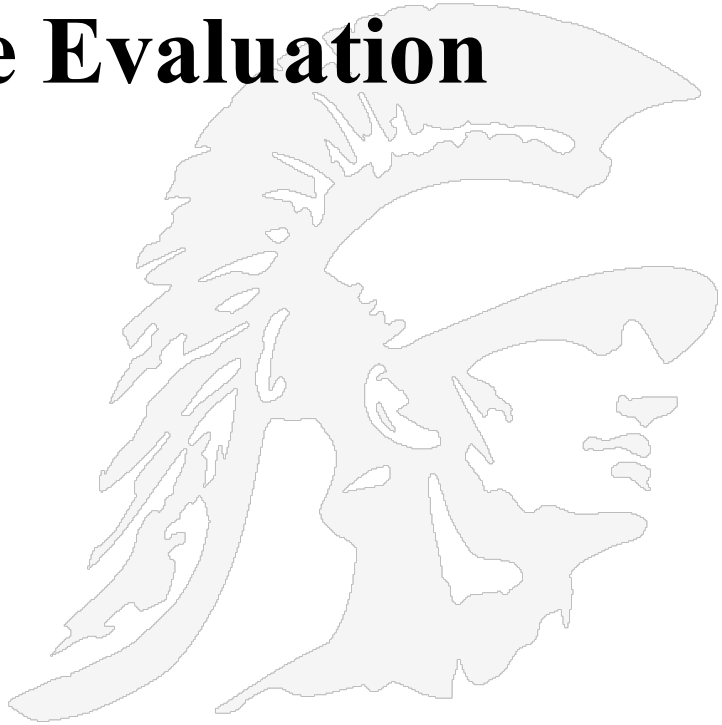
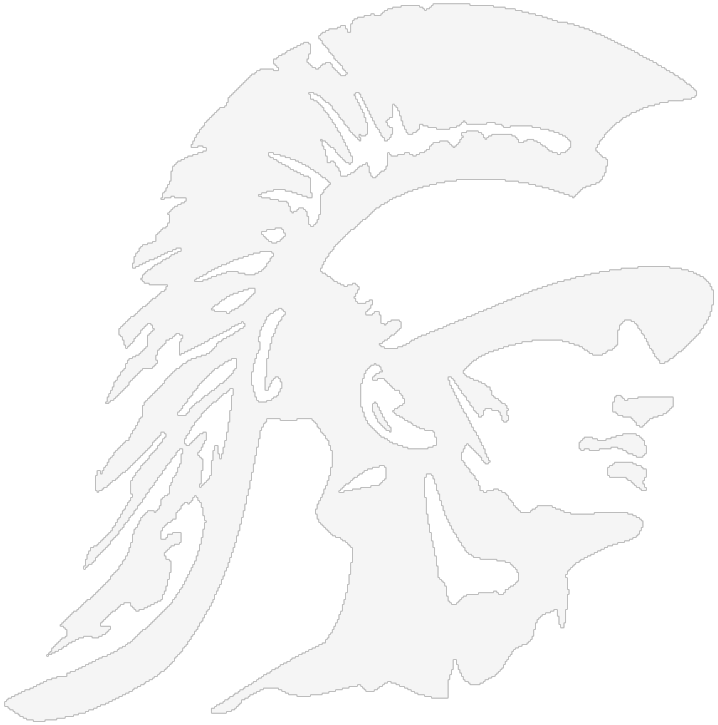
# Search Engine Evaluation

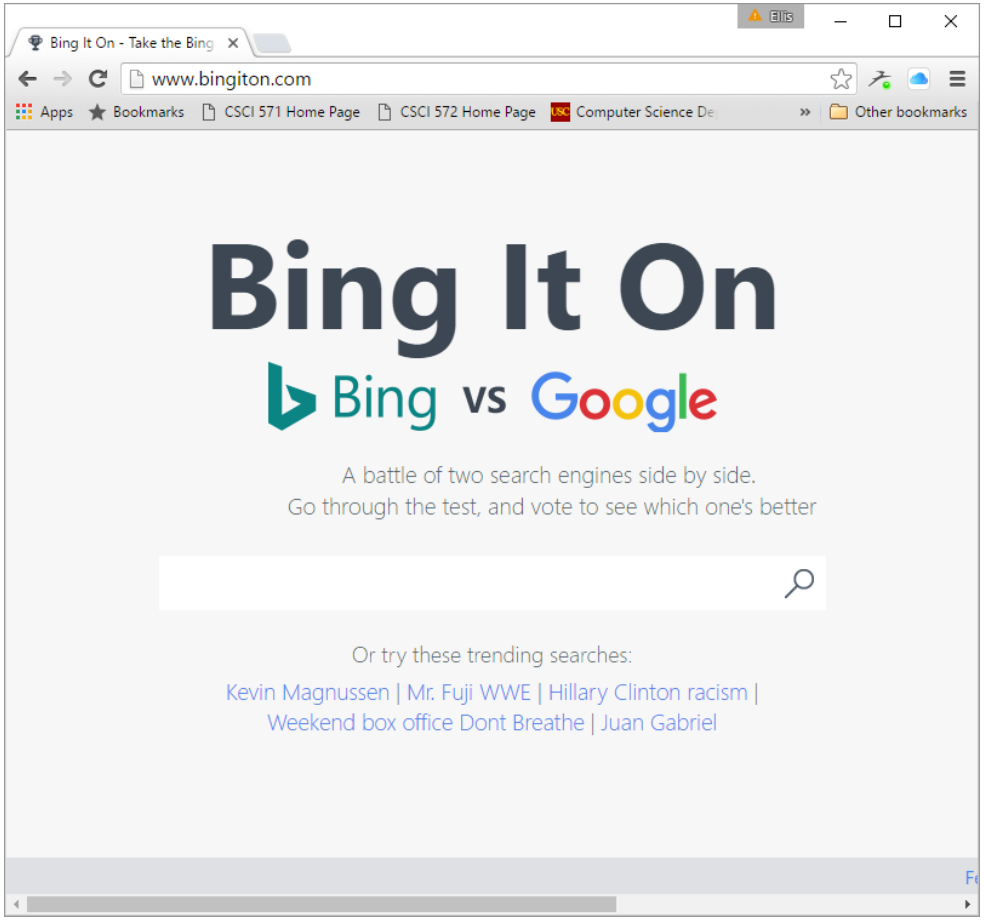


# Outline

- Defining precision/recall
- Mean Average Precision
- Harmonic Mean and F Measure
- Discounted Cumulative Gain
- Elements of Good Search Results
- Google's Search Quality Guidelines
- Using log files for evaluation
- A/B Testing



# Comparing Bing and Google




- This site is no longer active, but we can simulate the experiment

## Try it yourself!

here are some queries:

- ac versus dc current
- best bottled water
- worst hotel in Santa Monica
- how many gears do I need on a bicycle
- Clint Eastwood's best movie

# Precision/Recall

- How do we measure the quality of search engines?
- Precision = #(relevant items retrieved)
  divided by
  #(all retrieved items)

- Recall = #(relevant items retrieved)
  divided by
  #(all relevant items)

# Formalizing Precision/Recall

| | Relevant | Nonrelevant |
|---|---|---|
| Retrieved | True positive (tp) | False positive (fp) |
| Not retrieved | False negative (fn) | True negative (tn) |

$$\text{Precision} = tp/(tp + fp)$$

$$\text{Recall} = tp/(tp + fn)$$

- The accuracy of an engine is defined as:

the fraction of these classifications that are correct

$$(tp + tn) / ( tp + fp + fn + tn)$$

**For web applications,**
**Precision is more important than Recall**

# Precision/Recall Using Set Notation

$A$ is set of relevant documents,
$B$ is set of retrieved documents

| | Relevant | Non-Relevant |
|---|---|---|
| Retrieved | $A \cap B$ | $\overline{A} \cap B$ |
| Not Retrieved | $A \cap \overline{B}$ | $\overline{A} \cap \overline{B}$ |

you may not be able to see them, but A and B have a bar over them and it denotes the complement set

$$Recall = \frac{|A \cap B|}{|A|}$$

$$Precision = \frac{|A \cap B|}{|B|}$$

**https://en.wikipedia.org/wiki/Precision_and_recall**

# Precision/Recall Two Observations

- **You can get high recall (but low precision) by retrieving all docs for all queries!**
  - a rather foolish strategy
- **In a good system, precision decreases as the number of docs retrieved (or recall) increases**
  - This is not a theorem, but a result with strong empirical confirmation
  - E.g. viewing multiple pages of Google results often does not improve precision at all

# Harmonic Mean

- **There are three Pythagorean means**
  - 1. *arithmetic mean*, 2. *geometric mean*, 3. *harmonic mean*
  - of course we all know how to compute the arithmetic mean
  - the geometric mean is the *n*th root of the product of *n* numbers
- **The harmonic mean tends strongly toward the least element of the list making it useful in analyzing search engine results**
- **To find the harmonic mean of a set of *n* numbers**
  1. add the reciprocals of the numbers in the set
  2. divide the sum by *n*
  3. take the reciprocal of the result
- **e.g. for the numbers 3, 6, 9, and 12**
  - **The arithmetic mean is: (3+6+9+12)/4 = 7.5**
  - **The geometric mean is: nth-root(3*6*9*12) = $4^{th}$-root(1944) = 6.64**
  - **The harmonic mean is: (1/3+1/6+1/9+1/12)=(.33+.16+.11+.08)/4=0.17 and 1/0.17 = 5.88**

# F Measure

- The harmonic mean of the precision and the recall is often used as an aggregated performance score for the evaluation of algorithms and systems: called the

  **F-score (or F-measure).**

- *Harmonic mean* of recall and precision is defined as

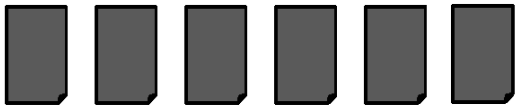
$$F = \frac{1}{\frac{1}{2}(\frac{1}{R}+\frac{1}{P})} = \frac{2RP}{(R+P)}$$

  - harmonic mean emphasizes the importance of small values, whereas the arithmetic mean is affected more by outliers that are unusually large

- More general form of F-Measure
  - β is a parameter that controls the relative importance of recall and precision

$$F_\beta = (\beta^2 + 1)RP/(R + \beta^2 P)$$

# Calculating Recall/Precision at Fixed Positions



= the relevant documents

**Steps**

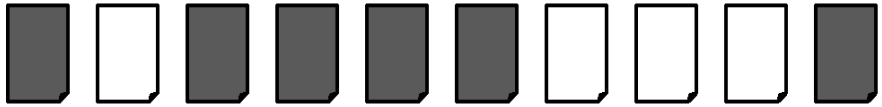
Recall:
1/6 = 0.17
Precision:
1/1

Recall:
1/6 = 0.17
Precision:
1/2 = 0.5

Recall:
2/6 = 0.33
Precision:
2/3 = 0.67

Recall:
3/6 = 0.5
Precision:
3/4 = 0.75

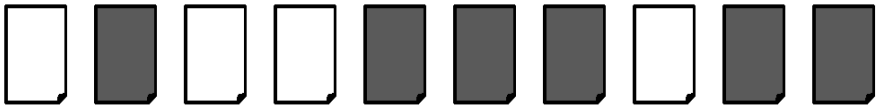
Ranking #1



| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Recall | 0.17 | 0.17 | 0.33 | 0.5 | 0.67 | 0.83 | 0.83 | 0.83 | 0.83 | 1.0 |
| Precision | 1.0 | 0.5 | 0.67 | 0.75 | 0.8 | 0.83 | 0.71 | 0.63 | 0.56 | 0.6 |

**e.g. Google Result**

Ranking #2

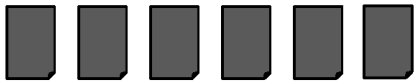


| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Recall | 0.0 | 0.17 | 0.17 | 0.17 | 0.33 | 0.5 | 0.67 | 0.67 | 0.83 | 1.0 |
| Precision | 0.0 | 0.5 | 0.33 | 0.25 | 0.4 | 0.5 | 0.57 | 0.5 | 0.56 | 0.6 |

**e.g. Bing Result**

*Recall=#RelevItemsRetr/allRelevItems*
*Prec=#RelevItemsRetr/allItemsRetr*

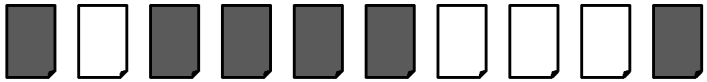
# Average Precision of the Relevant Documents



= the relevant documents

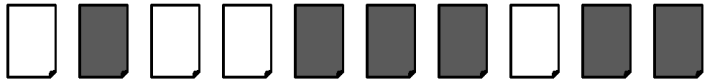
computes the sum of the precisions of the relevant documents

Ranking #1



| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Recall | 0.17 | 0.17 | 0.33 | 0.5 | 0.67 | 0.83 | 0.83 | 0.83 | 0.83 | 1.0 |
| Precision | 1.0 | 0.5 | 0.67 | 0.75 | 0.8 | 0.83 | 0.71 | 0.63 | 0.56 | 0.6 |

Ranking #2



| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Recall | 0.0 | 0.17 | 0.17 | 0.17 | 0.33 | 0.5 | 0.67 | 0.67 | 0.83 | 1.0 |
| Precision | 0.0 | 0.5 | 0.33 | 0.25 | 0.4 | 0.5 | 0.57 | 0.5 | 0.56 | 0.6 |

$$\text{Ranking \#1: } (1.0 + 0.67 + 0.75 + 0.8 + 0.83 + 0.6)/6 = 0.78$$

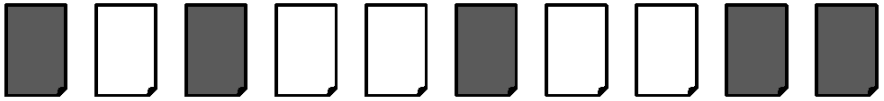
$$\text{Ranking \#2: } (0.5 + 0.4 + 0.5 + 0.57 + 0.56 + 0.6)/6 = 0.52$$

Conclusion: Ranking #1 for this query is best

# Averaging Across Queries


= relevant documents for query 1

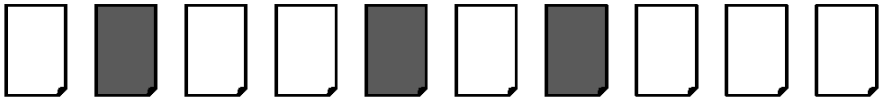
Ranking #1



| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Recall | 0.2 | 0.2 | 0.4 | 0.4 | 0.4 | 0.6 | 0.6 | 0.6 | 0.8 | 1.0 |
| Precision | 1.0 | 0.5 | 0.67 | 0.5 | 0.4 | 0.5 | 0.43 | 0.38 | 0.44 | 0.5 |


= relevant documents for query 2

Ranking #2



| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Recall | 0.0 | 0.33 | 0.33 | 0.33 | 0.67 | 0.67 | 1.0 | 1.0 | 1.0 | 1.0 |
| Precision | 0.0 | 0.5 | 0.33 | 0.25 | 0.4 | 0.33 | 0.43 | 0.38 | 0.33 | 0.3 |

Average precision across the two queries for relevant docs is:
(1 + .67 + .5 + .44 + .5 + .5 + .4 + .43)/8 = 0.55

# Averaging Across Queries

- ***Mean average precision (MAP)*** for a set of queries is the mean of the average precision scores for each query.

$$\text{MAP} = \frac{\sum_{q=1}^{Q} \text{AveP}(q)}{Q}$$

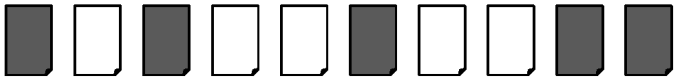
**where *Q* is the number of queries**

- **Summarize rankings from multiple queries by averaging average precision**
- **This is the *most commonly used* measure in research papers**
- **Assumes user is interested in finding many relevant documents for each query**
- **Requires many relevance judgments in text collection**

# Mean Average Precision Example


= relevant documents for query 1

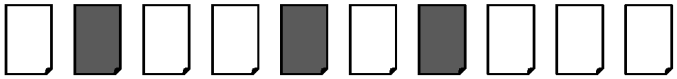
Ranking #1



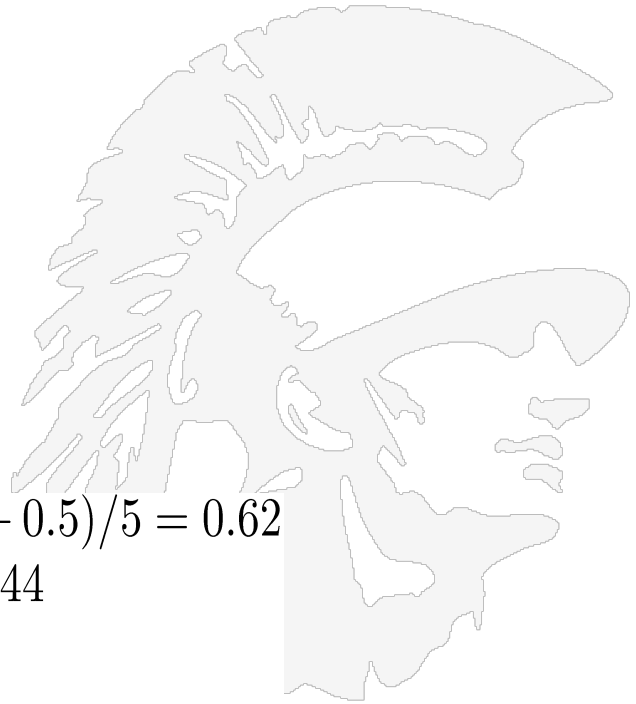
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Recall | 0.2 | 0.2 | 0.4 | 0.4 | 0.4 | 0.6 | 0.6 | 0.6 | 0.8 | 1.0 |
| Precision | 1.0 | 0.5 | 0.67 | 0.5 | 0.4 | 0.5 | 0.43 | 0.38 | 0.44 | 0.5 |


= relevant documents for query 2

Ranking #2



| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Recall | 0.0 | 0.33 | 0.33 | 0.33 | 0.67 | 0.67 | 1.0 | 1.0 | 1.0 | 1.0 |
| Precision | 0.0 | 0.5 | 0.33 | 0.25 | 0.4 | 0.33 | 0.43 | 0.38 | 0.33 | 0.3 |



$$average\ precision\ query\ 1 = (1.0 + 0.67 + 0.5 + 0.44 + 0.5)/5 = 0.62$$
$$average\ precision\ query\ 2 = (0.5 + 0.4 + 0.43)/3 = 0.44$$

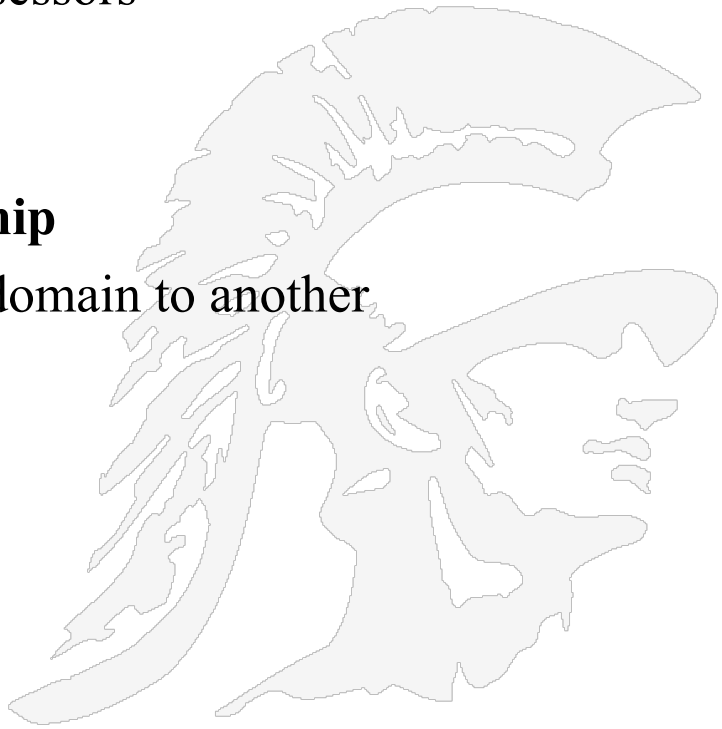
$$mean\ average\ precision = (0.62 + 0.44)/2 = 0.53$$

# More on Mean Average Precision Calculation

- **Mean Average Precision (MAP)**
  - Some negative aspects
  - If a relevant document never gets retrieved, we assume the precision corresponding to that relevant doc to be zero (this is actually reasonable)
  - Each query counts equally
  - MAP assumes user is interested in finding many relevant documents for each query
  - MAP requires many relevance judgments in the document collection

# Difficulties in Using Precision/Recall

- **Should average over large document collection and query ensembles**
- **Need human relevance assessments**
  - But people aren't always reliable assessors
- **Assessments have to be binary**
  - Nuanced assessments?
- **Heavily skewed by collection/authorship**
  - Results may not translate from one domain to another



# A Final Evaluation Measure: Discounted Cumulative Gain

- The premise of DCG is that highly relevant documents appearing lower in a search result list should be penalized as the graded relevance value is reduced logarithmically proportional to the position of the result.
- The discounted CG accumulated at a particular rank position *p* is defined as

$$\mathrm{DCG_p} = \sum_{i=1}^{p} \frac{rel_i}{\log_2(i+1)} = rel_1 + \sum_{i=2}^{p} \frac{rel_i}{\log_2(i+1)}$$

where $rel_i$ is the graded relevance of the result at position *i*

- Gain is accumulated starting at the top of the ranking and may be reduced, or *discounted*, at lower ranks
- Typical discount is 1/log *(rank)*
  - With base 2, the discount at rank 4 is 1/2, and at rank 8 it is 1/3
- An alternative formulation of DCG places stronger emphasis on retrieving relevant documents:

$$\mathrm{DCG_p} = \sum_{i=1}^{p} \frac{2^{rel_i} - 1}{\log_2(i+1)}$$

# Discounted Cumulative Gain Example

we want high weights for high rank documents, because searchers are likely to inspect them, and low weights for low rank documents that searchers are unlikely to ever see.

The discount factor is commonly chosen as log2(rank + 1) and is used to divide the relevance grade.

Using a logarithm for the position penalty makes the decay effect more gradual compared to using the position itself.

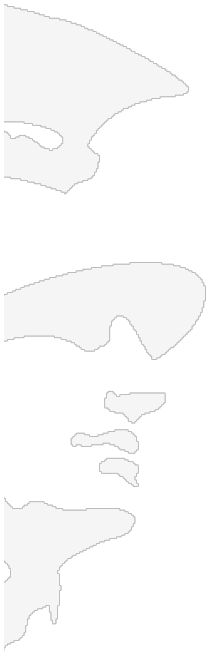
Discount examples

| Rank | Grade | Discount1 [1/rank] | Discount2 [log2(rank + 1)] | Discount1 Grade | Discount2 Grade |
|---|---|---|---|---|---|
| 1 | 4 | 1.000 | 1.000 | 4.000 | 4.000 |
| 2 | 3 | 0.500 | 0.631 | 1.500 | 1.893 |
| 3 | 2 | 0.333 | 0.500 | 0.667 | 1.000 |
| 4 | 1 | 0.250 | 0.431 | 0.250 | 0.431 |
| 5 | 1 | 0.200 | 0.387 | 0.200 | 0.387 |

# Search Engine Evaluation Metrics

## Metrics table

| Scale | Metric | Measures | Drawbacks |
|---|---|---|---|
| Binary | Precision (P) | The relevance of the entire results set (gridded results display) | Doesn't account for position |
| Binary | Average Precision (AP) | Relevance to a user scanning results sequentially | Large impact of low-rank results |
| Graded | Cumulative Gain (CG) | Information gain from a results set | Same as *Precision* doesn't factor in position |
| Graded | Discount Cumulative Gain (DCG) | Information gain with positional weighting | Difficult to compare across queries |
| Graded | normalized DCG (nDCG) | How close the results are to the best possible | No longer shows information gain |

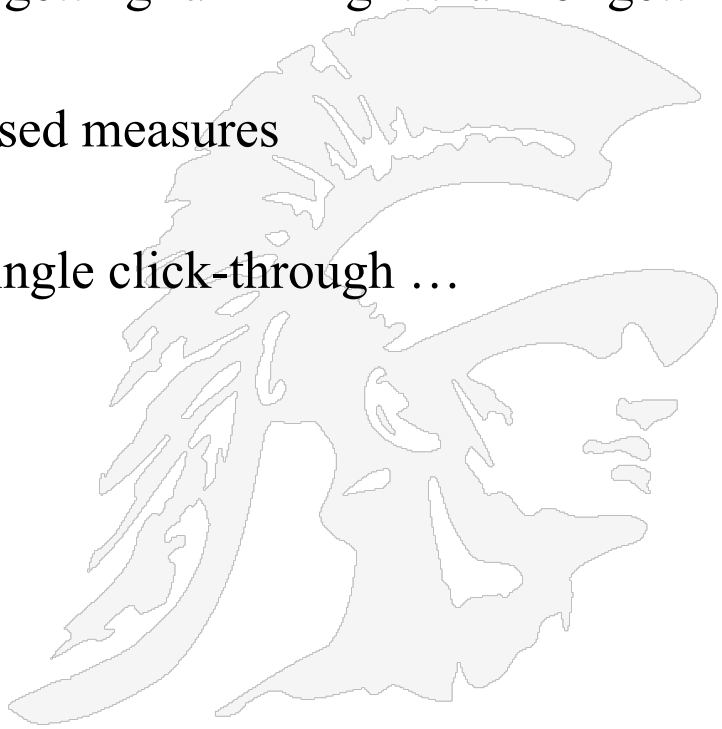


Finally see https://en.wikipedia.org/wiki/Evaluation_measures_(information_retrieval)

# How Evaluation is Done at Web Search Engines

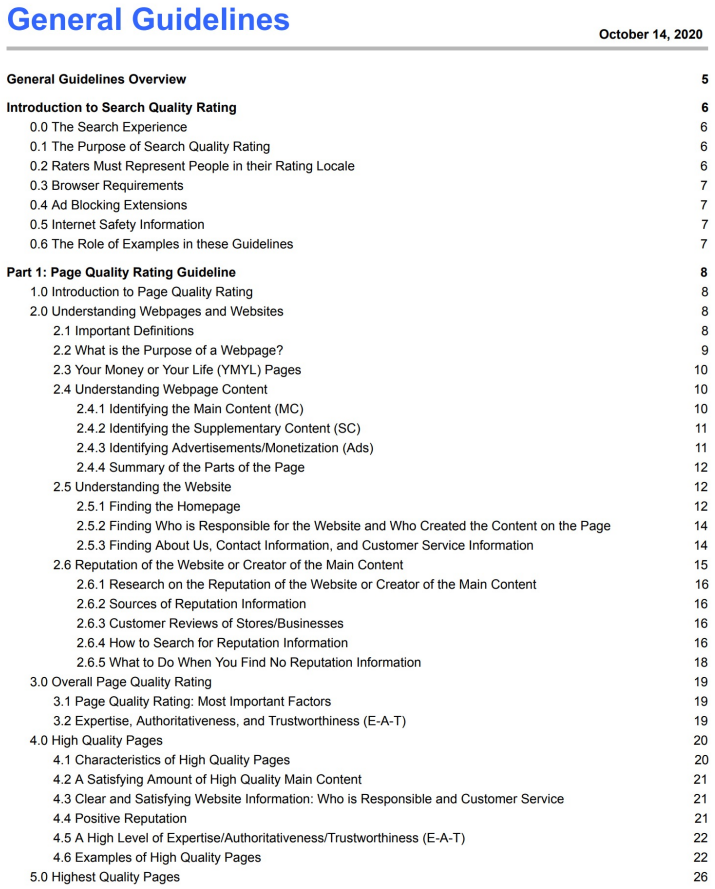
- Search engines have test collections of queries and hand-ranked results
- Recall is difficult to measure on the web
- Search engines often use precision at top *k* positions, e.g., *k = 10*
- . . . or measures that reward you more for getting rank *1* right than for getting rank *10* right.
- Search engines also use non-relevance-based measures
  - Click-through on first result
    - Not very reliable if you look at a single click-through …

    but pretty reliable in the aggregate.
  - Studies of user behavior in the lab
  - A/B testing



# Google's Search Quality Rating Guidelines Document

- **Google relies on raters, working in many countries and languages around the world**
- **The data they generate is rolled up statistically to give**
  - a view of the quality of search results and search experience over time, and
  - an ability to measure the effect of proposed changes to Google's search algorithms



General Guidelines

October 14, 2020

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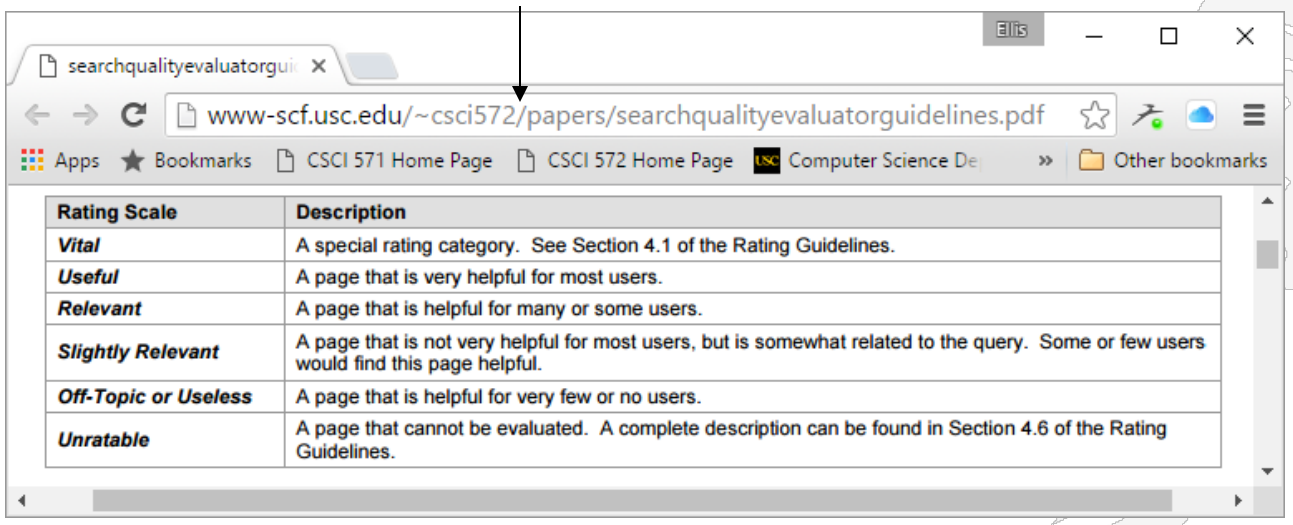
http://csci572.com/papers/2020_10searchqualityevaluatorguidelines.pdf

# Google's Search Quality Ratings Guidelines Document

- This document gives evaluators examples and guidelines for appropriate ratings.
- the evaluator looks at a search query and a result that could be returned. They rate the relevance of the result for that query on a scale described within the document.

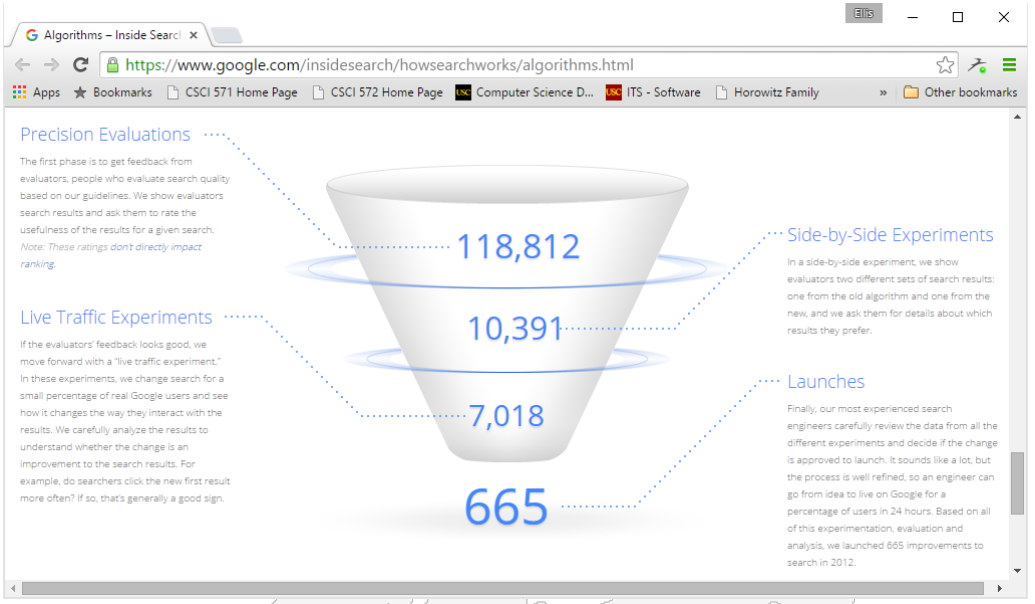
**The six rating scale categories**




| Rating Scale | Description |
|---|---|
| ***Vital*** | A special rating category. See Section 4.1 of the Rating Guidelines. |
| ***Useful*** | A page that is very helpful for most users. |
| ***Relevant*** | A page that is helpful for many or some users. |
| ***Slightly Relevant*** | A page that is not very helpful for most users, but is somewhat related to the query. Some or few users would find this page helpful. |
| ***Off-Topic or Useless*** | A page that is helpful for very few or no users. |
| ***Unratable*** | A page that cannot be evaluated. A complete description can be found in Section 4.6 of the Rating Guidelines. |

# Google's 4-Step Process for Changing Their Search Algorithm

1. **Precision Evaluations**
   People use the Guidelines to rate search results
2. **Side-by-Side Experiments**
   people are shown two different sets of search results and asked which they prefer
3. **Live Traffic Experiments**
   the search algorithm is altered for a small number of actual users
4. **Full Launch**
   A final analysis by Google engineers and the improvement is released



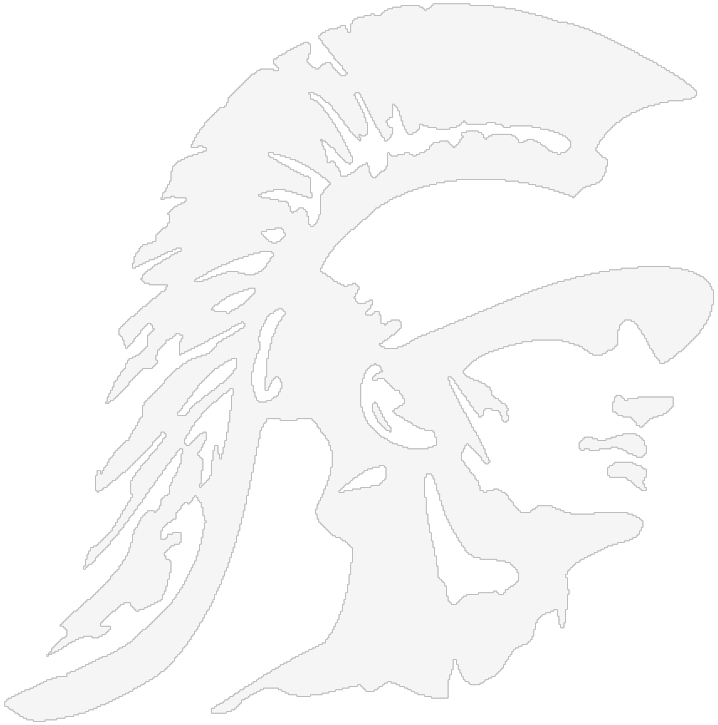
# A/B Testing at Web Search Engines

- **A/B testing** is comparing two versions of a web page to see which one performs better. You compare two web pages by showing the two variants (let's call them **A** and **B**) to similar visitors at the same time. The one that gives a better conversion rate, wins!

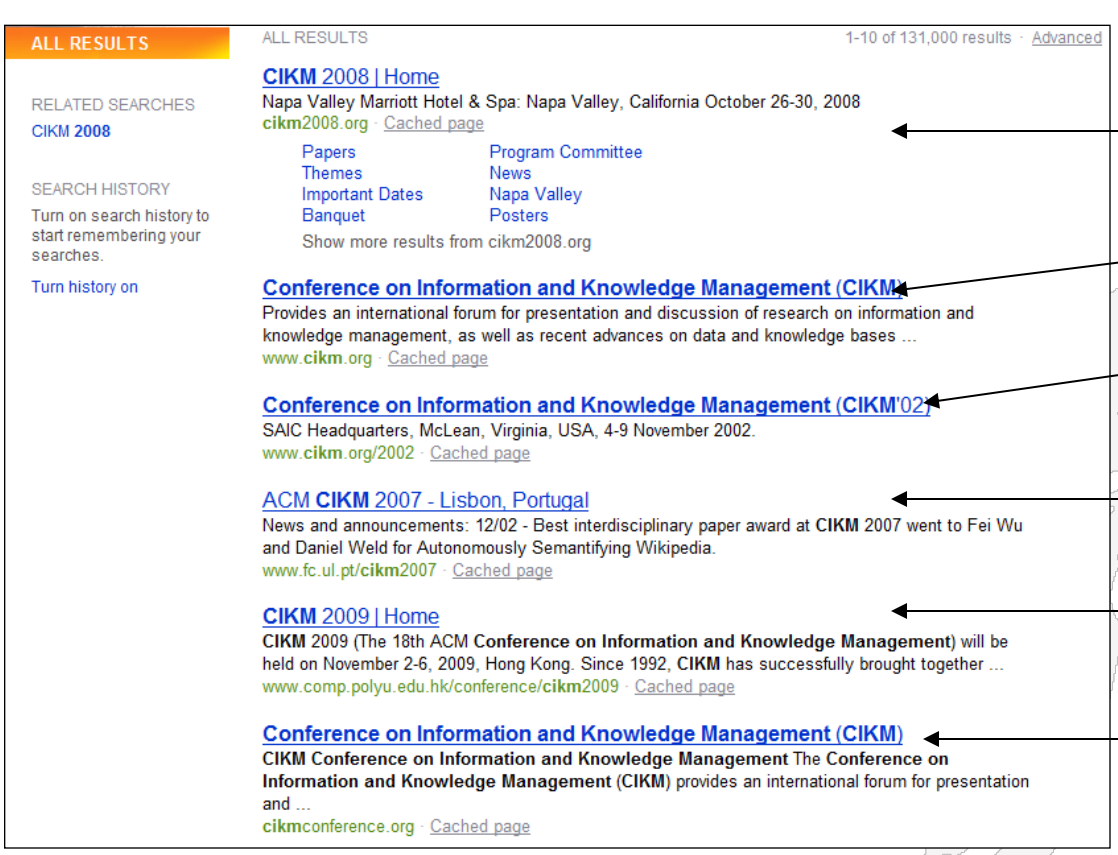
1. **Purpose:** Test a single innovation
2. **Prerequisite:** You have a large search engine up and running.
3. **Have most users use old system**
4. **Divert a small proportion of traffic (e.g., 1%) to an experiment to evaluate an innovation**
5. **Evaluate with an automatic measure like click through on first result**

- we directly see if the innovation does improve user happiness
- *This is the evaluation methodology large search engines trust the most*

# USING USER CLICKS FOR EVALUATION

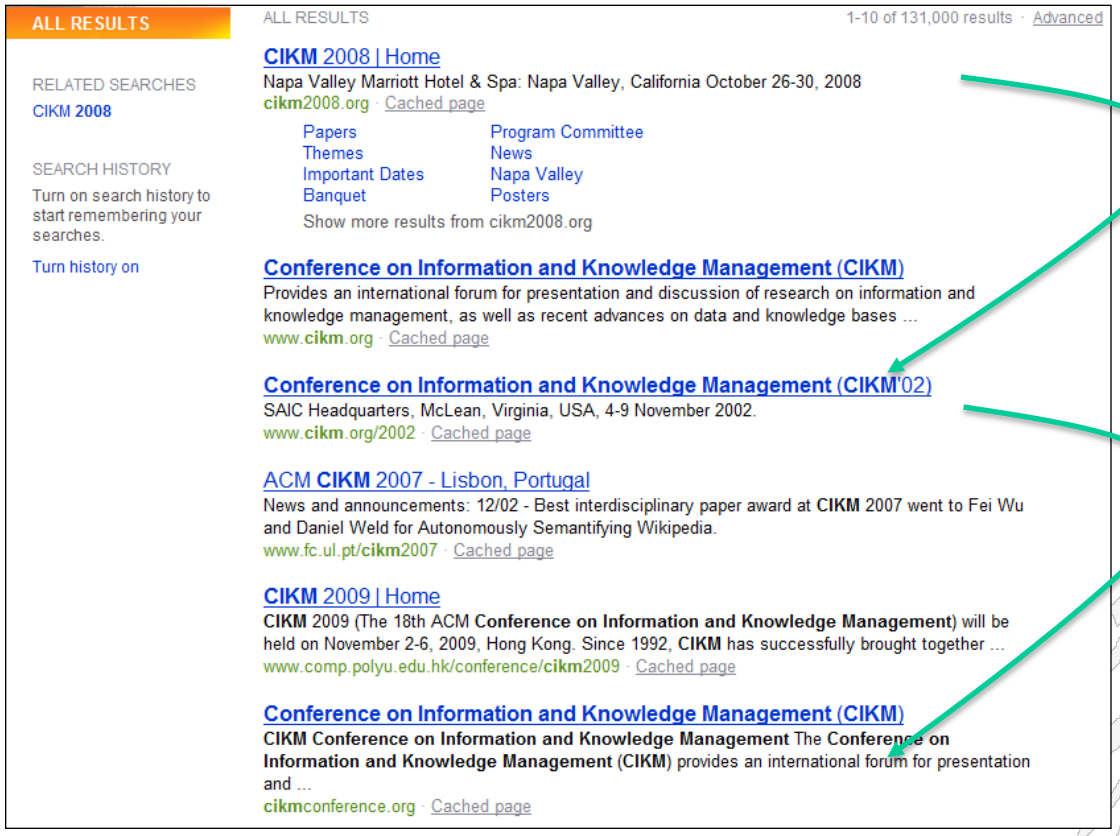


# What Do Clicks Tell Us?




There is strong position bias, so absolute click rates unreliable

# Relative vs Absolute Ratings

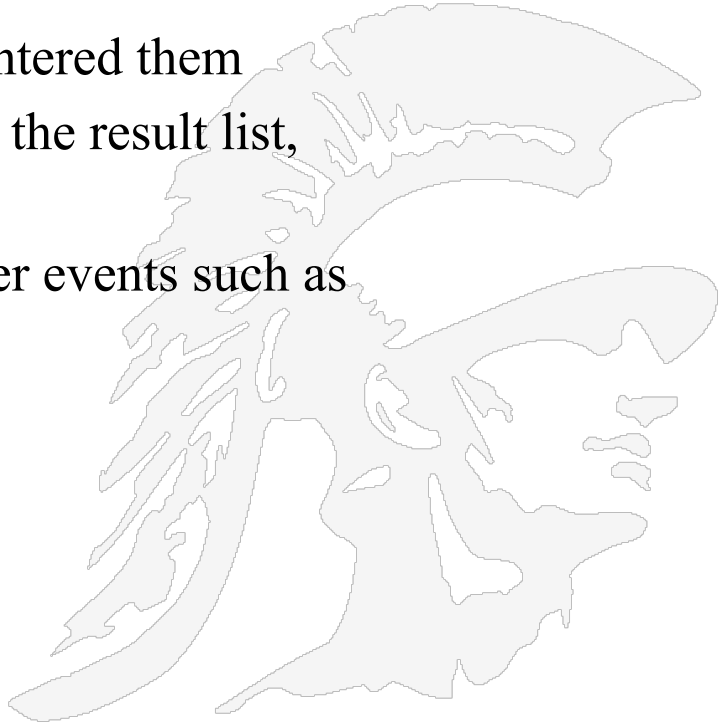



User's click sequence

Hard to conclude Result1 > Result3
Probably can conclude Result3 > Result2

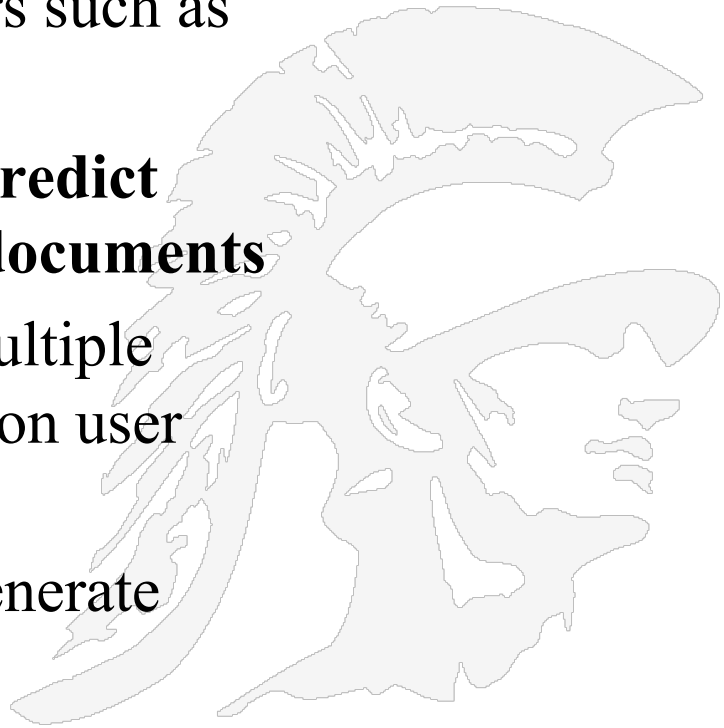
# Query Logs

- **Used for both tuning and evaluating search engines**
  - also for various techniques such as query suggestion
- **Typical contents of the query log files**
  - User identifier or user session identifier
  - Query terms - stored exactly as user entered them
  - List of URLs of results, their ranks on the result list, and whether they were clicked on
  - Timestamp(s) - records the time of user events such as query submission, clicks



# How Query Logs Can Be Used

- **Clicks are not relevance judgments**
  - although they are correlated
  - biased by a number of factors such as rank on result list
- **Can use clickthough data to predict *preferences* between pairs of documents**
  - appropriate for tasks with multiple levels of relevance, focused on user relevance
  - various "policies" used to generate preferences



# A Final Thought
# Google's Enhancements of Search Results

**Display improvements**
- immediate answers
- autocomplete anticipations

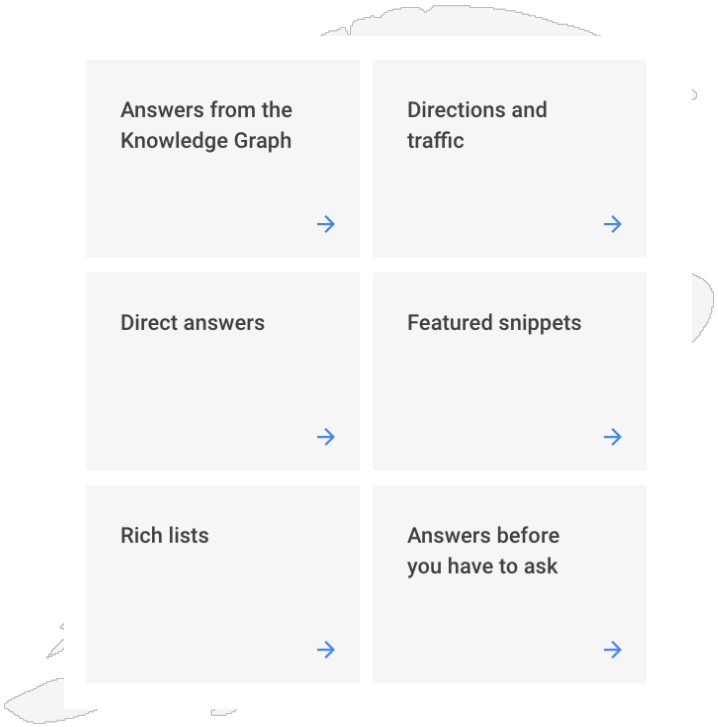
**Extensions to More Data**
- results from books
- results from news
- results from images
- results from patents
- results from air schedules

**New Input forms**
- search by voice
- search by image

**information retrieval improvements**
- snippets
- spelling correction
- translations
- People Also Ask boxes
- use of synonyms
- use of knowledge graph

**The page below discusses the many aspects that go into producing search results at Google**

**https://www.google.com/search/howsearchworks**



# Final Thought

- See wikipedia on
- https://en.wikipedia.org/wiki/Comparison_of_web_search_engines