

Introduction to Clicks Models for Web Search

Ilya Markov, University of Amsterdam
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Joint work with Aleksandr Chuklin and Maarten de Rijke

Who am I?


- 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



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Materials

- 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

Outline

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

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Web search

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Why clicks?

- Reflect user interests
- Help to improve search
- Help to evaluate search

- Ongoing and future research: other user search interactions
 - mouse movements
 - scrolling
 - touch gestures


What can we do with clicks?

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What can we do with clicks?

count

click-through rate (CTR)

- Global CTR = $\frac{\# \text{ clicks}}{\# \text{ shown docs}}$
- Rank-based CTR = $\frac{\# \text{ clicks at rank } r}{\# \text{ shown docs at rank } r}$
- Query-document CTR = $\frac{\# u \text{ is clicked for } q}{\# u \text{ is shown for } q}$

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

Why click models?

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Why click models?

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

Why click models?

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

Click log

0	0	Q	8	0	7	103	51	92	43	12	73	69	27	105
0	36	Q	174	0	1625	1627	1623	1626	1624	1622	1619	1621	1620	1618
0	50	Q	227	0	2094	2091	2087	2089	2093	2088	2090	2092	2095	2086
0	515	Q	174	0	1625	1627	1623	1626	1624	1622	1619	1621	1620	1618
0	524	Q	1974	0	17562	1627	1626	1623	2091	17559	17563	17558	17561	17560
0	527	C	17562											
0	528	C	1627											
0	529	C	1626											
1	0	Q	9	0	13	70	66	94	50	104	29	21	89	85
1	20	C	104											
1	123	C	21											
1	291	Q	1324	0	11807	11805	11812	11813	11804	11809	11806	11811	11808	11810
1	301	C	11813											
1	8605	C	11808											
1	8737	C	11810											
1	8884	C	11811											
2	0	Q	7	0	77	93	55	86	64	67	76	98	18	54
2	11	C	18											
2	1122	Q	4088	0	35554	35561	35562	35556	35557	35567	35550	35566	35568	35553
2	1127	C	35561											
2	1645	Q	5863	0	36505	36514	36508	36509	50480	36510	36507	50482	50483	50481
2	1646	C	36505											

Yandex Relevance Prediction Challenge
<http://imat-relpred.yandex.ru/en>

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

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P_{click}

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P_{click}

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P_{click}

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

$$P(C_u = 1) = \text{const} = \rho$$

Random click model

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P_{click}

P_{click}

P_{click}

P_{click}

P_{click}

$$\rho = ? = \text{Global CTR}$$

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Position-based model

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$$P_{read}(1), P_{click}(u_1q)$$

$$P_{read}(2), P_{click}(u_2q)$$

$$P_{read}(3), P_{click}(u_3q)$$

$$P_{read}(4), P_{click}(u_4q)$$

$$P_{read}(5), P_{click}(u_5q)$$

Position-based model: examination

- 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

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

Position-based model

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$$P_{read}(1), P_{click}(u_1q)$$

$$P_{read}(2), P_{click}(u_2q)$$

$$P_{read}(3), P_{click}(u_3q)$$

$$P_{read}(4), P_{click}(u_4q)$$

$$P_{read}(5), P_{click}(u_5q)$$

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

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

Position-based model

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$$\gamma_1, P_{click}(u_1q)$$

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$$\gamma_2, P_{click}(u_2q)$$

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$$\gamma_3, P_{click}(u_3q)$$

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$$\gamma_4, P_{click}(u_4q)$$

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$$\gamma_5, P_{click}(u_5q)$$

Position-based model: summary

$$P(E_{r_u} = 1) = \gamma_{r_u}$$

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

$$P(C_u = 1) = P(E_{r_u} = 1) \cdot P(A_u = 1)$$

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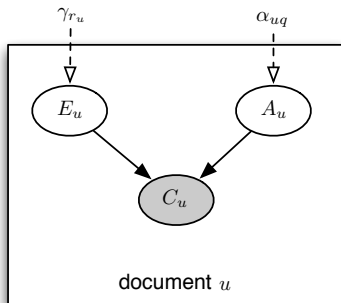
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Position-based model: probabilistic graphical model



Position-based model: exercises

$$P(E_{r_u} = 1) = \gamma_{r_u}$$

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

$$P(C_u = 1) = P(E_{r_u} = 1) \cdot P(A_u = 1)$$

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

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

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

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

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Chile & Easter Island - Santiago (Chapter): Santiago has always had its measured charms — fine dining, perfectly landscaped gardens, a famous seafood market...
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 - Cascade model
 - Parameters estimation
 - Click probabilities

Position-based model

$$P(E_{r_u} = 1) = \gamma_{r_u}$$

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

$$P(C_u = 1) = P(E_{r_u} = 1) \cdot P(A_u = 1)$$

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Cascade model

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

The screenshot shows a Yandex search engine interface. The search bar contains the text "santiago, chile" and indicates "2 million answers". Below the search bar, there are several search results listed under the "Web" category. A mouse cursor is positioned over the first result, which is a Wikipedia link for "Santiago".

Web

- Santiago** - Wikipedia, the free encyclopedia
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Santiago, also known as **Santiago de Chile** [sanˈtjaɔ̃ ðe ˈtʃile], is the capital and largest city of Chile. It is also the center of its largest conurbation. **Santiago** is located in the country's central valley, at an elevation of 520 m (1,706 ft) above me...
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Santiago, officially **Santiago de Chile**, is the federal capital of **Chile**, and the center of its largest metropolitan area, known as "Greater **Santiago**."
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 Chile & Easter Island - **Santiago** (Chapter). **Santiago** has always had its measured charms – fine dining, perfectly landscaped gardens, a famous seafood market...
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 image_shield = Coat of arms of **Santiago, Chile**.svg, mapsize = 200px, map_caption = Location of **Santiago** commune in Greater **Santiago** subdivision_type = Region...

Cascade model

$$E_r = 1 \text{ and } A_{u_r} = 1 \Leftrightarrow C_r = 1$$

$$P(A_{u_r} = 1) = ?$$

$$P(E_1 = 1) = 1$$

start from first

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

examine one by one

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

if click, then stop

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

otherwise, continue

Yandex 2 million answers

Web **Santiago** Wikipedia, the free encyclopedia
 en.wikipedia.org/wiki/Santiago
 Santiago, officially Santiago de Chile [sanˈtjaɔ de ˈtʃile], is the capital and largest city of Chile. It is also the center of its largest conurbation. Santiago is located in the country's central valley, at an elevation of 520 m (1,706 ft) above sea level.

Images

Video

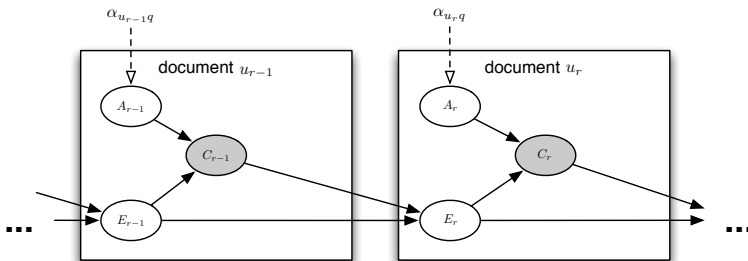
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More **Santiago, Chile** - Lonely Planet
 lonelyplanet.com/usa/chile/santiago
 Chile & Easter Island - Santiago (Chapter). Santiago has always had its measured charm — fine dining, perfectly landscaped gardens, a famous seafood market...

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Cascade model: probabilistic graphical model



Cascade model: exercises

$$E_r = 1 \text{ and } A_{u_r} = 1 \Leftrightarrow C_r = 1$$

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

$$P(E_1 = 1) = 1$$

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

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

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

$$E_3 = 0 \Rightarrow E_4 = ?$$

$$C_4 = 1 \Rightarrow E_5 = ?$$

$$E_2 = 1 \Rightarrow (E_3 = 1 \iff C_2 = 0)$$

$$C_5 = 0 \Rightarrow (E_6 = 1 \iff E_5 = 1)$$

Yandex 2 million answers

- Web **Santiago** - Wikipedia, the free encyclopedia
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- Images **Santiago**, Chile - Image of Chile [san'ʝago ðe 'tʃile], is the capital and largest city of Chile. It is also the center of its largest conurbation. **Santiago** is located in the country's central valley, at an elevation of 520 m (1,706 ft) above me...
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 lonelyplanet.com > chile/santiago
- Chile** & Easter Island - **Santiago** (Chapter). **Santiago** has always had its measured charms — the dining, perfectly landscaped gardens, a famous seafood market...
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Click models summary

- 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

Outline

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

Parameters estimation

- Maximum likelihood estimation – no hidden variables
 - ① 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
 - ① Set parameters to some initial values
 - ② Repeat until convergence
 - E-step: derive the expectation of the likelihood function
 - M-step: maximize this expectation

Outline

- 2 Click Models
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Click probabilities

- 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

$$P(C_r = 1 \mid C_1, \dots, C_{r-1})$$

The screenshot shows a Yandex search interface. The search bar contains the text "santiago, chile" and indicates "2 million answers". Below the search bar, there are several search results categorized by type:

- Web:**
 - Santiago** - Wikipedia, the free encyclopedia. <en.wikipedia.org/wiki/Santiago>
 - Santiago, Chile** - New World Encyclopedia. newworldencyclopedia.org/entry/Santiago,_Chile
- Images:**
 - Santiago, Chile** - Lonely Planet. <lonelyplanet.com/chile/santiago>
- Video:**
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- More:**
 - Santiago, Chile** - Academic.ru. <en.academic.ru/dic.nsf/enwiki/32957>

Outline

- 1 Introduction
- 2 Click Models
- 3 Evaluation**
 - Likelihood
 - Perplexity
- 4 Results
- 5 Data and Tools
- 6 Applications
- 7 Future Research
- 8 Recap

Outline

- 3 Evaluation
 - Likelihood
 - Perplexity

Notation

- C_r – ?
- $c_r^{(s)}$ – observed click at rank r in a search session s
 - There was a click at r in session s : $c_r^{(s)} = 1$
 - There was no click at r in session s : $c_r^{(s)} = 0$

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

Likelihood

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

- 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
- $P(C_1 = c_1^{(s)}, \dots, C_n = c_n^{(s)})$ – probability of observing sequence $c_1^{(s)}, \dots, c_n^{(s)}$ in session s

Likelihood

$$\begin{aligned}
 P_M(C_1 = c_1^{(s)}, \dots, C_n = c_n^{(s)}) \\
 &= P_M(C_1 = c_1^{(s)}) \cdot P_M(C_2 = c_2^{(s)}, \dots, C_n = c_n^{(s)} \mid C_1 = c_1^{(s)}) \\
 &= P_M(C_1 = c_1^{(s)}) \cdot P_M(C_2 = c_2^{(s)} \mid C_1 = c_1^{(s)}) \\
 &\quad \cdot P_M(C_3 = c_3^{(s)}, \dots, C_n = c_n^{(s)} \mid C_1 = c_1^{(s)}, C_2 = c_2^{(s)}) \\
 &= \prod_{r=1}^n P_M(C_r = c_r^{(s)} \mid \mathbf{C}_{<r} = \mathbf{c}_{<r}^{(s)})
 \end{aligned}$$

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

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

Likelihood: summary

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

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

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

Outline

- 3 Evaluation
 - Likelihood
 - Perplexity

Perplexity

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

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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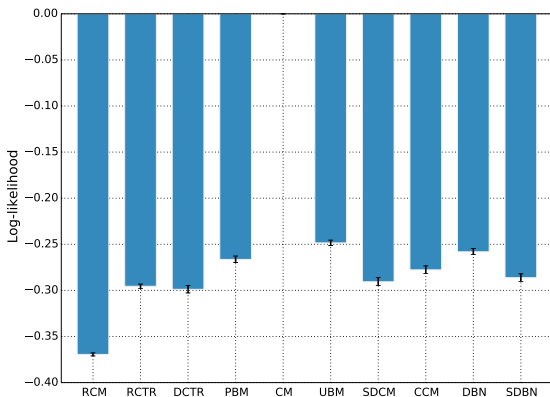
Experimental setup

- 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

Studied click models

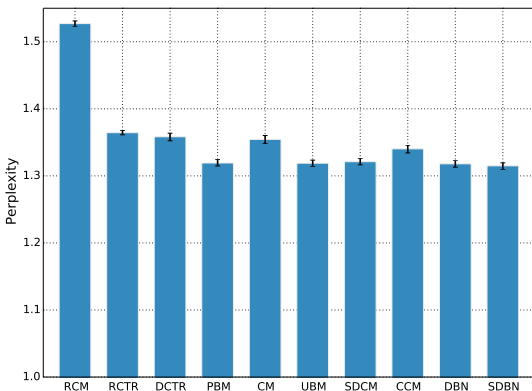
- Random click model (RCM): counting clicks
- Position-based model (PBM): examination and attractiveness
- Cascade model (CM): previous examinations and clicks matter

Log-likelihood



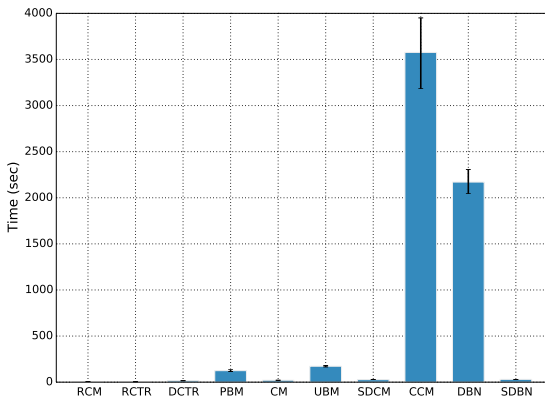
- Cascade model: $\mathcal{LL} = -\infty$
- Complex models (PBM) win over simple ones

Perplexity



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

Training time



- MLE is much faster than EM

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Datasets

- 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

Software

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

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Outline

- 6 Applications
 - Simulating users
 - Approximating document relevance

Simulating users

Algorithm 1 Simulating user clicks

Input: click model M , query session s

Output: vector of simulated clicks (c_1, \dots, 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**
-

Outline

- 6 Applications
 - Simulating users
 - Approximating document relevance

Approximating document relevance

Yandex

santiago, chile — 2 million answers



Search

Web

Santiago Wikipedia, the free encyclopedia

en.wikipedia.org › **Santiago** ▾

Images

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 $\alpha_{u_1 q}$

Video

Translate

Santiago, Chile - New World Encyclopedia

newworldencyclopedia.org › entry/**Santiago,_Chile** ▾

More

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 $\alpha_{u_2 q}$

Santiago, Chile - Lonely Planet

lonelyplanet.com › **chile/santiago** ▾

Chile & Easter Island - **Santiago** (Chapter). **Santiago** has always had its measured charms – fine dining, perfectly landscaped gardens, a famous seafood market...

 $\alpha_{u_3 q}$

Santiago de Chile travel guide - Wikitravel

wikitravel.org › **Santiago_de_Chile** ▾

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 $\alpha_{u_4 q}$

Santiago, Chile

en.academic.ru › dic.nsf/enwiki/32957 ▾

image_shield = Coat of arms of **Santiago, Chile**.svg. mapsize = 200px map_caption = Location of **Santiago** commune in Greater **Santiago** subdivision_type = Region...

 $\alpha_{u_5 q}$

Approximating document relevance

- Clicks are affected by rank \implies 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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Future research

- 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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Recap

- ① Click models
- ② Parameter estimation
- ③ Click probabilities
- ④ Evaluation
- ⑤ Experimental results
- ⑥ Data and tools
- ⑦ Applications
- ⑧ Future research

Questions, comments, suggestions, critiques are very welcome

Ilya Markov
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