

Introduction to Clicks Models for Web Search

Ilya Markov, University of Amsterdam i.markov@uva.nl

Joint work with Aleksandr Chuklin and Maarten de Rijke



- Graduated from St. Petersburg State University
- PhD at the University of Lugano
- Postdoctoral researcher at the University of Amsterdam
- Research interests: heterogeneous search environments
 - web search
 - mobile search
 - audio-visual archives
- Algorithmic aspect: distributed information retrieval, federated search, aggregated search
- User aspect: user behavior, user-oriented evaluation



AINL-ISMW FRUCT CONFERENCE YOUNG SCIENTIST ORIENTED EVENT

9-14 November Saint-Petersburg, Russia



- Authors' version of the book on which the tutorial is based:
 - Aleksandr Chuklin, Ilya Markov, Maarten de Rijke. *Click Models for Web Search*. Synthesis Lectures on Information Concepts, Retrieval, and Services. Morgan & Claypool, July, 2015
- See http://clickmodels.weebly.com for additional materials

Introduction	Click Models	Evaluation	Results	Data&Tools	Applications	Future	Recap
Outline							



- 2 Click Models
- 3 Evaluation

4 Results

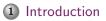
5 Data and Tools

6 Applications

7 Future Research

8 Recap

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- 2 Click Models
- 3 Evaluation
- 4 Results
- 5 Data and Tools
- 6 Applications
- 7 Future Research
- 8 Recap

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- Reflect user interests
- Help to improve search
- Help to evaluate search
- Ongoing and future research: other user search interactions
 - mouse movements
 - scrolling
 - touch gestures

Introduction

Results

Evaluation

Data&Tools

ools Applications

ations Future

Recap

What can we do with clicks?

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Introduction Click Models Evaluation Results Data&Tools Applications Future Recap What can we do with clicks?

count

click-through rate (CTR)

Some notation: u - URL (or document), q - query

Introduction

Click Models E

Evaluation Results

Data&Tools

Applications

Recap

Future

Why click models?

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Scientific modelling is a scientific activity, the aim of which is to make a particular part or feature of the world easier to understand, define, quantify, visualize, or simulate by referencing it to existing and usually commonly accepted knowledge.

Wikipedia, Scientific modelling

Introduction Click Models Evaluation Results Data&Tools Applications Future Recap Why click models?

> Click models make user clicks in web search easier to understand, define, quantify, visualize, or simulate using (mostly) probabilistic graphical models.

Introduction	Click Models	Evaluation	Results	Data&Tools	Applications	Future	Recap
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Yandex Relevance Prediction Challenge http://imat-relpred.yandex.ru/en

Introduction	Click Models	Evaluation	Results	Data&Tools	Applications	Future	Recap
Outline							



2 Click Models

- Random click model
- Position-based model
- Cascade model
- Parameters estimation
- Click probabilities

3 Evaluation

- 4 Results
- 5 Data and Tools

6 Applications

Introduction	Click Models	Evaluation	Results	Data&Tools	Applications	Future	Recap
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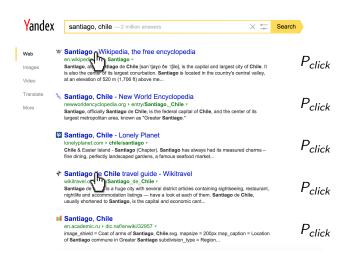
2 Click Models

Random click model

- Position-based model
- Cascade model
- Parameters estimation
- Click probabilities

Applications Future Recap

Random click model





Terminology

- C_u binary random variable denoting a click on document u
- Document *u* is clicked: $C_u = 1$
- Document *u* is not clicked: $C_u = 0$
- $P(C_u = 1)$ probability of click on document u

•
$$P(C_u = 0) = 1 - P(C_u = 1)$$

- Random click model (RCM)
 - Any document can be clicked with the same (fixed) probability

$$P(C_u = 1) = const = \rho$$

Recap

Random click model

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Introduction	Click Models	Evaluation	Results	Data&Tools	Applications	Future	Recap
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Position-based model

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- Terminology
 - Examination = reading a **snippet**
 - E_r binary random variable denoting examination of a snippet at rank r
 - Snippet at rank r is examined: $E_r = 1$
 - Snippet at rank r is not examined: $E_r = 0$
 - $P(E_r = 1)$ probability of examination of rank r

•
$$P(E_r = 0) = 1 - P(E_r = 1)$$

- Position-based model (PBM)
 - Examination depends on rank

$$P(E_r=1)=\gamma_r$$

Applications Future Recap

Position-based model

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Position-based model: attractiveness

- Terminology
 - Attractiveness = a user wants to click on a document after examining (reading) its snippet
 - A_u binary random variable showing whether document u is attractive to a user, given query q
 - Document u is attractive: $A_u = 1$
 - Document u is not attractive: $A_u = 0$
 - $P(A_u = 1)$ probability of attractiveness of document u
 - $P(A_u = 0) = 1 P(A_u = 1)$
- Position-based model (PBM)
 - Attractiveness depends on a query-document pair

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

Applications

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Position-based model

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* Santiago de Chile travel guide - Wikitravel wikitravel.or //Santiago_de_Chile -

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 γ_3 , $P_{click}(u_3q)$

 γ_4 , $P_{click}(u_4q)$

 γ_5 , $P_{click}(u_5q)$

Applications

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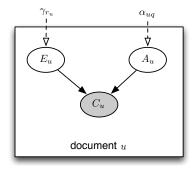
Position-based model: summary

$$egin{aligned} & {\sf P}({\sf E}_{r_u}=1)=\gamma_{r_u} \ & {\sf P}({\sf A}_u=1)=lpha_{uq} \ & {\sf P}({\sf C}_u=1)={\sf P}({\sf E}_{r_u}=1)\cdot{\sf P}({\sf A}_u=1) \end{aligned}$$

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 Position-based
 model:
 probabilistic graphical model



Position-based model: exercises

$$egin{aligned} & P(E_{r_u} = 1) = \gamma_{r_u} \ & P(A_u = 1) = lpha_{uq} \ & P(C_u = 1) = P(E_{r_u} = 1) \cdot P(A_u = 1) \end{aligned}$$

$$E_{r_u} = 0 \Rightarrow C_u = 0$$

$$A_u = 0 \Rightarrow C_u = 0$$

$$E_{r_u} = 1 \Rightarrow (C_u = 1 \iff A_u = 1)$$

$$A_u = 1 \Rightarrow (C_u = 1 \iff E_{r_u} = 1)$$

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Cascade model

- Parameters estimation
- Click probabilities

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Position-based model

$$\begin{aligned} & \mathsf{P}(E_{r_{u}} = 1) = \gamma_{r_{u}} \\ & \mathsf{P}(A_{u} = 1) = \alpha_{uq} \\ & \mathsf{P}(C_{u} = 1) = \mathsf{P}(E_{r_{u}} = 1) \cdot \mathsf{P}(A_{u} = 1) \end{aligned}$$

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Data&Tools

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Future

Cascade model

- Start from the first document 1
- Examine documents one by one 2
- If click, then stop 3
- Otherwise, continue 4

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$$E_{r} = 1 \text{ and } A_{u_{r}} = 1 \Leftrightarrow C_{r} = 1$$

$$P(A_{u_{r}} = 1) = ?$$

$$P(E_{1} = 1) = 1$$

$$P(E_{r} = 1 \mid E_{r-1} = 0) = ?$$

$$P(E_{r} = 1 \mid C_{r-1} = 1) = ?$$

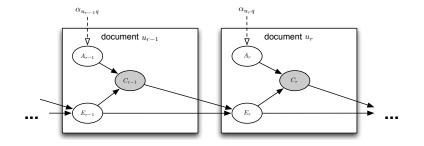
$$P(E_{r} = 1 \mid C_{r-1} = 1) = ?$$

$$P(E_{r} = 1 \mid E_{r-1} = 1, C_{r-1} = 0) = ?$$

otherwise, continue

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$$E_{r} = 1 \text{ and } A_{u_{r}} = 1 \Leftrightarrow C_{r} = 1$$

$$P(A_{u_{r}} = 1) = \alpha_{u_{r}q}$$

$$P(E_{1} = 1) = 1$$

$$P(E_{r} = 1 \mid E_{r-1} = 0) = 0$$

$$P(E_{r} = 1 \mid C_{r-1} = 1) = 0$$

$$P(E_{r} = 1 \mid E_{r-1} = 1, C_{r-1} = 0) = 1$$

$$\begin{split} E_3 &= 0 \Rightarrow E_4 = ?\\ C_4 &= 1 \Rightarrow E_5 = ?\\ E_2 &= 1 \Rightarrow (E_3 = 1 \iff C_2 = 0)\\ C_5 &= 0 \Rightarrow (E_6 = 1 \iff E_5 = 1) \end{split}$$

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- Random click model (RCM)
 - + count clicks (simple and fast)
 - do not distinguish examination and attractiveness
- Position-based model (PBM)
 - + examination and attractiveness
 - examination of a document at rank r does not depend on examinations and clicks above r
- Cascade model (CM)
 - + cascade dependency of examination at *r* on examinations and clicks above *r*
 - only one click is allowed

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2 Click Models

- Random click model
- Position-based model
- Cascade model

Parameters estimation

Click probabilities



- Maximum likelihood estimation no hidden variables
 - Derive the likelihood function
 - 2 Take its derivative with respect to the parameter in question
 - 3 Equate the derivative to zero and calculate the parameter value
- Expectation maximization hidden variables
 - Set parameters to some initial values
 - 2 Repeat until convergence
 - E-step: derive the expectation of the likelihood function
 - M-step: maximize this expectation

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2 Click Models

- Random click model
- Position-based model
- Cascade model
- Parameters estimation
- Click probabilities



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 Full probability – probability that a user clicks on a document at rank r

 $P(C_r = 1)$

 Conditional probability – probability that a user clicks on a document at rank r given previous clicks

 $P(C_r = 1 | C_1, \ldots, C_{r-1})$

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- 3 Evaluation Likelihood
 - Perplexity



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Likelihood Perplexity



$$P(C_{r+1} \mid C_r = c_r^{(s)}) = \begin{cases} P(C_{r+1} \mid C_r = 1), \text{ of there was a click at } r \\ P(C_{r+1} \mid C_r = 0), \text{ otherwise} \end{cases}$$
$$= + \frac{P(C_{r+1} \mid C_r = 1) \cdot c_r^{(s)}}{P(C_{r+1} \mid C_r = 0) \cdot (1 - c_r^{(s)})}$$

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$$\mathcal{LL}(M) = \frac{1}{|\mathcal{S}|} \sum_{s \in \mathcal{S}} \log P_M(C_1 = c_1^{(s)}, \dots, C_n = c_n^{(s)})$$

C_r - binary random variable denoting a click at rank r
c_r^(s) - observed click at rank r in a search session s
P(C_r = c_r^(s)) - probability of observing c_r^(s) in session s
P(C₁ = c₁^(s), ..., C_n = c_n^(s)) - probability of observing sequence c₁^(s), ..., c_n^(s) in session s

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$$P_{M}(C_{1} = c_{1}^{(s)}, \dots, C_{n} = c_{n}^{(s)})$$

$$= P_{M}(C_{1} = c_{1}^{(s)}) \cdot P_{M}(C_{2} = c_{2}^{(s)}, \dots, C_{n} = c_{n}^{(s)} | C_{1} = c_{1}^{(s)})$$

$$= P_{M}(C_{1} = c_{1}^{(s)}) \cdot P_{M}(C_{2} = c_{2}^{(s)} | C_{1} = c_{1}^{(s)})$$

$$\cdot P_{M}(C_{3} = c_{3}^{(s)}, \dots, C_{n} = c_{n}^{(s)} | C_{1} = c_{1}^{(s)}, C_{2} = c_{2}^{(s)})$$

$$= \prod_{r=1}^{n} P_{M}\left(C_{r} = c_{r}^{(s)} | \mathbf{C}_{< r} = \mathbf{c}_{< r}^{(s)}\right)$$

$$\mathcal{LL}(M) = \frac{1}{|S|} \sum_{s \in S} \log P_{M}(C_{1} = c_{1}^{(s)}, \dots, C_{n} = c_{n}^{(s)})$$

$$\mathcal{LL}(M) = \frac{1}{|\mathcal{S}|} \sum_{s \in \mathcal{S}} \sum_{r=1}^{n} \log P_M \left(C_r = c_r^{(s)} \mid \mathbf{C}_{< r} = \mathbf{c}_{< r}^{(s)} \right)$$



$$\mathcal{LL}(M) = \frac{1}{|\mathcal{S}|} \sum_{s \in \mathcal{S}} \sum_{r=1}^{n} \log \underbrace{\mathcal{P}_{M}\left(C_{r} = c_{r}^{(s)} \mid \mathbf{C}_{< r} = \mathbf{c}_{< r}^{(s)}\right)}_{\text{conditional click probability}}$$

Likelihood measures how well a click model estimates conditional click probabilities given observed clicks.

$$\mathcal{LL}(M) \in [-\infty..0]$$

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Perplexity



$$p_r(M) = 2^{-\frac{1}{|S|}\sum_{s\in S} (\log_2 P_M(C_r^{(s)} = c_r^{(s)}))}$$

Perplexity measures how well a click model estimates full click probabilities (i.e., when clicks are not observed).

$$p_r(M) \in [1..2]$$

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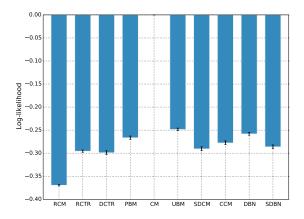
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- Data
 - first 1M query sessions from WSCD 2012 dataset
 - 75% for training, 25% for testing
 - repeat 15 times, each time with next 1M sessions
- PyClick
- 50 iterations for EM



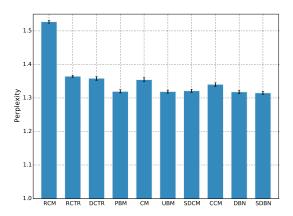
- Random click model (RCM): counting clicks
- Position-based model (PBM): examination and attractiveness
- Cascade model (CM): previous examinations and clicks matter

Log-likelihood



- Cascade model: $\mathcal{LL} = -\infty$
- Complex models (PBM) win over simple ones

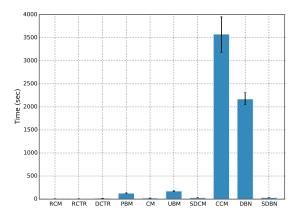




- Complex models win over simple ones
- Most complex models have similar perplexity

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• MLE is much faster than EM

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- AOL2006: raw queries and clicked documents (no SERPs)
- MSN2006: contains only clicked documents (no SERPs)
- Workshop on Web Search Click Data (WSCD)
 - WSCD2012: predict document relevance
 - WSCD2013: detect search engine switch
 - WSCD2014: search personalization
- SogouQ

Dataset statistics

Dataset	Queries	URLs	Users	Sessions
AOL 2006	10,154,742	1,632,788	657,426	21,011,340
MSN 2006	8,831,280	4,975,897	_	7,470,915
SogouQ 2012	8,939,569	15,095,269	9,739,704	25,530,711
WSCD 2012	30,717,251	117,093,258	_	146,278,823
WSCD 2013	10,139,547	49,029,185	956,536	17,784,583
WSCD 2014	21,073,569	70,348,426	5,736,333	65,172,853



- Click model packages
 - Click models project by Aleksandr Chuklin
 - PyClick
- Infer.NET
- Lerot
- General-purpose languages
 - Octave
 - Matlab

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- 5 Data and Tools
- 6 Applications
 - Simulating users
 - Approximating document relevance

7 Future Research





6 Applications

• Simulating users

• Approximating document relevance

Algorithm 1 Simulating user clicksInput: click model M, query session sOutput: vector of simulated clicks (c_1, \ldots, c_n)

1: for
$$r \leftarrow 1$$
 to $|s|$ do
2: $P_r \leftarrow \underbrace{P_M(C_r = 1 \mid C_1 = c_1, \dots, C_{r-1} = c_{r-1})}_{\text{conditional click probability}}$
3: Generate c_r from $Bernoulli(P_r)$
4: end for





6 Applications

- Approximating document relevance

Future

Approximating document relevance

Evaluation

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- Clicks are affected by rank \Longrightarrow do not represent document relevance directly
- Attractiveness does not depend on rank \implies can be used as an indicator of document relevance
- It is used by search engines as retrieval features
- Documents can simply be ranked by α_{uq}

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- Adding new variables not a good idea
- Work on the learning phase
 - Efficient learning
 - Online learning
- Why not learning the structure of a click model from data instead of defining it manually?
- Other interactions and environments
 - Interactions beyond clicks
 - Devices beyond desktop computers

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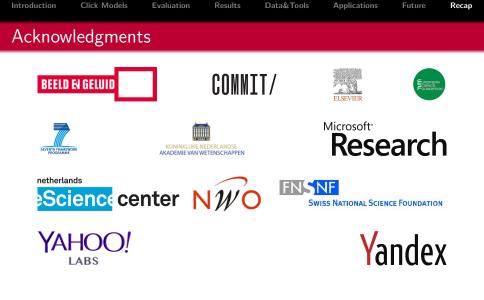


- Click models
- 2 Parameter estimation
- ③ Click probabilities
- ④ Evaluation
- 5 Experimental results
- 6 Data and tools
- ② Applications
- 8 Future research

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Questions, comments, suggestions, critiques are very welcome

Ilya Markov i.markov@uva.nl



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