

# Learning Socially Optimal Information Systems from Egoistic Users

Karthik Raman    Thorsten Joachims

Department of Computer Science  
Cornell University, Ithaca NY

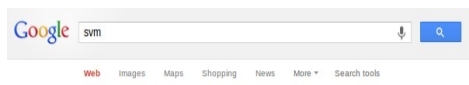
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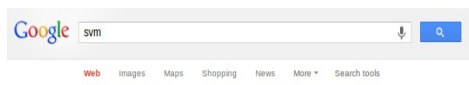
Sept 23, 2013



# Example: (Extrinsic) Diversity in Web Search

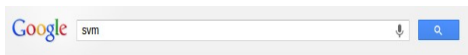


# Example: (Extrinsic) Diversity in Web Search



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# Example: (Extrinsic) Diversity in Web Search



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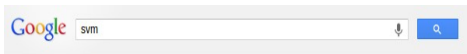
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7

# Example: (Extrinsic) Diversity in Web Search



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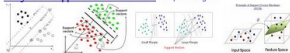
[Support vector machine](#) - Carles - Cited by 138  
[Least squares support vector machine classifiers](#) - Suykens - Cited by 3698  
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## [PDF] An Idiot's guide to Support vector machines (SVMs)

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**Support Vector Machine** (and Statistical Learning Theory) Tutorial. Jason Weston. NEC Labs America, 4 Independence Way, Princeton, USA.

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## [PDF] Support Vector Machines - CS 229

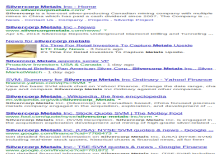
cs229.stanford.edu/notes/cs229-notes3.pdf  
CS229 Lecture notes. Andrew Ng. Part V. **Support Vector Machines**. This set of notes presents the **Support Vector Machine (SVM)** learning algorithm. SVMs are ...

## Support Vector Machines (SVM) - StatSoft

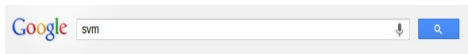
www.statsoft.com/textbook/support-vector-machines/  
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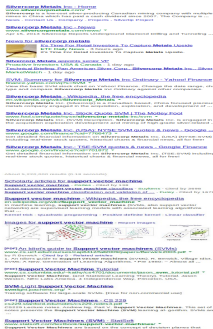
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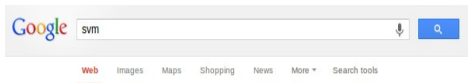
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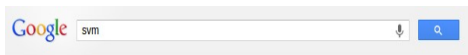
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[Kernel-Machines.Org — Kernel Machines](#)

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This page is devoted to learning methods building on kernels, such as the support vector machine. It grew out of earlier pages at the Max Planck Institute for ...

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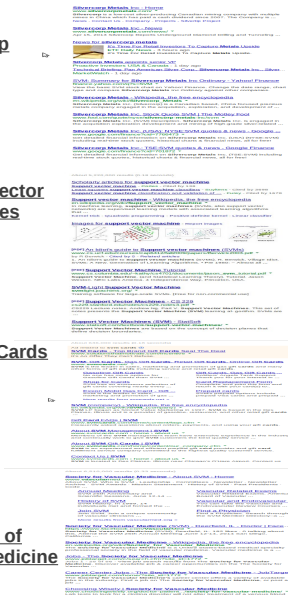
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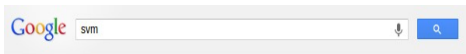
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# Socially optimal solutions in Information systems

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  - ▷ Hedge against uncertainty in user's preferences.

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User Interest	Pref Ranking
Company	$a_1, a_2, a_3, \dots$
ML	
Gift Cards	
<i>Social Opt</i>	

The screenshot shows a Google search for "svm". The search bar is at the top with "svm" entered. Below the search bar are tabs for "Web", "Images", "Maps", "Shopping", "News", and "More". The search results are listed below, with red X marks and green checkmarks indicating relevance to the user interests in the table to the left.

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<a href="#">Support vector machine - Wikipedia, the free encyclopedia</a> en.wikipedia.org/wiki/Support_vector_machine * In machine learning, support vector machines (SVMs, also support vector networks) are supervised learning models with associated learning algorithms that ... Kernel trick - Quadratic programming - Positive-definite kernel - Linear classifier	✗
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<a href="#">Kernel-Machines.org - Kernel Machines</a> www.kernel-machines.org/ * This page is devoted to learning methods building on kernels, such as the support vector machine. It grew out of earlier pages at the Max Planck Institute for ...	✗
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NYSE: SVM US\$3 26 +0.04 +1.08% Volume: 828,826 September 17, 2013. TSX: SVM CAD\$ 3.26 +0.03 +0.9% Volume: 91,387 September 17, 2013.

[Kernel Machines Org - Kernel Machines](#)  
www.kernelmachines.org/ \*  
This page is devoted to learning methods building on kernels, such as the support vector machine. It grew out of earlier pages at the Max Planck Institute for ...

[SVM Stock Quote - Silvercorp Metals Inc. Stock Price Today \(SVM ...](#)  
www.marketwatch.com/investing/stock/svm \*  
Updated stock quote for svm - including svm stock price today, earnings and estimates, stock charts, news, futures and other investing data.

[Society for Vascular Medicine \(SVM\) - Deerfield, IL - Doctor | Face ...](#)  
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Green checkmarks are placed to the right of the following results: Support vector machine - Wikipedia, SVM - Summary for Silvercorp Metals Inc Ordinary, SVM, SVM - Light Support Vector Machine, Kernel Machines Org - Kernel Machines.

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# Challenge of egoistic feedback

- **Challenge:** Learn from egoistic, weak, noisy user feedback.
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- **Not** social utility  $U$ .
  - ▷ As in the case of prior work [RSJ12] for the **intrinsic** diversity problem.
- Need to infer social utility from such **conflicting, individual** feedback.

User Interest	Pref Ranking
Company	$a_1, a_2, a_3, \dots$
ML	$b_1, b_2, b_3, \dots$
Gift Cards	$c_1, c_2, c_3, \dots$
<i>Social Opt</i>	

Google svm

Web Images Maps Shopping News More Search tools

[Support vector machine - Wikipedia, the free encyclopedia](#)  
en.wikipedia.org/wiki/Support\_vector\_machine  
In machine learning, support vector machines (SVMs, also support vector networks) are supervised learning models with associated learning algorithms that...  
Kernel trick - Quadratic programming - Positive-definite kernel - Linear classifier

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svm.light.joeltrons.org/  
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[Silvercorp Metals Inc. \(USA\) NYSE SVM quotes & news - Google](#)  
www.google.com/finance?cid=7766473  
Get detailed financial information on Silvercorp Metals Inc. (USA) (NYSE:SVM) including real-time stock quotes, historical charts & financial news, all for free!

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- SVM - Light Support Vector Machine  
- Silvercorp Metals Inc. (USA) NYSE SVM quotes & news - Google  
- Silvercorp Metals Inc - Home  
- Kernel-Machines.Org - Kernel Machines  
- SVM Stock Quote - Silvercorp Metals Inc. Stock Price Today (SVM)  
- Society for Vascular Medicine (SVM) - Deerfield, IL - Doctor | Face...

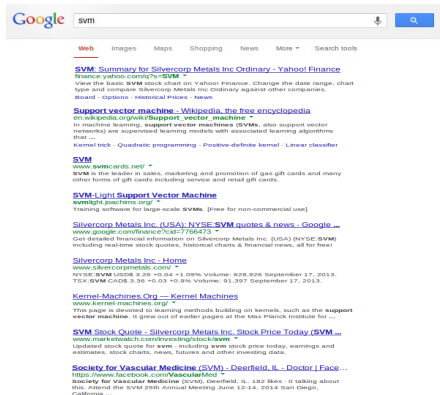
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- SVM

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<i>Social Opt</i>	$a_1, b_1, c_1, \dots$

- Even if social optimal is presented, users may indicate preferences for other rankings.



The screenshot shows a Google search for "svm". The search bar contains "svm" and the search button is visible. Below the search bar, there are tabs for "Web", "Images", "Maps", "Shopping", "News", and "More". The search results are listed below, including:

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- [CG98, ZCL03, CK06]: Address Extrinsic Diversity.
  - Do not use learning.
- [YJ08, SMO10, RJS11]: Use learning for diversity.
  - Require relevance labels for all user-document pairs.
- [RKJ08]: Uses online learning: Array of (decoupled) MA Bandits.
  - Learns very slowly. Does not generalize across queries.
- [SRG13]: Couples the arms together.
  - Does not generalize across queries. Hard-coded notion of diversity.
- [YG12]: Generalizes across queries.
  - Requires cardinal utilities.
- [RSJ12]: Learns from user preferences.
  - Requires all users directly optimize social utility  $U$ .

# Preferential Feedback

- *What feedback do we obtain from users?*

# Preferential Feedback

- *What feedback do we obtain from users?*
  - ▷ Implicit feedback (e.g. clicks) is timely and easily available.

Presented (y)

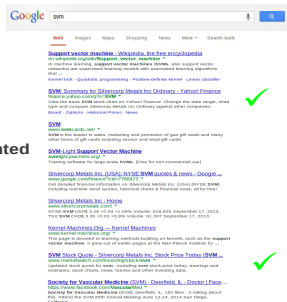
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www.support360.net SVM is the leader in sales, marketing and promotion of gift gift needs and many other lines of gift search including jewelry and retail gift cards.
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www101.pair.com/svm SVM Light is free software for large-scale SVMs. (from www.commercial.net)
- Silvercorp Metals Inc (NYSE:NYSE:SVM) Quotes & News - Google**  
www.google.com/finance?ticker=NYSE:SVM SVM: 2012 Q3 Earnings Report Includes Financial Information on Operating Results for 2012 Q3 (NYSE:SVM) including real-time stock quotes, historical charts & financial news, all for free!
- Silvercorp Metals Inc - F1000**  
www.silvercorpmetals.com F1000 SV100 SVML000 3.20 +0.24 +1.00% Volume: 428 828 September 17, 2013 7:58 PM EST 5.20 +0.20 +10.00% Volume: 31,297 September 17, 2013
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# Preferential Feedback

- *What feedback do we obtain from users?*
  - ▷ Implicit feedback (e.g. clicks) is timely and easily available.
- User feedback does not reflect cardinal utilities.
  - ▷ Shown in user studies [JGP<sup>+</sup>07].

Presented (y)



# Preferential Feedback

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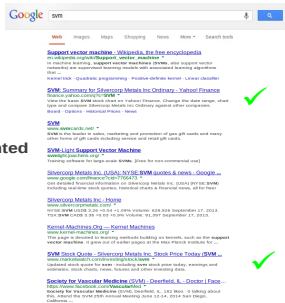
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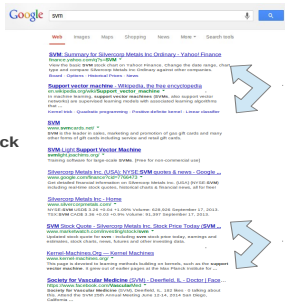
- ▷ Shown in user studies [JGP<sup>+</sup>07].

- **KEY:** Treat user feedback as preferences.

Presented (y)



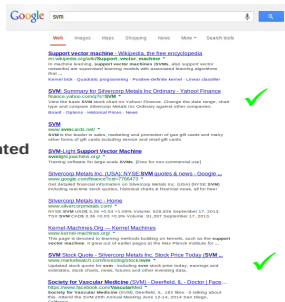
Feedback (y')



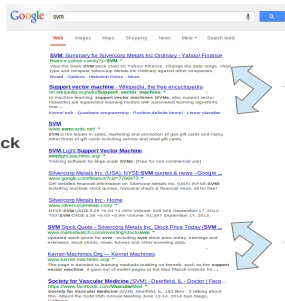
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- *What feedback do we obtain from users?*
  - ▷ Implicit feedback (e.g. clicks) is timely and easily available.
- User feedback does not reflect cardinal utilities.
  - ▷ Shown in user studies [JGP<sup>+</sup>07].
- **KEY:** Treat user feedback as preferences.
- How do we learn from such preferential feedback?

Presented (y)



Feedback (y)



## Learning model

### Repeat forever:

- System receives context  $\mathbf{x}_t$ .
- System makes prediction  $\mathbf{y}_t$ .

# Learning from Preferences: Coactive Learning [SJ12, RJSS13]

## Learning model

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e.g. : Search Engine

User Query

Ranking



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**Feedback received in terms of personal utilities  $U_i$ .  
But regret is in terms of social utility  $U$ .**

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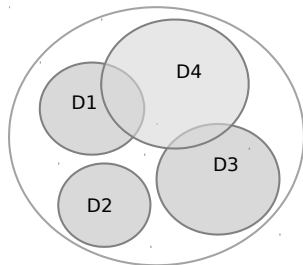
Social utility

**Feedback received in terms of personal utilities  $U_i$ .**  
**But regret is in terms of social utility  $U$ .**

*How does we model utilities?*

# Modeling User Utility: Submodularity

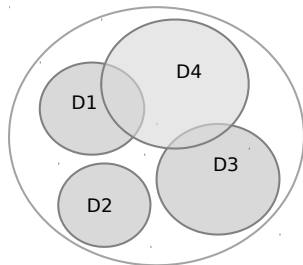
- Assume personal utilities are submodular.
- **Diminishing returns:** Marginal benefit of additional document on ML diminishes if 10 docs already shown vs only 1 previous doc.



- Computing ranking  $\approx$  Submodular maximization
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- *How does this lead to diversity?*

# Diversity via Submodularity: An example

Posn	Doc	machine	learning	metal	silver
1					
2					
3					
4					
MAX of Col					

Doc	Words
$d_1$	ma:3 le:3
$d_2$	ma:5 le:2
$d_3$	ma:2 le:5
$d_4$	ma:2 le:3
$d_5$	me:3 si:5
$d_6$	me:6 si:2
$d_7$	me:4 si:2 ma:1
$d_8$	me:3 si:1 ma:1

Doc	Marginal Benefit	
$d_1$		
$d_2$		
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$d_4$		
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Word	Weight
machine	5
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Posn	Doc	machine	learning	metal	silver
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Doc	Marginal Benefit	
$d_1$	$3*5 + 3*7$	36
$d_2$		
$d_3$		
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$d_5$		
$d_6$		
$d_7$		
$d_8$		

Doc	Words
$d_1$	ma:3 le:3
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Doc	Marginal Benefit	
$d_1$	$3*5 + 3*7$	36
$d_2$	$5*5 + 2*7$	39
$d_3$	$2*5 + 5*7$	<b>45</b>
$d_4$	$2*5 + 3*7$	31
$d_5$	$3*4 + 5*6$	42
$d_6$	$6*4 + 2*6$	36
$d_7$	$1*5 + 4*4 + 2*6$	33
$d_8$	$1*5 + 3*4 + 1*6$	23

Word	Weight
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# Diversity via Submodularity: An example

Posn	Doc	machine	learning	metal	silver
1	$d_3$	2	5	0	0
2					
3					
4					
MAX of Col		2	5	0	0

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Doc	Marginal Benefit	
$d_1$	$(3-2)*5$	5
$d_2$	$(5-2)*5$	15
$d_3$	-	-
$d_4$	0	0
$d_5$	$3*4 + 5*6$	<b>42</b>
$d_6$	$6*4 + 2*6$	36
$d_7$	$4*4 + 2*6$	28
$d_8$	$3*4 + 1*6$	18

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# Diversity via Submodularity: An example

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2	$d_5$	0	0	3	5
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4					
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$d_3$	-	-
$d_4$	0	0
$d_5$	-	-
$d_6$	$(6-3)*4$	12
$d_7$	$(4-3)*4$	4
$d_8$	0	0

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# Diversity via Submodularity: An example

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1	$d_3$	2	5	0	0
2	$d_5$	0	0	3	5
3	$d_2$	5	2	0	0
4	$d_6$	0	0	6	2
MAX of Col		5	5	6	5

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$d_7$	0	0
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silver	6

# More General Submodular Utility

- *Can we use other submodular functions?*

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✓ **Yes.**

- Given ranking/set  $\mathbf{y} = (d_{i_1}, \dots, d_{i_n})$ , aggregate features as:

$$\phi_F^j(\mathbf{x}, \mathbf{y}) = F(\gamma_1 \phi^j(\mathbf{x}, d_{i_1}), \gamma_2 \phi^j(\mathbf{x}, d_{i_2}), \dots, \gamma_n \phi^j(\mathbf{x}, d_{i_n}))$$

- ▷  $\phi^j(\mathbf{x}, d_i)$  is  $j^{\text{th}}$  feature of  $d_i$ .
- ▷  $F$  is a submodular function (modeling decision).
- ▷  $\gamma_1 \geq \gamma_2 \geq \dots \geq \gamma_n \geq 0$  are position-discount factors



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  - ▷  $\gamma_1 \geq \gamma_2 \geq \dots \geq \gamma_n \geq 0$  are position-discount factors
- Utility modeled as linear in aggregate features:  $U(\mathbf{x}, \mathbf{y}) = \mathbf{w}_*^T \phi_F(\mathbf{x}, \mathbf{y})$ 
    - ▷ Submodular aggregation leads to diversity.

# Social Perceptron for Ranking

- 1 Initialize weight vector  $\mathbf{w}_1 \leftarrow \mathbf{0}$ .
- 2 Given context  $\mathbf{x}_t$  compute  $\mathbf{y}_t \leftarrow \operatorname{argmax}_{\mathbf{y}} \mathbf{w}_t^\top \phi(\mathbf{x}_t, \mathbf{y})$ .
- 3 Observe user clicks  $\mathcal{D}$ .
- 4 Construct preference feedback  $\bar{\mathbf{y}}_t \leftarrow \text{PrefFeedback}(\mathbf{y}_t, \mathcal{D})$ .
- 5  $\bar{\mathbf{w}}_{t+1} \leftarrow \mathbf{w}_t + \phi(\mathbf{x}_t, \bar{\mathbf{y}}_t) - \phi(\mathbf{x}_t, \mathbf{y}_t)$
- 6 Clip:  $\mathbf{w}_{t+1}^j \leftarrow \max(\bar{\mathbf{w}}_{t+1}^j, 0)$
- 7 Repeat from step 2.

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  - ▷ Perceptron update.
- 6 Clip:  $\mathbf{w}_{t+1}^j \leftarrow \max(\bar{\mathbf{w}}_{t+1}^j, 0)$ 
  - ▷ To ensure submodularity.
- 7 Repeat from step 2.

## Definition

User feedback is **expected  $\alpha_i, \delta_i$ -informative** if  $\bar{\xi}_t \in \mathfrak{R}$  is chosen s.t. :

$$\mathbf{E}_{\bar{\mathbf{y}}_t}[U_i(\mathbf{x}_t, \bar{\mathbf{y}}_t)] \geq (1 + \delta_i)U_i(\mathbf{x}_t, \mathbf{y}_t) + \alpha_i \left( U_i(\mathbf{x}_t, \mathbf{y}_t^{*,i}) - U_i(\mathbf{x}_t, \mathbf{y}_t) \right) - \bar{\xi}_t.$$

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## Theorem

For any  $\mathbf{w}_* \in \mathbf{R}^m$  and  $\|\phi(\mathbf{x}, \mathbf{y})\|_{\ell_2} \leq R$  the average regret of the SoPer-R algorithm can be upper bounded as:

$$REG_T \leq \frac{1}{\eta T} \sum_{t=0}^{T-1} \mathbf{E}_i[p_i \bar{\xi}_t] + \frac{R\|\mathbf{w}_*\|}{2\eta} + \frac{\sqrt{15}R\|\mathbf{w}_*\|}{\eta\sqrt{2T}}.$$

with:  $\delta_i \geq \left( \Gamma_F \cdot \frac{1 - p_i}{p_i} \right)$ ,  $\eta = \min_i p_i \alpha_i$ .

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- Does not depend on number of dimensions.
  - ▷ Only on feature ball radius  $R$ .
- Decays gracefully with noisy feedback (the  $\alpha_i$ s and  $\eta$ ).
- **Need not converge to optimal.**
  - ▷ Partly due to NP-hardness of submodular maximization.

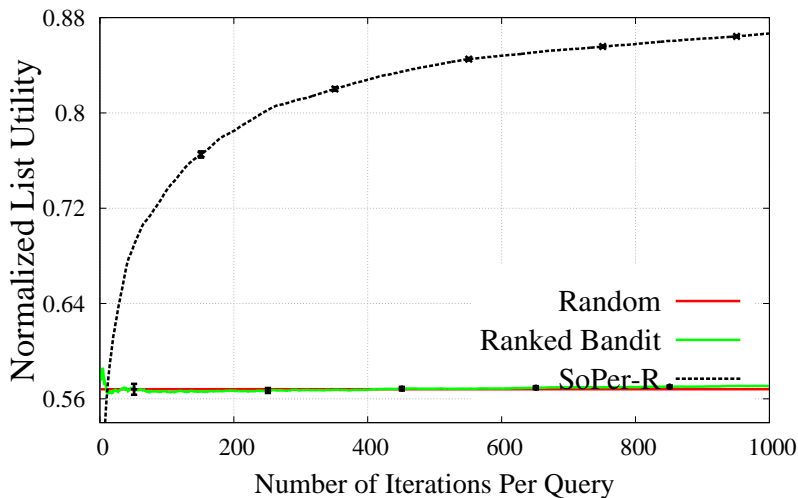


- **SoPer-S** Algorithm for predicting diverse sets.
- See paper for more details.

# Experimental Setup

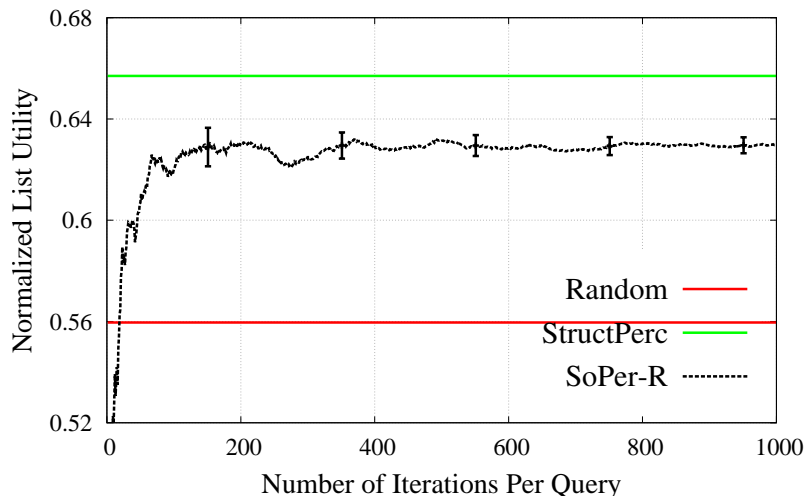
- Used standard **TREC 6-8 Interactive** search-diversification dataset:
  - ▷ Each query has 7-56 user types.
- Setup as in previous work [BJYB11, RJS11].
- Simulated user behavior:
  - ▷ Users scan rankings top to bottom.
  - ▷ Click on first document relevant to them (with small error chance).
- Utility function: Normalized DCG-coverage function (*i.e.*  
$$F(x_1, \dots, x_n) = \max_i \gamma_i x_i$$
) upto rank 5.

# Learning to Diversify: Single Query



- Improved learning for single-query diversification.

# Learning to Diversify: Cross-Query



- *StructPerc* is (rough) skyline: Uses optimal for training.
- **First method** to learn cross-query diversity from implicit feedback.

User Fncn	SoPer-R Function		Rand
	MAX	SQRT	
MAX	.630 $\pm$ .007	.620 $\pm$ .006	.557 $\pm$ .006
SQRT	.656 $\pm$ .007	.654 $\pm$ .007	.610 $\pm$ .007

- Robust to difference between submodular functions used in *User's* utility and *Algorithm's* utility.

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- Robust to difference between submodular functions used in *User's* utility and *Algorithm's* utility.

Random	No Noise	Noise
.557 $\pm$ .006	.630 $\pm$ .007	.631 $\pm$ .007

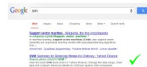
- Works even if user feedback is noisy

- Proposed online-learning algorithms for aggregating conflicting user preferences of a diverse population.
  - ▷ Utilizes the coactive learning model.
- Modeled user utilities as submodular.
- Provided regret bounds for algorithms.
- Works well empirically and is robust.

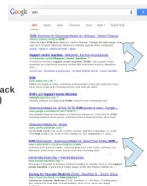
# THANKS



What did the user mean?

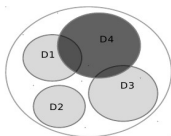


Presented ( $y$ )



Feedback ( $y'$ )

## QUESTIONS?



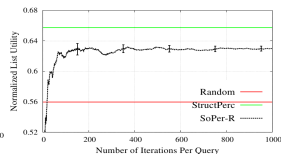
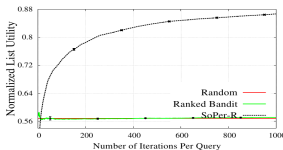
### Poster #15

#### Theorem

Average regret of the SoPer-R algorithm can be upper bounded as:

$$REG_T \leq \frac{1}{\eta T} \sum_{t=0}^{T-1} \mathbf{E}[\rho_t \tilde{L}_t] + \frac{R \|\mathbf{w}_*\|}{2\eta} + \frac{\sqrt{15R} \|\mathbf{w}_*\|}{\eta \sqrt{2T}}$$

with:  $\delta_t \geq \left( \Gamma_F \cdot \frac{1 - \beta_t}{\beta_t} \right)$ ,  $\eta = \min \beta_t \alpha_t$ .





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In *NIPS*, pages 2483–2491, 2012.



Yisong Yue and Thorsten Joachims.

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Cheng Xiang Zhai, William W. Cohen, and John Lafferty.

Beyond independent relevance: methods and evaluation metrics for subtopic retrieval.

In *SIGIR*, pages 10–17, 2003.

- **TREC 6-8 Interactive** diversification dataset:
  - ▷ Contains 17 queries. Each has 7-56 user types. Binary relevance labels.
  - ▷ Similar results observed for WEB diversification dataset.
- Setup details:
  - ▷ Re-ranking documents relevant to  $\geq 1$  user.
  - ▷ Probability of user type  $\propto$  # of documents relevant to user.
- DCG-position discounting:  $\gamma_i = \frac{1}{\log_2(1+i)}$ .

# Regret Bound

## Definition

User feedback is **expected**  $\alpha_i, \delta_i$ -**informative** for user with personal utility function  $U_i$ , if  $\bar{\xi}_t \in \mathfrak{R}$  is chosen s.t. for some given  $\alpha_i \in [0, 1]$  and  $\delta_i > 0$ :

$$\mathbf{E}_{\bar{\mathbf{y}}_t}[U_i(\mathbf{x}_t, \bar{\mathbf{y}}_t)] \geq (1 + \delta_i)U_i(\mathbf{x}_t, \mathbf{y}_t) + \alpha_i \left( U_i(\mathbf{x}_t, \mathbf{y}_t^{*,i}) - U_i(\mathbf{x}_t, \mathbf{y}_t) \right) - \bar{\xi}_t.$$

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with:  $\delta_i \geq \left( \Gamma_F \cdot \frac{1 - p_i}{p_i} \right)$ ,  $\eta = \min_i p_i \alpha_i$  and  $\beta = (1 - \beta_{gr}) = \frac{1}{2}$ .