

# NEW PERSPECTIVES ON SEARCH CLICK MODELING

SHEN, Si

# OUTLINE

- Search Engine and Click Model
- Motivation
- Perspective 1: Personalized Click Model (WSDM '12)
- Perspective 2: Whole Page Click Model (AAAI '11)
- Conclusion

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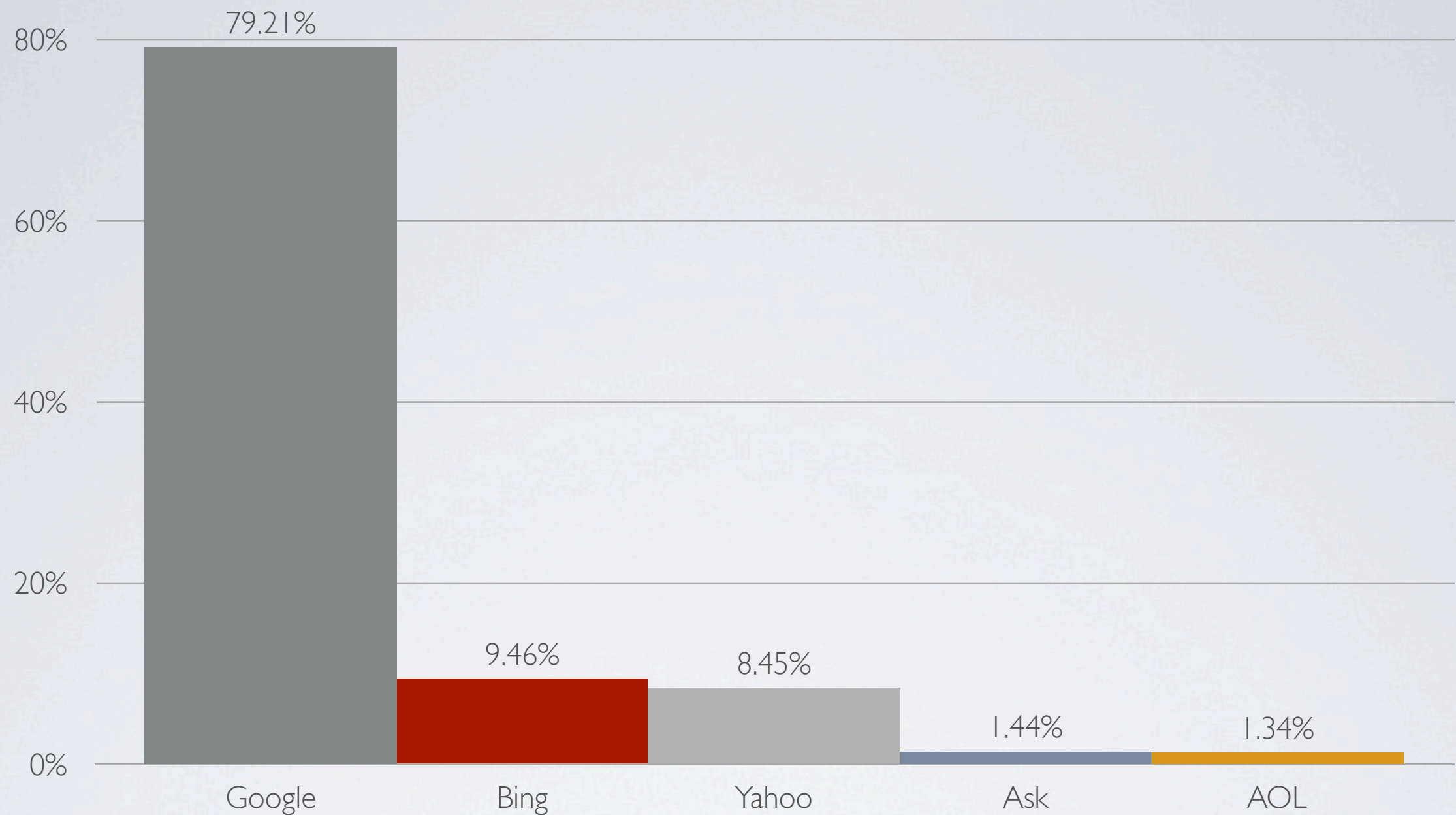


# TOP 10 MOST VISITED SITES

174 million unique U. S. people visited Google in Nov 2011.

Source: Nielsen

Rank	Brand	Total Internet Audience (ooo)
1	Google	174,314
2	Facebook	156,247
3	Yahoo!	145,406
4	MSN/WindowsLive/Bing	130,896
5	YouTube	127,004
6	Microsoft	98,121
7	AOL Media Network	87,005
8	Amazon	84,233
9	Wikipedia	79,688
10	Apple	74,793



# SEARCH ENGINE MARKET SHARE

220 million visitors to search engines in Nov 2011.

Source: Statowl



bing

movie rating site

Web Movies Videos More▼

RELATED SEARCHES

- Family Movie Review Site
- Movie Review Sites for Parents
- Best Movie Ratings Site
- Christian Movie Rating Sites

SEARCH HISTORY

- movie site
- imdb
- Similar searches
- movie site
- movie reviews and ratings
- movie rating
- See all
- Clear all · Turn off

ALL RESULTS

1-10 of 846,000,000 results · [Advanced](#)

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Movies · DVD · In Theaters  
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**Rating** Planned for Terminator 5 11; Disney Heads to Space with Chronicle Scribe 0  
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IMDbPro; IMDb Resume; Apps. Apps Home; iPhone App; iPad App; Android Phones ...  
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[Reasons for Movie Ratings \(CARA\)](#)  
**Film Ratings** - Reasons for **Movie Ratings** (CARA) Home About Us About Us - Voluntary **Movie**  
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[www.filmratings.com](#) · [Cached page](#)

[Kids-In-Mind: Movie Ratings That Actually Work](#)  
Furthermore, we do neither solicit nor choose our advertisers so that when we **review** a **movie** there  
are no conflicts of interest. We want to keep it that way, and you ...  
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[Reviews and Ratings for Family Movies, TV Shows, Websites, Video ...](#)  
Offers family friendly **ratings** and reviews on **movies**, TV, games, music, websites, and books.  
Includes **ratings** of potentially offensive content by category.  
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There's nothing worse than spending \$10 at the local multiplex to see a **movie** that totally sucks, and  
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Ads

[Local Movie Showtimes](#)  
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[Rate & Review Films](#)  
Speak Your Mind About Films & Shows  
You've Loved or Hated at IFC.  
[www.ifc.com](#)

[Movie Theaters](#)  
Find Local **Movie** Theaters.  
[yellowpages.lycos.com](#)  
[See your message here](#)

SEARCH ENGINE RESULT PAGE (SERP)



# SERP TRAFFIC ANALYSIS

99% of the traffic on SERP is on first page, making it critical.

Source: Statowl



# SEARCH CLICK MODELING

- Ranking documents matters significantly.
  - A relevance score for the document given a query.
  - Relevance score is related to click probabilities.
  - Put highly relevant documents to on top.
- Tremendous search click logs preserved by search engines.
  - **Using click logs to infer relevance and predict click probabilities.**
  - Documents can be organic search results or ads recommendations.



# RELEVANCE VS. CLICK

- A user is prone to click a document with high relevance score.
- A user may not click a document if
  - it is truly not relevant.
  - it is relevant, but he/she does not see it.
  - it is relevant, but he/she finds adequate information.
  - it is relevant, but he/she finds the snippet irrelevant.
  - .....
- Real click behaviors are not always consistent with simple relevance score.
  - **Click Modeling infers true relevance scores by studying various biases.**

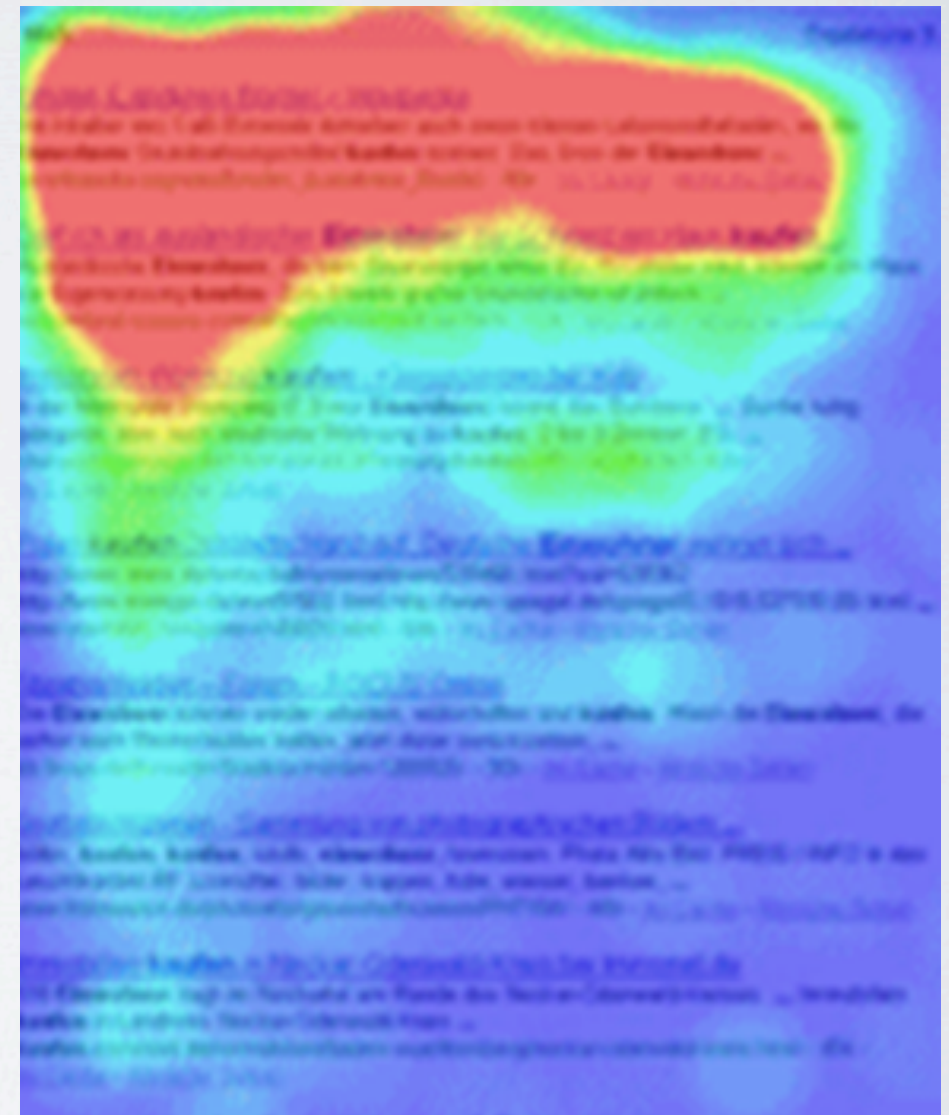
# PREVIOUS CLICK MODELS

- Position Model
- User Browsing Model (UBM)
- Cascade Model
- Dynamic Bayesian Network (DBN)



# POSITION MODEL

- Documents on top attract more attention.
- Position bias: the influence of document position on the probability of click.
- Examination Hypothesis
  - Documents must be examined before clicked.
  - After examining the documents, probability of click depends on relevance score.



$$\begin{aligned}
& P(C_i = 1 | q, d) \\
&= \sum_{E_i} P(C_i = 1 | E_i, q, d) P(E_i) \\
&= \underbrace{P(C_i = 1 | E_i = 1, q, d)}_{\text{document relevance}} \underbrace{P(E_i = 1)}_{\text{position bias}} \\
&= \alpha_{qd} \beta_i
\end{aligned}$$

# EXAMINATION HYPOTHESIS

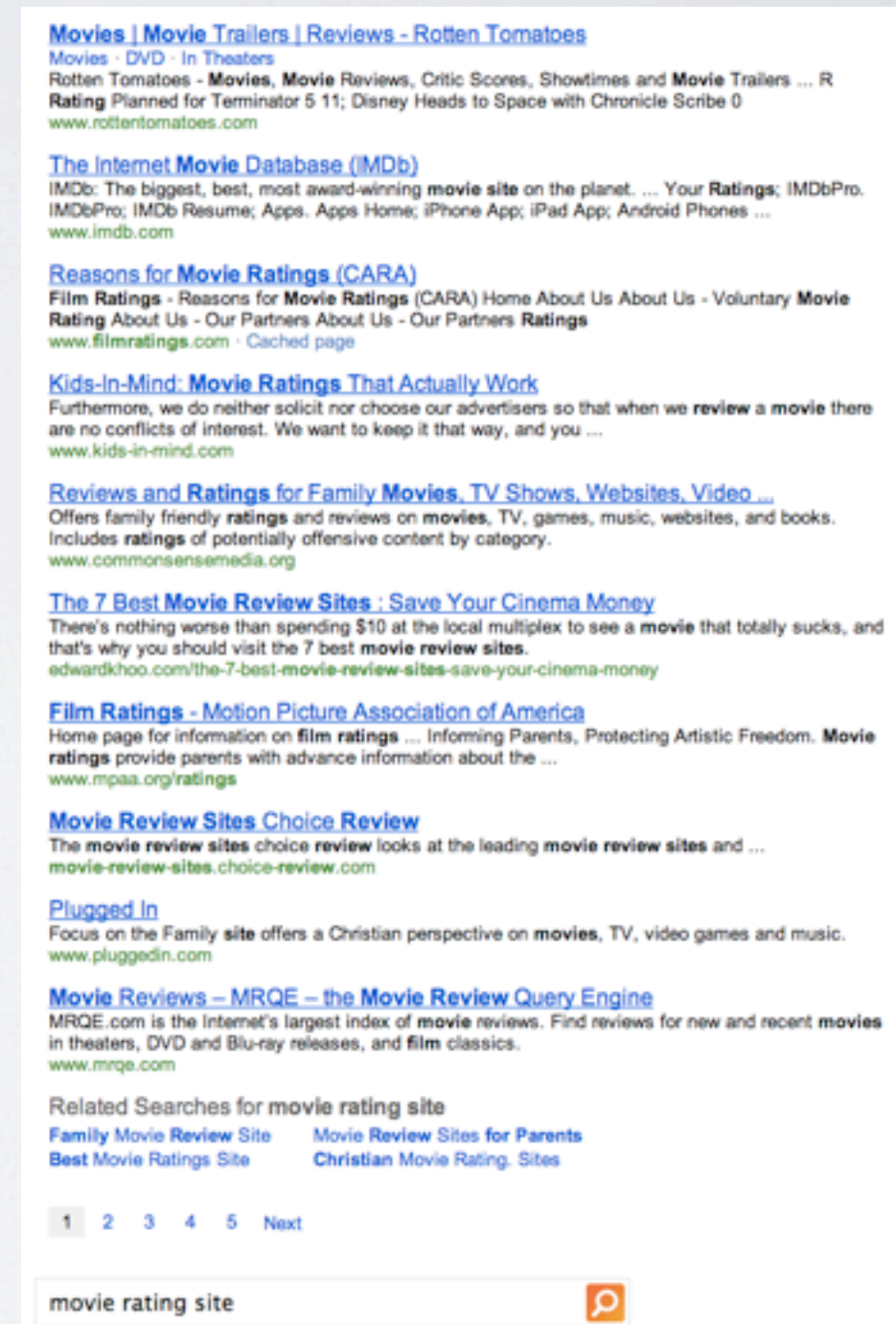
E: the event of examination; C: the event of click; i: position; q: query; d: document

Inference by Expectation-Maximization Algorithm, iteratively updating relevance & position bias



# USER BROWSING MODEL

- May not terminate after a click.
  - The probabilities of examining following documents change.
- Position bias depends on
  - current position  $i$ , as in Examination Hypothesis, and
  - distance to the position of the latest clicked document.



# CASCADE MODEL

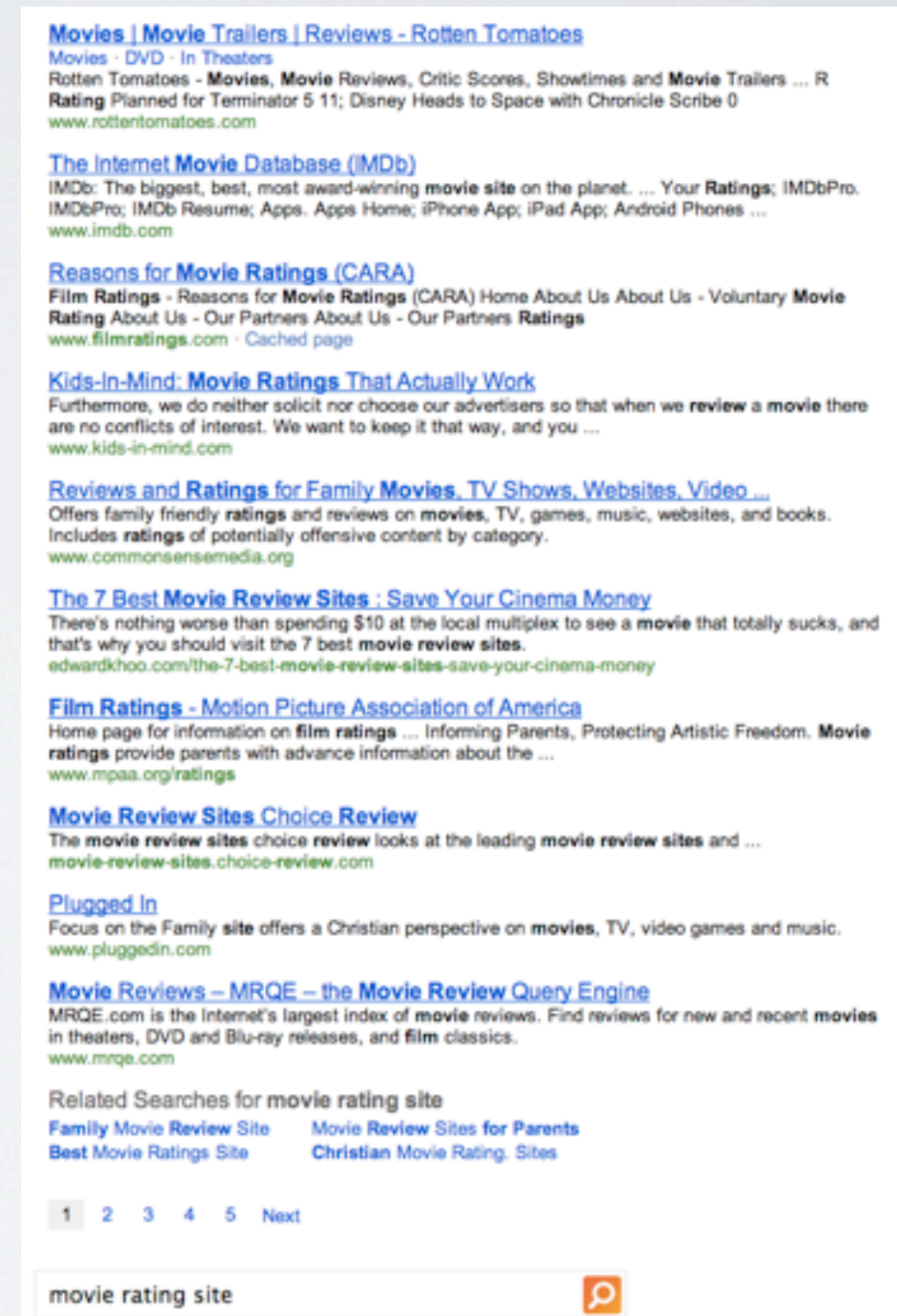
- Session-based model
  - Documents are examined one by one from top of SERP.
  - Terminate if the document is relevant, and therefore clicked.
  - Continue to the next if the document is irrelevant.
- Implicit study of position bias.
- Sessions with more than one click are discarded.





# DYNAMIC BAYESIAN NETWORK

- Relax the one-click restriction of Cascade Model.
- May not terminate after a click.
  - Click only signals document attractiveness to the user.
  - Terminate if the user is satisfied with the document.
  - If the user is not satisfied, he/she will
    - come back to SERP to examine following documents, with probability  $r$ .
    - discard the session.
- Position bias then also depends on user persistence, a global parameter  $r$ .



# OUTLINE

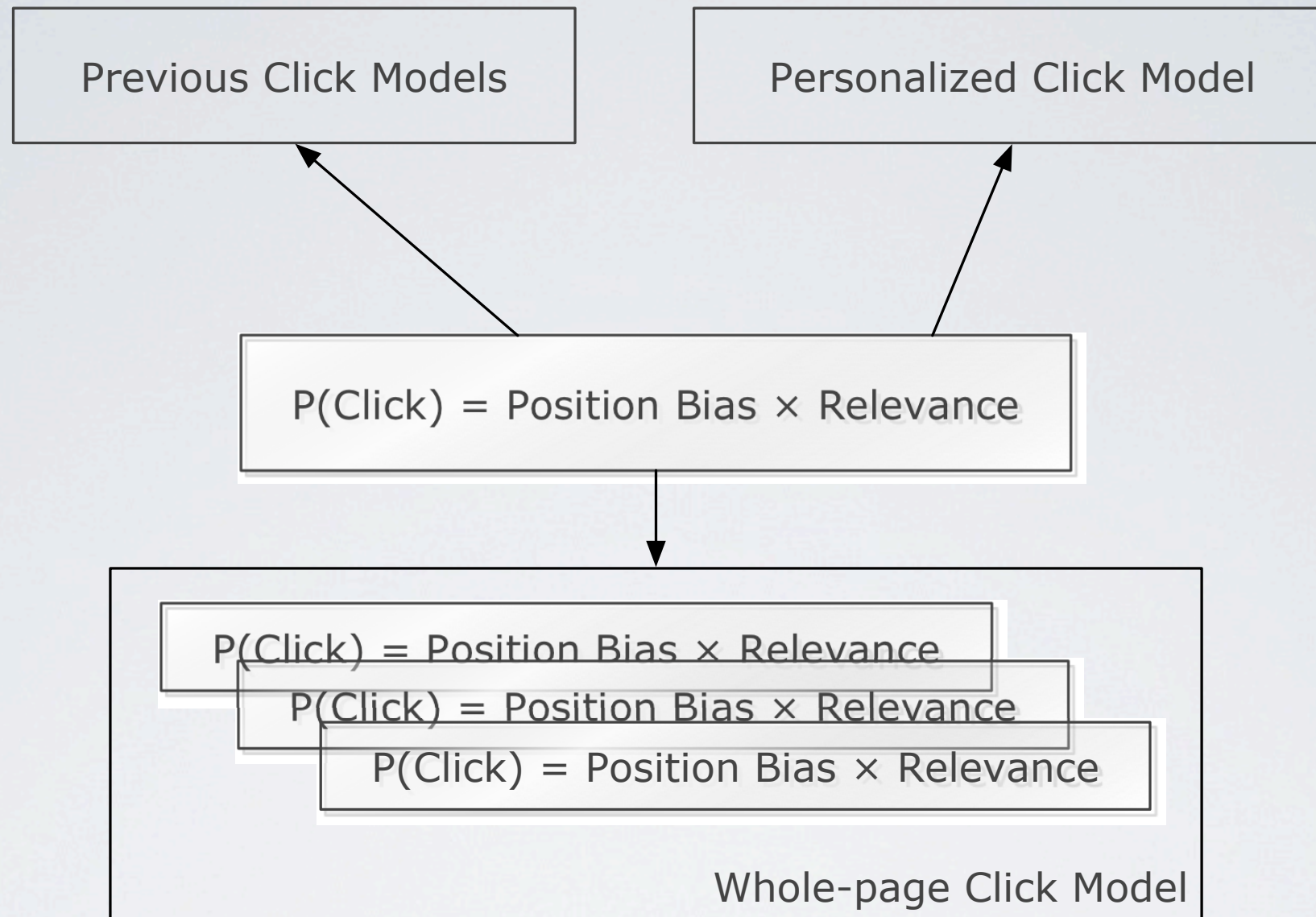
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# EXAMINATION HYPOTHESIS REVISITED

- The probability of click depends on document relevance and position bias.
- Position bias can be inferred by various session-based models.
- Document relevance is subject to a particular query-document pair.
- Sessions are restricted to either organic search or ads block.

$$\begin{aligned} &P(C_i = 1|q, d) \\ &= \sum_{E_i} P(C_i = 1|E_i, q, d) P(E_i) \\ &= \underbrace{P(C_i = 1|E_i = 1, q, d)}_{\text{document relevance}} \underbrace{P(E_i = 1)}_{\text{position bias}} \\ &= \alpha_{qd} \beta_i \end{aligned}$$



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 Offers family friendly **ratings** and reviews on **movies**, TV, games, music, websites, and books.  
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**Movie Theaters**  
 Find Local **Movie** Theaters.  
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# THE NEED OF PERSONALIZATION







# PERSONALIZED RELEVANCE

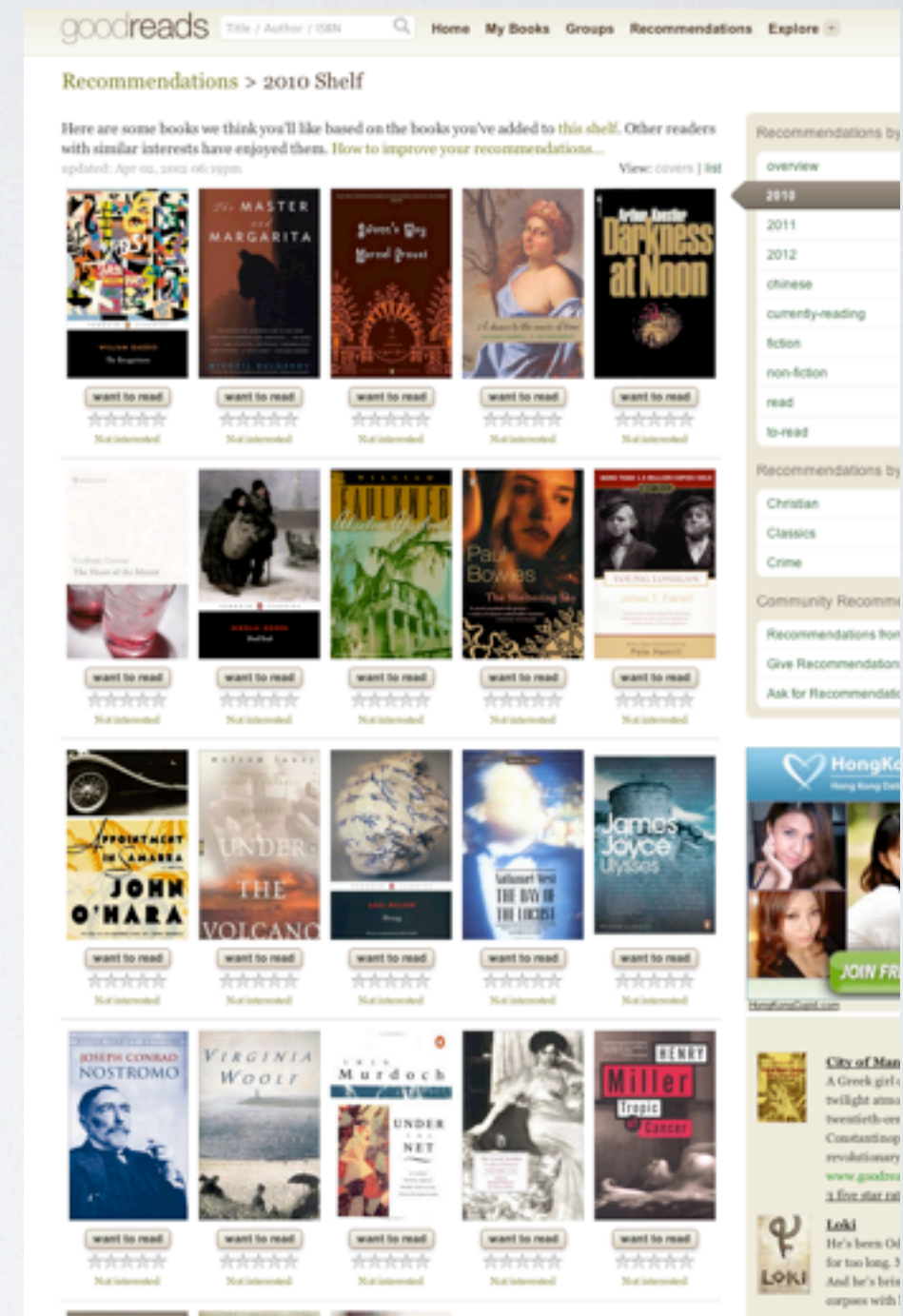
- Previously in Examination Hypothesis, document relevance depends on the pair:
  - query  $q$
  - document  $d$
- Adding user  $u$  to make it a triple.
- The inference of relevance will be hard due to data sparsity.

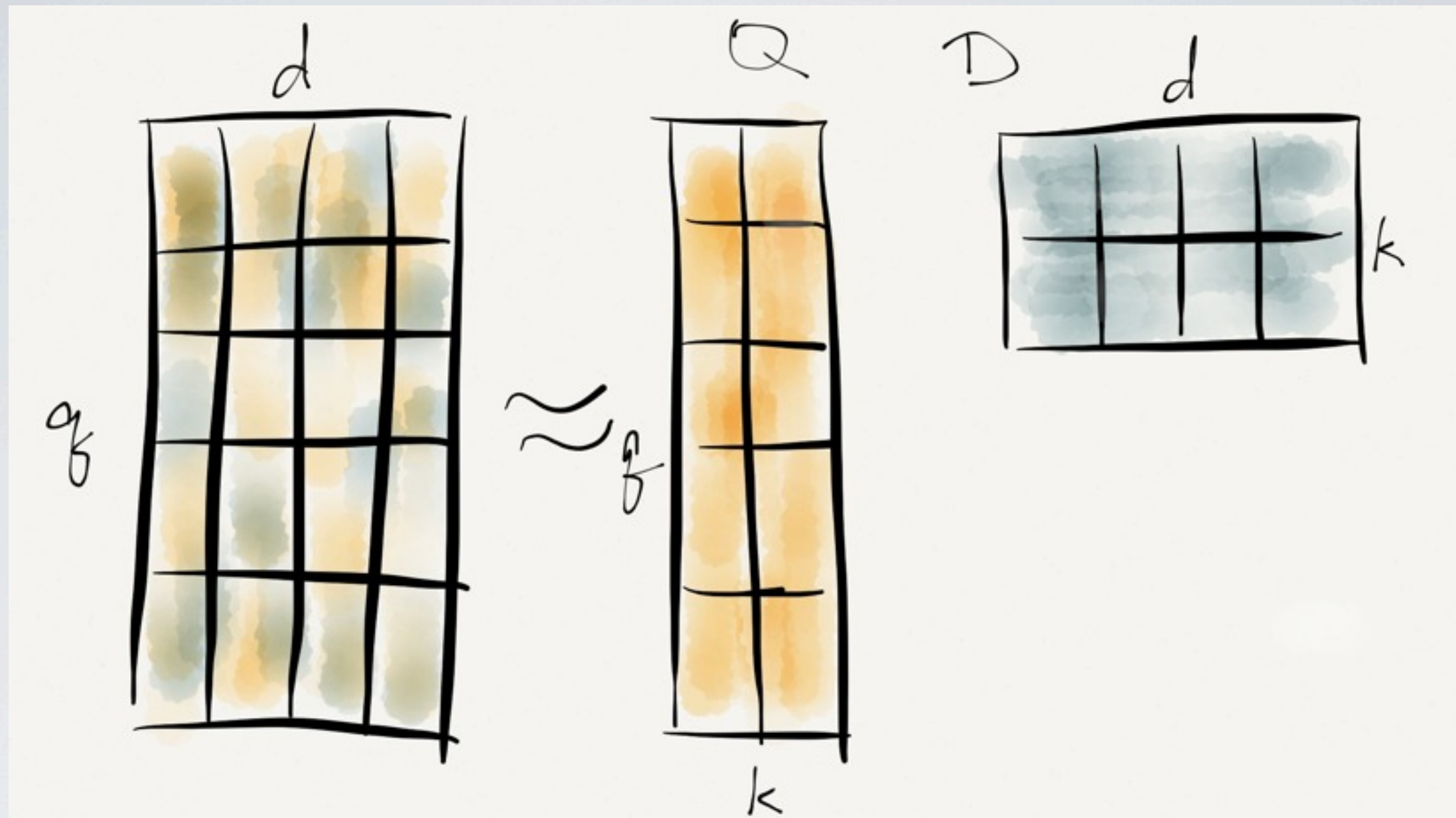
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# COLLABORATIVE FILTERING

- A typical personalized recommendation setting:
  - users giving ratings to books they have read.
  - recommending new books based on similarities of users and books.
- Input: user-item rating matrix with missing values.
- Output: complete user-item rating matrix





QUERY - DOCUMENT MATRIX FACTORIZATION



# MATRIX FACTORIZATION CLICK MODEL (MFCM)

- Direct utilization of matrix factorization in Position:

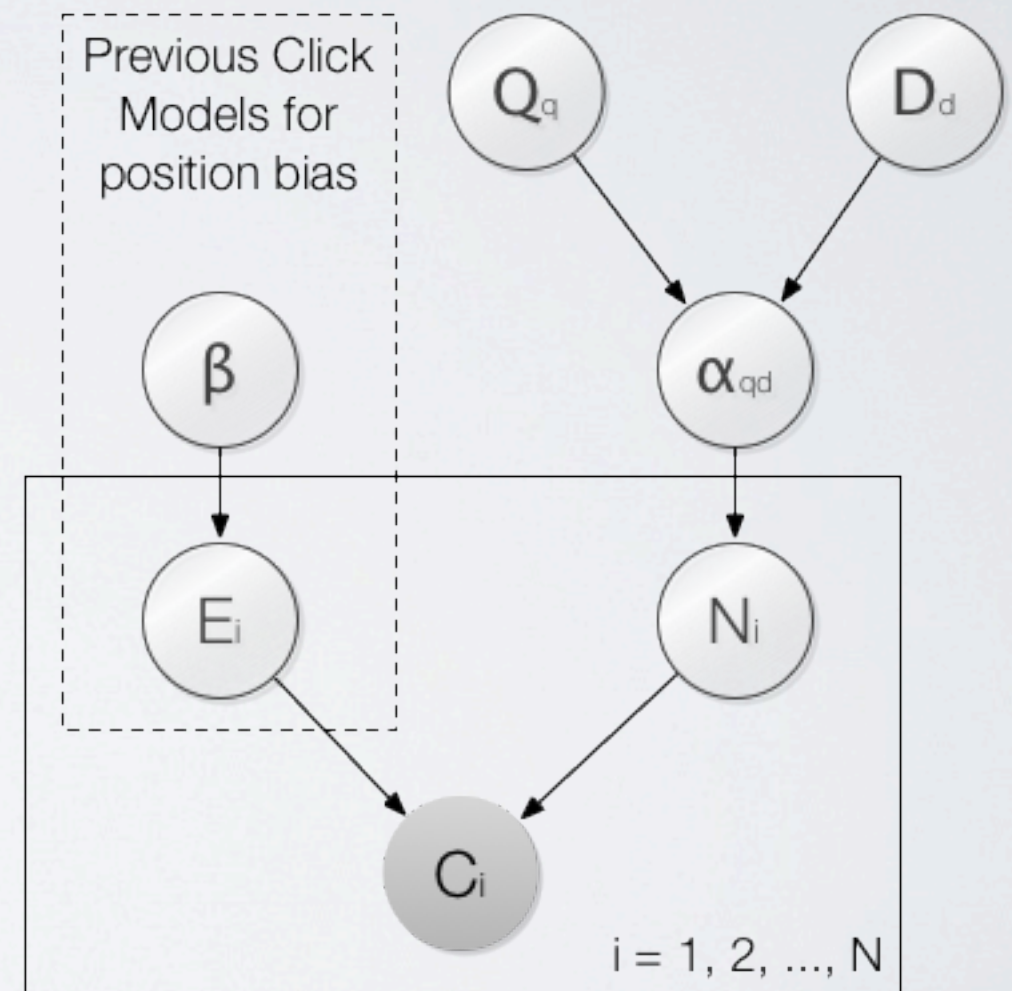
$$P(\alpha_{qd_i} | Q_q, D_d, \sigma) \sim \mathcal{N}((Q_q \circ D_{d_i}), \sigma^2)$$

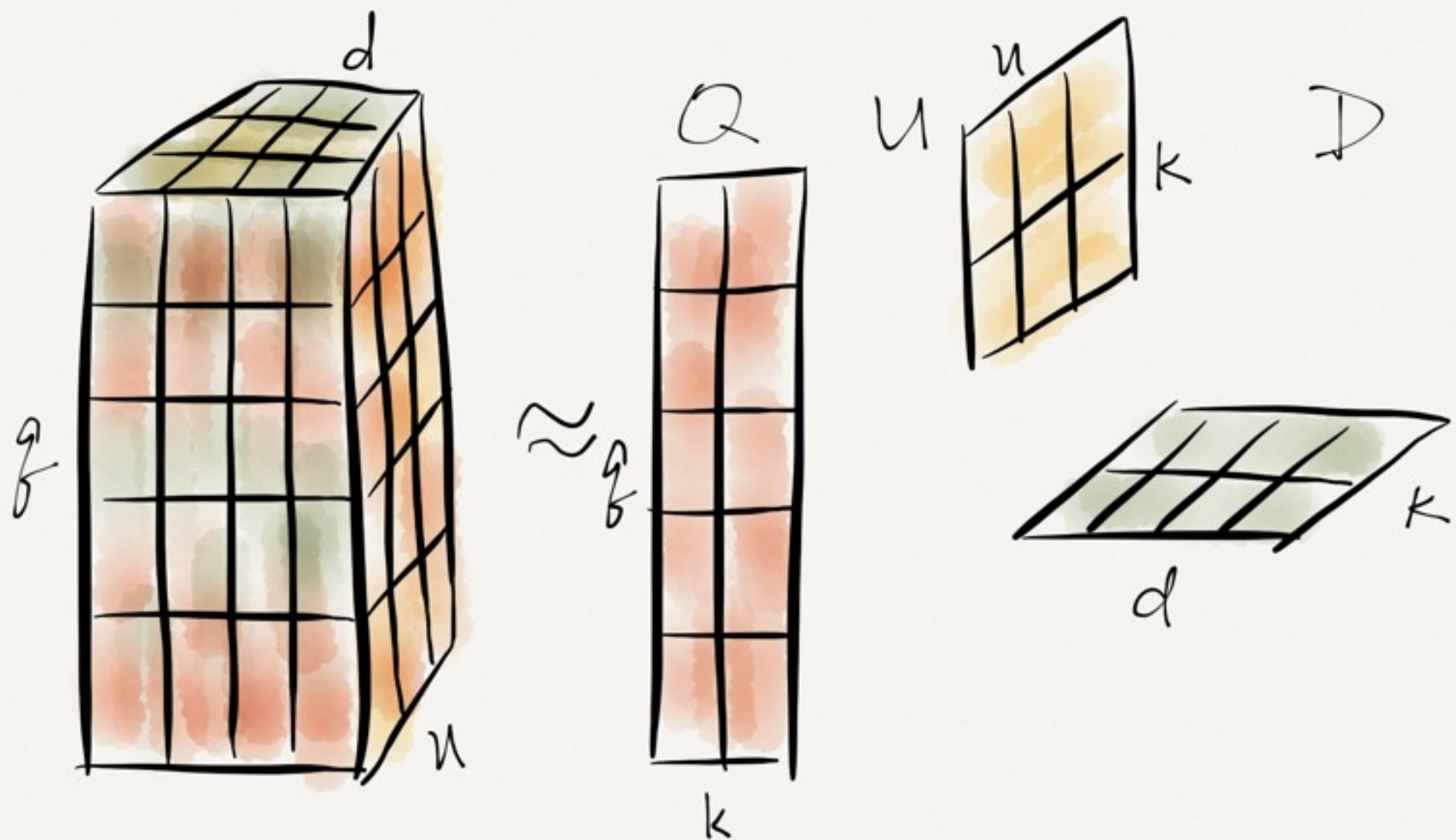
$$P(Q_q | \sigma_Q) \sim \mathcal{N}(0, \sigma_Q^2 I)$$

$$P(D_d | \sigma_D) \sim \mathcal{N}(0, \sigma_D^2 I)$$

$$Q_q \circ D_{d_i} = \sum_{f=1}^F Q_{fq} D_{fd_i}$$

- N: the event of click, given that the document is examined.





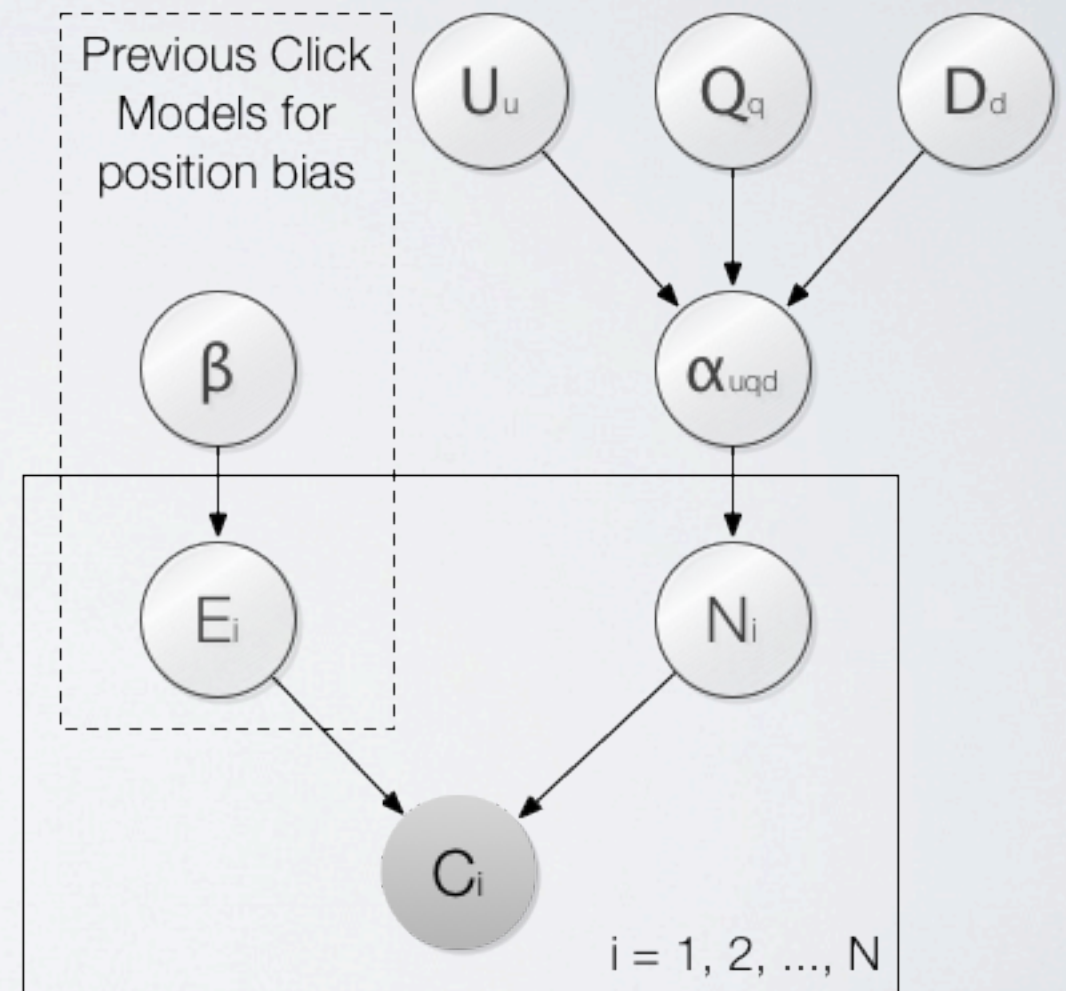
## USER - QUERY - DOCUMENT TENSOR FACTORIZATION



# PERSONALIZED CLICK MODEL (PCM)

- Adding user dimension.
- Considering implicit interactions among users, queries and documents through factorization.
- $P(\alpha_{uqd_i} | U_u, Q_q, D_d, \sigma) \sim \mathcal{N}((U_u \circ Q_q \circ D_{d_i}), \sigma^2)$   
 $P(U_u | \sigma_U) \sim \mathcal{N}(0, \sigma_U^2 I)$   
 $P(Q_q | \sigma_Q) \sim \mathcal{N}(0, \sigma_Q^2 I)$   
 $P(D_d | \sigma_D) \sim \mathcal{N}(0, \sigma_D^2 I)$   

$$U_u \circ Q_q \circ D_{d_i} = \sum_{f=1}^F U_{fu} Q_{fq} D_{fd_i}$$
- For queries where personal differentiation is insignificant, easily over-fit.



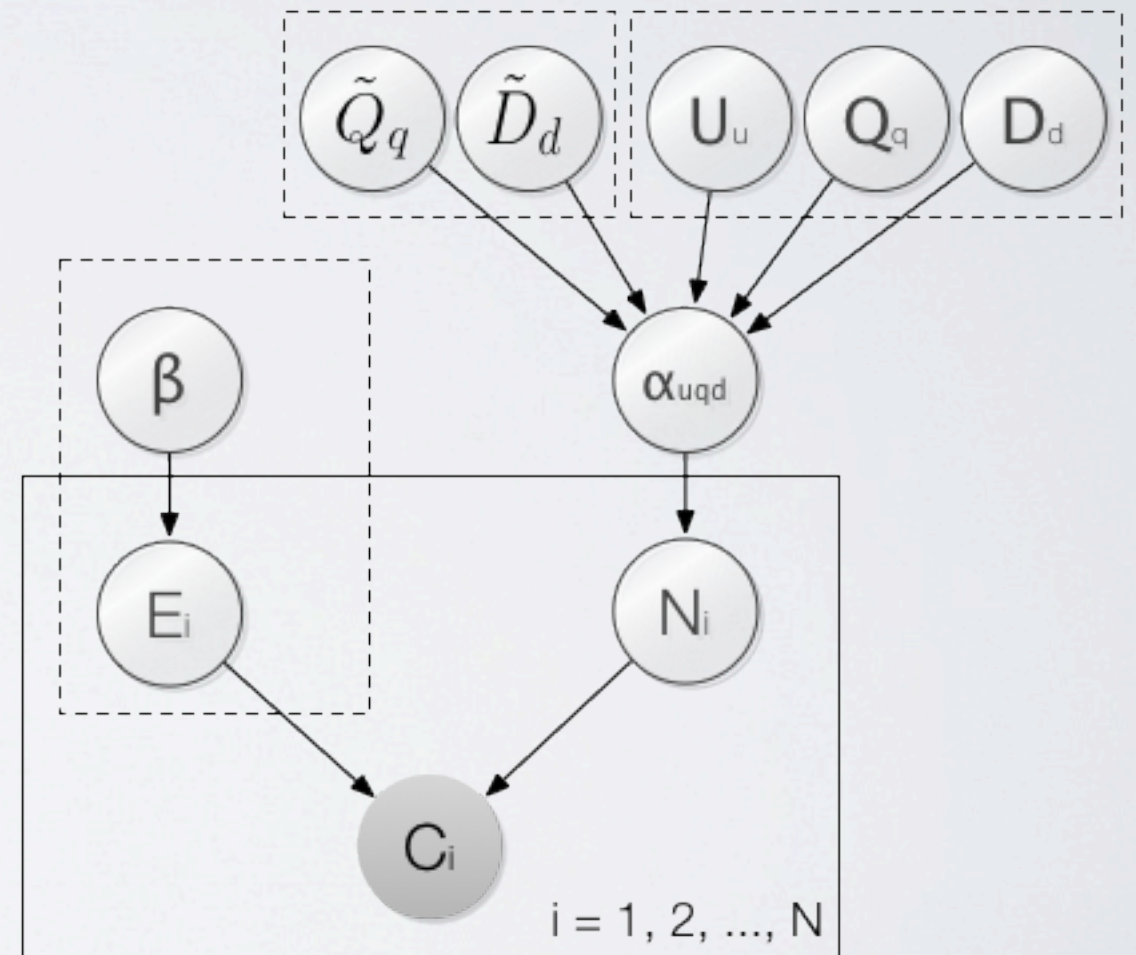
# HYBRID PERSONALIZED MODEL (HPCM)

- Focusing on interactions between queries and documents.
- Only residuals are factorized to describe user deviations.

- $$P(\alpha_{uqd_i} | \tilde{Q}_q, \tilde{D}_d, U_u, Q_q, D_d, \sigma)$$

$$\sim \mathcal{N}(\underbrace{\tilde{Q}_q \circ \tilde{D}_{d_i}}_{\text{query-doc bias}} + \underbrace{U_u \circ Q_q \circ D_{d_i}}_{\text{user diversity}}, \sigma^2)$$

- $\alpha$  becomes a personalized relevance score.





# INFERENCE

- EM algorithm is utilized during inference, with the event of examination as the hidden variable.
- Position bias and personalized relevance can be inferred rather independently.
- After updating user-adjusted relevance within one iteration of EM, relevance cube is filled through factorization.

MFCM:

$$P(\alpha_{qd_i} | Q_q, D_d, \sigma) \\ \sim \mathcal{N}((Q_q \circ D_{d_i}), \sigma^2)$$

PCM:

$$P(\alpha_{uqd_i} | U_u, Q_q, D_d, \sigma) \\ \sim \mathcal{N}((U_u \circ Q_q \circ D_{d_i}), \sigma^2)$$

HPCM:

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# EXPERIMENTS

- 2 weeks click data from a commercial English search engine in U. S. market.
- 1 session defined as:
  - an input query
  - a list of returned documents on 1st page of SERP
  - a list of clicked positions (all submitted in organic search), and
  - a cookie ID representing a user.
- 66 million sessions, 2 million queries, 3 million users, and 25 million documents.
  - 4 users / query, and 2 queries / user.
  - 28.9% new query-document pairs, 67.75% new query-document-user triples.
- Using UBM for both position bias inference and baseline model.

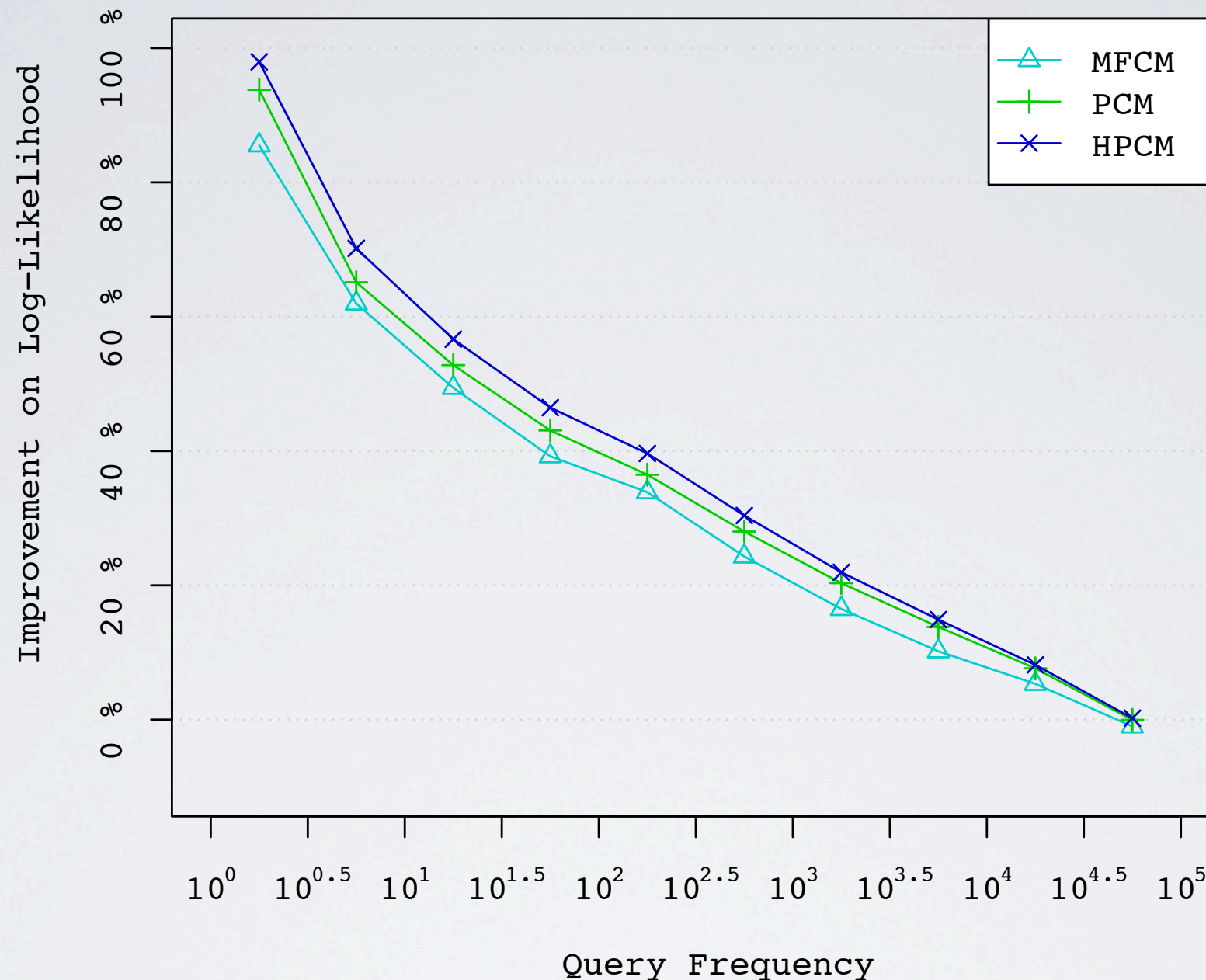


Model	Log-Likelihood	Improvement over UBM
UBM	-0.4236	-
MFCM	-0.3055	8.53%
PCM	-0.2577	12.18%
HPCM	-0.2448	13.20%

## PERFORMANCE MEASURED BY LOG LIKELIHOOD

Log Likelihood is the target to maximize during inference.

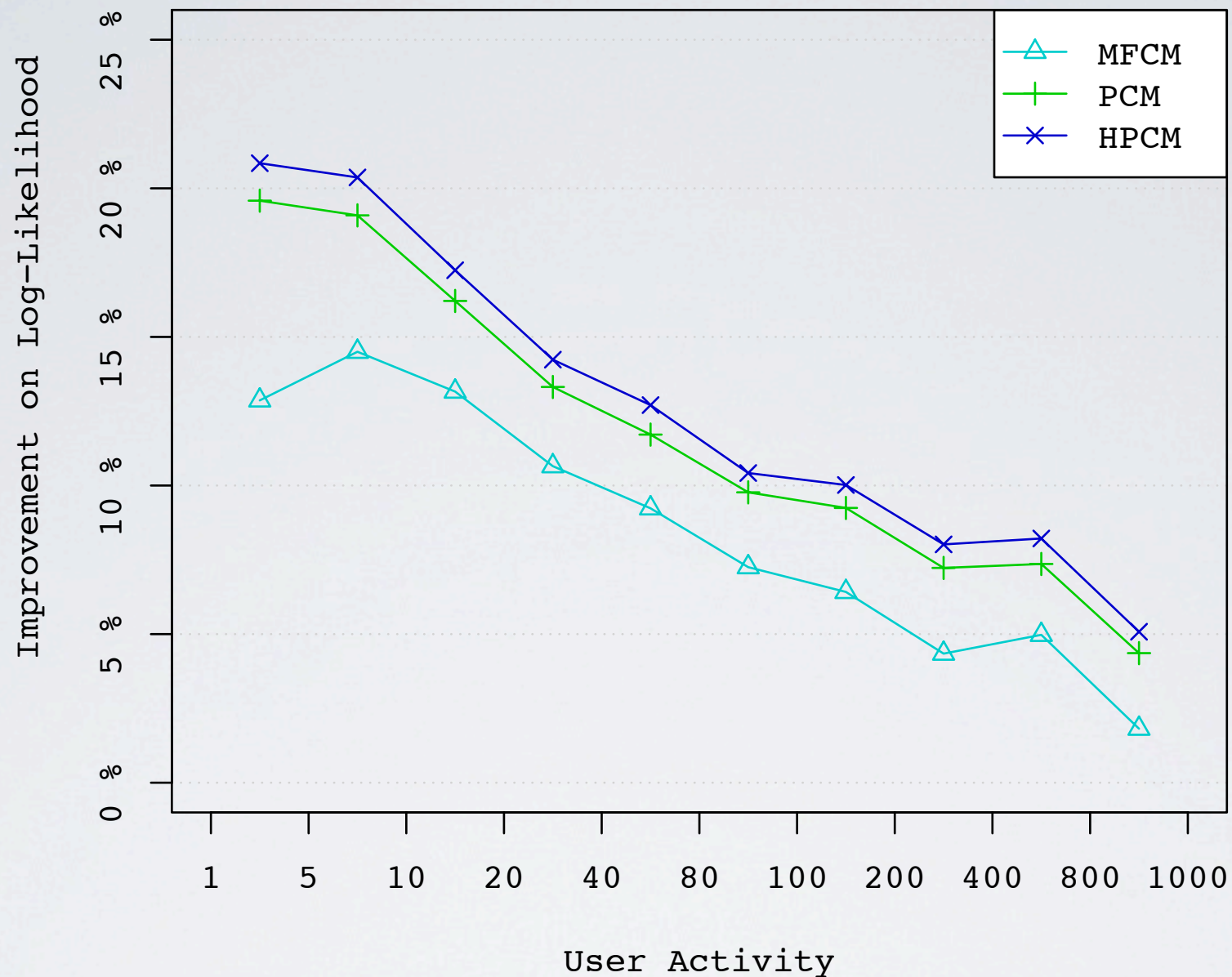
Zero if perfectly-fit. The smaller Log Likelihood, the worse fit of estimators.



# QUERY FREQUENCY

Significant improvement on tail queries, where UBM is weak.  
UBM is sufficient for high-frequency queries.

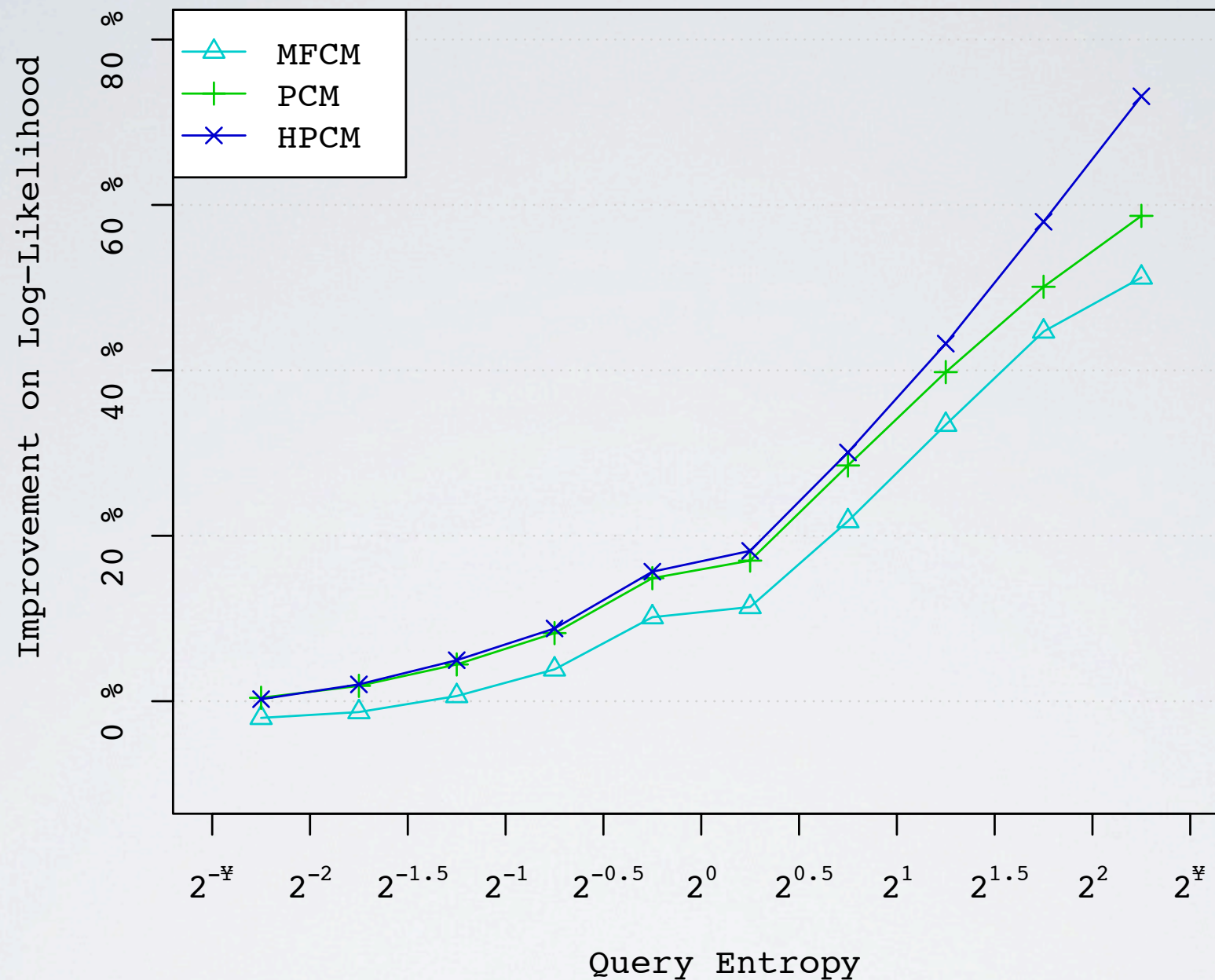




# USER ACTIVENESS

Impressive performance for unfrequent users.

Collaborative filtering can provide missing information through latent factors.



# NAVIGATIONAL VS. INFORMATIONAL QUERIES

High entropy queries suggest informational queries.

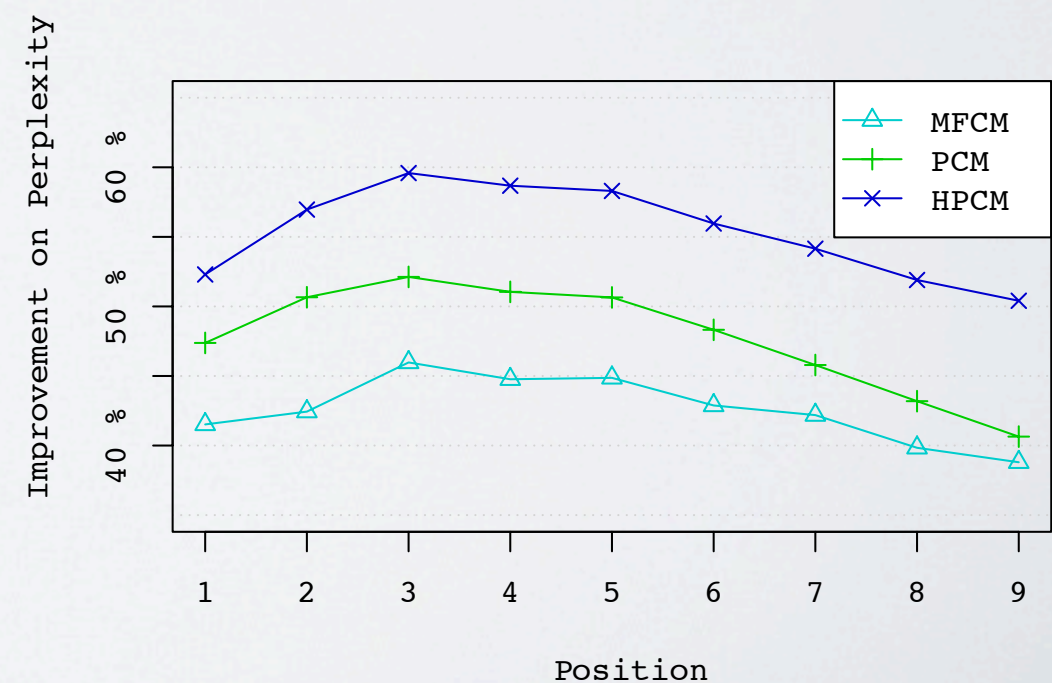
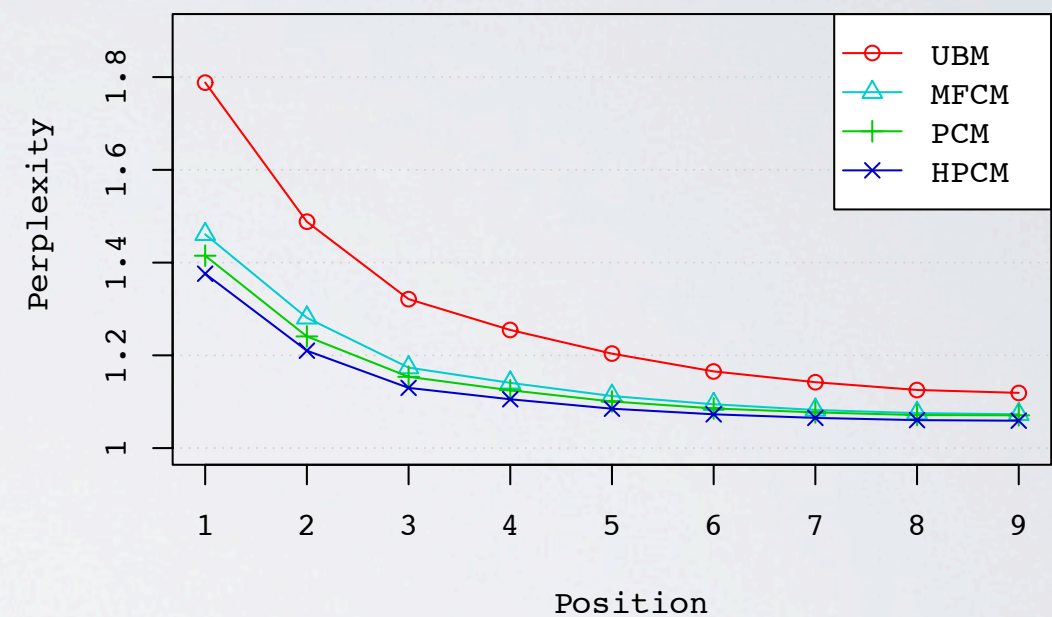
Queries with complicated click logs are difficult for session-based click models.

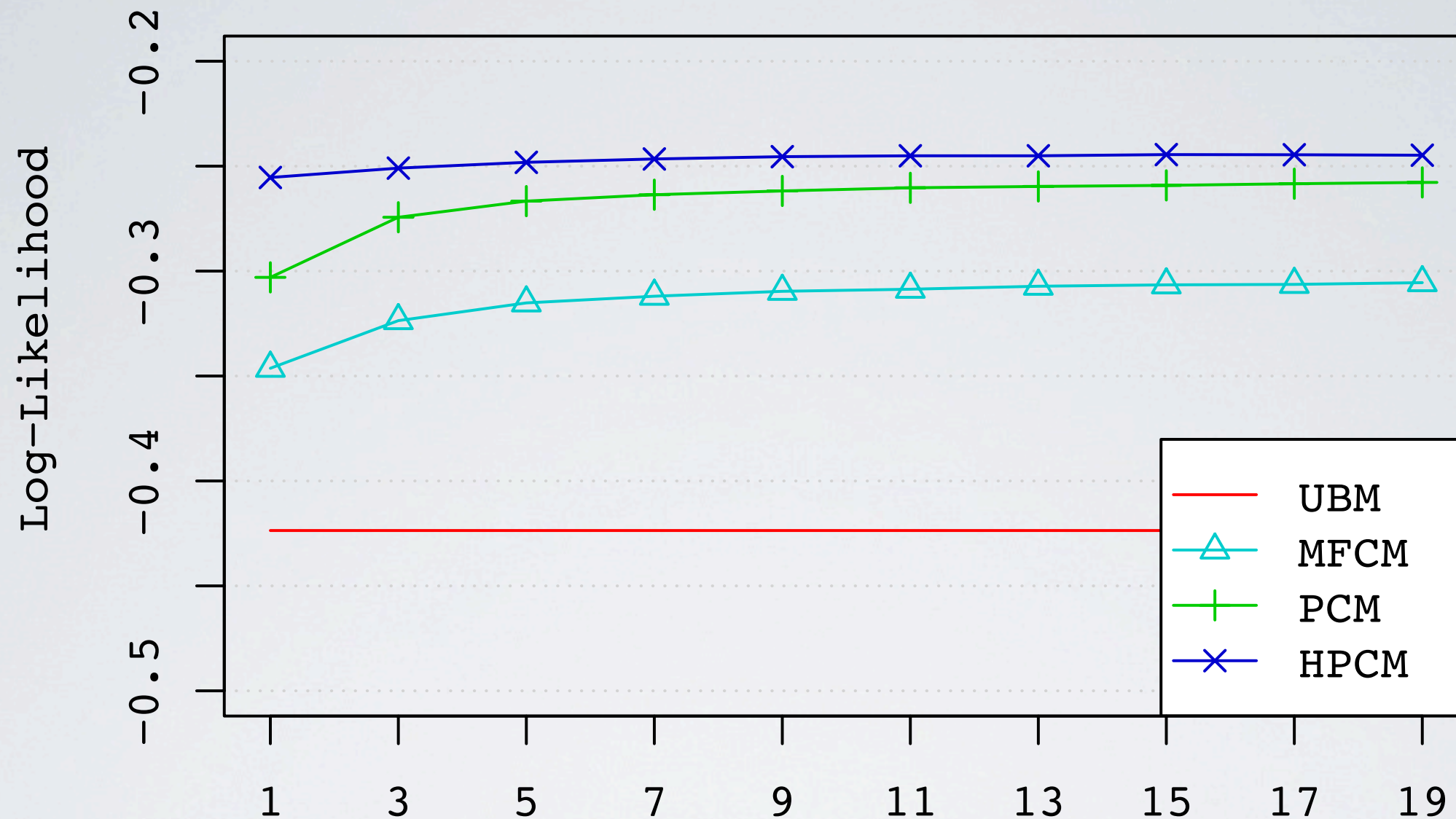


# PERPLEXITY BY POSITION

$$\text{perplexity}_i = 2^{-\text{Log Likelihood at Position } i}$$

Model	Average Perplexity	Improvement over UBM
UBM	1.2898	
MFCM	1.1659	42.74%
PCM	1.1488	48.65%
HPCM	1.1293	55.39%

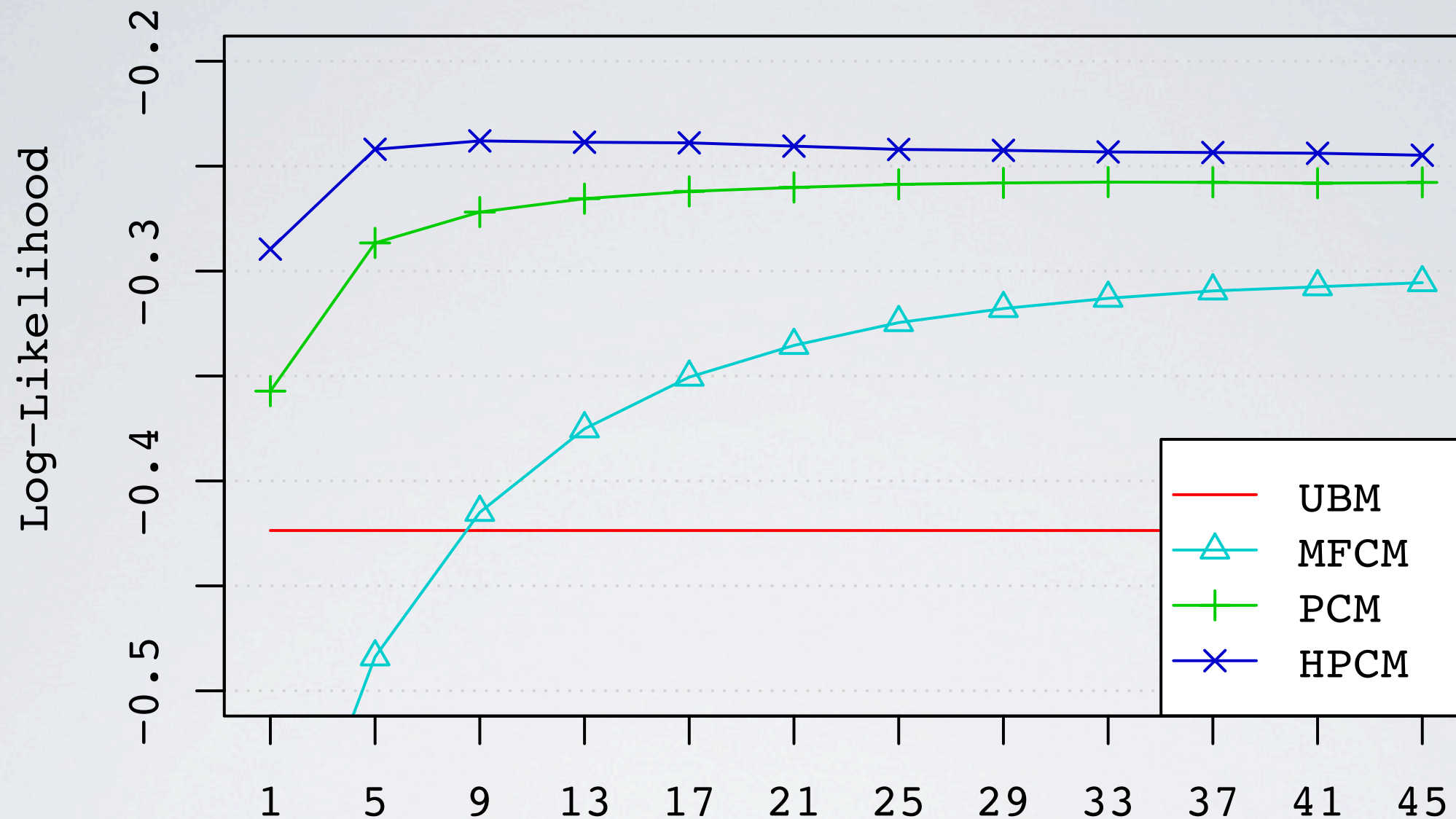




# NUMBER OF FACTORS

Few factors are required to achieve an adequate performance.  
The more parameters to be estimated, the fewer factors needed.





# NUMBER OF ITERATION

Run Stochastic Gradient Descent iteratively within one EM iteration.  
All models converge as the iteration number goes up.

# SUMMARY

- Introducing Collaborative Filtering into click models to address the issue of personalization.
- Handling rare or even new query- document combinations.
- Supremacy over previous click models, especially on some challenging data.



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# ISOLATION ASSUMPTION REVISITED

- In Personalized Click Model, sessions with clicks outside organic search block are discarded.
- Previous click models focus either on organic search or ads recommendation.
- User behavior is a whole chain of clicks that should all be considered.



Garden Flowers  
Cheap Flowers  
Wedding Flowers  
List of Flowers  
Names of Flowers  
Wholesale Flowers  
Pictures All Types  
Flowers  
Flower Tattoos

SEARCH HISTORY  
Search more to see  
your history  
  
See all  
Clear all · Turn off

**Related  
Search  
Block**

**Flowers at 1-800-FLOWERS** · 1800flowers.com · Bing cashback · Sponsored sites  
Flowers & Gifts at 1-800-FLOWERS. 30% Cash Back. 100% Satisfaction!  
**Save \$10 On Flowers** · www.Teleflora.com  
Surprise Friends Near and Far. Same Day Delivery by Local Florists.  
**Free Vase & Delivery Inc.** · Flowers.ms/flowers  
Delivery Included. FTD Florist Member Satisfaction 7

**Top Ads block**

**Flower** - Wikipedia, the free encyclopedia  
Flower specialization ... · Morphology · Development · Pollination  
A **flower**, sometimes known as a bloom or blossom, is the reproductive structure found in flowering plants (plants of the division Magnoliophyta, also called angiosperms).  
en.wikipedia.org/wiki/Flower · Cached page · Mark as spam  
  
**Flowers Day Florist Flowers Delivery**  
Flower Delivery at Flower.com. Send flowers and gifts online for same day flower delivery nationwide. Flower.com is the home of the perfect flower delivery so send flowers today.  
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**flower: Definition, Synonyms from Answers.com**  
(Click to enlarge) **flower** (Elizabeth Morales) n. The reproductive structure of some seed-bearing plants, characteristically having either specialized male or female organs or ...  
www.answers.com/topic/flower · Cached page · Mark as spam  
  
**Flowers & Gifts for Delivery - Send Flowers from ProFlowers**  
ProFlowers even offers international flower delivery. Flowers For Every Occasion. We have flowers for every occasion: birthday flowers, get well flowers, anniversary flowers, sympathy ...  
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Order flowers, roses, gift baskets and more. Get same-day flower delivery for birthdays, anniversaries, and all other occasions. Find fresh flowers at 1800Flowers.com.  
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**Search Block**

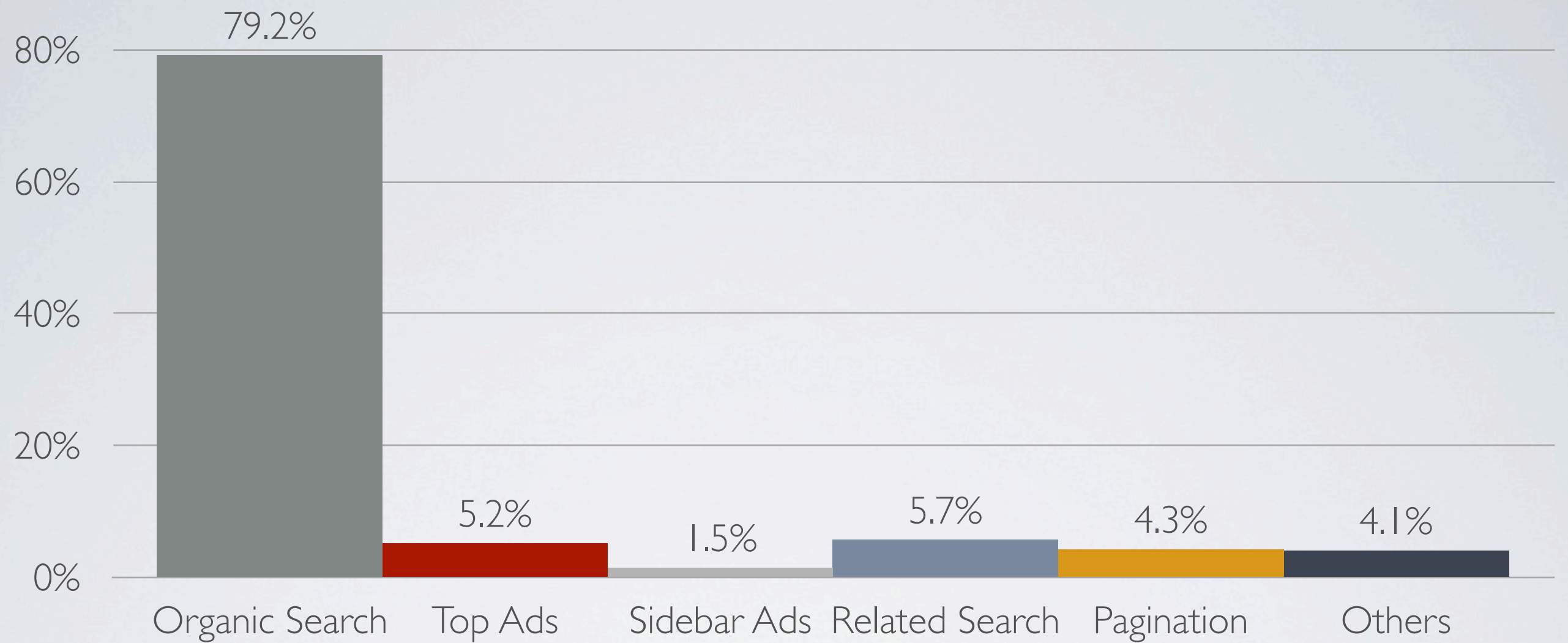
**50% Off All Flowers Today**  
Join Others Who Have Saved 50%,  
Plus Get Same Day Delivery!  
www.BloomsToday.com  
  
**FTD® Official Site**  
Rated "Best Overall," CBS News 2009.  
Buy Now for 25% Off Best Sellers!  
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**Flowers Starting at 19.99**  
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Grown In California & Delivered Farm-  
Direct To Your Door Step!  
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**Fresh Flower Delivery**  
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Hidden Fees Plus 25% Bing Cashback!  
www.FloraFlora.com  
Bing cashback  
See your message here

**Right Ads  
Block**

1 2 3 4 5 Next

**Pagination Block**

# BLOCKS ON SERP



CLICK DISTRIBUTION OVER DIFFERENT BLOCKS



# WHOLE PAGE CLICK (WPC) MODEL

## THE TWO-LAYER STRUCTURE

- The macro layer
  - characterizes the user block switch behavior, or user transition behavior among blocks.
  - models the block transition route as a Markov chain.
- The micro layer
  - focuses on the user click behavior inside a single block.
  - assumes that each click is decided within the block independently.
  - can incorporate traditional click models, like DBN and UBM.

# EXPERIMENTS

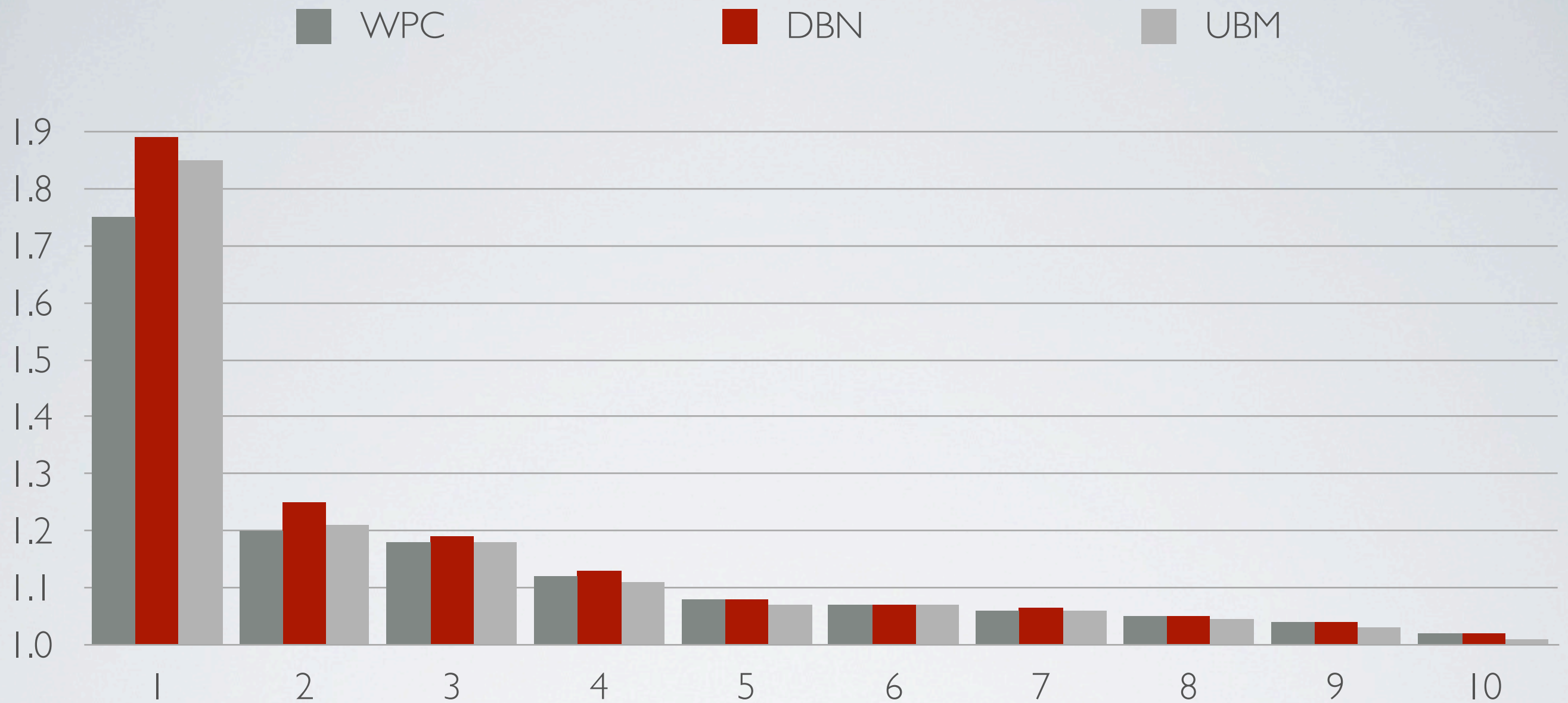
- A commercial English search engine in the US market
  - over one week in Oct, 2010
  - 2 million distinct queries
  - 88 million sessions
- Employing UBM as micro-layer of WPC Model.
- Using DBN and UBM as baselines.
- Measuring model performance by perplexity.



Model	Whole Page	Search	Top Ads	Side Ads	Related Search	Pagination
WPC	1.067	1.156	1.213	1.019	1.0211	1.006
DBN	1.088	1.175	1.530	1.084	1.0245	1.010
WPC Over DBN	23.8%	10.8%	59.1%	77.0%	13.8%	0.4%
UBM	1.082	1.163	1.440	1.064	1.0238	1.009
WPC Over UBM	18.2%	4.3%	51.5%	70.3%	11.3%	0.33%

## AVERAGE PERPLEXITY FOR THREE CLICK MODELS

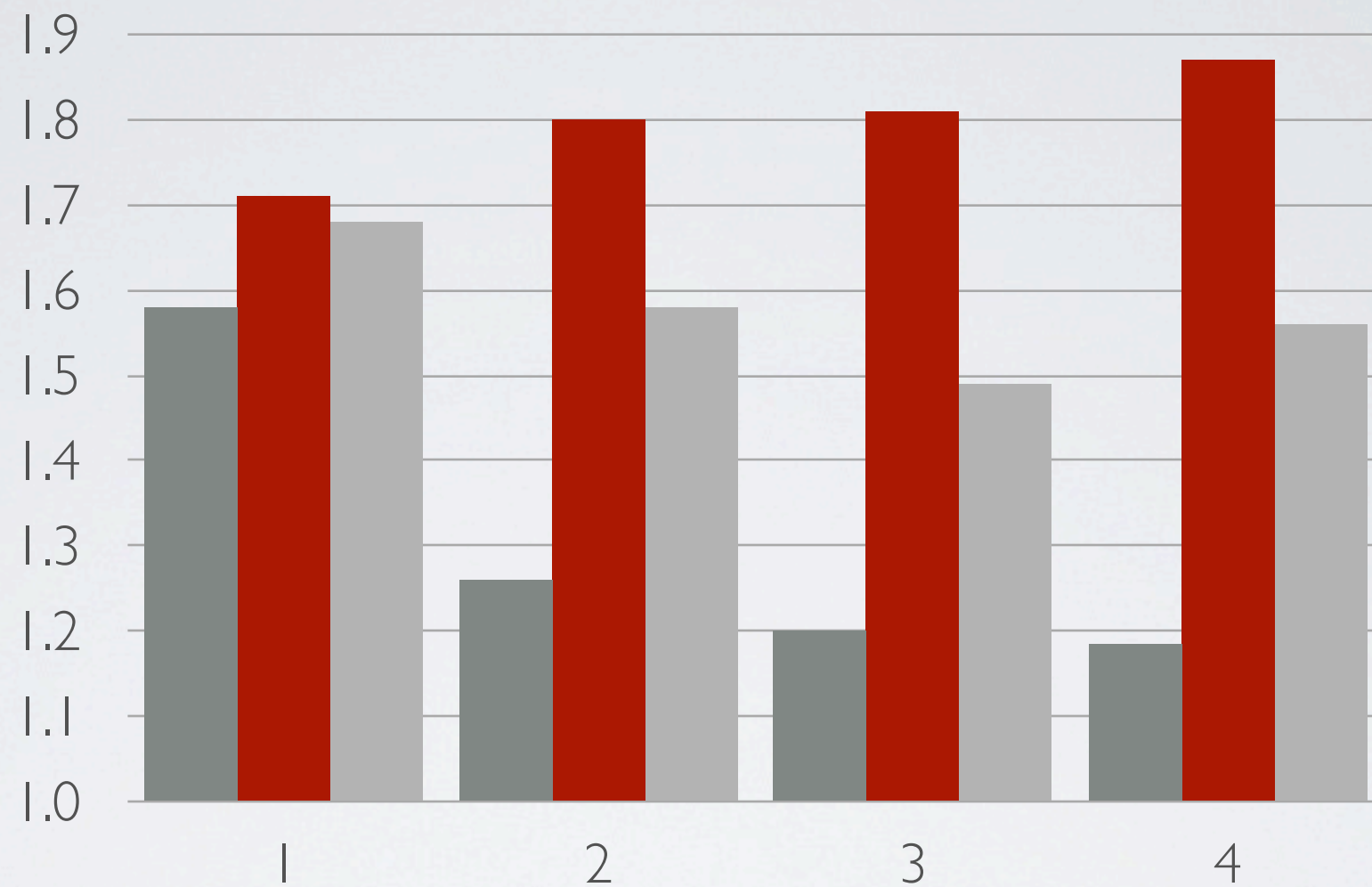
UBM is slightly better than DBN, consistent with previous result.  
All improvements pass the hypothesis test.



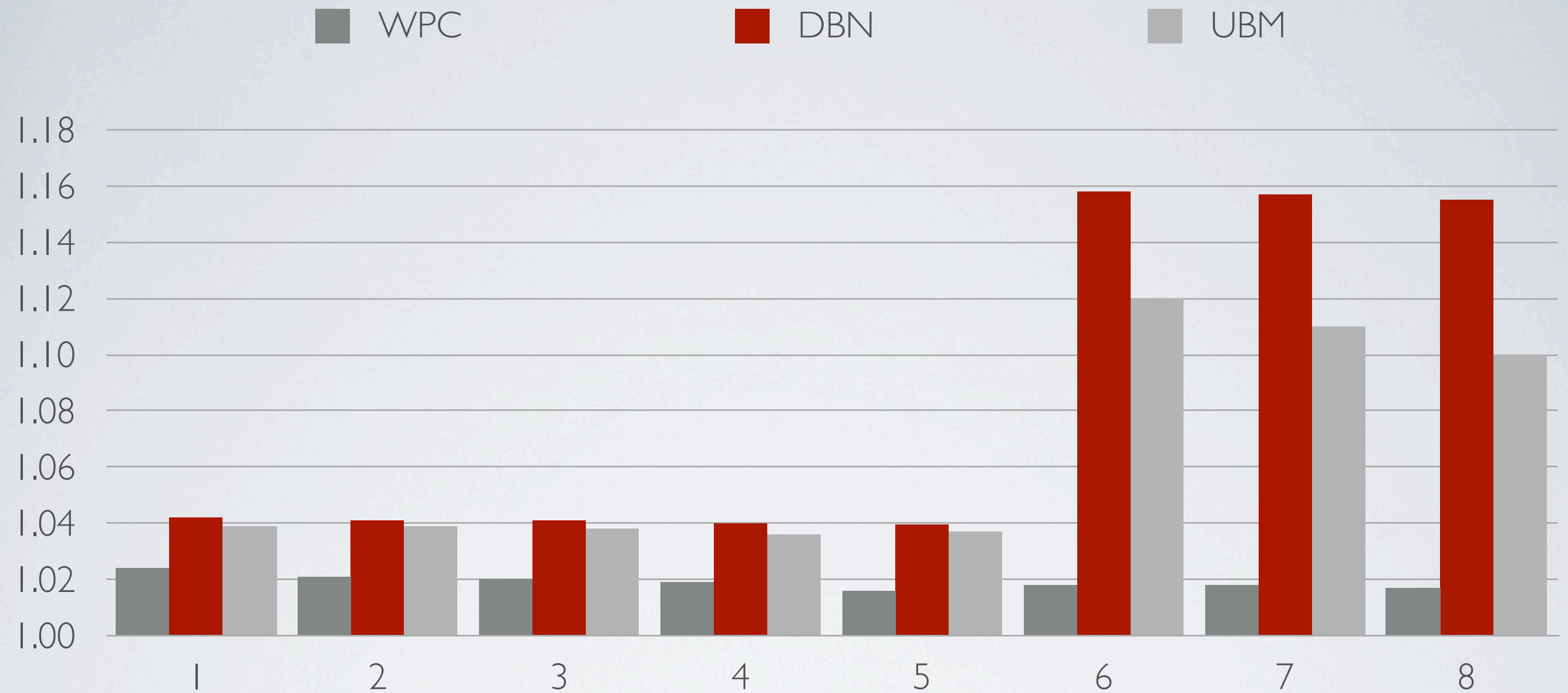
PERPLEXITY BY POSITION IN ORGANIC SEARCH BLOCK



■ WPC                      ■ DBN                      ■ UBM



PERPLEXITY BY POSITION IN TOP ADS BLOCK



PERPLEXITY BY POSITION IN SIDE ADS BLOCK



# SUMMARY

- A nested framework to consider the whole user click chain.
- Experimental results prove that WPC model outperforms previous works.
- Prediction in ads block is significantly boosted.

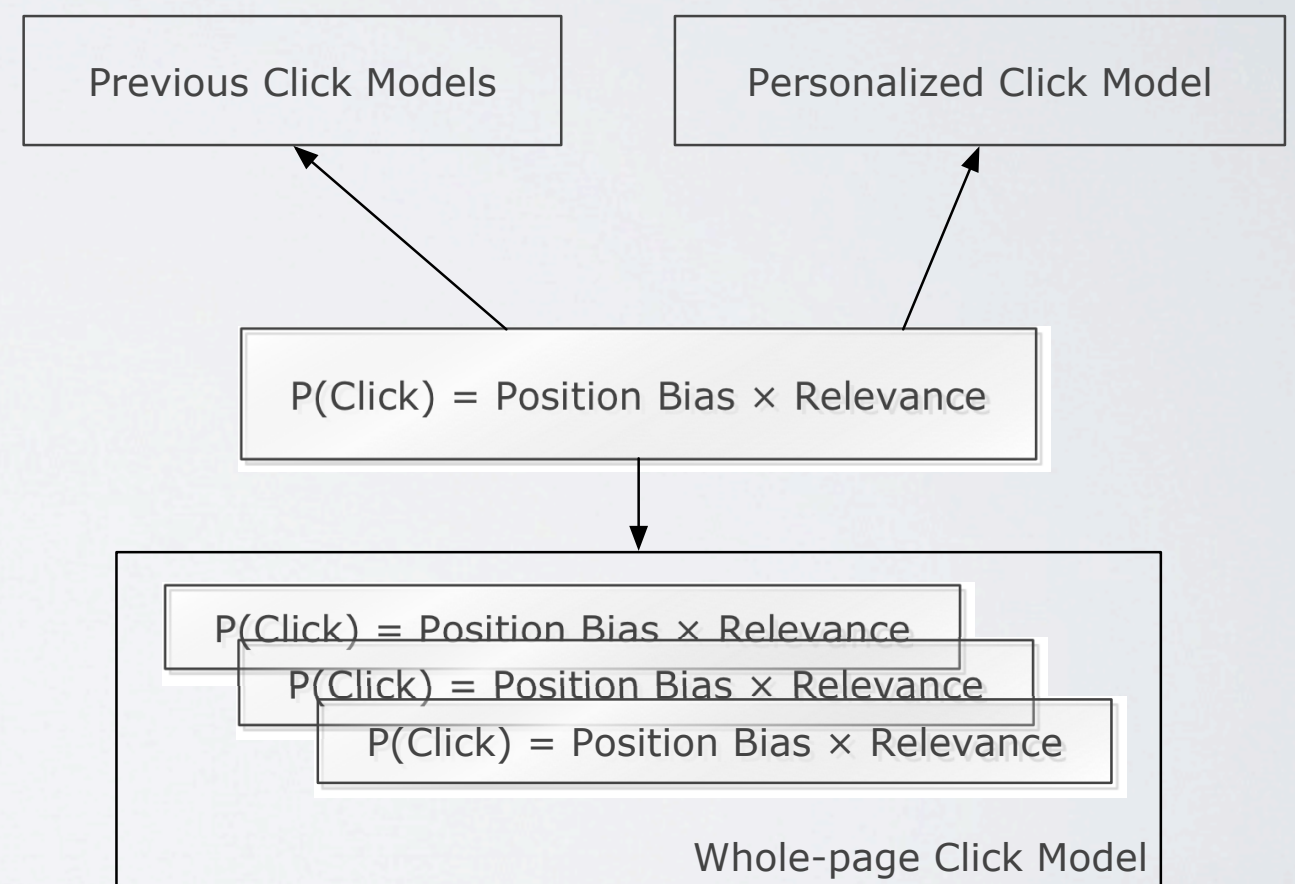
# OUTLINE

- Search Engine and Click Model
- Motivation
- Perspective 1: Personalized Click Model (WSDM '12)
- Perspective 2: Whole Page Click Model (AAAI '11)
- Conclusion



# CONCLUSION

- Put forward two extensions for click models from different angles.
- Both serve as frameworks that can easily incorporate previous click models.
- Large-scale experiments on real data-set reveals the capability for particular circumstances.



# FUTURE WORK

- To add more algorithms to the frameworks:
  - different approaches to personalization for PCM.
  - various stochastic processes for WPC Model.
- To further study traditionally challenging data subsets



THANK YOU.