

# Learning from User Interactions through Interventions

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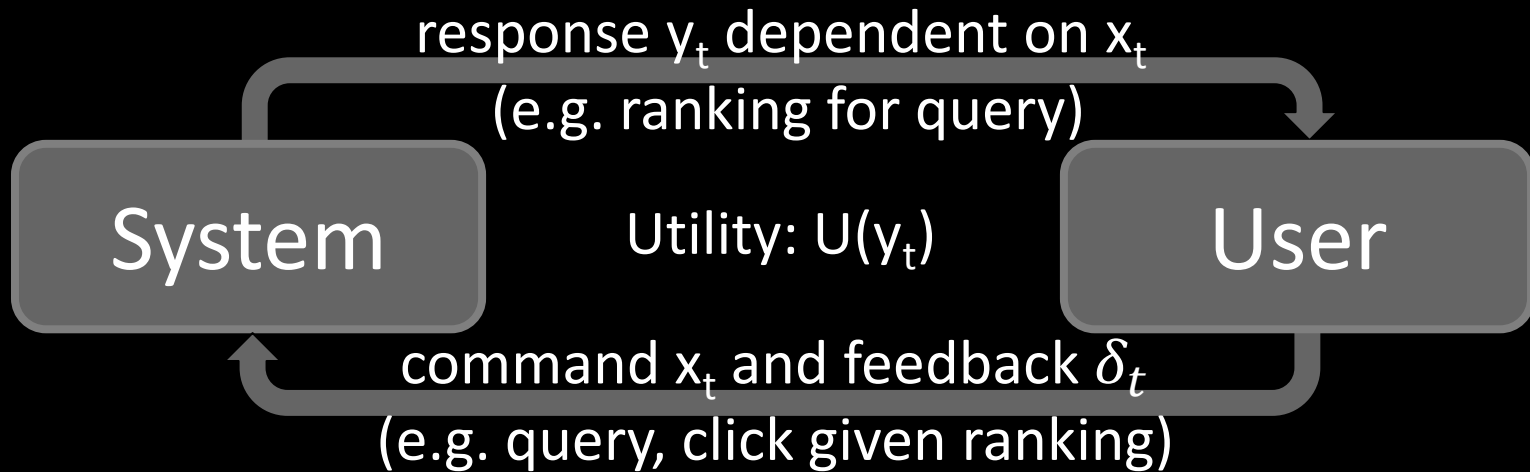
# Interactive Learning Systems

- Examples
  - Search engines
  - Entertainment media
  - E-commerce
  - Smart devices
- Learning
  - Gathering and maintenance of knowledge
  - Measure and optimize performance
  - Personalization

## Interventions



# Interactive Learning System



- • Designing Information Elicitation Interventions
- Online Learning with Interventions
- Offline Learning with Logged Intervention Data

# Decide between two Ranking Functions

Distribution  $P(x)$   
of  $x=(\text{user, query})$

$\vdots$   
 $(t_j, \text{"SVM"})$   
 $\vdots$

Retrieval Function 1

$$f_1(x) \rightarrow y_1$$

Which one  
is better?

Retrieval Function 2

$$f_2(x) \rightarrow y_2$$

1. Kernel Machines  
<http://svm.first.gmd.de/>
2. SVM-Light Support Vector Machine  
<http://svmlight.joachims.org/>
3. School of Veterinary Medicine at UPenn  
<http://www.vet.upenn.edu/>
4. An Introduction to Support Vector Machines  
<http://www.support-vector.net/>
5. Service Master Company  
<http://www.servicemaster.com/>

$\vdots$

$U(t_j, \text{"SVM"}, y_1)$

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<http://www.vet.upenn.edu/>
2. Service Master Company  
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<http://jbolivar.freesevers.com/>
4. Archives of SUPPORT-VECTOR-MACHINES  
<http://www.jiscmail.ac.uk/lists/SUPPORT...>
5. SVM-Light Support Vector Machine  
[http://ais.gmd.de/~thorsten/svm light/](http://ais.gmd.de/~thorsten/svm%20light/)

$\vdots$

$U(t_j, \text{"SVM"}, y_2)$

# Measuring Utility

| Name                  | Description                                       | Aggregation | Hypothesized Change with Decreased Quality |
|-----------------------|---|-------------|--|
| Abandonment Rate      | % of queries with no click                        | N/A         | Increase                                   |
| Reformulation Rate    | % of queries that are followed by reformulation   | N/A         | Increase                                   |
| Queries per Session   | Session = no interruption of more than 30 minutes | Mean        | Increase                                   |
| Clicks per Query      | Number of clicks                                  | Mean        | Decrease                                   |
| Click@1               | % of queries with clicks at position 1            | N/A         | Decrease                                   |
| Max Reciprocal Rank*  | 1/rank for highest click                          | Mean        | Decrease                                   |
| Mean Reciprocal Rank* | Mean of 1/rank for all clicks                     | Mean        | Decrease                                   |
| Time to First Click*  | Seconds before first click                        | Median      | Increase                                   |
| Time to Last Click*   | Seconds before final click                        | Median      | Decrease                                   |

(\*) only queries with at least one click count

# ArXiv.org: User Study

## User Study in ArXiv.org

- Natural user and query population
- User in natural context, not lab
- Live and operational search engine
- Ground truth by construction

ORIG  $\succ$  SWAP2  $\succ$  SWAP4

- ORIG: Hand-tuned fielded
- SWAP2: ORIG with 2 pairs swapped
- SWAP4: ORIG with 4 pairs swapped

ORIG  $\succ$  FLAT  $\succ$  RAND

- ORIG: Hand-tuned fielded
- FLAT: No field weights
- RAND : Top 10 of FLAT shuffled

arXiv.org Full Text Search Results

Displaying hits 1 to 10 of 622. [Reorder by date.](#)

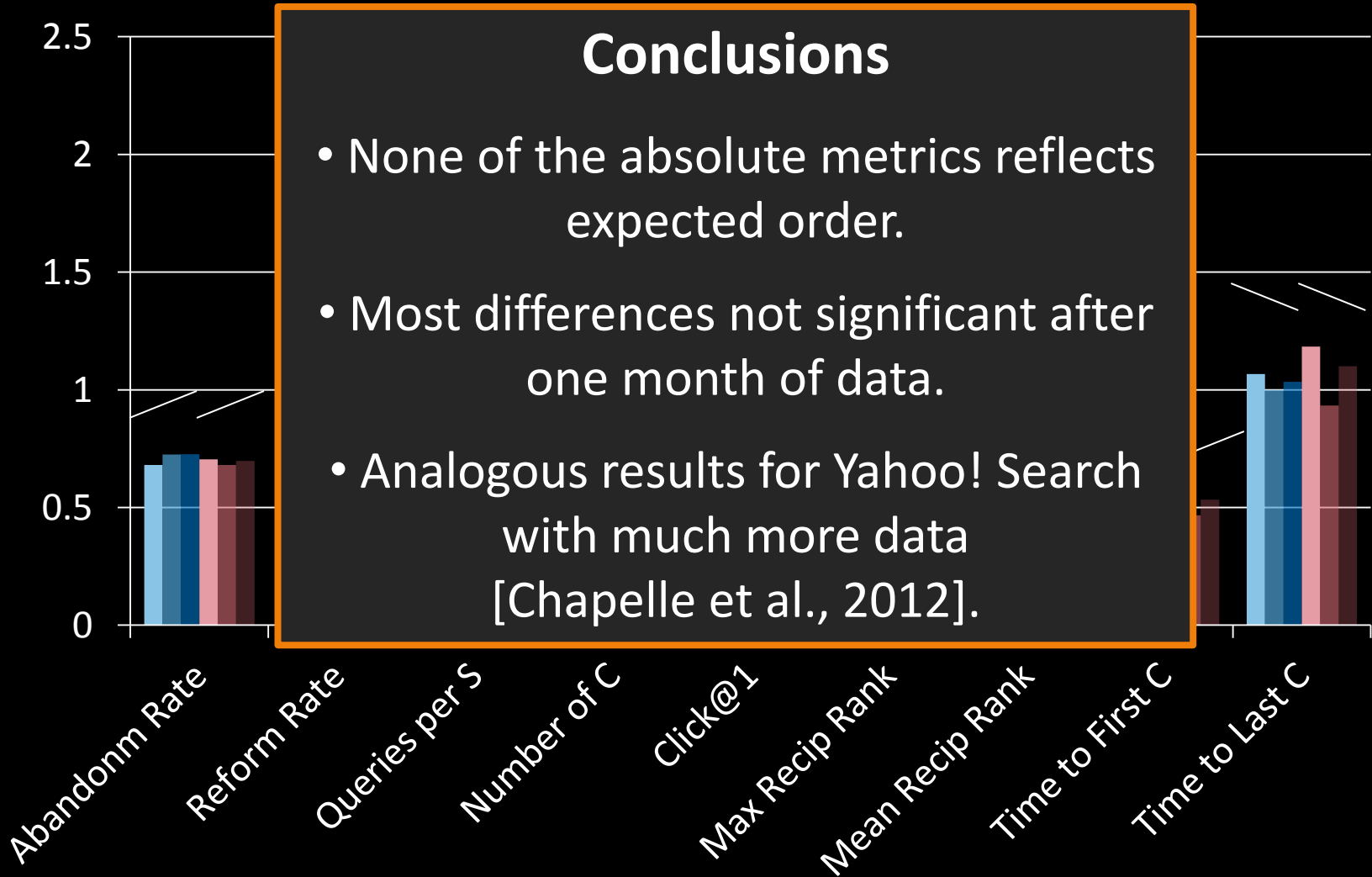
- [Emmanuel Monfni, Yann Guemeur, A Quadratic Loss Multi-Class SVM \(2008\)](#)  
abstract: ... on the leave-one-out error of the pattern recognition SVM have been derived. Among these bounds, the most popular one ... bound. It applies to the hard margin pattern recognition SVM, and by extension to the 2-norm SVM. In this report, we introduce a quadratic loss M-SVM, the M-SVM<sup>2</sup>, as a di ...  
<http://arxiv.org/abs/0804.4898>
- [Nathalie Villa, Fabrice Rossi, Un résultat de consistance pour des SVM fonctionnels par interpolation spline \(2007\)](#)  
abstract: ... for function classification with Support Vector Machine (SVM). Rather than relying on projection on a truncated ... an implicit spline interpolation that allows us to compute SVM on the derivatives of the studied functions. To that end, w ...  
<http://arxiv.org/abs/0705.0210>
- [François Rapoport, Emmanuel Berthet and Jean-Philippe Vert, Classification of arrayCGH data using a fused SVM \(2008\)](#)  
abstract: ... a new method for supervised classification of arrayCGH data. The method is a variant of support vector machine (SVM) that incorporates the biological specificities of DNA copy number variations along the genome as prior knowledge. The ...  
<http://arxiv.org/abs/0801.3007>
- [Seung-ho Wu, Hui Zou, Ming Yuan, Structure variable selection in support vector machines \(2007\)](#)  
abstract: When applying the support vector machine (SVM) to high-dimensional classification problems, we often impose a sparse structure in the SVM to eliminate the influences of the irrelevant predictors. ... selection techniques have been successfully used in the SVM to perform automatic variable selection ...  
<http://arxiv.org/abs/0710.0508>
- [Marco Frullis, Oriana Mansutti, Praveen Boine et al., A third level trigger programmable on FPGA for the gamma/hadron separation in a Cherenkov telescope using pseudo-Zernike moments and the SVM classifier \(2005\)](#)  
abstract: ... computed Pseudo-Zernike features as classification parameters. We implemented on a FPGA board a kernel function of the SVM and the Pseudo-Zernike features to build a third level trigger for the gamma-hadron separation task of the MAGIC Expen ...  
<http://arxiv.org/abs/cs/0602083>
- [Hao Helen Zhang, Yufeng Liu, Yichao Wu et al., Variable selection for the multiclass SVM via adaptive sup-norm regularization \(2008\)](#)  
abstract: The Support Vector Machine (SVM) is a popular classification paradigm in machine learning ... great success in real applications. However, the standard SVM can not select variables ... of regularization in the context of the multiclass SVM (MSVM) for simultaneous classification and variable sel ...  
<http://arxiv.org/abs/0803.3676>
- [Seung-chan Ahn, Gene Kim and MyungHo Kim, A Note on Applications of Support Vector Machine \(2001\)](#)  
abstract: We describe in a rudimentary fashion how SVM (support vector machine) plays the role of classifier in a mathematical setting. We then discuss its application in the ...  
<http://arxiv.org/abs/math/0105169>
- [Haoshen Li, J. W. Clark, E. Mavrommatis et al., Modeling Nuclear Properties with Support Vector Machines \(2005\)](#)  
abstract: ... studies of the potential of support vector machines (SVM) for providing statistical models of nuclear systematics with demonstrable predictive power. Using SVM regression and classification procedures, we have created ...  
<http://arxiv.org/abs/nuc-th/0506080>
- [Gilles Blanchard, Olivier Bousquet, Pascal Massart, Statistical performance of support vector machines \(2008\)](#)  
abstract: ... studies of the potential of support vector machines (SVM) for providing statistical models of nuclear systematics with demonstrable predictive power. Using SVM regression and classification procedures, we have created ... compare to the penalty actually used in the SVM algorithm; (2) is ...  
<http://arxiv.org/abs/0804.0931>
- [Emidio Capriotti and Rita Casadio, The evaluation of protein folding rate constant is improved by predicting the folding kinetic order with a SVM-based method \(2006\)](#)  
abstract: ... first we describe a support vector machine-based method (SVM-KO) to predict for a given protein the kinetic order of the ... value can be obtained as a linear regression task with a SVM-based method. In this paper we show that linear correlation ...  
<http://arxiv.org/abs/q-bio.BM/0602013>

[Next >>](#)

# ArXiv.org: Experiment Setup

- Experiment Setup
  - Phase I: 36 days
    - Users randomly receive ranking from Orig, Flat, Rand
  - Phase II: 30 days
    - Users randomly receive ranking from Orig, Swap2, Swap4
  - User are permanently assigned to one experimental condition based on IP address and browser.
- Basic Statistics
  - ~700 queries per day / ~300 distinct users per day
- Quality Control and Data Cleaning
  - Test run for 32 days
  - Heuristics to identify bots and spammers
  - All evaluation code was written twice and cross-validated

# Arxiv.org: Results





# Economic Models of Decision Making

- Rational Choice
  - Alternatives  $\mathcal{Y}$
  - Utility function  $U(y)$
  - Decision  $y^* = \operatorname{argmax}_{y \in \mathcal{Y}} \{U(y)\}$
- Bounded Rationality
  - Time constraints
  - Computation constraints
  - Approximate  $U(y)$
- Behavioral Economics
  - Framing
  - Fairness
  - Loss aversion
  - Handling uncertainty



# A Model of how Users Click in Search

- Model of clicking:
  - Users explore ranking to position  $k$
  - Users click on most relevant (looking) links in top  $k$
  - Users stop clicking when time budget up or other action more promising (e.g. reformulation)
  - Empirically supported by [Granka et al., 2004]

The screenshot shows a Google search for 'svm' in Microsoft Internet Explorer. The search results are displayed in a list format. A red arrow labeled 'Click' points to the 'SVM-Light Support Vector Machine' result. An orange bracket highlights the top results, and a grey box contains the formula  $\operatorname{argmax}_{y \in \text{Top } k} U(y)$ .

Google Search: svm - Microsoft Internet Explorer

Address: <http://www.google.com/search?sourceid=navclient&ie=UTF-8&oe=UTF-8&q=svm>

Google Search

Searched the web for **svm**. Results 1 - 10 of about 329,000. Search took 0.29 seconds.

Categories: [Computers > Artificial Intelligence > Machine Learning](#)  
[Computers > Artificial Intelligence > Neural Networks > Software](#)

[Show stock quotes for SVM \(ServiceMaster Company The\)](#)

[Bienvenue sur svm.vnunet.fr !](#) - [ Translate this page ]  
... Les forums de SVM. Participez aux grands débats de la rédaction. De vous à vous. Les meilleures réponses sélectionnées sur le forum de SVM. ...  
svm.vnunet.fr/ - 39k - Mar 1, 2004 - Cached - Similar pages

[SVM-Light Support Vector Machine](#)  
SVM-Light Support Vector Machine. Hier finden Sie Informationen zu den folgenden Themen: Thorsten Joachims, SVMlight, Support Vector ...  
Description: Training software for SVMs. [Free for non-commercial use]  
Category: [Computers > Artificial Intelligence > Software](#)  
svm.light.joachims.org/ - 3k - Mar 1, 2004 - Cached - Similar pages

[Support Vector Machine](#)  
... Support Vector Machine. The most recent SVM light page can now be found at <http://svmlight.joachims.org/>. Older versions are still available from here. ...  
[www.ai.cs.uni-dortmund.de/SOFTWARE/SVM\\_LIGHT/svm\\_light.html](http://www.ai.cs.uni-dortmund.de/SOFTWARE/SVM_LIGHT/svm_light.html) - 6k - Cached - Similar pages

[ServiceMaster -- We Are Home](#)  
ServiceMaster Issues Information on Tax Treatment of Dividends. ServiceMaster Reports 2003 Fourth Quarter Revenues and Profits. ServiceMaster ...  
[www.svm.com/](http://www.svm.com/) - 13k - Mar 1, 2004 - Cached - Similar pages

[Kernel Machines](#)  
Description: A central source of information on kernel based methods, including support vector machines, Gaussian ...  
Category: [Computers > Artificial Intelligence > Support Vector Machines](#)  
[www.kernel-machines.org/](http://www.kernel-machines.org/) - 1k - Cached - Similar pages

[SVM Application List](#)  
SVM Application List. This list of Support Vector Machine applications grows thanks to visitors like you who ADD new entries. ... svm learning. ...

$\operatorname{argmax}_{y \in \text{Top } k} U(y)$

# Decide between two Ranking Functions

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of  $x=(\text{user, query})$

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$\vdots$

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<http://www.jiscmail.ac.uk/lists/SUPPORT...>
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[http://ais.gmd.de/~thorsten/svm light/](http://ais.gmd.de/~thorsten/svm%20light/)

$\vdots$

$U(t_j, \text{"SVM"}, y_2)$

# Balanced Interleaving

$$x=(u=tj, q="svm")$$

$$f_1(x) \rightarrow y_1$$

$$f_2(x) \rightarrow y_2$$

1. Kernel Machines  
<http://svm.first.gmd.de/>
2. Support Vector Machine  
<http://jbolivar.freesevers.com/>
3. An Introduction to Support Vector Machines  
<http://www.support-vector.net/>
4. Archives of SUPPORT-VECTOR-MACHINES ...  
<http://www.jiscmail.ac.uk/lists/SUPPORT...>
5. SVM-Light Support Vector Machine  
[http://ais.gmd.de/~thorsten/svm\\_light/](http://ais.gmd.de/~thorsten/svm_light/)

1. Kernel Machines  
<http://svm.first.gmd.de/>
2. SVM-Light Support Vector Machine  
[http://ais.gmd.de/~thorsten/svm\\_light/](http://ais.gmd.de/~thorsten/svm_light/)
3. Support Vector Machine and Kernel ... References  
<http://svm.research.bell-labs.com/SVMrefs.html>
4. Lucent Technologies: SVM demo applet  
<http://svm.research.bell-labs.com/SVT/SVMsvt.html>
5. Royal Holloway Support Vector Machine  
<http://svm.dcs.rhnc.ac.uk>

## Interleaving( $y_1, y_2$ )

- |    |   |   |
|----|---|---|
| 1. | Kernel Machines   | 1 |
|    | <a href="http://svm.first.gmd.de/">http://svm.first.gmd.de/</a>   |   |
| 2. | Support Vector Machine  | 2 |
|    | <a href="http://jbolivar.freesevers.com/">http://jbolivar.freesevers.com/</a>                                     |   |
| 3. | SVM-Light Support Vector Machine  | 2 |
|    | <a href="http://ais.gmd.de/~thorsten/svm_light/">http://ais.gmd.de/~thorsten/svm_light/</a>                       |   |
| 4. | An Introduction to Support Vector Machines  | 3 |
|    | <a href="http://www.support-vector.net/">http://www.support-vector.net/</a>                                       |   |
| 5. | Support Vector Machine and Kernel ... References  | 3 |
|    | <a href="http://svm.research.bell-labs.com/SVMrefs.html">http://svm.research.bell-labs.com/SVMrefs.html</a>       |   |
| 6. | Archives of SUPPORT-VECTOR-MACHINES ...   | 4 |
|    | <a href="http://www.jiscmail.ac.uk/lists/SUPPORT...">http://www.jiscmail.ac.uk/lists/SUPPORT...</a>               |   |
| 7. | Lucent Technologies: SVM demo applet  | 4 |
|    | <a href="http://svm.research.bell-labs.com/SVT/SVMsvt.html">http://svm.research.bell-labs.com/SVT/SVMsvt.html</a> |   |

### Model of User:

Better retrieval functions  
is more likely to get more  
clicks.

### Invariant:

For all  $k$ , top  $k$  of  
balanced interleaving is  
union of top  $k_1$  of  $r_1$  and  
top  $k_2$  of  $r_2$  with  $k_1=k_2 \pm 1$ .

**Interpretation:**  $(y_1 \succ y_2) \Leftrightarrow \text{clicks}(\text{topk}(y_1)) > \text{clicks}(\text{topk}(y_2))$

$\rightarrow$  see also [Radlinski, Craswell, 2012] [Hofmann, 2012]

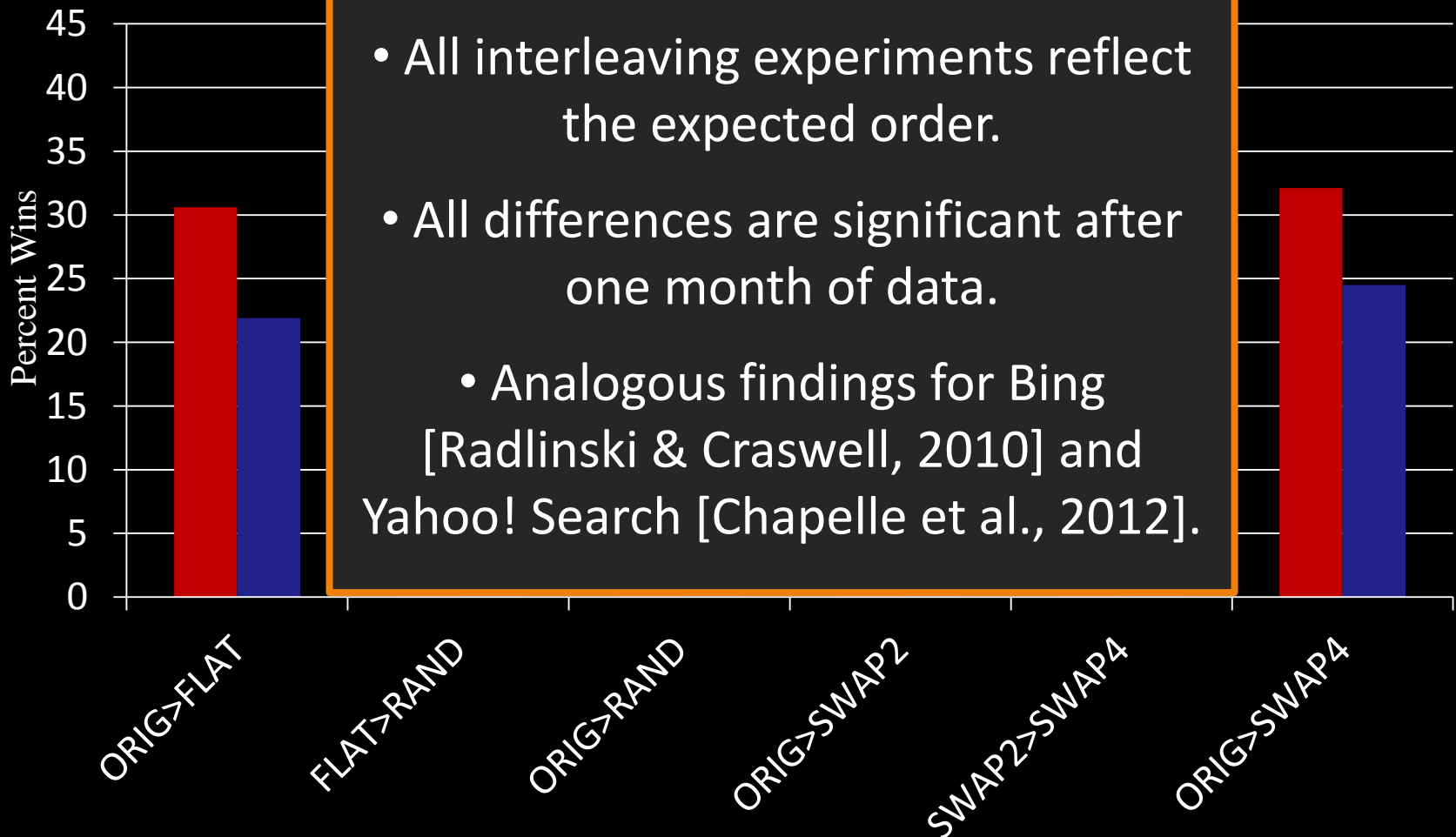
# Arxiv.org: Interleaving Experiment

- Experiment Setup
  - Phase I: 36 days
    - Balanced Interleaving of (Orig,Flat) (Flat,Rand) (Orig,Rand)
  - Phase II: 30 days
    - Balanced Interleaving of (Orig,Swap2) (Swap2,Swap4) (Orig,Swap4)
- Quality Control and Data Cleaning
  - Same as for absolute metrics

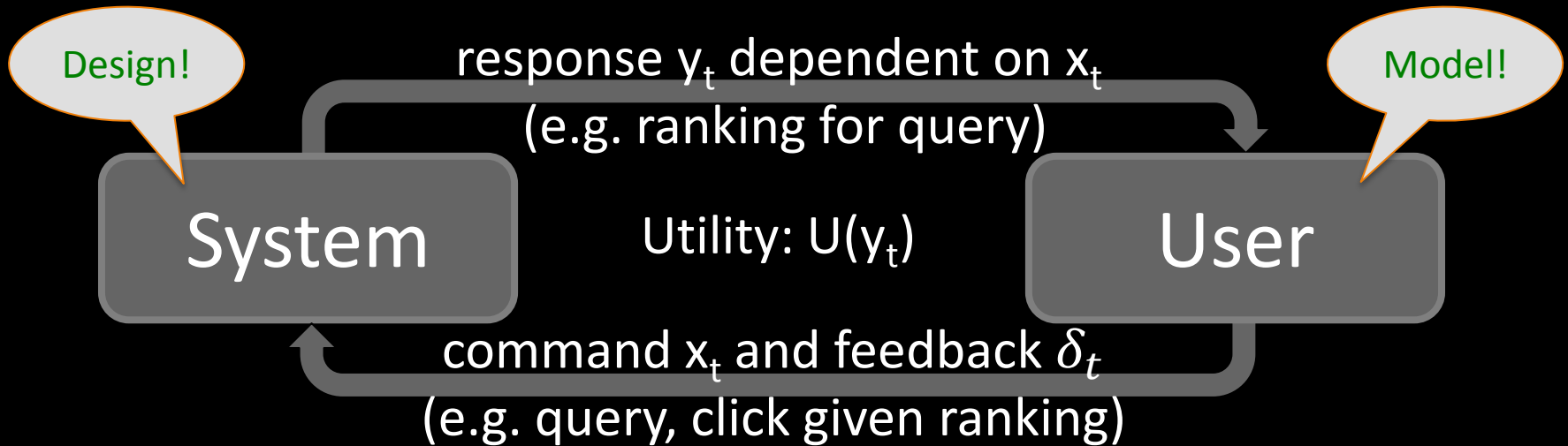
# Arxiv.org: Interleaving Results

## Conclusions

- All interleaving experiments reflect the expected order.
- All differences are significant after one month of data.
  - Analogous findings for Bing [Radlinski & Craswell, 2010] and Yahoo! Search [Chapelle et al., 2012].



# Interactive Learning System



- Designing Information Elicitation Interventions
  - Model user's decision process  $\rightarrow$  derive intervention design
- $\rightarrow$  • Online Learning with Interventions
- Offline Learning with Logged Intervention Data

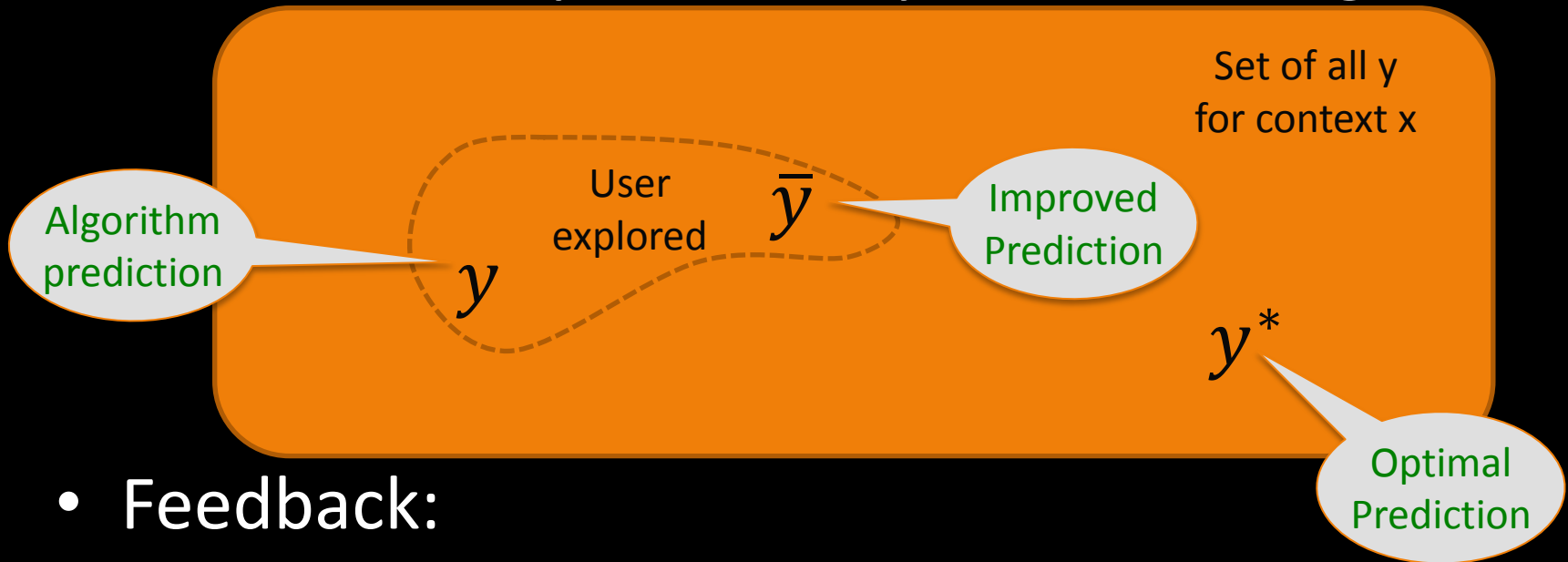
# Coactive Exploration Example 1

The image shows a screenshot of the Netflix website interface. The browser address bar indicates the URL `movies.netflix.com/WiMovie/Lie_to_Me/70140406?trkid=13462049`. The page features a red navigation bar with the Netflix logo, 'Watch Instantly', 'Just for Kids', 'Taste Profile', 'DVDs', and 'DVD Queue'. A search bar contains the text 'Movies, TV shows, actors, directors, genres' and a user profile icon for 'Thorsten'. Below the navigation bar, a pagination control shows '1' selected out of a total of 75 items. The main content area is titled 'More Like Lie to Me' and displays a row of movie posters: NUMB3RS, BONES, FLASHPOINT, AWAKE, CSI: NY, and KEEPER. The footer contains copyright information for 2013 Netflix, Inc., and a list of links including Membership, Subtitles & Captions, Test Participation, Gifts, Buy / Redeem, Support, Company, About Us, Affiliates, Investor Relations, Media Center, Jobs, Contact Us, and Blog. A 'Service Code' section at the bottom states: 'Use of the Netflix service and this Web site constitutes acceptance of our Terms of Use and Privacy Policy. All rights reserved. About Cookies and Internet Advertising (1-ef8b98a)'.



# Coactive Feedback Model

- Intervention: prediction  $y$  and browsing network



- Feedback:

– Improved prediction  $\bar{y}_t$

$$U(\bar{y}_t | x_t) > U(y_t | x_t)$$

– Supervised learning: optimal prediction  $y_t^*$

$$y_t^* = \operatorname{argmax}_y U(y | x_t)$$

# Coactive Exploration

## Example 2

The image shows a screenshot of a Google search for "svm". The search results are displayed in a browser window. The search bar contains "svm" and the results show "About 16,600,000 results (0.11 seconds)".

The search results are categorized by type:

- Everything**: [Support vector machine - Wikipedia, the free encyclopedia](#) (en.wikipedia.org/wiki/Support\_vector\_machine). A support vector machine (SVM) is a concept in statistics and computer science for a set of related supervised learning methods that analyze data and recognize ...  
[Formal definition - History - Motivation - Linear SVM](#)
- News**: [SVM: Summary for Silvercorp Metals Inc Ordinary - Yahoo! Finance](#) (finance.yahoo.com/q?s=SVM). View the basic SVM stock chart on Yahoo! Finance. Change the date range, chart type and compare Silvercorp Metals Inc Ordinary against other companies.
- Any time**: [SVM, LP](#) (www.svmcards.net/). SVM. A leader in the gift card industry and devoted to helping your business reward, promote, entice and grow. Established in 1997, we handle the sales, ...
- Any time**: [SVM Asset Management - Home](#) (www.svmonline.co.uk/). Founded in 1990, SVM Asset Management is a privately-owned firm based in Edinburgh. The three founding directors continue to own 100% of the equity, with ...
- LIBSVM -- A Library for Support Vector Machines** (www.csie.ntu.edu.tw/~cjlin/libsvm/). 5 Nov 2011 - An integrated software tool for support vector classification and regression.

Annotations on the screenshot include:

- A red starburst with the word "Click" pointing to the LIBSVM link.
- A blue arrow pointing from the "Past 24 hours" filter to the LIBSVM link.
- A blue arrow pointing from the "Past 24 hours" filter to the SVM Asset Management link.
- A blue arrow pointing from the "Past 24 hours" filter to the SVM, LP link.
- A blue arrow pointing from the "Past 24 hours" filter to the SVM: Summary for Silvercorp Metals Inc Ordinary link.

# Coactive Exploration Example 3

The image shows two browser windows illustrating a coactive exploration process. The left window displays search results for 'svm', and the right window displays search results for 'sv meppen'. An orange arrow points from the 'svm' results to the 'sv meppen' results, indicating a transition in the search process. A red starburst with the word 'Click' points to a specific result in the 'sv meppen' window, highlighting the user's interaction with the search results.

**Left Window: svm - Google Search**

Search: About 16,600,000 results (0.11 seconds)

Everything: [Support vector machine - Wikipedia, the free encyclopedia](#)  
en.wikipedia.org/wiki/Support\_vector\_machine  
A support vector machine (SVM) is a concept in statistics and computer science and machine learning that analyzes data and recognizes patterns. Formal definition - History - Motivation - Linear SVM

Images: [SVM: Summary for Silvercorp Metals Inc Ordinary - Yahoo! Finance](#)  
finance.yahoo.com/q?s=SVM  
View the basic SVM stock chart on Yahoo! Finance. Change the data and compare Silvercorp Metals Inc Ordinary against other companies

Maps: [SVM LP](#)  
www.svmcards.net/  
SVM. A leader in the gift card industry and devoted to helping your business promote, entice and grow. Established in 1997, we handle the sales, distribution and marketing of gift cards.

Videos: [SVM Asset Management - Home](#)  
www.svmonline.co.uk/  
Founded in 1990, SVM Asset Management is a privately-owned firm. The three founding directors continue to own 100% of the equity, with a focus on providing high-quality investment management services.

News: [LIBSVM -- A Library for Support Vector Machines](#)  
www.csie.ntu.edu.tw/~cjlin/libsvm/  
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Shopping: [SVM Asset Management - Home](#)  
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More: [SVM Asset Management - Home](#)  
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Founded in 1990, SVM Asset Management is a privately-owned firm. The three founding directors continue to own 100% of the equity, with a focus on providing high-quality investment management services.

Any time: Past hour, Past 24 hours, Past 2 days, Past week, Past month, Past year, Custom range...

All results: Related searches, More search tools

**Right Window: sv meppen - Google Search**

Search: About 939,000 results (0.09 seconds)

Everything: [SV Meppen 1912 e.V. - Offizielle Webseite](#)  
www.svmeppen.de/  
Die offizielle Homepage des am 29. November 1912 gegründeten Fußballvereins präsentiert einen Live-Ticketverkauf und informiert über die Mannschaft.

Images: [Willkommen auf www.svmeppen.de - SV Meppen 1912 e.V. ...](#)  
1912.svmeppen.de/ - Translate this page  
SV Meppen e.V. 1912 - Offizielle Website- ... SV Meppen, meppen, emsland, oberliga, oberliga nord, fussball, fußball, lingen, steve haensel, webcomtech.net, ...

Maps: [SV Meppen - Wikipedia, the free encyclopedia](#)  
en.wikipedia.org/wiki/SV\_Meppen  
SV Meppen is a German association football club playing in Meppen, Lower Saxony. The club was founded on 29 November 1912 as Amisia Meppen and ...  
History - Stadium - Records - Literature

Videos: [SV Meppen - Nachrichten, Liveticker, Bilder vom SV Meppen in der ...](#)  
www.noz.de/sport/sv-meppen - Translate this page  
Berichte, Liveticker, Bilder und Audios vom SV Meppen, mehr zur Mannschaft sowie Analysen der Gegner in der Fußball-Regionalliga.

News: [SV Meppen - Fußballverein - transfermarkt.de](#)  
www.transfermarkt.de/.../sv-meppen/.../verein\_24... - Translate this page  
Mit dieser Nachricht hatte Stephen Famewo (Foto) nicht gerechnet. Als unumstrittener Stammspieler trug er dazu bei, dass der SV Meppen in die Regionalliga ...

Shopping: [SV Meppen - Fußballverein - transfermarkt.de](#)  
www.transfermarkt.de/.../sv-meppen/.../verein\_24... - Translate this page  
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Show search tools

# Coactive Exploration Machine Translation

$x_t$

We propose Coactive Learning as a model of interaction between a learning system and a human user, where both have the common goal of providing results of maximum utility to the user.

$y_t$

Wir schlagen vor, koaktive Learning als ein Modell der Wechselwirkung zwischen einem Lernsystem und menschlichen Benutzer, wobei sowohl die gemeinsame Ziel, die Ergebnisse der maximalen Nutzen für den Benutzer.



Wir schlagen ~~vor~~, koaktive Learning als ein Modell ~~der Wechselwirkung des Dialogs~~ zwischen einem Lernsystem und menschlichen Benutzer, wobei ~~sowohl die beide das~~ gemeinsame Ziel ~~haben~~, die Ergebnisse der maximalen Nutzen für den Benutzer ~~zu liefern~~.

$\bar{y}_t$

# Coactive Preference Perceptron

- Model
  - Linear model of user utility:  $U(y|x) = w^T \phi(x,y)$
- Algorithm
  - FOR  $t = 1$  TO  $T$  DO
    - Observe  $x_t$
    - Present  $y_t = \operatorname{argmax}_y \{ w_t^T \phi(x_t, y) \}$
    - Obtain feedback  $\bar{y}_t$  from user
    - Update  $w_{t+1} = w_t + \phi(x_t, \bar{y}_t) - \phi(x_t, y_t)$
- This may look similar to a multi-class Perceptron, but
  - Feedback  $\bar{y}_t$  is different (not get the correct class label)
  - Regret is different (misclassifications vs. utility difference)

$$R(A) = \frac{1}{T} \sum_{t=1}^T [U(y_t^*|x) - U(y_t|x)]$$

Never revealed:  
• cardinal feedback  
• optimal  $y^*$

# Coactive Perceptron: Regret Bound

- Model

$$U(\mathbf{y}|\mathbf{x}) = \mathbf{w}^\top \phi(\mathbf{x}, \mathbf{y}), \text{ where } \mathbf{w} \text{ is unknown}$$

- Feedback:  $\xi$ -Approximately  $\alpha$ -Informative

$$E[U(x_t, \bar{y}_t)] \geq U(x_t, y_t) + \alpha(U(x_t, y_t^*) - U(x_t, y_t)) - \xi_t$$

- Theorem

user feedback

system prediction

gap to optimal

model error

For user feedback  $\bar{\mathbf{y}}$  that is  $\alpha$ -informative in expectation, the expected average regret of the Preference Perceptron is bounded by

$$E \left[ \frac{1}{T} \sum_{t=1}^T U(y_t^* | x) - U(y_t | x) \right] \leq \frac{1}{\alpha T} \sum_{t=1}^T \xi_t + \frac{2R \|\mathbf{w}\|}{\alpha \sqrt{T}}$$

→ zero

model error

# Preference Perceptron: Experiment

## Experiment:

- Automatically optimize Arxiv.org Fulltext Search

Analogous  
to DCG

## Model

- Utility of ranking  $y$  for query  $x$ :  $U_t(y|x) = \sum_i \gamma_i w_t^\top \phi(x, y^{(i)})$  [ $\sim 1000$  features]  
→ Computing argmax ranking: sort by  $w_t^\top \phi(x, y^{(i)})$

## Feedback

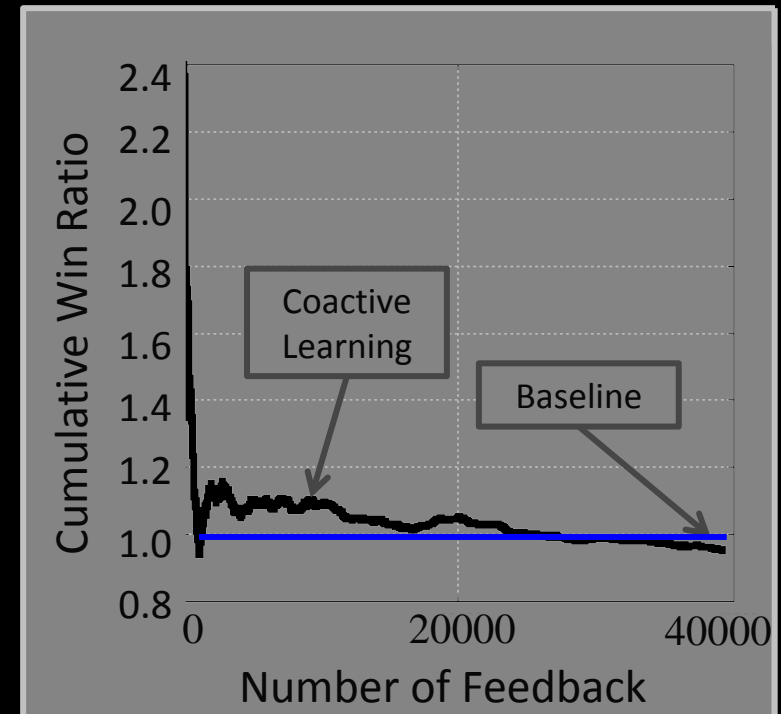
- Construct  $\bar{y}_t$  from  $y_t$  by moving clicked links one position higher.

## Baseline

- Handtuned  $w_{\text{base}}$  for  $U_{\text{base}}(y|x)$

## Evaluation

- Interleaving of ranking from  $U_t(y|x)$  and  $U_{\text{base}}(y|x)$



# Why did it fail?

- Assume

$$U_t(y|x) = U(y|x)$$

- Prediction

$$y = y^* = \operatorname{argmax}_y U_t(y|x)$$

- Feedback quality

$$\begin{aligned} E[U(x, \bar{y})] &\geq U(x, y) + \alpha(U(x, y^*) - U(x, y)) - \xi \\ &= U(x, y^*) - \xi \end{aligned}$$

→ any presence of click noise implies  $\xi > 0$

→ biased gradient





# Optimizing the User Feedback

- Assume

$$U_t(y|x) = U(y|x)$$

- Prediction

$$y = y^* = \operatorname{argmax}_y U_t(y|x)$$

- Intervention

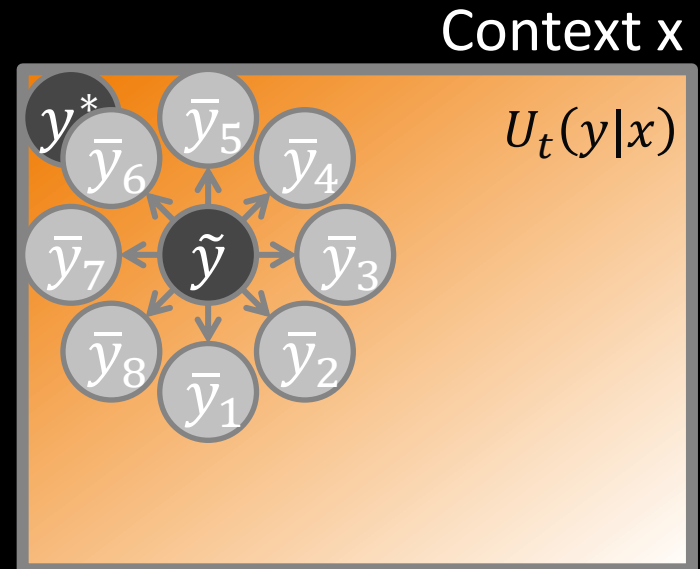
$$\text{Present } \tilde{y} = \text{Perturb}(y)$$

- Feedback quality

$$E[U(x, \bar{y})] \geq U(x, \tilde{y}) + \alpha(U(x, y^*) - U(x, \tilde{y})) - \xi$$

$$\rightarrow \xi = 0 \text{ (or small)}$$

$$\rightarrow \text{unbiased gradient at cost } U(x, y^*) - U(x, \tilde{y})$$



# FairPair Perturbation

- Idea
  - Perturb by swapping adjacent pairs
  - Generate preferences only within pair
- Randomizes out bias from presentation and feedback generation



# Preference Perceptron: Experiment

## Experiment:

- Automatically optimize Arxiv.org Fulltext Search

## Model

- Utility of ranking  $y$  for query  $x$ :  $U_t(y|x) = \sum_i \gamma_i w_t^\top \phi(x, y^{(i)})$  [ $\sim 1000$  features]  
→ Computing argmax ranking: sort by  $w_t^\top \phi(x, y^{(i)})$

## Feedback

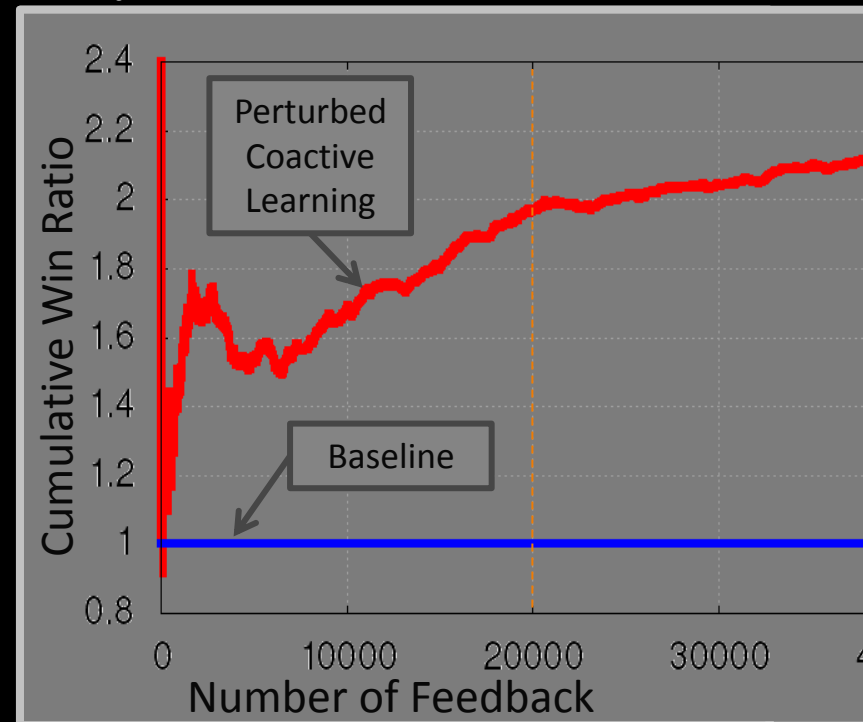
- **FairPair Perturbation**
- Construct  $\bar{y}_t$  from  $y_t$  by moving clicked links one position higher.

## Baseline

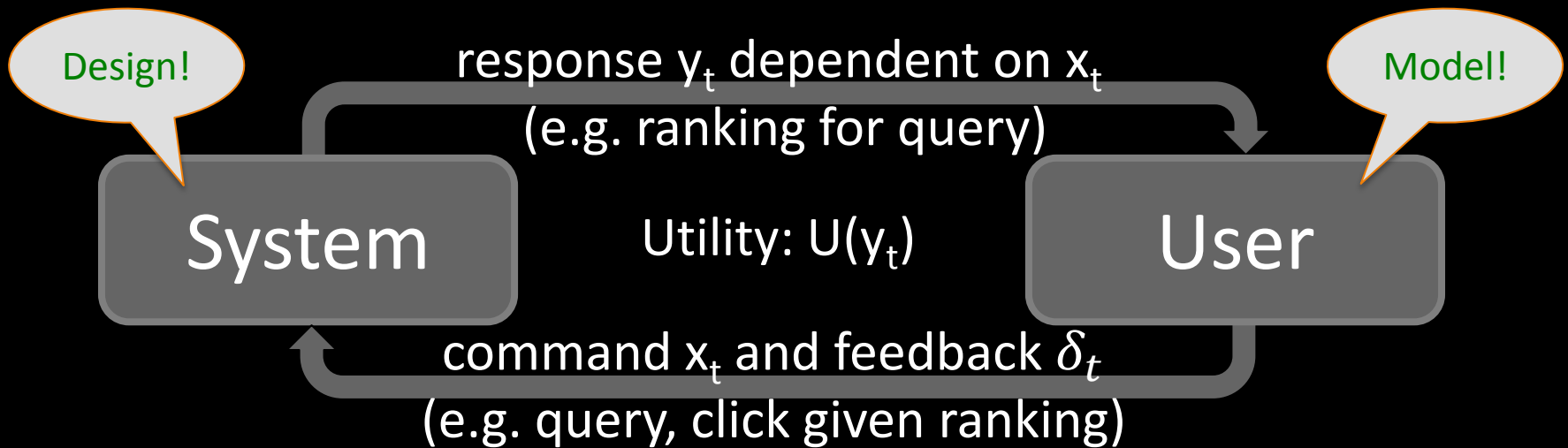
- Handtuned  $w_{\text{base}}$  for  $U_{\text{base}}(y|x)$

## Evaluation

- Interleaving of ranking from  $U_t(y|x)$  and  $U_{\text{base}}(y|x)$



# Interactive Learning System



- Designing Information Elicitation Interventions
  - Model user's decision process  $\rightarrow$  derive intervention design
- Online Learning with Interventions
  - Design space: LearningSystem = { Algorithm } x { Interventions }
- $\rightarrow$  • Offline Learning with Logged Intervention Data

# Information in Interaction Logs

- Partial Information (aka “Bandit”) Feedback
  - Search engine  $f_0$  interleaves ranking  $y$  for query  $x$  with baseline ranker and observes win/loss  $\delta$
  - News recommender  $f_0$  presents set  $y$  of articles for user  $x$  and observes that user reads  $\delta$  minutes
  - Ad system  $f_0$  presents ad  $y$  to user  $x$  and observe click/no-click  $\delta$
  - MT system  $f_0$  predicts translation  $y$  for  $x$  and receives rating  $\delta$

→ Data:  $S = ((x_1, y_1, \delta_1), \dots, (x_n, y_n, \delta_n))$

context

$f_0$  action

reward

# Changing History

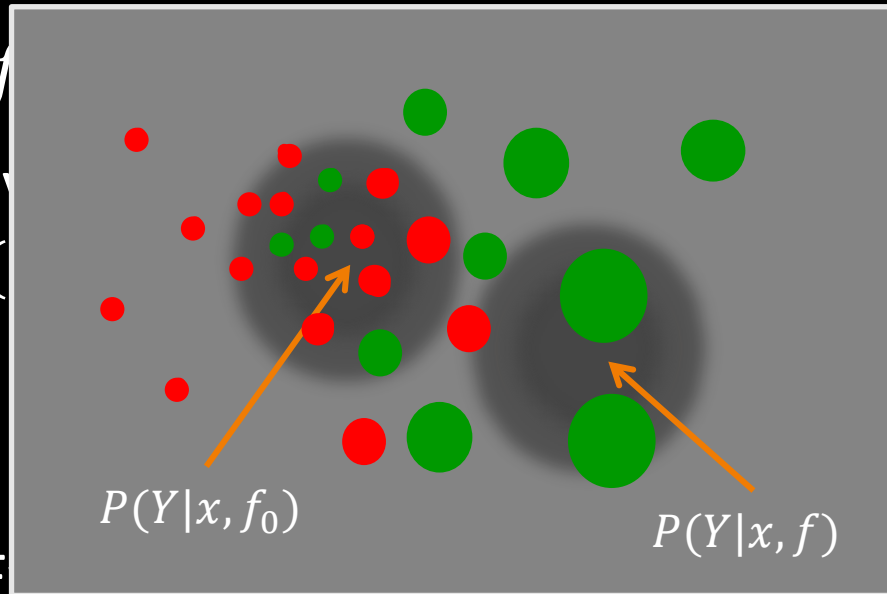
- Expected Performance of Stochastic Policy  $f$ :  $P(y|x, f)$

$R(f)$

- On-Policy Estimation

Given  $S = (x_1, y_1, \delta_1), \dots, (x_n, y_n, \delta_n)$  collected under  $f_0$ ,

collected under  $f_0$ ,



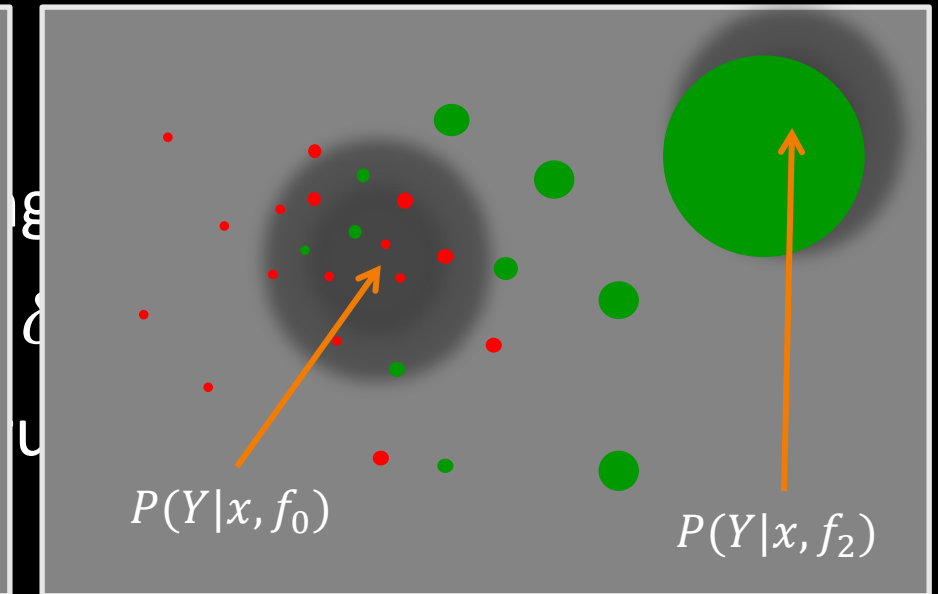
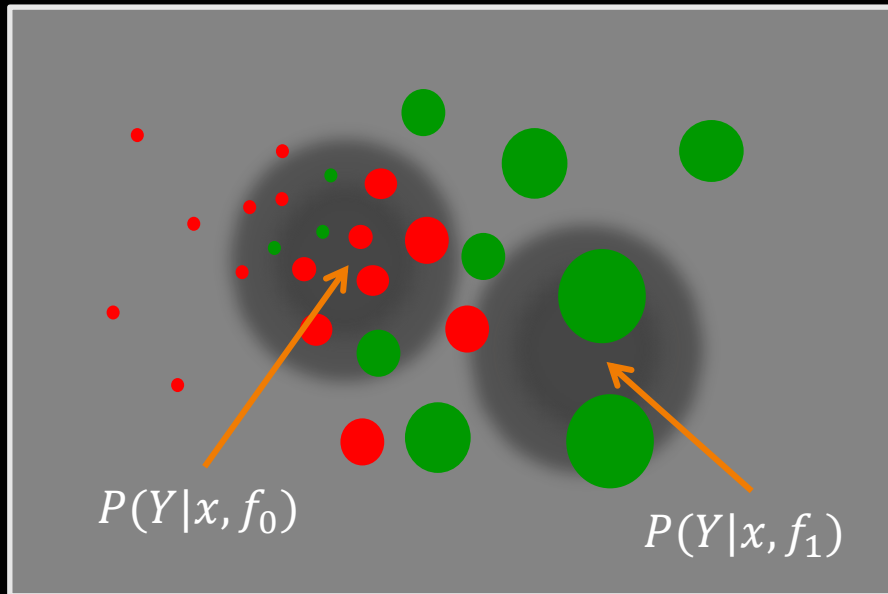
- Off-Policy Estimation

Given  $S = ((x_1, y_1, \delta_1), \dots, (x_n, y_n, \delta_n))$  collected under  $f_0$ ,

$$\hat{R}(f) = \frac{1}{n} \sum_{i=1}^n \delta_i \frac{P(y_i|x_i, f)}{P(y_i|x_i, f_0)}$$

Propensity weight

# Partial Information Empirical Risk Minimization



$$\hat{f} := \operatorname{argmax}_{f \in H} \sum_i^n \frac{P(y_i | x_i, h)}{p_i} \delta_i$$

# Counterfactual Risk Minimization

- Theorem [Generalization Error Bound]
  - For any bounded capacity  $H$ , for all  $f \in H$  with probability  $1 - \eta$

$$U(f) \geq \widehat{Mean} \left( \frac{P(y_i|x_i,f)}{p_i} \delta_i \right) - O \left( \sqrt{\widehat{Var} \left( \frac{P(y_i|x_i,f)}{p_i} \delta_i \right)} \right)$$

Unbiased  
Estimator

Variance  
Control

- Intuition
  - De-bias estimator through propensity weighting
  - Correct for differences in variance of estimator for  $f \in H$

→ Constructive principle for designing learning algorithms:  
Counterfactual Risk Minimization (CRM)



# CoStA Learning Algorithm

- Counterfactual Stochastic Approximator (CoStA)

- Hypothesis space

- $P(y|x, w) = \exp(w \cdot \phi(x, y)) / Z(x)$

- Training objective

$$w = \operatorname{argmax}_{w \in \mathcal{R}^N} \left[ \widehat{\operatorname{Mean}} \left( \frac{P(y_i|x_i, w)}{p_i} \delta_i \right) - \lambda_1 \sqrt{\widehat{\operatorname{Var}} \left( \frac{P(y_i|x_i, w)}{p_i} \delta_i \right)} \right]$$

Unbiased  
Estimator

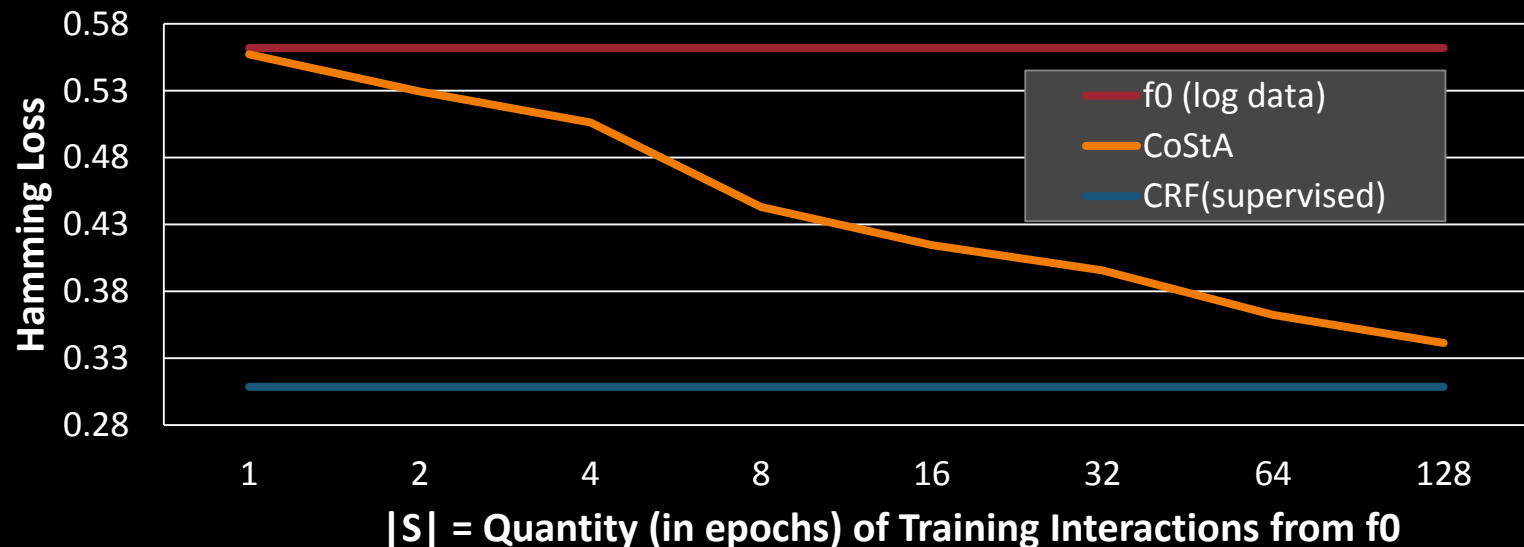
Variance  
Control

- Optimization

- successive Taylor majorization  $\rightarrow$  stochastic gradient

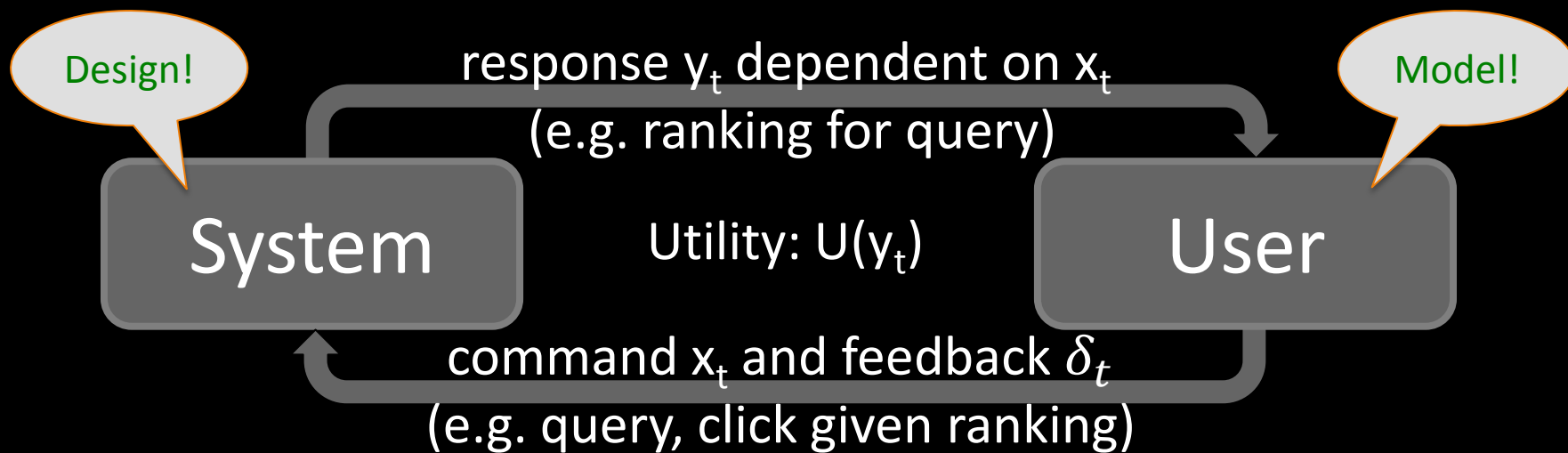
# CoStA Experiment

- Experiment Setup
  - $x$ : Reuters RCV1 text document
  - $y$ : label vector with 4 binary labels
  - $\delta$ : number of incorrect labels
  - $H$ : Isomorphic to CRF with one weight vector per label
- Results
  - Use  $f_0$  to collect logs and train CoStA



# Learning from User Interactions

## Conclusions



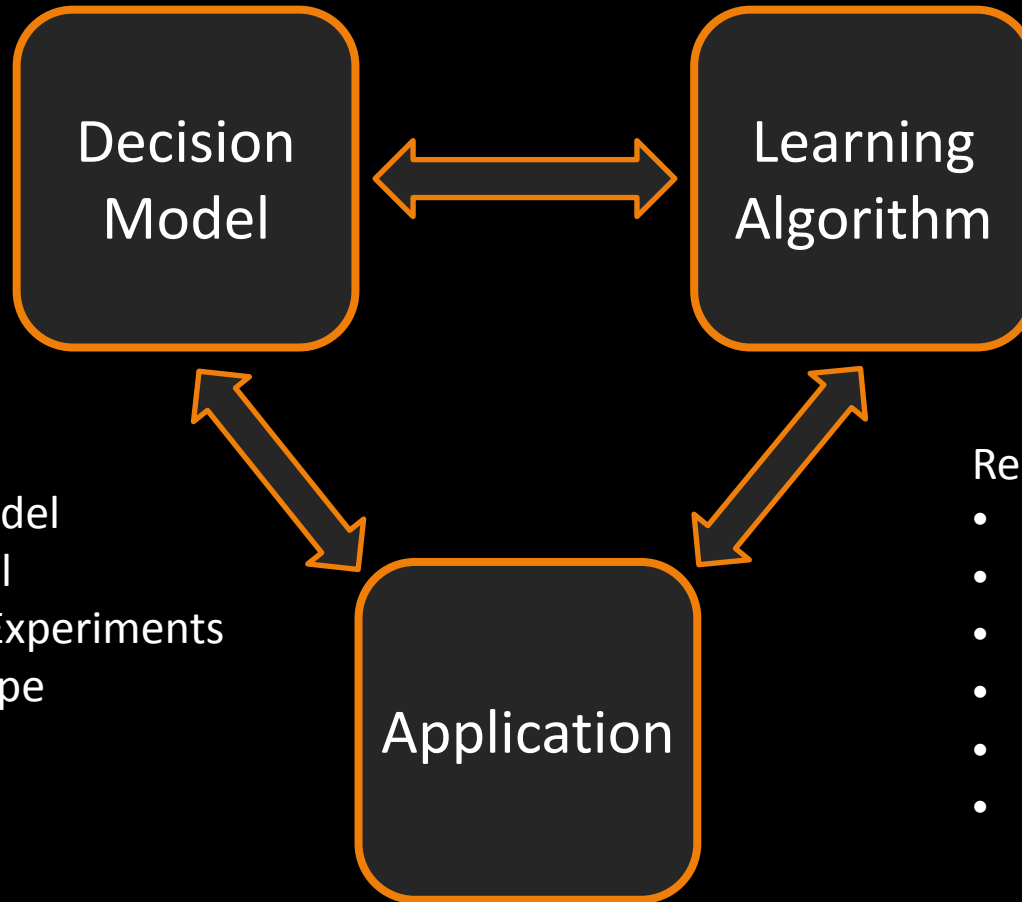
- Designing Information Elicitation Interventions

**ML =**

**Algorithm + Interventions**

– Counterfactual Risk Minimization and CoSA Algorithm

# Learning from Human Decisions



## Design Space:

- Decision Model
- Utility Model
- Interaction Experiments
- Feedback Type
- Regret
- Applications

## Related Fields:

- Micro Economics
- Decision Theory
- Econometrics
- Psychology
- Communications
- Cognitive Science

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