Advertising on the Web

Advanced Search Techniques for Large Scale Data Analytics

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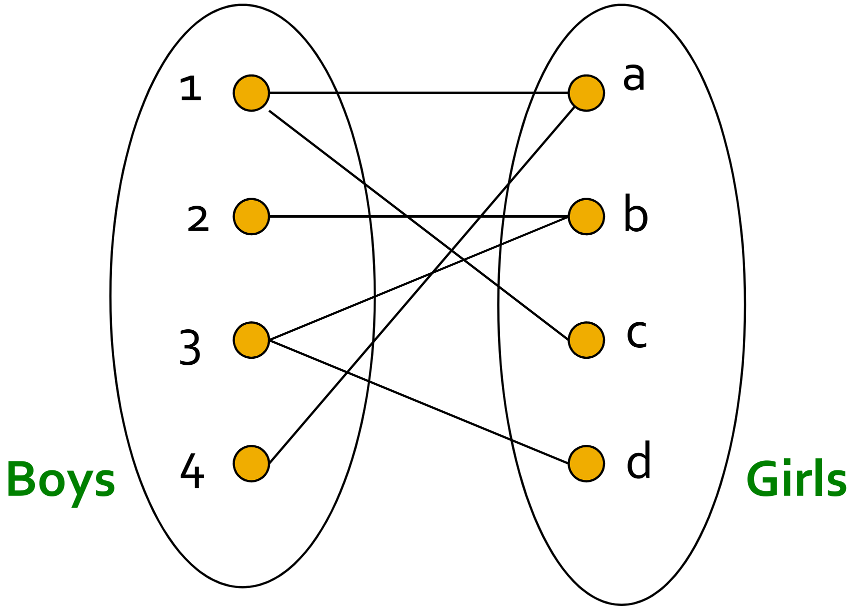
Online Algorithms

- Classic model of algorithms
  - You get to see the entire input, then compute some function of it
  - In this context, “offline algorithm”
- Online Algorithms
  - You get to see the input one piece at a time, and need to make irrevocable decisions along the way
  - **Similar to the data stream model**

Online Bipartite Matching

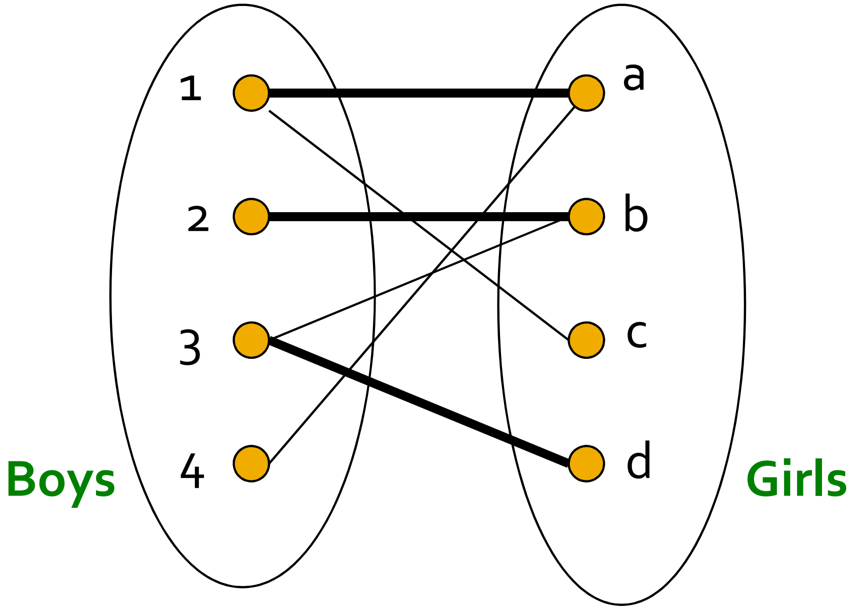
Example: Bipartite Matching



Nodes: Boys and Girls; Edges: Preferences

Goal: Match boys to girls so that maximum number of preferences is satisfied

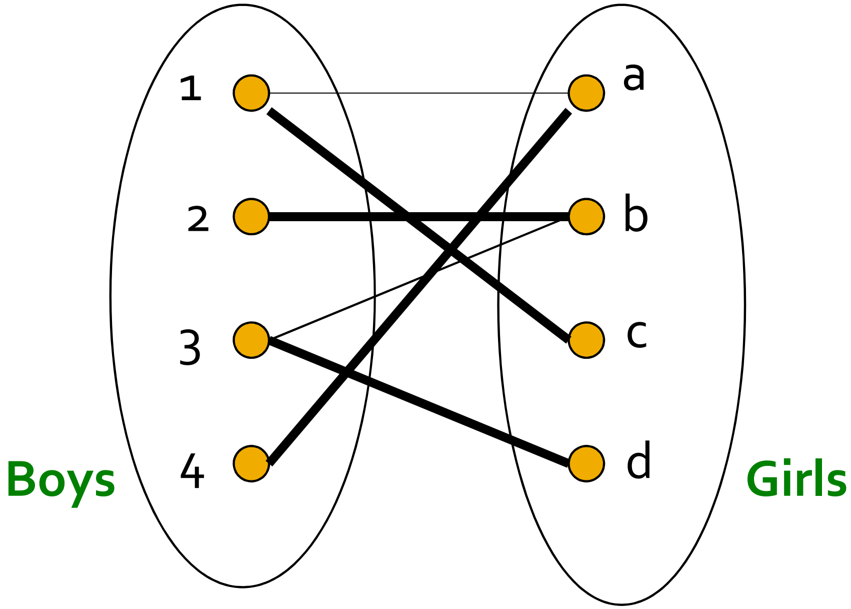
Example: Bipartite Matching



M = {(1,a),(2,b),(3,d)} is a **matching**

Cardinality of matching = |M| = 3

Example: Bipartite Matching



M = {(1,c),(2,b),(3,d),(4,a)} is a

perfect matching

Perfect matching … all vertices of the graph are matched
Maximum matching … a matching that contains the largest possible number of matches

Matching Algorithm

- **Problem: Find a maximum matching for a given bipartite graph**
  - A perfect one if it exists

- There is a polynomial-time offline algorithm based on augmenting paths (Hopcroft & Karp 1973, see http://en.wikipedia.org/wiki/Hopcroft-Karp_algorithm)

- **But what if we do not know the entire graph upfront?**

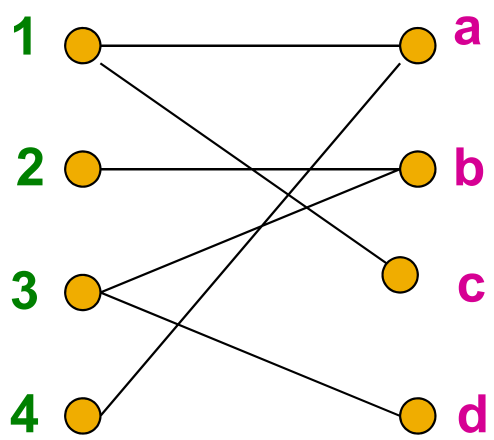
Online Graph Matching Problem

- Initially, we are given the set **boys**
- In each **round**, **one girl's choices are revealed**
  - That is, girl's **edges** are revealed
- **At that time, we have to decide to either:**
  - Pair the **girl** with a **boy**
  - Do not pair the **girl** with any **boy**

- **Example of application:**

  Assigning tasks to servers

Online Graph Matching: Example



(1,a)
(2,b)
(3,d)

Greedy Algorithm

- **Greedy algorithm for the online graph matching problem:**
  - Pair the new girl with **any** eligible boy
    - If there is none, do not pair girl
- **How good is the algorithm?**

Competitive Ratio

- For input ***I***, suppose greedy produces matching $\boldsymbol{M_{greedy}}$ while an optimal matching is $\boldsymbol{M_{opt}}$

Competitive ratio =

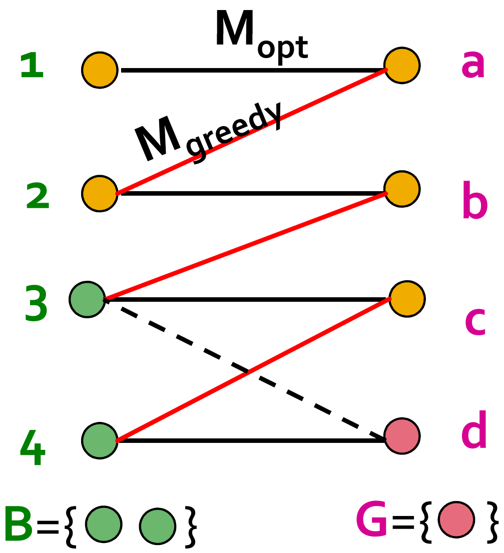
$$\min_{\text{all possible inputs } I} \left(|M_{greedy}|/|M_{opt}|\right)$$

(what is greedy's <u>worst</u> performance <u>over all possible</u> inputs *I*)

Analyzing the Greedy Algorithm

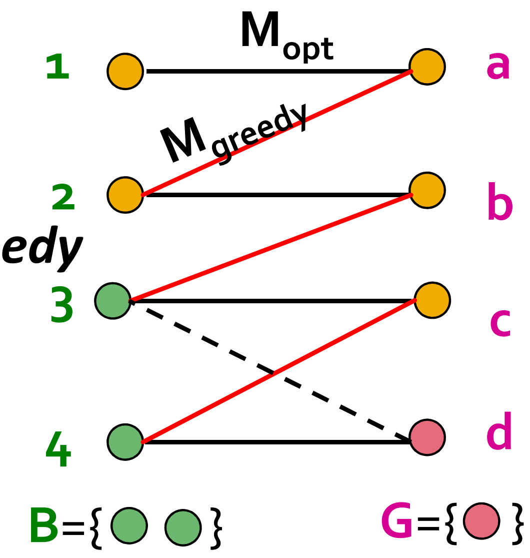
- Consider a case: $M_{greedy} \neq M_{opt}$
- Consider the set G of girls matched in M_{opt} but not in M_{greedy}
- Then every boy B adjacent to girls in G is already matched in M_{greedy}:
  - If there would exist such non-matched (by M_{greedy}) boy adjacent to a non-matched girl then greedy would have matched them
- Since boys B are already matched in M_{greedy} then

(1) $|M_{greedy}| \geq |B|$

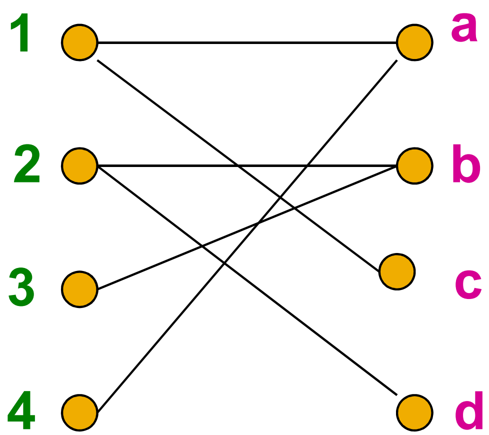


Analyzing the Greedy Algorithm

- **Summary so far:**
  - Girls G matched in M_{opt} but not in M_{greedy}
  - **(1)** $|M_{greedy}| \geq |B|$
- There are at least $|G|$ such boys ($|G| \leq |B|$) otherwise the optimal algorithm couldn’t have matched all girls in G
  - **So:** $|G| \leq |B| \leq |M_{greedy}|$
- By definition of G also: $|M_{opt}| \leq |M_{greedy}| + |G|$
  - Worst case is when $|G| = |B| = |M_{greedy}|$
- $|M_{opt}| \leq 2|M_{greedy}|$ **then** $|M_{greedy}|/|M_{opt}| \geq 1/2$



Worst-case Scenario

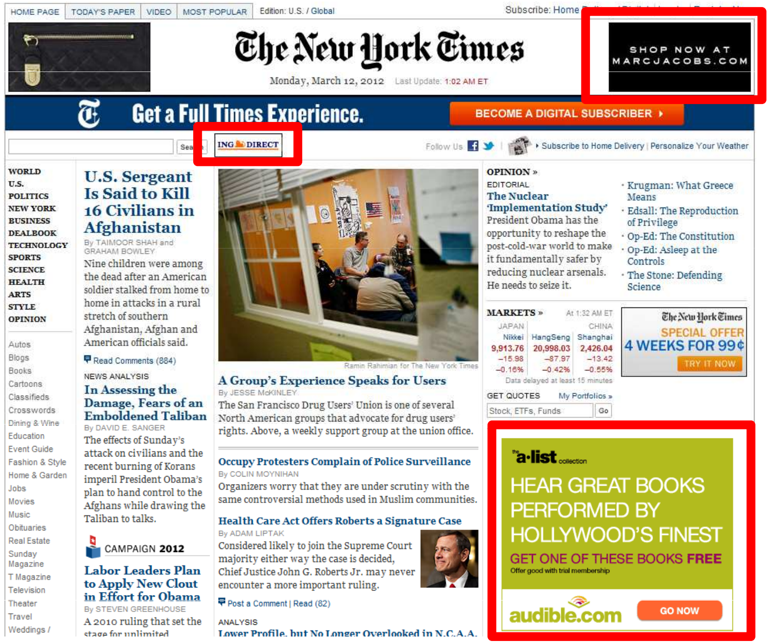


(1,a)
(2,b)

Web Advertising

History of Web Advertising

- **Banner ads (1995-2001)**
  - Initial form of web advertising
  - Popular websites charged *X*$ for every 1,000 “impressions” of the ad
    - Called “**CPM**” rate (Cost per thousand impressions)
    - Modeled similar to TV, magazine ads
  - From **untargeted** to **demographically targeted**
  - **Low click-through rates**
    - Low ROI for advertisers



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U.S. Sergeant Is Said to Kill 16 Civilians in Afghanistan

By TAIMOOR SHAH and GRAHAM BOWLEY

Nine children were among the dead after an American soldier stalked from home to home in attacks in a rural stretch of southern Afghanistan, Afghan and American officials said.

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A 2010 ruling that set the stage for unlimited

Ramin Rahimian for The New York Times

A Group’s Experience Speaks for Users

By JESSE McKINLEY

The San Francisco Drug Users’ Union is one of several North American groups that advocate for drug users’ rights. Above, a weekly support group at the union office.

Occupy Protesters Complain of Police Surveillance

By COLIN MOYNIHAN

Organizers worry that they are under scrutiny with the same controversial methods used in Muslim communities.

Health Care Act Offers Roberts a Signature Case

By ADAM LIPTAK

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ANALYSIS

Lower Profile, but No Longer Overlooked in N.C.A.A.

OPINION »

EDITORIAL

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President Obama has the opportunity to reshape the post-cold-war world to make it fundamentally safer by reducing nuclear arsenals. He needs to seize it.

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MARKETS » At 1:32 AM ET

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Nikkei	HangSeng	Shanghai
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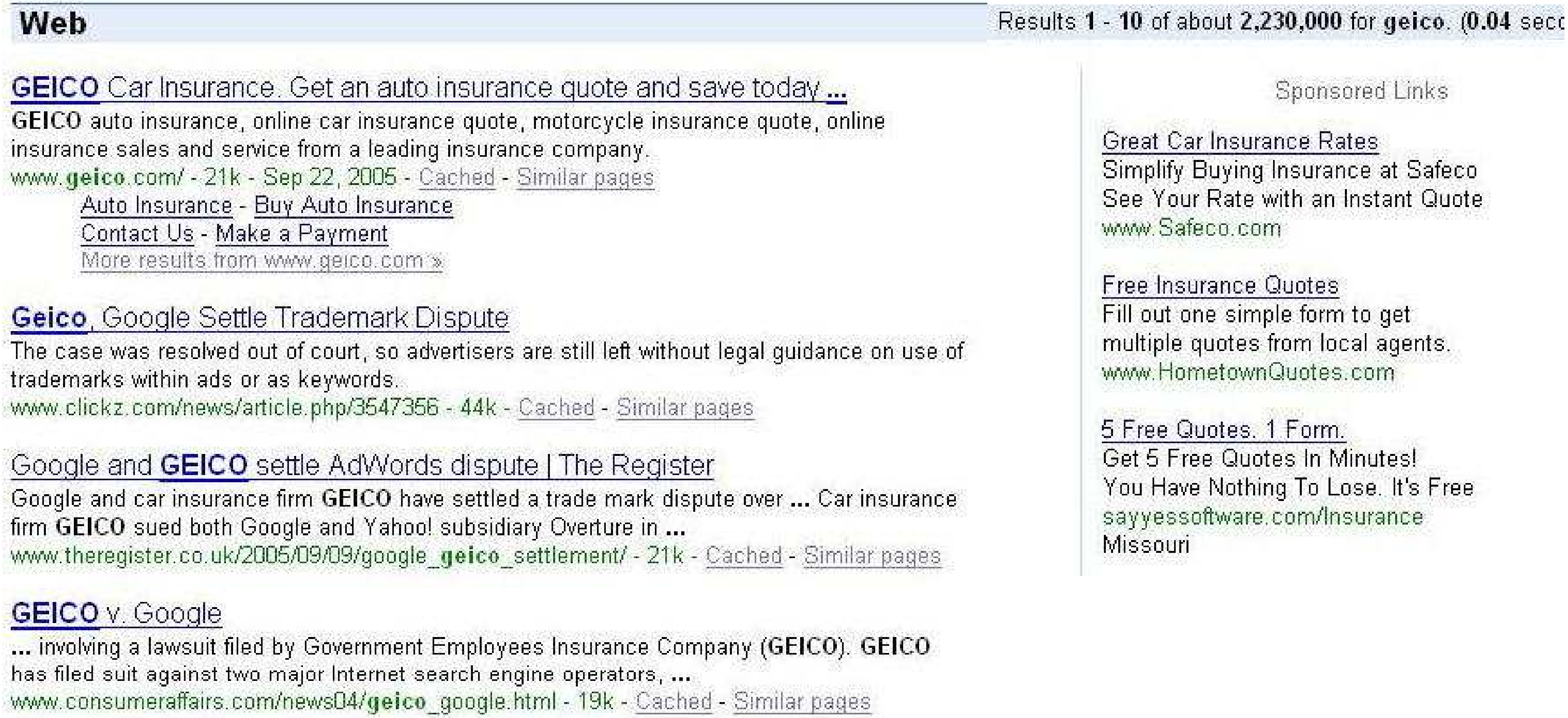
CPM…cost per *mille*

Mille…thousand in Latin

Performance-based Advertising

- **Introduced by Overture around 2000**
  - Advertisers **bid** on **search keywords**
  - When someone searches for that keyword, the **highest bidder's ad is shown**
  - Advertiser is charged only if the ad is clicked on
- Similar model adopted by Google with some changes around 2002
  - Called **Adwords**

Ads vs. Search Results



Web

Results **1** - **10** of about **2,230,000** for **geico**. (**0.04** secc

GEICO Car Insurance. Get an auto insurance quote and save today **...**

GEICO auto insurance, online car insurance quote, motorcycle insurance quote, online insurance sales and service from a leading insurance company.

www.**geico**.com/ - 21k - Sep 22, 2005 - Cached - Similar pages

Auto Insurance - Buy Auto Insurance

Contact Us - Make a Payment

More results from www.geico.com »

Geico, Google Settle Trademark Dispute

The case was resolved out of court, so advertisers are still left without legal guidance on use of trademarks within ads or as keywords.

www.clickz.com/news/article.php/3547356 - 44k - Cached - Similar pages

Google and **GEICO** settle AdWords dispute | The Register

Google and car insurance firm **GEICO** have settled a trade mark dispute over **...** Car insurance firm **GEICO** sued both Google and Yahoo! subsidiary Overture in **...**

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GEICO v. Google

... involving a lawsuit filed by Government Employees Insurance Company (**GEICO**). **GEICO** has filed suit against two major Internet search engine operators, **...**

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Web 2.0

- **Performance-based advertising works!**
  - Multi-billion-dollar industry

- **Interesting problem:**
  What ads to show for a given query?

Adwords Problem

- **Given:**
  - **1.** A set of bids by advertisers for search queries
  - **2.** A click-through rate for each advertiser-query pair
  - **3.** A budget for each advertiser (say for 1 month)
  - **4.** A limit on the number of ads to be displayed with each search query
- **Respond to each search query with a set of advertisers such that:**
  - **1.** The size of the set is no larger than the limit on the number of ads per query
  - **2.** Each advertiser has bid on the search query
  - **3.** Each advertiser has enough budget left to pay for the ad if it is clicked upon

Adwords Problem

- A stream of queries arrives at the search engine: $\boldsymbol{q_1, q_2}$, …
- Several advertisers bid on each query
- When query $\boldsymbol{q_i}$ arrives, search engine must pick a subset of advertisers whose ads are shown

- **Goal: Maximize search engine's revenues**
  - **Simple solution:** Instead of raw bids, use the "**expected revenue per click**" (i.e., **Bid*CTR**)
- **Clearly we need an online algorithm!**

The Adwords Innovation

Advertiser	Bid	CTR	Bid * CTR
A	$1.00	1%	1 cent
B	$0.75	2%	1.5 cents
C	$0.50	2.5%	1.125 cents
		Click through rate	Expected revenue

Complications: Budget

- Two complications:
  - Budget
  - CTR of an ad is unknown

- Each advertiser has a limited budget
  - Search engine guarantees that the advertiser will not be charged more than their daily budget

Complications: CTR

- **CTR: Each ad has a different likelihood of being clicked**
  - **Advertiser 1** bids \$2, click probability = 0.1
  - **Advertiser 2** bids \$1, click probability = 0.5
  - **Clickthrough rate (CTR)** is measured **historically**
    - **Very hard problem: Exploration vs. exploitation**

      Exploit: Should we keep showing an ad for which we have good estimates of click-through rate

      or

      Explore: Shall we show a brand new ad to get a better sense of its click-through rate

Greedy Algorithm

- **Our setting: Simplified environment**
  - There is **1** ad shown for each query
  - All advertisers have the same budget ***B***
  - All ads are equally likely to be clicked
  - Value of each ad is the same (=**1**)

- **Simplest algorithm is greedy:**
  - For a query pick any advertiser who has bid **1** for that query
  - **Competitive ratio of greedy is 1/2**

Bad Scenario for Greedy

- **Two advertisers A_1 and A_2**
  - $\boldsymbol{A_1}$ bids on query $\boldsymbol{x}$, $\boldsymbol{A_2}$ bids on $\boldsymbol{x}$ and $\boldsymbol{y}$
  - Both have budgets of **$4**
- **Query stream:** $\boldsymbol{x\ x\ x\ x\ y\ y\ y\ y}$
  - Worst case greedy choice: $\boldsymbol{A_2\ A_2\ A_2\ A_2}$ _ _ _ _
  - Optimal: $\boldsymbol{A_1\ A_1\ A_1\ A_1\ A_2\ A_2\ A_2\ A_2}$
  - **Competitive ratio = ½**
- **This is the worst case!**
  - **Note:** Greedy algorithm is deterministic – it always resolves draws in the same way

BALANCE Algorithm [MSVV]

- **BALANCE** Algorithm by Mehta, Saberi, Vazirani, and Vazirani
  - **For each query, pick the advertiser with the largest unspent budget**
    - Break ties arbitrarily (**but in a deterministic way**)

Example: BALANCE

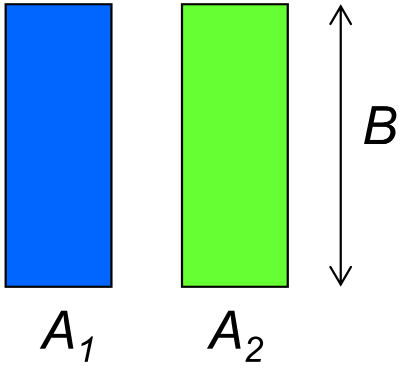
- **Two advertisers A_1 and A_2**
  - $\mathbf{A_1}$ bids on query ***x***, $\mathbf{A_2}$ bids on ***x*** and ***y***
  - Both have budgets of **$4**
- **Query stream:** ***x x x x y y y y***
- **BALANCE choice:** $\mathbf{A_1\ A_2\ A_1\ A_2\ A_2\ A_2}$ **_ _**
  - Optimal: $\mathbf{A_1\ A_1\ A_1\ A_1\ A_2\ A_2\ A_2\ A_2}$
- **In general:** For **BALANCE** on **2** advertisers **Competitive ratio = ¾**

Analyzing BALANCE

- **Consider simple case (w.l.o.g.):**
  - **2** advertisers, $\mathbf{A_1}$ and $\mathbf{A_2}$, each with budget **B** (≥1)
  - Optimal solution exhausts both advertisers' budgets

- **BALANCE must exhaust at least one advertiser's budget:**
  - **If not, we can allocate more queries**
    - Whenever BALANCE makes a mistake (both advertisers bid on the query), advertiser's unspent budget only decreases
    - Since optimal exhausts both budgets, one will for sure get exhausted
  - Assume BALANCE exhausts A_2's budget, but allocates x queries fewer than the optimal
  - **Revenue:** $BAL = 2B - x$

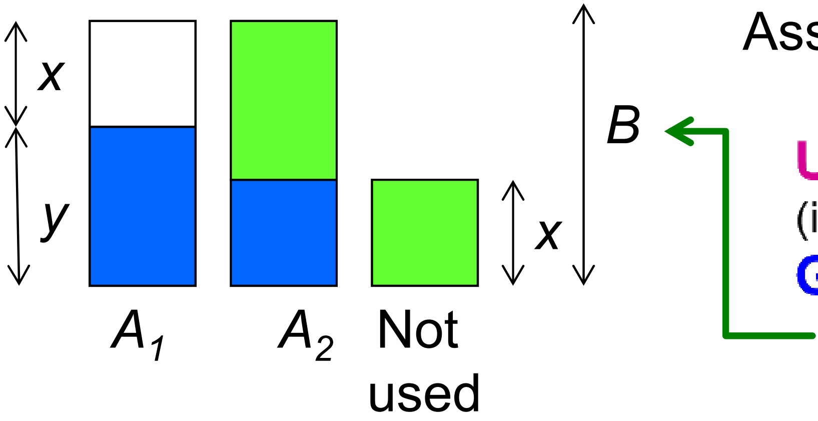
Analyzing Balance



🟦 Queries allocated to $\boldsymbol{A_1}$ in the optimal solution

🟩 Queries allocated to $\boldsymbol{A_2}$ in the optimal solution

Optimal revenue = **2B**
Assume Balance gives revenue **= 2B-x = B+y**

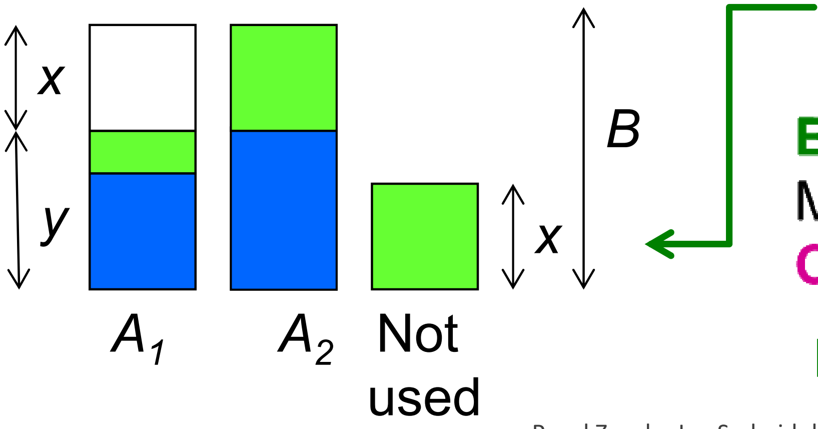


Unassigned queries should be assigned to A_2
(if we could assign to A_1 we would since we still have the budget)

Goal: Show we have **$y \geq x$**

Case 1) ≤ ½ of $\mathbf{A_1}$'s queries got assigned to $\mathbf{A_2}$
then $y \geq B/2$

Case 2) > ½ of $\mathbf{A_1}$'s queries got assigned to $\mathbf{A_2}$
then $x \leq B/2$ and $x + y = B$



Balance revenue is minimum for $x = y = B/2$

Minimum Balance revenue = $3B/2$

Competitive Ratio = 3/4

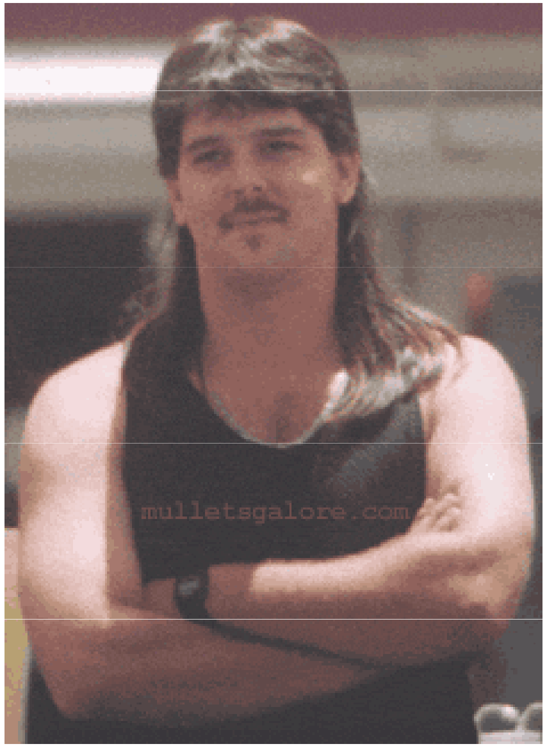
BALANCE exhausts A_2's budget

BALANCE: General Result

- **In the general case with *N* advertisers, worst competitive ratio of BALANCE is 1–1/e = approx. 0.63**
  - Interestingly, no online algorithm has a better competitive ratio!

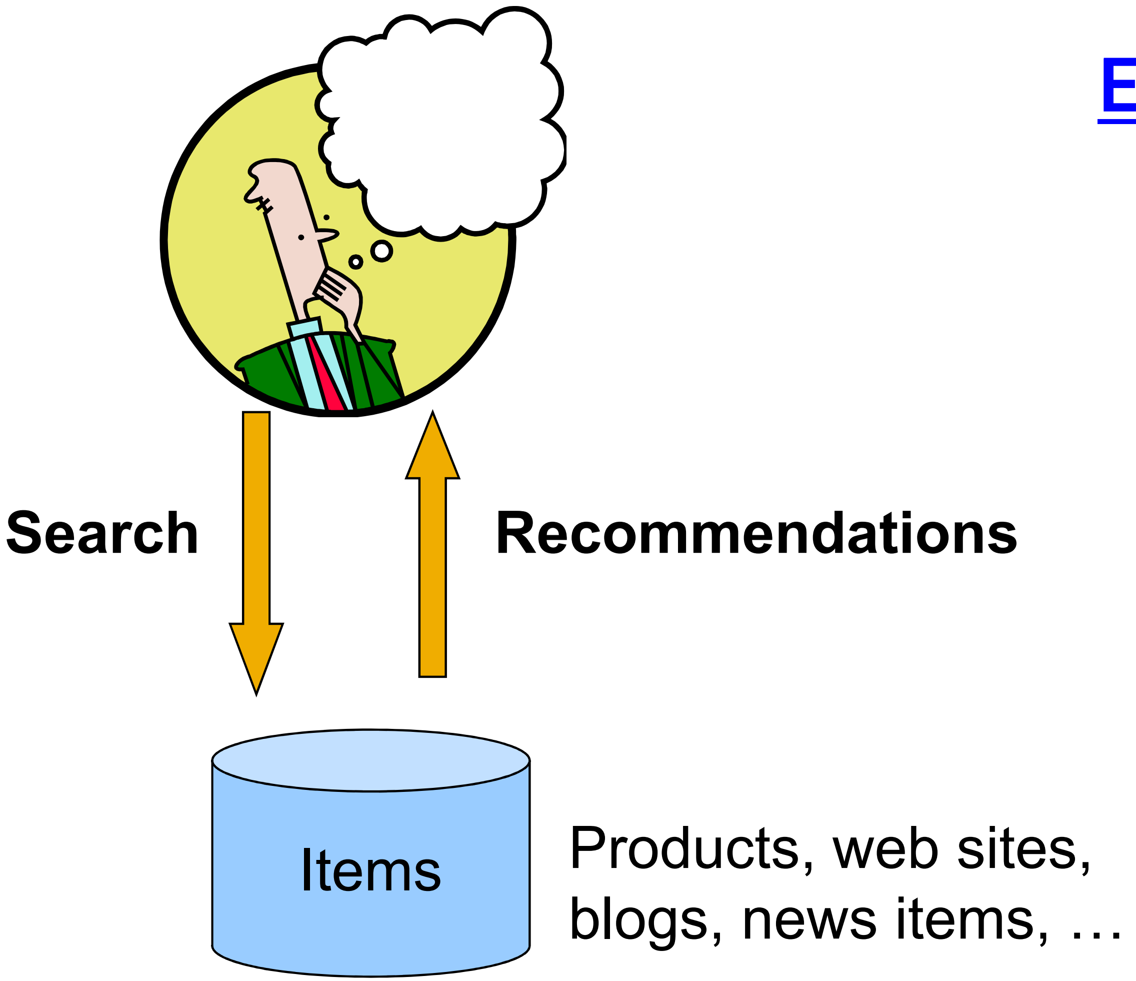
Recommender Systems: Content-based Systems & Collaborative Filtering

Example: Recommender Systems



- **Customer X**
  - Buys Metallica CD
  - Buys Megadeth CD
- **Customer Y**
  - Does search on Metallica
  - Recommender system suggests Megadeth from data collected about customer **X**

Recommendations



Products, web sites,
blogs, news items, …

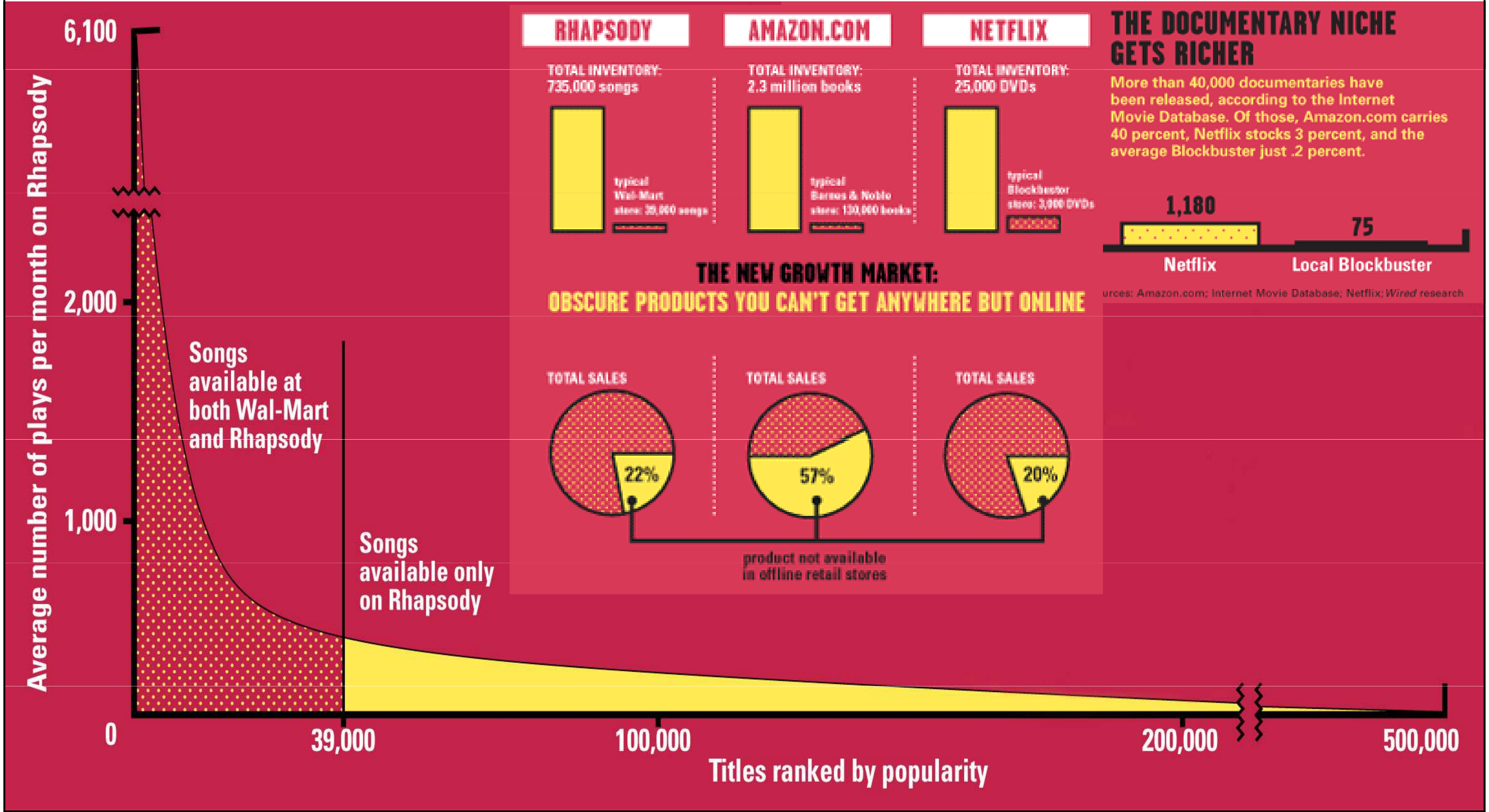
Examples:

- amazon.com
- PANDORA
- StumbleUpon
- del.icio.us
- NETFLIX
- movielens helping you find the *right* movies
- last.fm the social music revolution
- Google News
- YouTube
- XBOX LIVE

From Scarcity to Abundance

- **Shelf space is a scarce commodity for traditional retailers**
  - Also: TV networks, movie theaters,…
- **Web enables near-zero-cost dissemination of information about products**
  - From scarcity to abundance
- **More choice necessitates better filters**
  - Recommendation engines
  - How **Into Thin Air** made **Touching the Void** a bestseller: http://www.wired.com/wired/archive/12.10/tail.html

Sidenote: The Long Tail



More than 40,000 documentaries have been released, according to the Internet Movie Database. Of those, Amazon.com carries 40 percent, Netflix stocks 3 percent, and the average Blockbuster just .2 percent.

Sources: Erik Brynjolfsson and Jeffrey Hu, MIT, and Michael Smith, Carnegie Mellon; Barnes & Noble; Netflix; RealNetworks

Source: Chris Anderson (2004)

Types of Recommendations

- **Editorial and hand curated**
  - List of favorites
  - Lists of “essential” items
- **Simple aggregates**
  - Top 10, Most Popular, Recent Uploads
- **Tailored to individual users**
  - Amazon, Netflix, …

Formal Model

- ***X*** = set of **Customers**
- ***S*** = set of **Items**

- **Utility function** $\boldsymbol{u}: \boldsymbol{X} \times \boldsymbol{S} \rightarrow \boldsymbol{R}$
  - ***R*** = set of ratings
  - ***R*** is a totally ordered set
  - e.g., **0-5** stars, real number in **[0,1]**

Utility Matrix

	Avatar	LOTR	Matrix	Pirates
Alice	1		0.2	
Bob		0.5		0.3
Carol	0.2		1	
David				0.4

Key Problems

- **(1) Gathering “known” ratings for matrix**
  - How to collect the data in the utility matrix
- **(2) Extrapolate unknown ratings from the known ones**
  - Mainly interested in high unknown ratings
    - We are not interested in knowing what you don’t like but what you like
- **(3) Evaluating extrapolation methods**
  - How to measure success/performance of recommendation methods

(1) Gathering Ratings

- **Explicit**
  - Ask people to rate items
  - Doesn’t work well in practice – people can’t be bothered
- **Implicit**
  - Learn ratings from user actions
    - E.g., purchase implies high rating
  - What about low ratings?

(2) Extrapolating Utilities

- **Key problem:** Utility matrix ***U*** is **sparse**
  - Most people have not rated most items
  - **Cold start:**
    - New items have no ratings
    - New users have no history

- **Three approaches to recommender systems:**
  - **1)** Content-based
  - **2)** Collaborative
  - **3)** Latent factor based

Content-based Recommender Systems

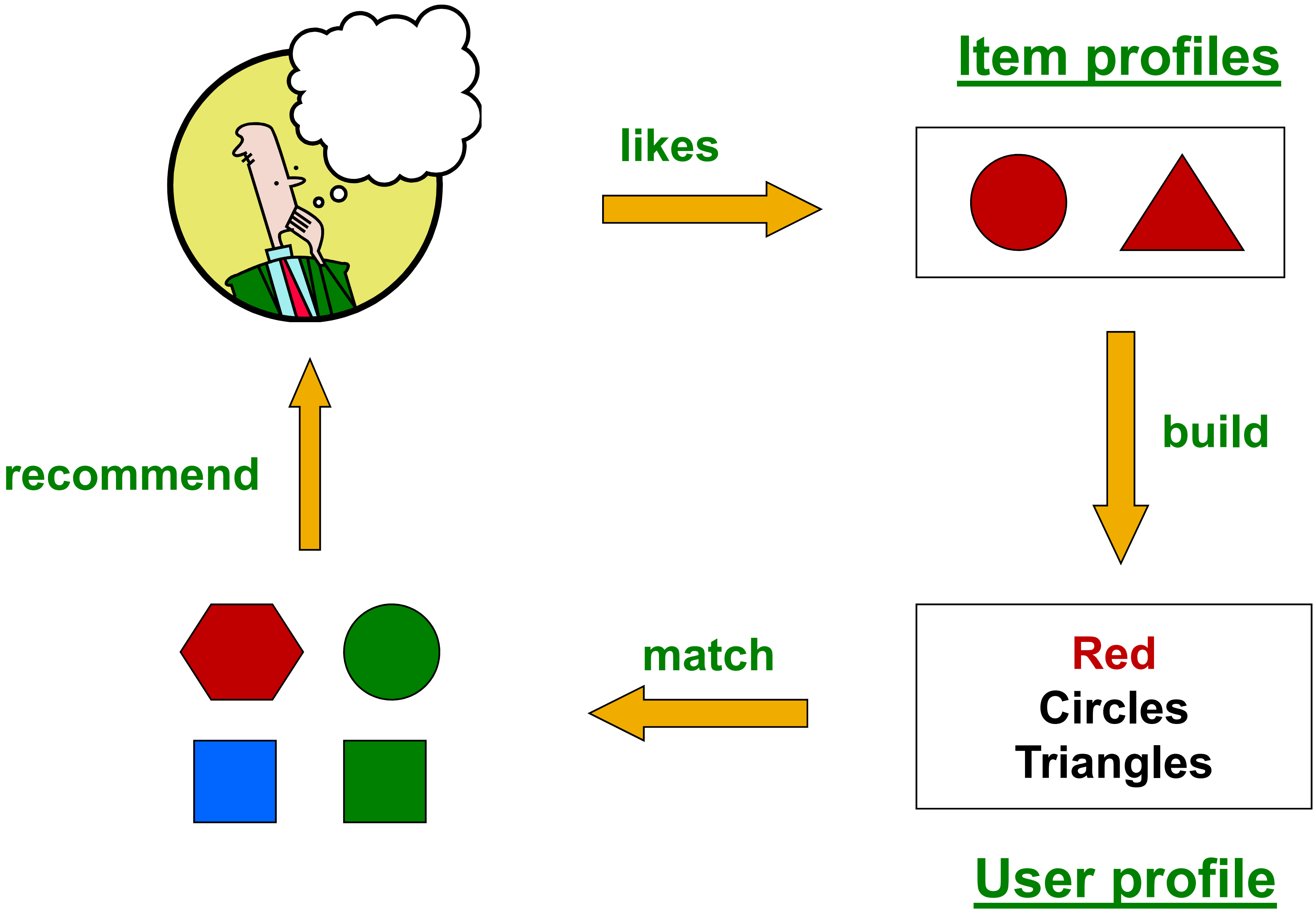
Content-based Recommendations

- **Main idea:** Recommend items to customer ***x*** similar to previous items rated highly by ***x***

Example:

- **Movie recommendations**
  - Recommend movies with same actor(s), director, genre, …
- **Websites, blogs, news**
  - Recommend other sites with “similar” content

Plan of Action



Item profiles

likes

build

Red
Circles
Triangles

User profile

match

recommend

User Profiles and Prediction

- **User profile possibilities:**
  - Weighted average of rated item profiles
  - **Variation:** weight by difference from average rating for item
  - …
- **Prediction heuristic:**
  - Given user profile ***x*** and item profile ***i***, estimate

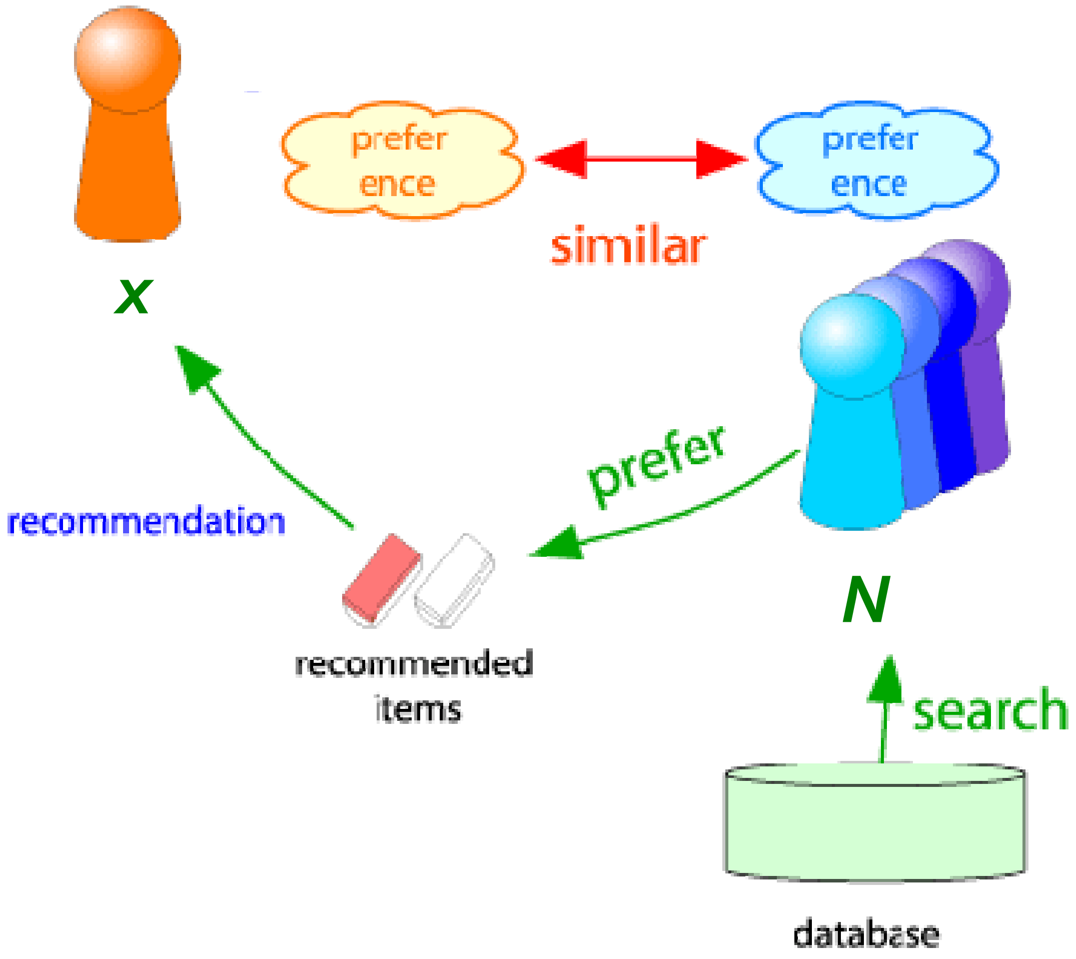
$$u(\boldsymbol{x}, \boldsymbol{i}) = \cos(\boldsymbol{x}, \boldsymbol{i}) = \frac{\boldsymbol{x} \cdot \boldsymbol{i}}{||\boldsymbol{x}|| \cdot ||\boldsymbol{i}||}$$

Collaborative Filtering

Harnessing quality judgments of other users

Collaborative Filtering

- Consider user ***x***
- Find set ***N*** of other users whose ratings are "**similar**" to ***x***'s ratings
- Estimate ***x***'s ratings based on ratings of users in ***N***



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prefer ence
similar
x
recommendation
prefer
N
recommended items
search
database