Placement in Search Engines

- With the increased economic impact of the Web, it is crucial for businesses to have high Web visibility.
- With the absolute reliance on search engines for finding online resources, Web visibility translates into attaining high placement in search engines’ results for queries related to the business.
- With searchers often browsing just one result page per query, “high placement” means showing up among the first 10 results of the relevant queries:
  - Preferably “above the fold”
  - ... and being #1 would be great, thank you.
Heat Maps

Warm colors indicate higher CTR (click-through rate)

Means of Achieving High Placement

1. Being a near-unanimous top page for a query, having appropriate links and anchor text from the “public”
   - Very difficult in competitive settings
2. Designing “search engine friendly” sites, carefully choosing text, and developing connectivity
   - Search engine optimization (SEO) firms can help
   - SEO is a thriving multi-billion dollar business
3. Spamming (both text and links)
   - Some “black hat” SEOs also resort to this
4. Advertising with the engines, and having your message shown alongside the algorithmic search results
   - Spending money to gain mindshare and visibility
Online Advertising: Sponsored Search

textual ads served on search results pages, triggered by query terms on which advertisers bid

Sponsored Search Market Size

Search Ad Spending Worldwide, 2013-2019

<table>
<thead>
<tr>
<th>Year</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>531.6</td>
<td>570.18</td>
<td>615.8</td>
</tr>
<tr>
<td>2014</td>
<td>581.59</td>
<td>593.87</td>
<td>615.81</td>
</tr>
<tr>
<td>2015</td>
<td>591.58</td>
<td>510.88</td>
<td>510.88</td>
</tr>
</tbody>
</table>

Note: Includes advertising that appears on desktops and laptop computers as well as mobile phones and tablets; paid listings, contextual text links and paid inclusion.

Source: eMarketer, March 2015

Net Search Ad Revenues Worldwide, by Company, 2013-2015 (billions, % change and % of total)

<table>
<thead>
<tr>
<th>Company</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google</td>
<td>$32.63</td>
<td>$36.42</td>
<td>$44.64</td>
</tr>
<tr>
<td>Microsoft</td>
<td>$2.19</td>
<td>$2.91</td>
<td>$3.45</td>
</tr>
<tr>
<td>Baidu</td>
<td>$3.79</td>
<td>$5.35</td>
<td>$7.18</td>
</tr>
<tr>
<td>Yahoo!</td>
<td>$1.70</td>
<td>$1.70</td>
<td>$1.70</td>
</tr>
<tr>
<td>Sohu</td>
<td>$0.18</td>
<td>$0.32</td>
<td>$0.52</td>
</tr>
<tr>
<td>Total spending</td>
<td>$59.16</td>
<td>$70.18</td>
<td>$81.58</td>
</tr>
</tbody>
</table>

Note: Includes advertising that appears on desktops and laptop computers as well as mobile phones and tablets; net ad revenues after company pays traffic acquisition costs. Excludes private offers, promotions and private placements.

Source: company reports, eMarketer, March 2015

The Online Advertising Market

- Global total ad spend 2014: ~$537B
- Global online ad spend 2014: ~$121B
- Internet advertising is growing faster than old media advertising (radio, TV, newspapers & magazines, mail, outdoors)
  - 16% YOY in 2014-2016 compared to less than 3% YOY for “old advertising”
- Online advertising budgets still lagging in proportion to time spent online, which is growing fast at the expense of old media
  - Seen as a driver to continued growth of online advertising market

The Online Advertising Market

- Traditional advertising:
  - Few, expensive opportunities
  - Targeting en-masse, by immediate context only
  - Difficult to measure effectiveness

- Internet advertising:
  - Tens of billions of opportunities daily
  - Open to personalization and fine-grained targeting
  - Effectiveness is measurable: can measure click-through rates as % of impressions, and conversions as % of clicks

Online Advertising: Display Ads

Graphical elements (e.g. banners) of standard sizes, served on publisher pages, mainly targeting audience demographics

- Guaranteed delivery (GD): advertiser buys a display campaign months in advance, requesting ## impressions to certain demographics in a given time period; publisher pays fine for under-delivery

- Non-guaranteed delivery (NGD): advertiser bids in real time for impressions through an ad exchange, with no guarantees that ads will be shown
Online Advertising: Contextual Ads (a.k.a. Content Match)

- Textual ads served on third-party (“publisher”) pages, triggered by content of page on which advertisers bid.

Online Advertising: Content Marketing

- Recommendations of promoted content, served by a content discovery service, (mainly) on article pages of online publishers.
- Content promoter pays when the recommendation is clicked by a user (CPC).
- Payment is shared between the discovery service and the publisher.
Online Advertising: Native Ads

- The latest trend: ads and sponsored content that share format with - and are embedded within - the non-ad items around the,
- Often sold in cost-per-click models
- Still evolving

Internet Advertising Pricing Models

1. Cost per Impression, called CPM for "Cost per Mille", (Mille = 1000 impressions) – advertiser pays for ad to be shown
   - Main model for display advertising
2. Cost per Click – advertiser only pays when ad is clicked by user
   - Main model for sponsored search, contextual ads and content marketing
3. Cost per Action – advertiser only pays when the user's interaction with the ad is followed by some transaction (not necessarily purchase or conversion)
   - Special cases: cost per install (of mobile app); cost per social share
4. Cost per View – advertiser pays when user views a video, or some portion thereof
5. ...
Online Advertising Business Models

CPM – Cost per 1000 Impressions

- Advertiser is charged whenever ad is shown
- Mainly used for building brand recognition
- Very simple mechanism
  - But requires trust between publisher and advertiser
- Risk is mostly on the advertiser (will pay publisher whether campaign is effective or not)
- Not spammable (but subject to ad blocking & injection)
- High algorithmic complexity due to mixture of guaranteed and non-guaranteed contracts

Search Advertising Business Models

CPC – Cost per Click

- The main business model of search engines since the turn of the century
  - Transformed the search industry into a profitable business
- Still a relatively simple mechanism
- Shared risk/win-win situation – the success of an ad campaign is in the best interest of all parties (search engine, advertiser)
  - On the search page itself, the engine is the publisher
- Trackable by all parties, which seems to overcome the trust issue
  - However, invalid clicks are an issue
CPC Figures (Q3 2012)


CPC Issue: Invalid Clicks

- Loose definition: superfluous clicks on an ad-impression
  - Causes increased expenses and lower ROI to the advertiser (and increased revenue to search engines/publishers)
  - Click fraud: clicks being done maliciously, with intent to increase the costs of an advertiser (competitive gain) or the profits of the publisher (financial gain)
    - Sometimes by “click-bots” or other types of software
- Search engines don’t charge advertisers for clicks that are determined to be invalid
  - However, the intent behind a click is not easily determined
Click Fraud is a Big Deal

- Independent click-tracking companies claim that in some ad campaigns the percentage of fraudulent clicks was around 30%
  - That’s certainly not a typical number
- The search engines claim that the percentage is much smaller, but do not report numbers
- The engines take click fraud seriously and have established engineering teams tasked to the problem
  - Pattern recognition, data mining and human analysis is at work
  - But advertisers say the engines aren’t doing enough, and need to act with more transparency
- Both Yahoo and Google have settled class action law-suits in 2006 by offering tens of millions of dollars in compensation to advertisers who claimed they were charged for fraudulent clicks

Online Advertising Business Models

CPA – Cost per Action/Acquisition

- Also known as cost per conversion
- Ad-tech company gets a fee only if the user, upon clicking an ad, completes some transaction at the advertiser’s site
  - Doesn’t necessarily mean that the user buys something
- Amazon were the among the pioneers of this model by paying referral fees when revenue was generated
- Risk is all on the ad-tech company
- Complex mechanism that requires the advertiser to share some business data with ad tech company
  - But more difficult to spam
Online Advertising Business Models

<table>
<thead>
<tr>
<th></th>
<th>Popularity</th>
<th>Risk borne by</th>
<th>Simplicity</th>
<th>Spammable</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPM</td>
<td>Exclusive model in mid-90s; main model in use today for display advertising</td>
<td>Advertiser</td>
<td>Simple</td>
<td>No, but requires trust</td>
</tr>
<tr>
<td>CPC</td>
<td>The most popular model in search since the early 2000s</td>
<td>Shared by all parties</td>
<td>Still pretty simple</td>
<td>Yes</td>
</tr>
<tr>
<td>CPA</td>
<td>Still small, but on the rise</td>
<td>Ad-tech</td>
<td>No</td>
<td>No, but requires sharing of business data</td>
</tr>
</tbody>
</table>

Sponsored Search

Textual ads served on search results pages, triggered by query terms on which advertisers bid

Typical model is CPC (cost per click):
Advertiser pays engine once a user clicks on ad

Multiple slots on page – higher slots receive more attention (and clicks) and are thus preferred by advertisers
Multi-Item Auctions

- There are $k$ items for sale, and $n$ bidders compete for them
  - In our case, $k$ ad slots per query; $n$ advertisers
- Each bidder $i$ has a private valuation $v_{ij}$ for item $j$ – how much is it worth for bidder $i$ to win item $j$
- Each bidder $i$ reports to the auctioneer a bid $b_{ij}$ for item $j$
- The auctioneer, through a mechanism (=algorithm):
  1. Assigns the items to the bidders
  2. Charges the winning bidders by some payment amount (no greater than their bids)
- The mechanism is usually designed to maximize some function
  - Social welfare – sum of bidder utilities (valuations minus payments)
  - Sum of payments to the auctioneer

Auction Mechanisms

In order for the players (=bidders) to act rationally, the auctioneer (search engine, in this case) must disclose the mechanism:

1. How bids are collected
2. How goods (ad slots per query) are awarded
3. How much are winners charged (per click on a particular ad impression)

Definition: a mechanism is considered truthful (incentive-compatible) if truth-telling is a dominant strategy for each player

- Players cannot increase their utility by not disclosing their true valuations of the available goods to the auctioneer, i.e. their utility is maximized when $b_{ij}=v_{ij}$
- Crucial property if auctioneer aims to maximize social welfare
**Single Item Auction Mechanisms**

- First-Price Auction: award the item to the highest bidder, and charge the winning bid
  - First price auctions are not truthful and suffer from “winner’s remorse”

- Second-Price Auction: award the item to the highest bidder, and charge the minimal bid it could have given while maintaining its victory
  - Namely, the second highest bid
  - Truthful!

---

**Toy Example of a CPC Auction**

- A search engine auctions a single ad per query, and assigns the ad slot to the highest bidder

- 2 advertisers (A,B) compete for the ad spot of some query Q

- A gains $v_A$ when his ad is clicked; B gains $v_B$ per click
  - Assume $v_A > v_B$ (the value of a click is higher for A)

- When multiple rounds of a first-price auction are played, the game will stabilize when A bids $v_B$ for the ad
  - Exactly the outcome of the corresponding second-price auction
Toy Example (cont.)

- The engine aims to maximize its expected revenue per ad placement.
- Assume A’s ad is clicked by users with probability $P_A$ and B’s ad is clicked with probability $P_B$.
- In a first-price auction, the engine is better off awarding the ad slot to A whenever $P_A \times \text{bid}(A) > P_B \times \text{bid}(B)$.
- Over multiple rounds, the game will stabilize with A winning only if $P_A \times v_A > P_B \times v_B$, in which case A’s last bid will be $v_B \times P_B / P_A$.
- Again, exactly the second-price outcome.

Multi-Slot Sponsored Search

- In practice, search engines auction multiple (k) ad slots per query.
- Let there be n advertisers competing for the slots, and denote the ad of advertiser i by $a_i$.
- Assume that the CTR (click-through rate) on $a_i$ in slot s is a product of some inherent relevance of the ad, $r_i$, and the prominence of slot s, $p_s$.
  - $\text{CTR}_{i,s} = r_i \times p_s$.
- Also assume $p_{s-1} > p_s$, i.e. the higher the slot, the higher the CTR.
Generalized Second Price Auction

- Each advertiser submits a single (secret) bid $b_i$, preferring the highest slot this bid can buy.
- The engine ranks the bids by $b_i r_i$, and assigns the $k$ slots according to those ranks.
- Assume advertisers are numbered according to their bid*relevance ranks, i.e. $b_1 r_1 > b_2 r_2 > \ldots > b_n r_n$.
- Each advertiser is charged according to the minimum bid that would have secured the same position, i.e. for $s=1 \ldots k$, advertiser $s$ is charged $b_{s+1} r_{s+1} / r_s$.

Issues with GSP Auctions

- In second-price auctions of a single item, truth telling is a dominant strategy, i.e. players will benefit from truth-telling.
- In generalized second price auctions this is no longer the case. In particular, two types of “cheating” arise:
  - Under-bidding: if the CTRs of neighboring slots are nearly the same (i.e. $p_s \approx p_{s+1}$), players may want to lower their bids and be assigned the $s+1$ position at lower cost.
  - Vindictive bidding: a player at rank $s>1$ may raise his bid while maintaining the same position (i.e. without winning spot $s-1$)
    - Own charge per click won’t change.
    - But the charge of the $s-1$’th ranked player – a competitor – will increase!
    - [possible in a second price auction with two players too]
The VCG Mechanism: Socially Optimal Auctioning of Multiple Items

- VCG: Vickrey – Clarke - Groves

- Let there be \( n \) players, and a space \( A \) of alternatives - e.g. all ways to assign the \( k \) ad slots among the \( n \) players, i.e. \(|A| = n!/(n-k)!\)

- Let each player \( i \) have a valuation \( v_i(a) \) for every alternative \( a \in A \); denote by \( v_i = \{v_i(a) | a \in A\} \) the valuation profile of player \( i \)

- Let \( f \) be the “social welfare” function, which finds the alternative that maximizes the overall value gained by the players:
  \[
  f: (v_1, v_2, \ldots, v_n) = \max_{a \in A} \sum_{i} v_i(a)
  \]

- The VCG mechanism, given \( n \) valuation profiles, picks the social welfare alternative \( a^* \) (defined above), and charges each player the payment \( p_i \) as follows:
  \[
  p_i = \max_{b \in A} \sum_{x \neq i} v_x(b) - \sum_{x \neq i} v_x(a^*)
  \]

The VCG Mechanism (cont.)

- VCG is truthful (incentive compatible)!

- Examining the payments:
  \[
  p_i = \max_{b \in A} \sum_{x \neq i} v_x(b) - \sum_{x \neq i} v_x(a^*)
  \]

- \( p_i \) is surely non-negative, as the other players can only gain more when \( i \) is ignored by the social welfare function

- Examining player \( i \)’s gain:
  \[
  v_i(a^*) - p_i = \sum_{j \neq i} v_j(a^*) - \max_{b \in A} \sum_{x \neq i} v_x(b)
  \]

  Will be non-negative whenever all players’ valuations of all alternatives in \( A \) are non-negative
The VCG Mechanism (cont.)

- While having the advantage of being truthful, VCG has several drawbacks:
  - More expensive to compute, hence less appropriate for online or real-time auctions
  - Lower revenues for the auctioneer
  - Very difficult to explain to players
- Therefore, GSP is used in practice

Multi Query Online Game, Simplified

- N advertisers (players), M queries, single ad slot per query
- Assume that the number of submissions per query is known
  - \( t_q \) – number of submissions of query \( q \)
- \( b_{i,q} \) – bid of player \( i \) on query \( q \)
- Assume a mechanism where advertisers are charged their bid (first price auction) per impression (i.e. not per click)
- \( B_i \) – budget of advertiser \( i \) (bound on total spending)
Online Game, Simplified (cont.)

The linear program to solve for engine revenue maximization:

\[
\text{Max } \sum_{i,q} x_{i,q} \cdot b_{i,q} \\
\text{Subject to } \\
\forall i \sum_q x_{i,q} \cdot b_{i,q} \leq B_i \\
\forall q \sum_i x_{i,q} \leq t_q
\]

Let \( \beta_i \) denote the derivative of the objective function with respect to \( B_i \), i.e. if \( B_i \) were to grow by \( \Delta \), the optimal objective function would grow by \( \Delta \beta_i \).

In the optimal solution, the engine allocates query \( q \) to the bidder with maximal \( b_{i,q}(1- \beta_i) = b_{i,q} - b_{i,q} \beta_i \)

Algorithmic Game Theory

New and exciting area of research tying Computer Science and Game Theory

Motivated in large part by the Internet, which is operated by the strategic interaction of many independent entities

Studies the efficient computation of equilibria in games and auction mechanisms

Studies the inefficiencies introduced by selfish (rational) agents reaching equilibria vs. centralized policies acting for the “common good”

So-called “Price of Anarchy”

Easily merits a course of its own!