.256	0.594
[500,∞)	0.249	0.622

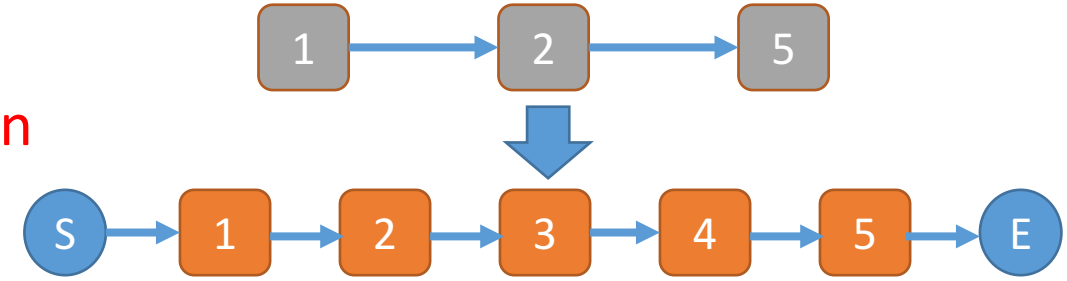
Label	Been Revisited	Never Been Revisited
bad	0.031	0.073
fair	0.075	0.151
good	0.310	0.364
excellent	0.513	0.399
perfect	0.071	0.013

Danqing Xu, Yiqun Liu, et al. Incorporating Revisiting Behaviors into Click Models. WSDM 2012

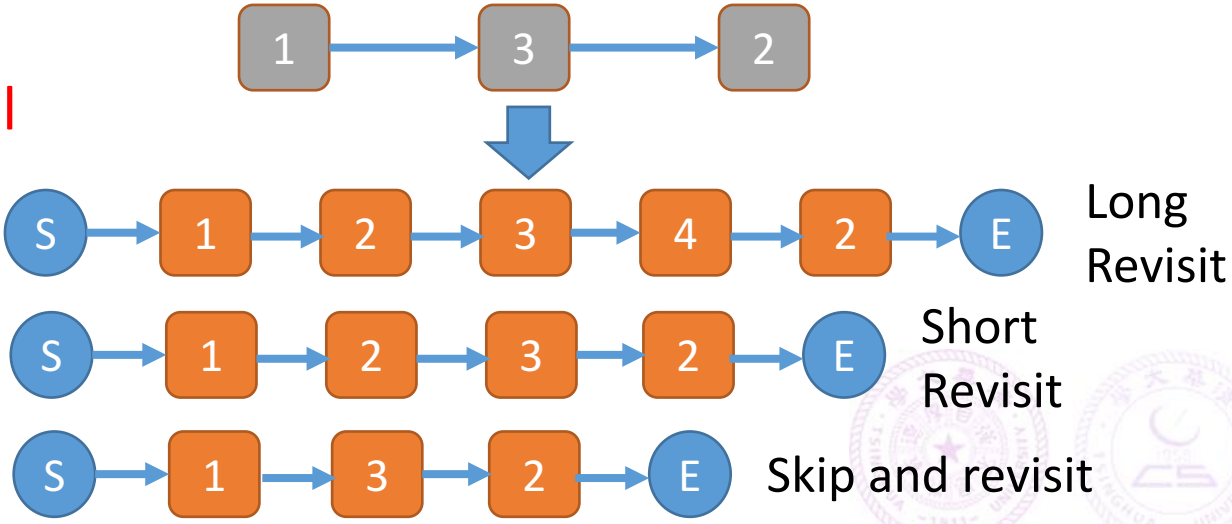
2. Clicking/Examination Behavior

- **2.3 Examination sequence of search users**

Cascade assumption

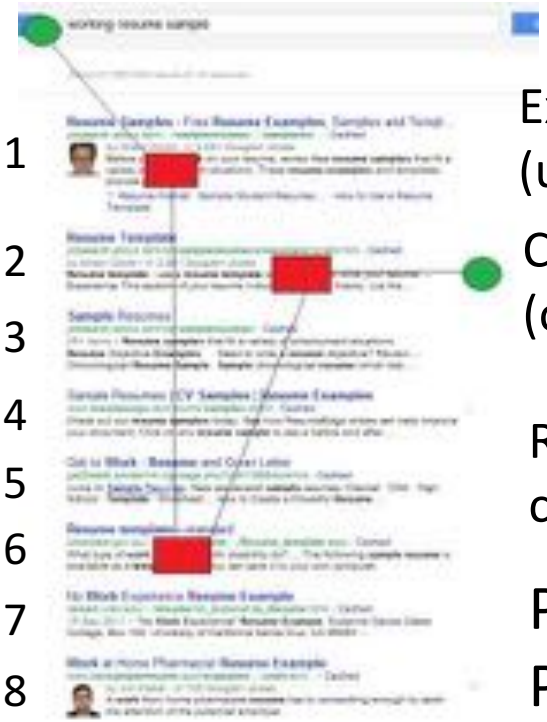


Retaining Sequential Information



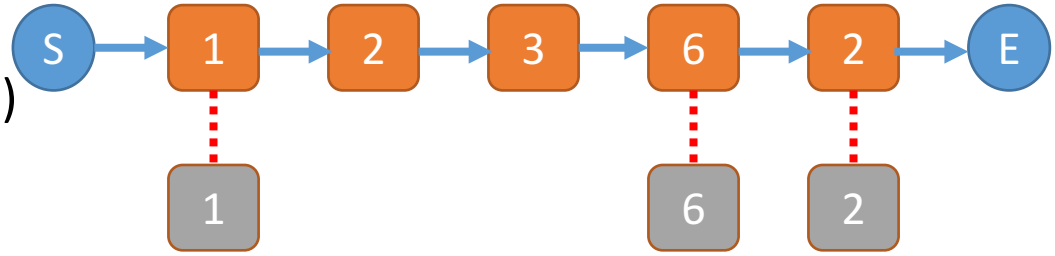
2. Clicking/Examination Behavior

- **2.3 Examination sequence of search users**
  - The necessity of retaining sequential information



Examine (unobserved)

Click (observed)



Reorganize data with cascade assumption

Problem#1: not the true ***last click***

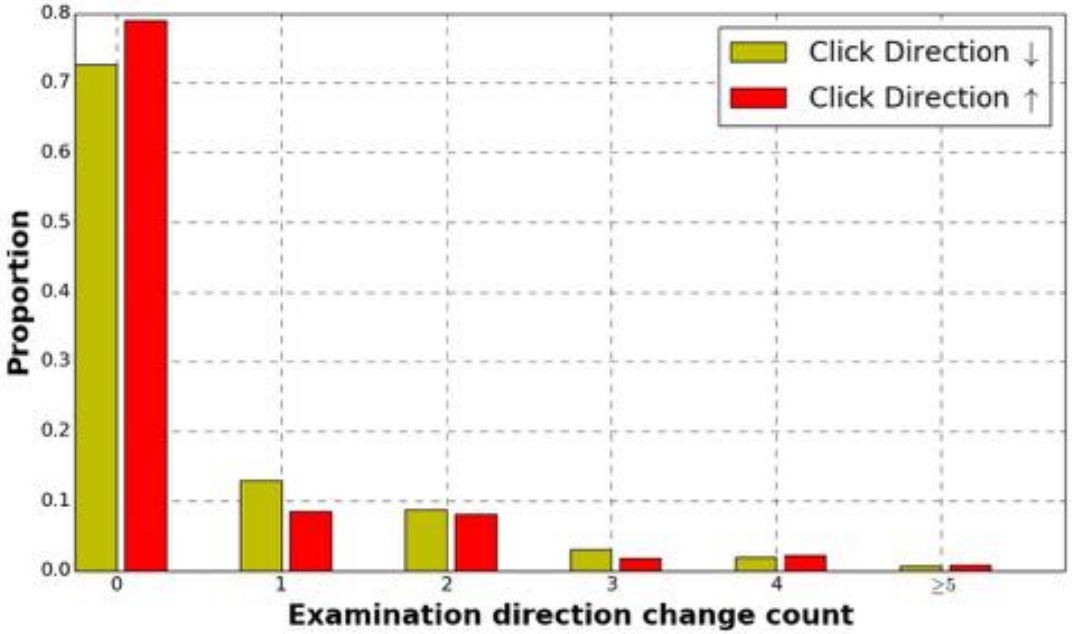
Problem#2: ***decision process*** is missing

2. Clicking/Examination Behavior

- **2.3 Examination sequence of search users**
  - How often do users change the direction of examination between clicks?

2. Clicking/Examination Behavior

- **2.3 Examination sequence of search users**
  - Locally Unidirectional Examination: users tend to examine search results in a single direction without changes between their clicks



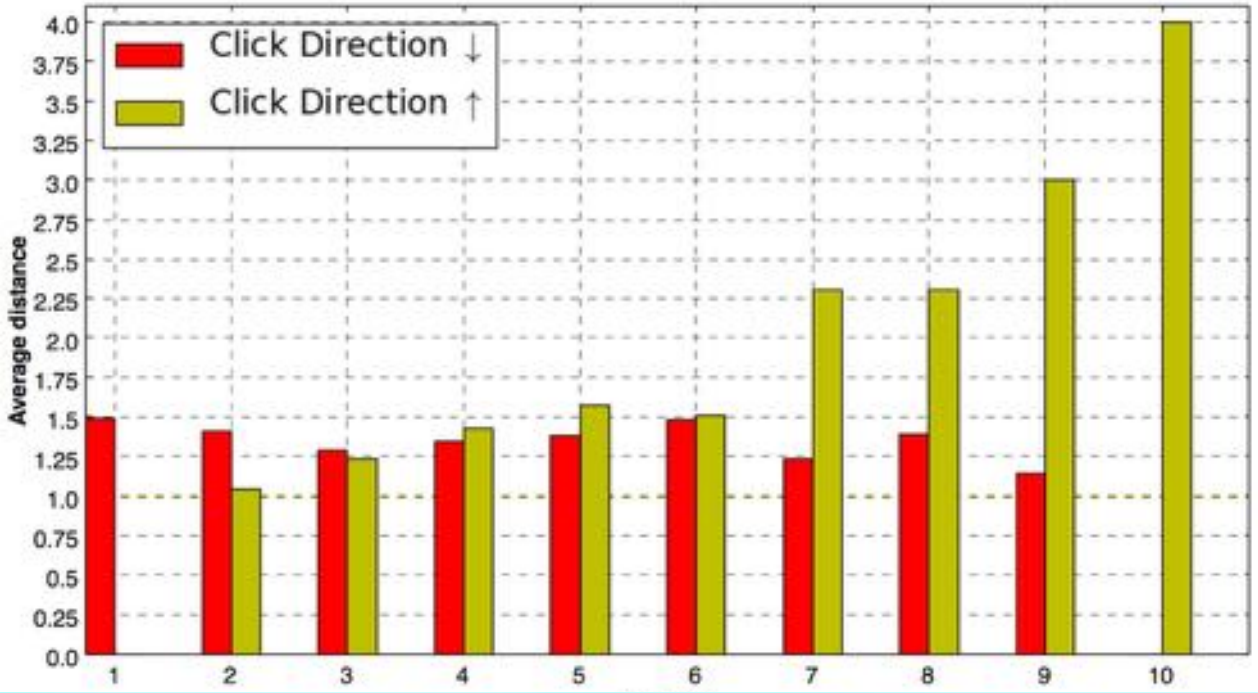
Chao Wang, Yiqun Liu, et al., Incorporating Non-sequential Behavior into Click Models. In: SIGIR2015

2. Clicking/Examination Behavior

- **2.3 Examination sequence of search users**
  - How far do users' eye fixations jump after examining the current clicked result?

2. Clicking/Examination Behavior

- **2.3 Examination sequence of search users**
  - Non First-order Examination: Users always skip a few results and examine a result at some distance from the current one between clicks

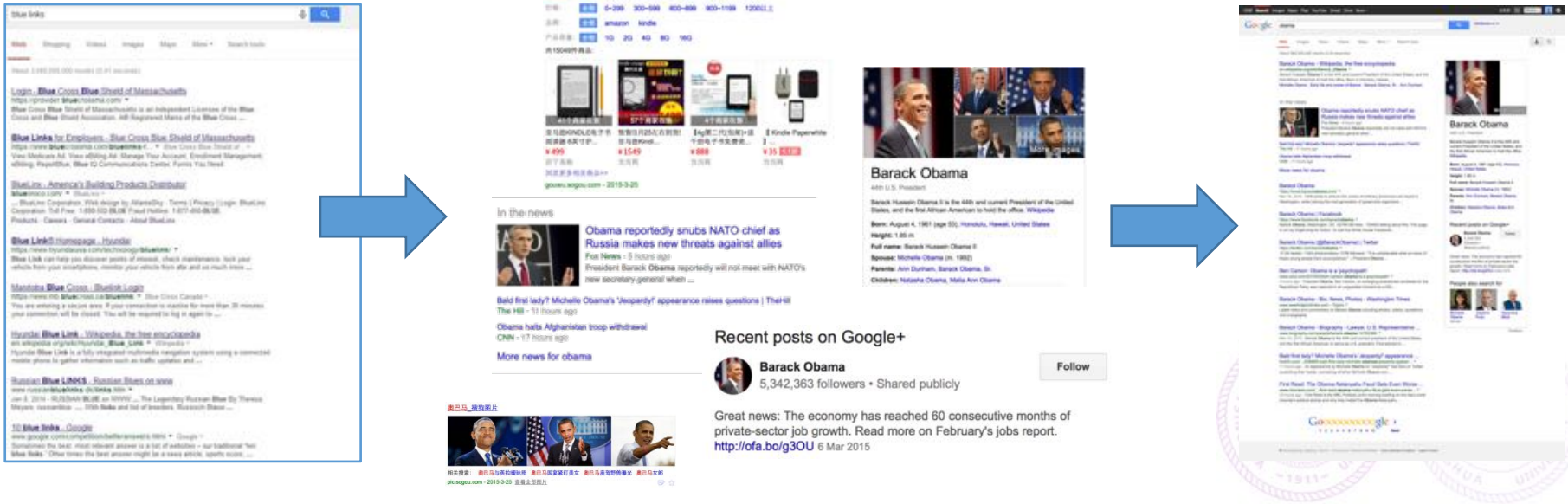


2. Clicking/Examination Behavior

- **2.3 Examination sequence of search users**
  - Users usually follow a cascade pattern in examination (he/she examines search results one by one from top to bottom)
  - It is also common for users to revisit some results (he/she examines/clicks a higher ranked search result after examining/clicking a lower ranked one)
  - During revisiting, he/she usually examines search results from bottom to top with some skips

2. Clicking/Examination Behavior

- **2.4 Influence of Heterogeneous Results**
  - Over 80% of SERPs are with ≥1 verticals in Chinese search Engines
  - It is impossible to ignore their influences



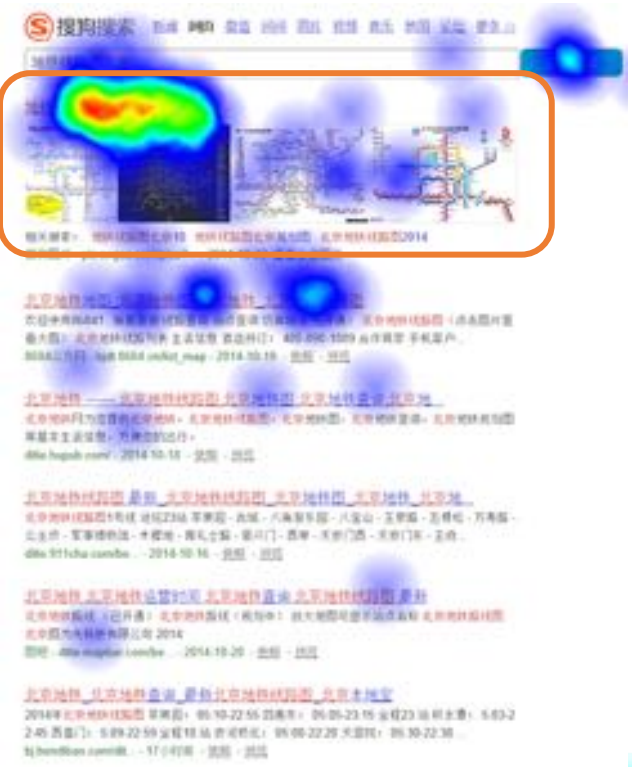
2. Clicking/Examination Behavior

- **2.4 Influence of Heterogeneous Results**

2. Clicking/Examination Behavior

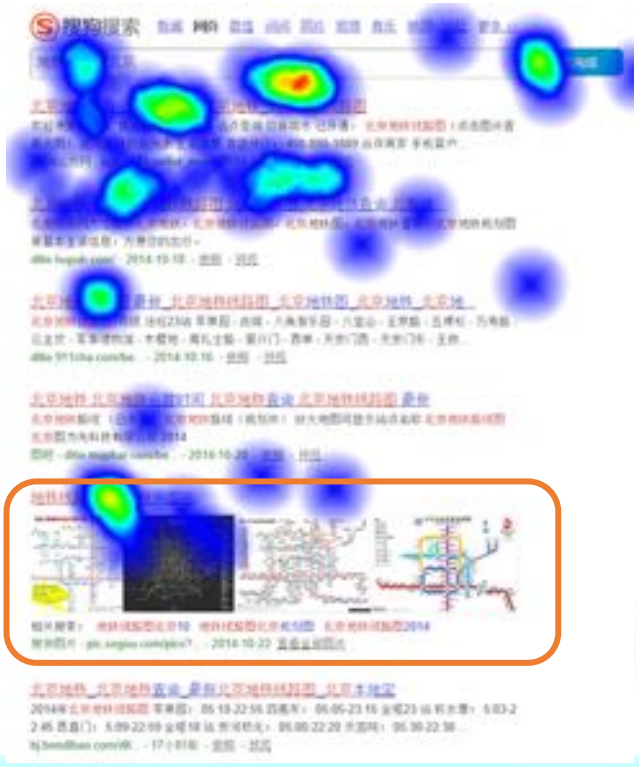
- **2.4 Heterogeneous Results: Attractiveness Effect**
  - Certain verticals draw more attention

Rank 1st



Rank 3rd

Rank 5th



2. Clicking/Examination Behavior

- **2.4 Heterogeneous Results: Cut-off Effect**
  - After users have viewed on-topic verticals, they are more likely to decrease their visual attention on the organic results which are below verticals.

Relevant Vertical	Textual	Encyclo-pedia	Image-only	Application -download	News
	Position = 3				
Organic	34.61%				
Vertical	30.13%	16.70%	8.44%	13.04%	22.61%
Diff	-12.95%	**-51.74%***	**-75.62%****	**-62.32%****	-34.68%
	Position = 5				
Organic	25.27%				
Vertical	26.30%	19.27%	10.33%	6.21%	38.69%
Diff	4.09%	-23.76%	**-59.10%***	**-75.44%***	53.09%

2. Clicking/Examination Behavior

- **2.4 Heterogeneous Results: Spill-over Effect**
  - Users spend more attention on the organic results after they have examined irrelevant vertical results.

Relevant Vertical

1	61.6%*	24.90%	6.63%	1.25%*	2.21%	3.41%
3	45.15%	20.88%	24.97%**	2.49%	4.00%	2.51%
5	51.61%	17.1%*	9.45%	7.49%	10.89%**	3.47%

Irrelevant Vertical

1	33.09%	31.59%	14.56%	6.66%	4.75%	9.35%
3	43.06%	18.20%	11.68%	10.46%*	6.15%	10.46%
5	54.15%	17.27%*	7.03%	6.16%	7.04%	8.35%

2. Clicking/Examination Behavior

- **2.5 Summary of Findings**
  - Position bias: Users pay more attention on higher-ranked results
  - Non-sequential examination: in about 30% cases, there exist non-sequential examination behaviors, in which users usually follow Locally Unidirectional Examination and Non First-order Examination patterns
  - Heterogeneous results: in about 80% of the SERPs, there exist heterogeneous results. Attractiveness effect, Cut-off effect, Spill-over effect

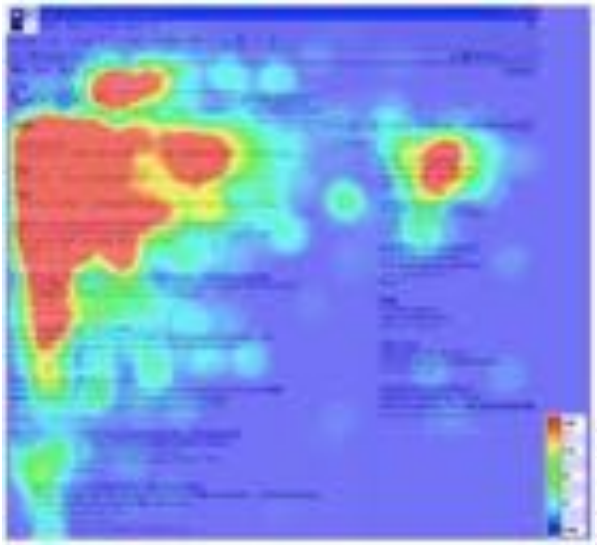
Outlines

1. Introduction and Background
2. Click and Examination during Web Search
3. **Constructing Click Models**

3. Constructing Click Models

- **How to improve ranking with user behavior?**
  - Simple solution: click = voting
  - Problem: position bias
  - How to estimate relevance without position effect?

"Golden Triangle"



Courtesy of http://hubdesignsmagazine.com/2011/03/27/its-good-to-be-on-the-first-page-of-google/

3. Constructing Click Models

- **3.1 Examination Hypothesis**
  - The likelihood that a user will click on a search result is influenced by
    - Whether the user examined the search result
    - Whether the result is attractive/relevant

$$C_i = 1 \rightarrow \quad E_i = 1, R_i = 1$$

  - Examination: user has comprehended (part of) the result and made a decision on whether to click.
  - How to estimate the probability of examination?

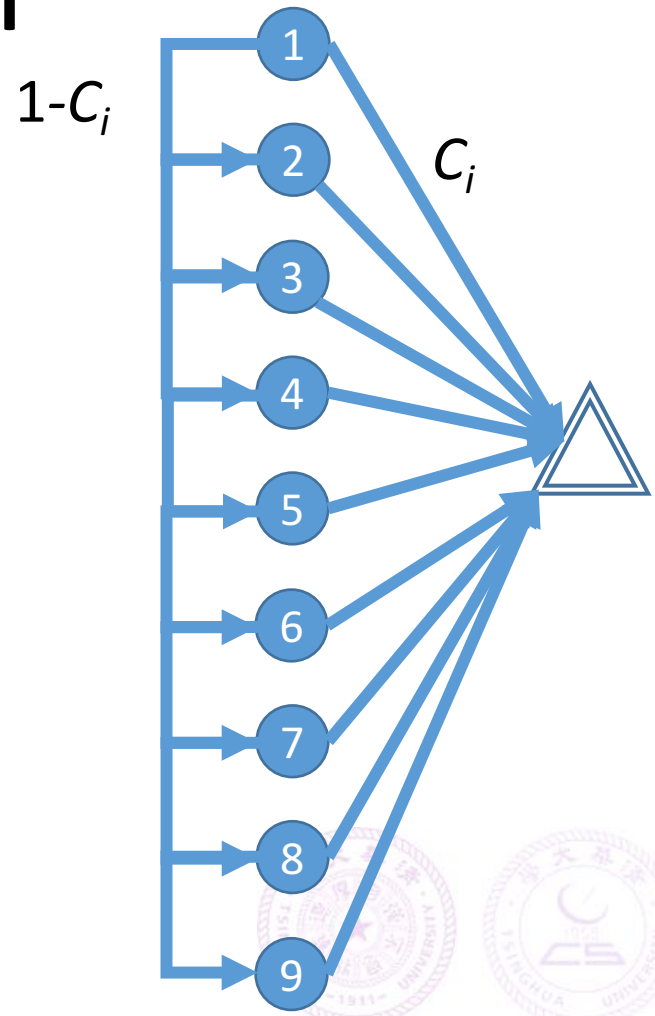
M. Richardson, et al. Predicting clicks: estimating the click-through rate for new ads. WWW 2007, pp. 521-530.

3. Constructing Click Models

- **3.2 Click Models: cascade model**
  - User examines sequentially
  - User will not stop examining until he/she clicks a result
  - User will stop immediately after clicking a result

$$P(E_{i+1} = 1 | E_i = 1, C_i) = 1 - C_i$$

  - Suitable for navigational or transactional search tasks

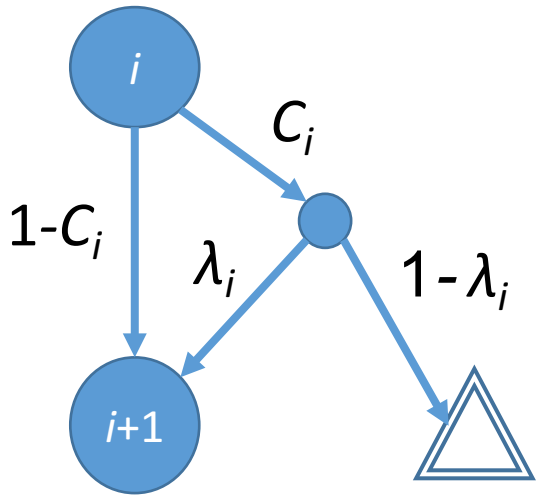


3. Constructing Click Models

- **3.2 Click Models: Dependent click model (DCM)**
  - User examines sequentially
  - User will not stop examining until he/she clicks a result
  - User has probability λ_i to continue after clicking a result

$$P(E_{i+1} = 1 | E_i = 1, C_i = 0) = 1$$

$$P(E_{i+1} = 1 | E_i = 1, C_i = 1) = \lambda_i$$



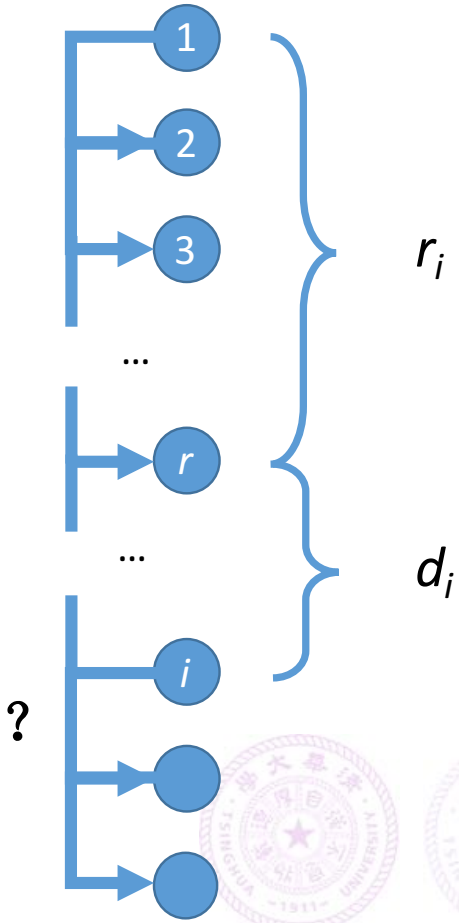
  - More powerful and practical than cascade model

3. Constructing Click Models

- **3.2 Click Models: User Browsing Model (UBM)**
  - The probability of user's examination is related with both the last clicking position and the distance from that position.
  - UBM take users' attention decaying factor into consideration

$$P(E_i = 1 | C_{1 \ldots i-1}) = \lambda_{r_i, d_i}$$

  - More powerful, more parameters to be estimated

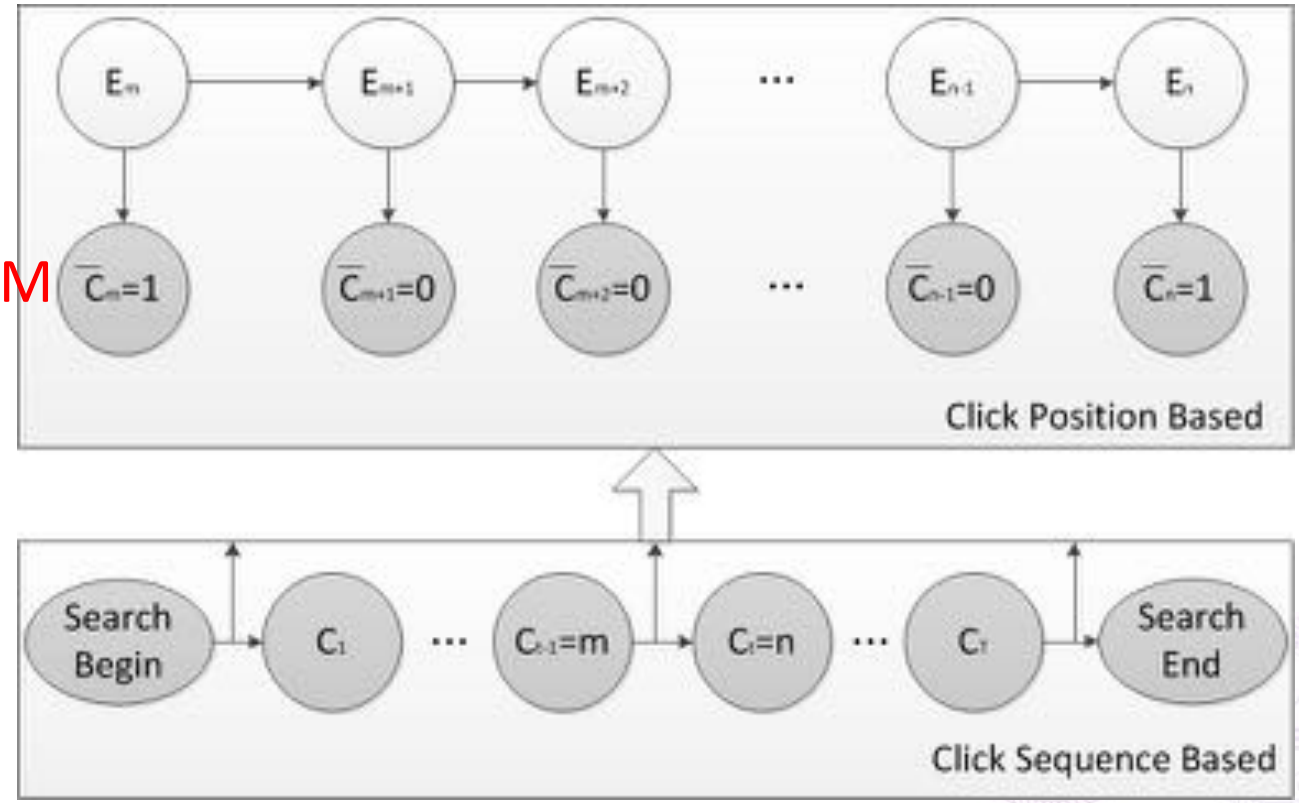


3. Constructing Click Models

- **3.3.1 Partially Sequential Click Model (PSCM,** *SIGIR'15, best paper honorable mention*)

First-order Examination: Position based UBM

Locally Unidirectional: Ei between Clicks



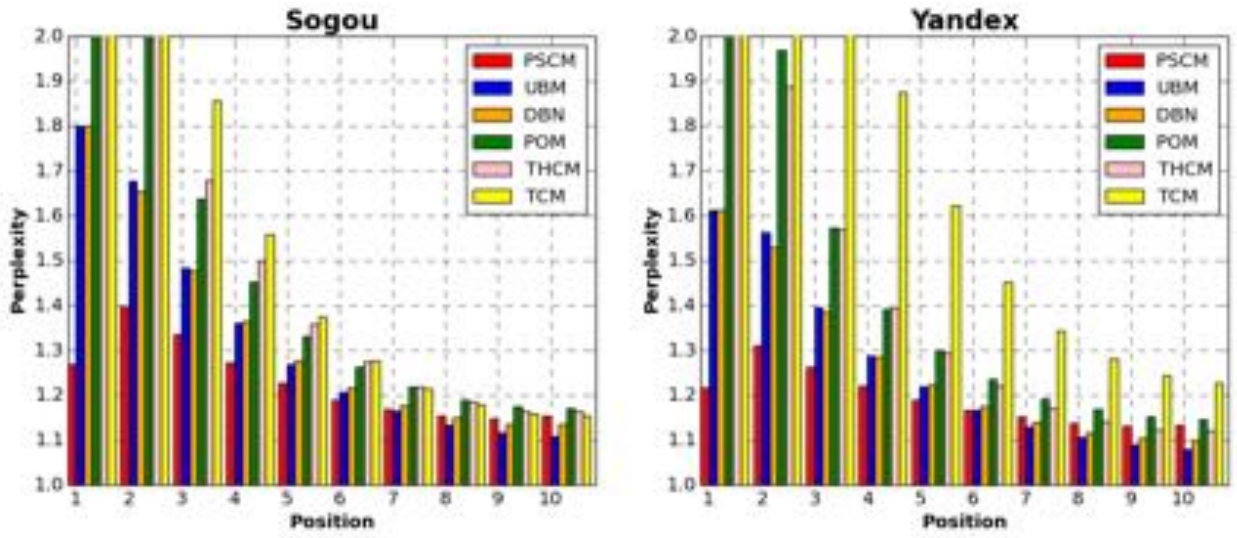
3. Constructing Click Models

- **3.3.1 PSCM Experimental Results**

	Sogou (2014.02)	Yandex (2012)
Session	7,174,251	23,995,960
Multi-click session	2,195,615	6,019,314
Non-sequential session	612,799	1,884,647

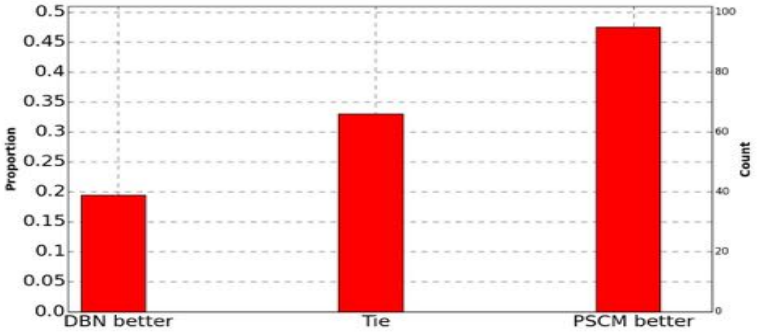
PSCM VS. UBM
Sogou: +30.1%,
Yandex: +27.4%)

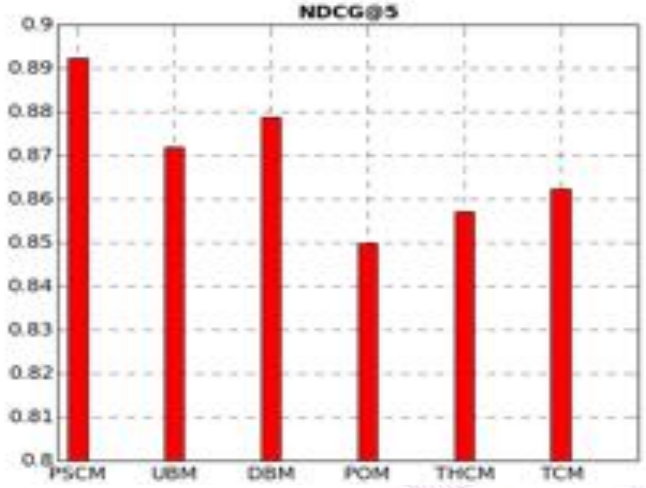
PSCM VS. DBN
Sogou: +31.6%,
Yandex: +27.9%)



3. Constructing Click Models

- **3.3.1 PSCM Experimental Results**
  - Side-by-side user preference test (SBS): 20 assessors





3. Constructing Click Models

- **3.3.2 Time-aware Click Model (TAM, *TOIS'16*)**
  - Dwell time on clicked pages is a signal for relevance

$$P(C_t|C_{t-1},...,C_1,St-1,...,S_1) = P(C_t|C_{t-1},S_{t-1})$$

$$S_{t-1}=1 \rightarrow C_t = 0$$ User stops clicking after satisfaction

Slightly-revised PSCM

$$P(C_t = n|C_{t-1} = m) =$$
$$P(\bar{C}_m = 1,...,\bar{C}_i = 0,...,\bar{C}_n = 1)$$

$$P(\bar{E}_i = 1|C_{t-1} = m, C_t = n) =$$
$$\begin{cases} \gamma_{imn}, m \le i \le n \ or \ n \le i \le m \\ 0, other \end{cases}$$

$$\bar{C}_i = 1 \Leftrightarrow \bar{E}_i = 1, R_i = 1$$

$$P(R_i = 1) = \alpha_{uq}$$

$$P(S_t = 1) = P(R_t = 1) \times F(DwellTime_t)$$

Linear Mapping

$$F(DwellTime_t) = \frac{min(DwellTime + \delta, 30 - \delta)}{30}$$

Exponential Mapping

$$F(DwellTime_t) = e^{-DwellTime \times \frac{ln2}{h}}$$

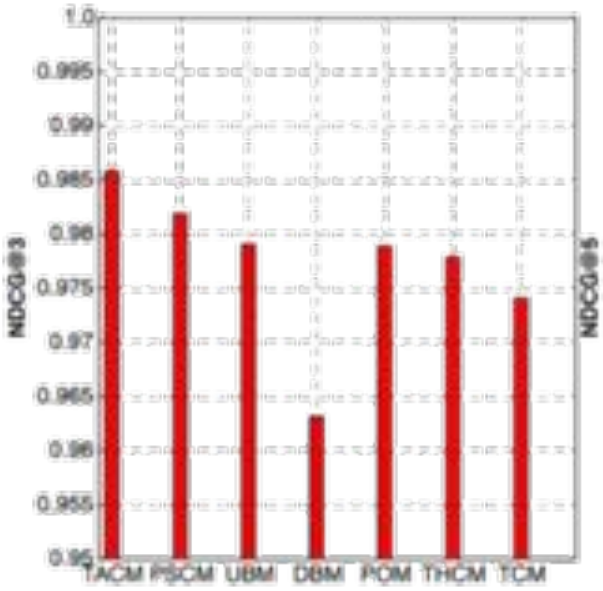
Rayleigh/Weibull Mapping

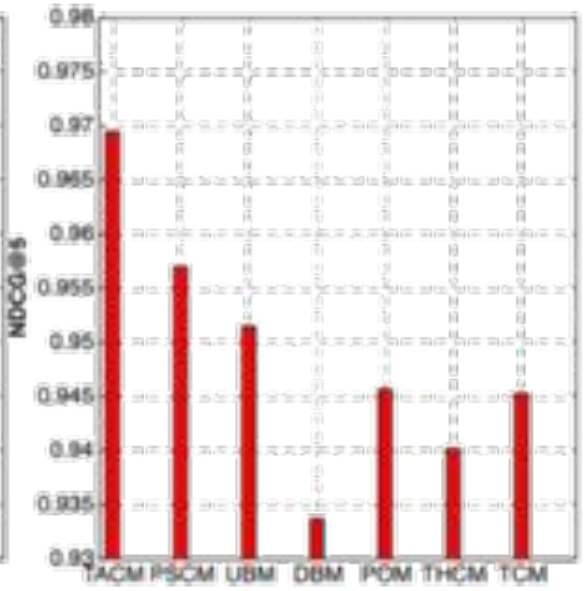
$$F(DwellTime_t) = \frac{2 \times DwellTime}{h^2} \times e^{-(\frac{DwellTime}{h})^2}$$

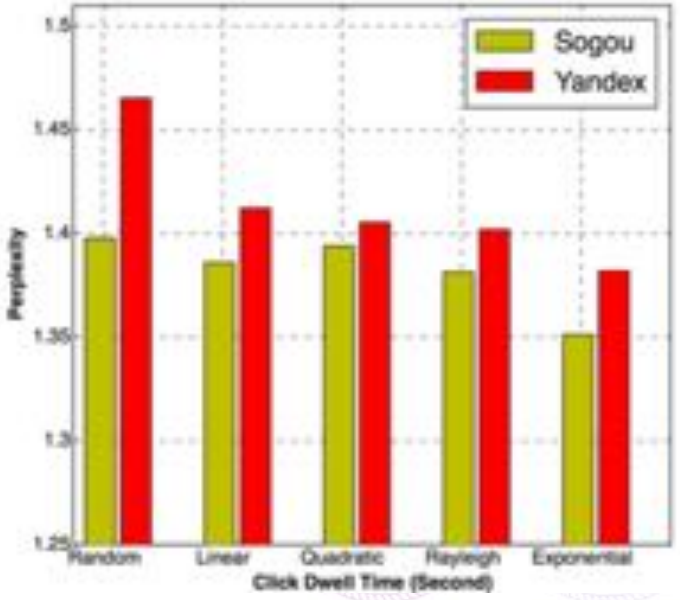
3. Constructing Click Models

- **3.3.2 TACM Experimental Results**

	Sogou (2015)	Yandex (2012)
Distinct Query	149,947	2,643,339
Multi-click session	2,195,615	5,999,999







3. Constructing Click Models

- **3.3.3 Vertical-aware Click Model (VCM, *SIGIR'13*)**
  - Trivial parameter combination for EM inference

Original UBM

$$P(C_i = 1|E_i = 0) = 0$$
$$P(C_i = 1|E_i = 1) = P(A_i = 1|E_i = 1)$$
$$P(E_i = 1|F = 0, C_{1:i-1}) = \gamma_{i,i-l_i}$$
$$P(A_i = 1|E_i = 1, F = 0) = \alpha_{q,i}$$

Users examine vertical results at first

$$P(F = 1) = \phi_{t_v,l_v}$$

Simplified case: difficult to quantify the effect when not all results are affected

Effect on Examination

$$P(E_i = 1|F = 1, C_{1:i-1}) = \gamma_{i,i-l_i} + \theta_{q,i}$$

Effect on Click-through

$$P(A_i = 1|E_i = 1, F = 1) = \alpha_{q,i} + \beta_{q,i}$$

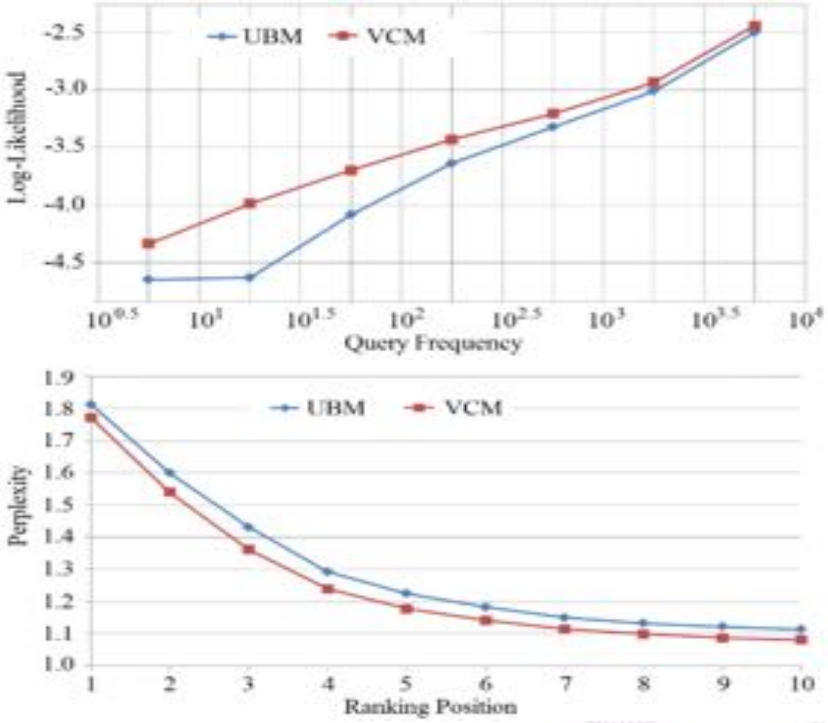
Effect on behavior sequence

$$P(B = 1|F = 0) = 0$$
$$P(B = 1|F = 1) = \sigma_{t_v,l_v}$$

3. Constructing Click Models

- **3.3.3 VCM Experimental Results**
  - About 300,000 queries and 11,000,000 sessions collected from a major Chinese search engine

Query Frequency	# Queries	# Sessions
1-10	228,290	688,129
10-$10^{1.5}$	43,280	777,642
$10^{1.5}$-10^{2}	21,060	1,157,448
10^{2}-$10^{2.5}$	9,103	1,573,706
$10^{2.5}$-10^{3}	3,341	1,802,170
10^{3}-$10^{3.5}$	1,140	1,980,876
$10^{3.5}$-10^{4}	536	3,578,045



Some Useful Resources

- **SIGIR2015 Tutorial**
  - http://clickmodels.weebly.com/sigir-2015-tutorials.html
- **Textbook: Click models**
  - http://www.morganclaypool.com/doi/10.2200/S00654ED1V01Y201507ICR043
- **Open source projects (from THUIR and UxA)**
  - Clickmodels: https://github.com/varepsilon/clickmodels; https://github.com/THUIR/PSCMModel; WSCD Dataset: http://research.microsoft.com/en-us/um/people/nickcr/wscd2012/ , Sogou Lab: http://www.sogou.com/labs

Thank you

Dataset is available for academic use:
Eye fixations, mouse movement features, clicks, relevance annotation, examination feedback, …

http://www.thuir.cn/group/~YQLiu/