Learning to Rank

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Applications of L2R

- Information Retrieval
- Collaborative Filtering
- Automated Essay Scoring
- Machine Translation
- Parsing

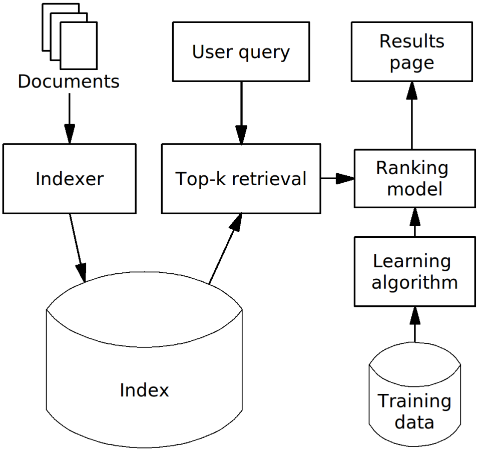
Applications of L2R

- Information Retrieval
- Collaborative Filtering
- Automated Essay Scoring
- Machine Translation
- Parsing
- Applicable to many tasks where you wish to specify an ordering over items in a collection

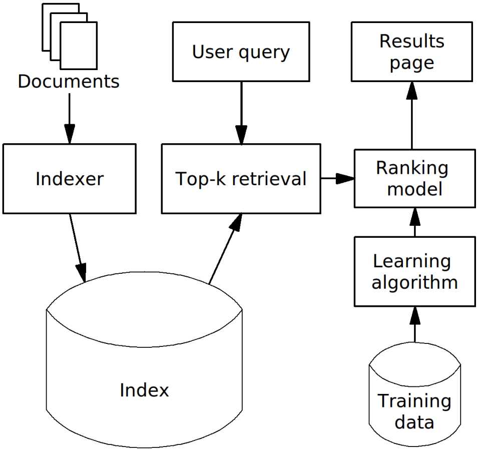
Difference with Other Learning Models

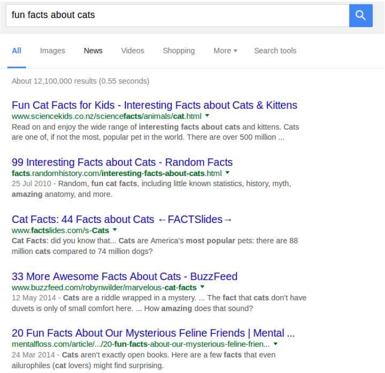
- No need to predict the absolute value of items (unlike regression)
- No need to predict the absolute class of items (unlike classification and ordinal regression)
- The relative ranking of items is all that is important (at least for information retrieval)

Example: Information Retrieval



Example: Information Retrieval





Example: Information Retrieval

- Information retrieval often involves ranking documents in order of *relevance*
- E.g. highly relevant, relevant, partially-relevant, non-relevant
- Assume that we can describe documents (items) using feature vectors $\vec{x}_i^q = \Phi(q, d_i)$ that correspond to features of the query-document pair:

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Example Features

- # of query keywords in document
- BM25 score
- document length
- page-rank
- sum of term-frequencies
- ...
- ...

Example of Input Vectors in $\mathcal{R}^N$

y_i	input vectors $\vec{x_i}$		
	$\vec{x}_{i1}$	$\vec{x}_{i2}$	$\vec{x}_{i3}$
3	7.0	9.2	3.2
2	2.0	9.2	4.1
0	2.0	3.5	0.2
2	2.0	9.2	11.2
1	3.0	5.3	2.2
0	0.0	3.2	0.5

Table : Sample Dataset

Problem Formulation

- Given a set of input vectors $\{\vec{x_i}\}_{i=1}^{n}$ and corresponding labels $\{y_i\}_{i=1}^{n}$ where $\mathcal{Y} = \{1, 2, 3, 4, ..l\}$ specifying a total order on the labels.
- Determine a function f that specifies a ranking over the vectors $\{\vec{x_i}\}_{i=1}^{n}$ such that f minimises some cost $\mathcal{C}$
- In general you would like to use a cost function $\mathcal{C}$ that is closely correlated to the most suitable measure of performance for the task
- This is not always easy

Three Common Approaches

- Pointwise - Regression, Classification, Ordinal regression (items to be ranked are treated in isolation)
- Pairwise - Rank-preference models (items to be ranked are treated in pairs)
- Listwise - Treat each list as an instance. Usually tries to directly optimise an evaluation measure calculated over a list (e.g. mean average precision)

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- Listwise - Treat each list as an instance. Usually tries to directly optimise an evaluation measure calculated over a list (e.g. mean average precision)
- We'll just consider linear functions of the form $f(\vec{x}) = < \vec{x}, \vec{w} > + b$

Pointwise Outline

General Criteria

The ranking function f learns to assign an *absolute* score (categories) to each item in isolation.

[1]Adapted from [Hang(2009)Hang]

Pointwise Outline

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	Regression	Classification
Input	input vector $\vec{x}$	
Output	Real Number $y = f(\vec{x})$	Category $y = sign(f(\vec{x}))$
Model	Ranking Function $f(\vec{x})$	
Loss	Regression Loss	Classification Loss

Table : Learning in Pointwise approaches[1]

[1] Adapted from [Hang(2009)Hang]

Example of Input Vectors

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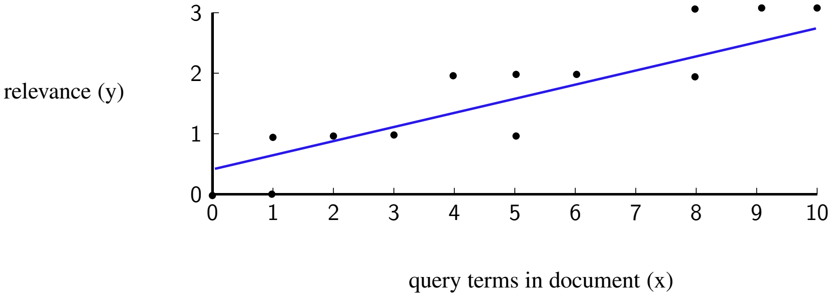
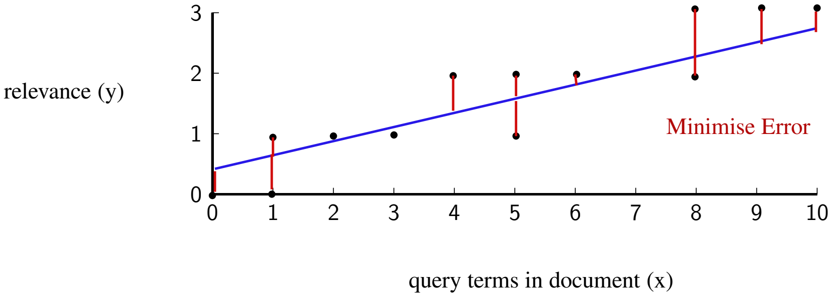
A Simple Pointwise Example



A Simple Pointwise Example



Regression summary

- Each instance is treated in isolation
- The error from the absolute gold score is minimised

Regression summary

- Each instance is treated in isolation
- The error from the absolute gold score is minimised
- We have imposed some real value on the labels (possibly a poor assumption)
- In general, this is solving a more difficult problem than is necessary

Classification

- Build a multi-class classifier for the problem (highly relevant, relevant, partially relevant, non relevant)
- Each instance is treated in isolation
- Minimise the misclassification error

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- Build a multi-class classifier for the problem (highly relevant, relevant, partially relevant, non relevant)
- Each instance is treated in isolation
- Minimise the misclassification error
- Ranking between classes is not used during training
- An assumption that all mis-classifications are equally poor (not true in reality)

Pairwise Outline I

General Criteria

The ranking function f learns to rank pairs of items (i.e. for $\{\vec{x_i}, \vec{x_j}\}$, is y_i greater than y_j?).

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Pairwise Outline I

General Criteria

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	Learning	Ranking
Input	Order input vector pair $\{\vec{x_i}, \vec{x_j}\}$	Feature vectors $\{x_i\}_{i=1}^n$
Output	Classifier of pairs $y_{ij} = sign(f(\vec{x_i} - \vec{x_j}))$	Permutation over vectors $y = sort(\{f(\vec{x_i})\}_{i=1}^n)$
Model	Ranking Function $f(\vec{x})$	
Loss	Pairwise misclassification	Ranking evaluation measure

Table : Learning in Pairwise approaches[2]

[2]Adapted from [Hang(2009)Hang]

Pairwise Outline II

- Cost function typically minimises misclassification of pairwise *difference vectors*
- The function learns using paired input vectors $f(\vec{x_i} - \vec{x_j})$
- Any binary classifier can be used for implementation
- Although svm^{rank} is a commonly used implementation[3]

[3] https://www.cs.cornell.edu/people/tj/svm_light/svm_rank.html

Pairwise Transformation

y_i	input vectors $\vec{x_i}$		
	x_{i1}	x_{i2}	x_{i3}
hr (3)	7.0	9.2	3.2
r (2)	2.0	9.2	4.1
nr (0)	2.0	3.5	0.2
r (2)	2.0	9.2	11.2
pr (1)	3.0	5.3	2.2
nr (0)	0.0	3.2	0.5

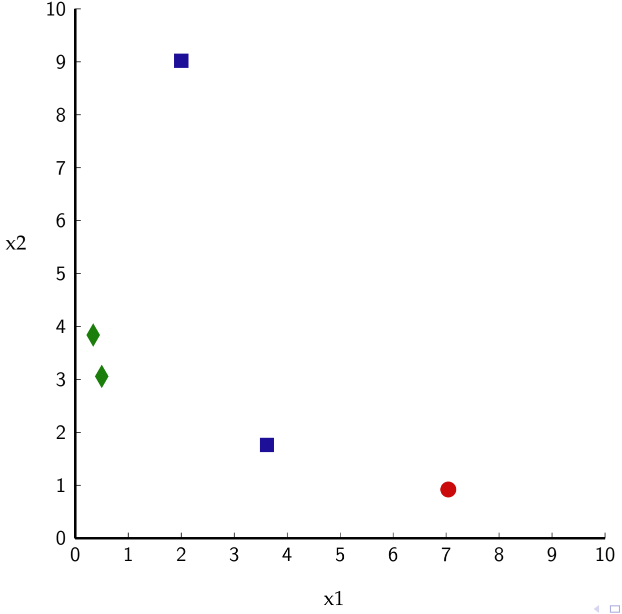
Table : Sample Dataset

Pairwise Transformation

y'_{ij}	input vectors $\vec{x_i} - \vec{x_j}$		
	$x_{i1} - x_{j1}$	$x_{i2} - x_{j2}$	$x_{i3} - x_{j3}$
+(hr-r)	5.0	0.0	-0.9
+(hr-nr)	5.0	5.7	3.0
+(hr-r)	5.0	0.0	-8.0
+(hr-pr)	4.0	3.9	1.0
+(hr-nr)	7.0	6.0	2.7
+(r-nr)	0.0	5.7	3.9
+(r-pr)	-1.0	3.9	1.9
+(r-nr)	2.0	6.0	3.6
...	...	...	...
-(hr-r)	-5.0	0.0	0.9
...	...	...	...

Table : Transformed Dataset

A Graphical Example I



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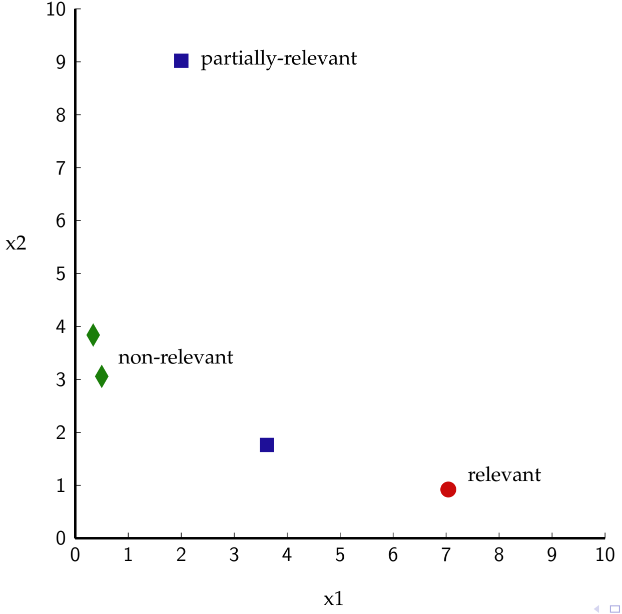
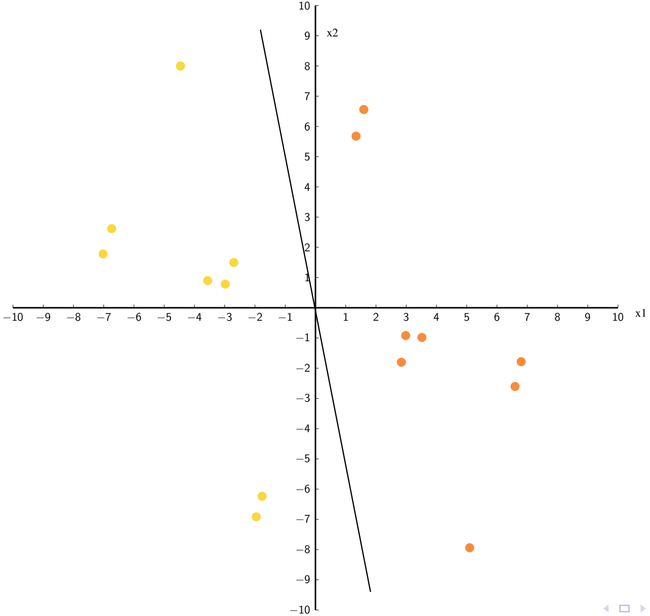
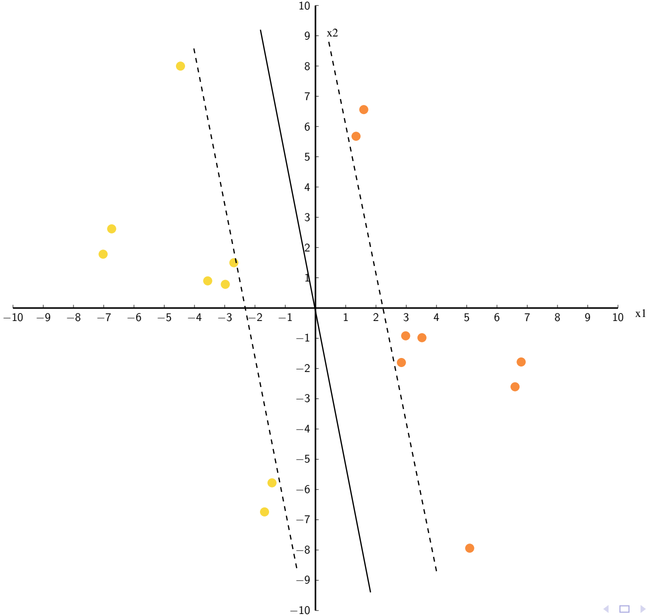


A Graphical Example II



A Graphical Example II



Pairwise Summary

- In general, pairwise approaches outperform pointwise approaches in IR
- Pairwise preference models can be biased towards rankings containing many instances
- However, pairwise approaches often do not optimise the cost function that is usually used for evaluation (e.g. average precision or NDCG)
- For example, correctly ranking items at the top of the list is often more important than correctly ranking items lower down

Example

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Example

- $\{RRRNNN\}$ vs $\{NRRRNN\} \implies ap = 0.638$

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Example

- $\{RRRNNN\}$ vs $\{NRRRNN\} \implies ap = 0.638$
- $\{RRRNNN\}$ vs $\{RRNNNR\} \implies ap = 0.833$

where R and N are relevant and non-relevant respectively.

Listwise outline

- Many listwise approaches aim to directly optimise the most appropriate task-specific metric (e.g. for IR it may be average precision or NDCG)
- However, for rank-based approaches these metrics are often non-continuous w.r.t the scores
- E.g. the score of documents could change without any change in ranking
- Two-broad approaches to handling this:
  - Modify the cost function to a continuous (smooth) version
  - Use (or modify) an algorithm that can navigate discrete spaces

Listwise example I

- We'll use SVM^{map} [Yue *et al.*(2007)Yue, Finley, Radlinski, and Joachims] as a brief example
- Each permutation (list) of items is treated as an instance
- Aim to find weight vector $\vec{w}$ that ranks these permutations according to a loss function
- $h(\vec{q};\vec{w}) = arg\_max_{\vec{y}\in\mathcal{Y}} F(\vec{q},\vec{y};\vec{w})$
- And $F(\vec{q},\vec{y};\vec{w}) = \vec{w}\Psi(\vec{q},\vec{y})$

Listwise example II

- One idea is to encode each permutation as summation of pairwise difference vectors in the ranking
- As a result, each list instance is mapped to a feature vector in $\mathcal{R}^N$
- As each input vector is a list, a list-based metric can be used as a smooth loss function (hinge-loss)

Listwise example II

- One idea is to encode each permutation as summation of pairwise difference vectors in the ranking
- As a result, each list instance is mapped to a feature vector in $\mathcal{R}^N$
- As each input vector is a list, a list-based metric can be used as a smooth loss function (hinge-loss)
- Number of permutations (rankings) is extremely large and so *all* lists are not used for training (see [Yue *et al.*(2007)Yue, Finley, Radlinski, and Joachims] for details)

Other Listwise Approaches

- In general when you can represent a list as a vector in $\mathcal{R}^N$, you can optimize w such that it can rank these lists
- lambdaRANK [Burges *et al.*(2006)Burges, Ragno, and Le]
- softRANK [Taylor *et al.*(2008)Taylor, Guiver, Robertson, and Minka]

Open Questions

- Learning to rank for other tasks/domains (e.g. essay scoring)
- Optimising the "true loss" for ranking. What might that be?
- Ranking using deep learning
- Ranking natural language texts using distributed representations

Datasets

- LETOR Datasets [4]
- Yahoo! Learning to Rank Challenge
  https://webscope.sandbox.yahoo.com/#datasets
- FCE dataset (ESL essays)
  http://ilexir.co.uk/datasets/index.html

[4] http://research.microsoft.com/en-us/um/beijing/projects/letor/

Take-away Messages

- Applications of learning to rank abound
- Three main categories of approaches:
  - pointwise
  - pairwise
  - listwise
- Challenges in L2R
- Many open research questions

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