The Ad Exchange Game - Specification Version 1.4

Mariano Schain Yishay Mansour

January 31, 2015

Abstract

Brand advertising through web display ads, aimed at driving up brand awareness and purchase intentions, is the cornerstone of the Internet economic ecosystem. The ever increasing penetration of the Internet and recent technological advances allow for cost effective targeting and gave rise to an array of new interconnected entities - e.g., the pivotal Ad Exchange (AdX) - offering added value to publishers and advertisers.

We specify the AdX game for the Trading Agent Competition (TAC), reflecting the challenges faced by an Ad Network as it bids for display ads opportunities. The key conflict that Ad Networks face is to fulfill advertising contracts at minimum cost while sustaining and attracting advertisers by achieving high quality targeting. Therefore, efficient marketing effectiveness is the main concern of an agent implementing the Ad Network strategy.

Preface - A Concise Description of the AdX Game

We briefly describe the key elements of the game and related essential details that may be used to quickly start playing:

In the AdX game each competitor implements a software agent that performs the bidding strategy of an Ad Network (AdNet), while a game server simulates the behavior of users, web sites, advertisers, and an Ad Exchange. Advertising campaigns are created by advertisers to promote their brands, and the AdNet's role is to carry out such advertising campaigns. Each campaign targets a designated subset (*Market Segment*) of the Internet user's population and has a predefined required number of impressions (*Reach*) and duration. Each campaign is auctioned among the competing AdNets, and is allocated to the AdNet that bids to execute the campaign at the lowest cost [1] to the advertiser (*Budget*).

An AdNet carries out a campaign by bidding for impression opportunities at the Ad Exchange (*AdX*). Each impression opportunity is the result of an Internet User (*User*) visiting a Web Site (*Publisher*), and is allocated by the AdX to the highest bidding AdNet. Upon the termination of a campaign, the AdNet gets paid by the Advertiser an amount that depends on the Budget and the actual Reach achieved [2]. Deducting from this amount the price paid through the AdX for the user's impressions results in the AdNet's net income related to the campaign.

The game server simulates up to 60 days.[3] A new campaign is announced and auctioned every day.[4]. Each day, every user[5] visits one or more Publisher's web sites (The sites visited are randomly chosen according to the user's attributes and the Publishers' predefined orientation), and the resulting impression opportunities are handled by the AdX and assigned to AdNet's campaigns. The ability of an AdNet to access the user attributes related to an impression opportunity (such attributes highly influence the relevance of the impression to a campaign and as a result its value to the AdNet and the related bid) is determined by the current User Classification Service (*UCS*) level of the AdNet. The AdNets bid daily for the UCS level. Upon game termination, the total score of each competing AdNet is the sum of campaign related net income deducted by the accumulated UCS cost. The game entities and relations are illustrated in Figure 2.

The competing AdNetwork agents communicate with the game server over the Internet. The server communication details (address, ports, and additional agent information such as the agent name and password) are detailed in a dedicated configuration file used at agent runtime. Once an agent is registered at the server (using the server's web interface), it may join and take part in games.

The game's daily flow (illustrated in Figure 1) is the following: The first message received on day 0 is a campaign-allocation message - each agent gets allocated a random campaign (of random targeted audience and reach, scheduled to start on day 1) to carry out. The first message received by agents on a typical day n (where $n > 1$) is a

[1] With some restrictions, to be detailed later.

[2] The *Quality Rating* of the AdNet - its ability to execute a campaign as contracted - is also updated and used in the campaign allocation auction.

[3] This figure, and many other game parameters are configurable through a configuration file.

[4] Therefore, a competing AdNet may be executing several campaigns simultaneously!

[5] A population of 10000 users is simulated by default.

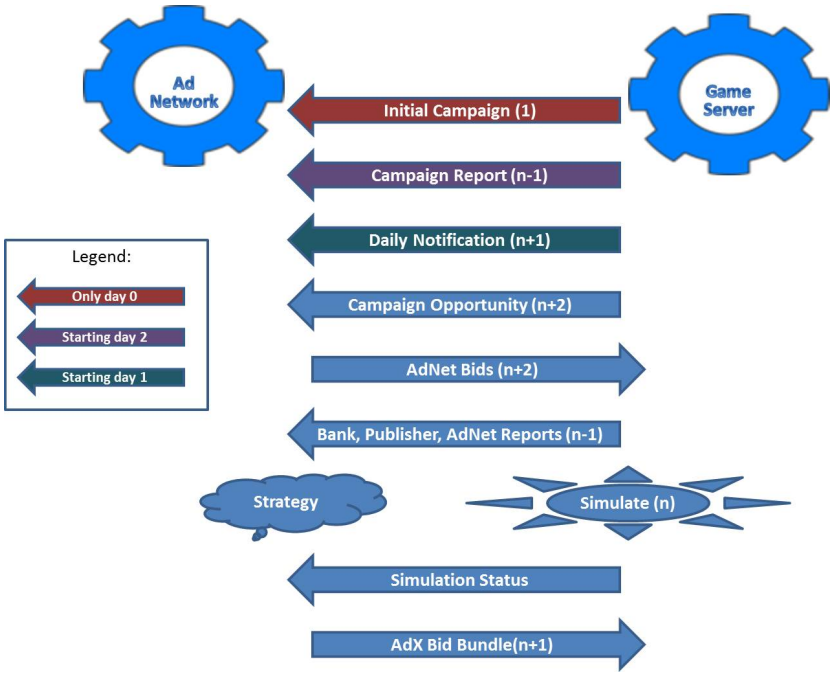

Figure 1: Message flow in the AdX game. The number in parenthesis indicates the day referenced in the message content. For example, the content of the Daily Notification message sent on day n announces the winning AdNetwork for the campaign to begin on day $n+1$, and the UCS level and Quality Rating to be in effect for the AdNet during day $n+1$. Note also that sending the AdNet Bids message may be deferred until after the reception of the Simulation Status message.

report regarding their allocated campaigns (accumulated statistics - up to and including day $n-1$ of achieved impressions and related costs). A campaign-opportunity message follows with details regarding the targeted audience, reach, and duration of a campaign that is scheduled to start on day $n+2$. An agent may respond with a bid-message that includes both the agent's bid regarding the budget of the campaign announced and the agent's bid with respect to the UCS. The results of the campaign and UCS auctions and the updated quality score (those to be in effect starting day $n+1$) are reported on a typical day $n > 0$ by the game server to the AdNets in a daily-notification-message that is sent before the campaign-opportunity message. Finally, after an additional set of reports sent by the server to the AdNets (a bank-status message, a publisher-report with web-site statistics, and an AdNet report with AdX bidding statistics, both regarding day $n-1$) the server simulates the users behavior of day n and during that time the agents may calculate their bid bundles to the AdX (the bid bundle includes the campaign allocation probability and bid amount to be used upon an impression opportunity, as a function of the impression attributes: the market segment the user may belong to, the access device used - mobile or desktop - and the ad type - video or text).

The bid-bundle message is then sent by each AdNet to the game server upon request (a simulation-status-message).

Contents

1 Background and Motivation

Similarly to traditional communication platforms such as radio and television, online advertising is the most significant business paradigm of the Internet. Most business models for Internet-based services depend on online advertising revenues to enable the huge investments that are needed in order to provide their services at attractive (or no) cost to users.

The Internet as an advertising platform is used by advertisers during the different stages of the purchase funnel: Display ads (the ads displayed alongside web content) are mostly used to strengthen brands by creating awareness and interest, while sponsored search ads (the ads displayed alongside search results) are mainly used to directly induce sales of products or services. This difference also results in different pricing schemes for the ads: while advertisers pay a *cost per click* (CPC) for sponsored search, the display ads are usually priced per thousand impressions - *Cost Per Mille* (CPM). The effectiveness of both schemes however (from the advertiser's perspective) relies on the ability to target the right audience.

While the effectiveness of sponsored search advertising is straightforward to measure (direct effect on sales), the situation is more challenging for brand advertising where brand awareness and purchase intentions may only be indirectly deduced. Nevertheless, brand advertising accounts for a significant portion of the Internet advertising activity (see [6]). It is therefore not surprising that with the advent of some key enabling technologies[6] the ecosystem has evolved from direct advertiser-publisher interaction for setting (upfront) the price of the impressions inventory, to an interconnected network of entities[7] (each adding value to the advertisers, publishers, or both) in which the inventory prices are dynamically set.

As the number of interactions between advertisers and publishers increased, Supply Side Platforms (SSPs) were introduced to assist the publishers optimize their inventory allocation decisions (e.g., by dynamically assigning each ad impression opportunity to one of several contracted advertisers). Ad Exchanges were introduced in turn to increase ad value to publishers, offering liquidity of inventory (e.g., impression opportunities that did not fit any ongoing pre-contracted campaign) and value discovery (i.e., impressions that may be sold for higher value than the contracted price) through a platform that enabled interested advertisers (or ad networks and agencies acting on their behalf) to bid for impression opportunities. Similarly to SSPs and Ad Exchanges, Demand Side Platforms (DSPs) were introduced to assist the ad agencies and networks in optimizing their decisions (e.g., budget allocation of the advertising campaigns across publishers and ad exchanges, and impression opportunities bid levels) such that market targeting goals are met. Finally, audience classification is key both for publishers and advertisers (the former may get higher prices for impressions in which the audience attributes are specified, the latter uses the audience attributes to ensure proper targeting). Therefore, user classification services are also provided by dedicated entities based on cookie matching technologies.

As noted, the Ad Exchange (AdX) is a pivotal entity in the display ad ecosystem. It

[6] Mainly user classification services and real-time bidding.

[7] Some other entities (such as ad delivery servers and content distribution systems) take part in the display ad ecosystem but are less relevant to the proposed setting, and are omitted from the game.

interacts with most interested entities, provides added value both to the publishers and the advertising agencies, and is best positioned to extract value from the aggregated information that flows through it as bidding takes place (e.g., the true value of ad impressions to different advertisers, the orientation of the audience of different publishers, etc.).

Naturally, this has spawned research activity aimed at analyzing and establishing the methods used by the different entities involved (as surveyed in [1]): e.g, the auction mechanism at the AdX [2], the reserve price decision by the publisher [3] (or more generally, the decision whether to submit an impression opportunity to an AdX or consume a prepaid inventory [4]), and, in a somewhat different setting, the bid price decision by the ad network [5].

We consider a reality in which advertisers (or ad agencies, on advertisers' behalf) contract ad networks upfront to execute advertising campaigns with agreed-upon total budget and *reach*[8] (thereby effectively setting the CPM upfront). Since an ad network may conduct several campaigns simultaneously, a key challenge for the ad network in this setting is therefore the choice of advertising campaign to serve for each impression opportunity. This gives rise to a fundamental conflict faced by ad networks which are required to balance the long term profitability goal (attracting advertisers by providing sustainable high quality targeting) with the short term campaign profitability goal (which depends on its ability to win properly targeted impression at low cost, compared to the agreed upon CPM). Taking the ad network perspective, we design the AdX game around this conflict, while simulating many of the new above-mentioned methods and mechanisms of the other entities involved, mainly the reserve price optimization by publishers [9], an approximation of the the real-time bidding at the Ad Exchange, and an auction for user classification service level as a way to reveal the actual value of such information.

2 Game Overview

A competing agent implements the functionality of the Ad Network: As typical in the Trading Agent Competition[10] and architecturally similar to the TAC Ad Auctions[11] (TAC-AA) game [7], the game consists of a sequence of periods (each lasting one day) in which the competing Ad Networks aim to win user impressions in order to fulfill their contracted advertising campaigns. Every simulated day the agent bids to win advertising campaign contracts and submits a bidding strategy to the Ad Exchange. The Game server simulates the daily activity of a population of users who visit web sites, each visit resulting in an impression opportunity announced to the Ad Exchange. Upon every impression opportunity the game server (simulating the Ad Exchange functionality) conducts an auction based on the agent's submitted bidding strategies and the impression is allocated accordingly.

[8] The *reach* of an advertising campaign is the number of unique users of the required market segment that are exposed to the campaign.

[9] A too high reserve price might result in unsold impressions and therefore unrealized potential profits

[10] See www.sics.se/tac.

[11] See aa.tradingagents.org/

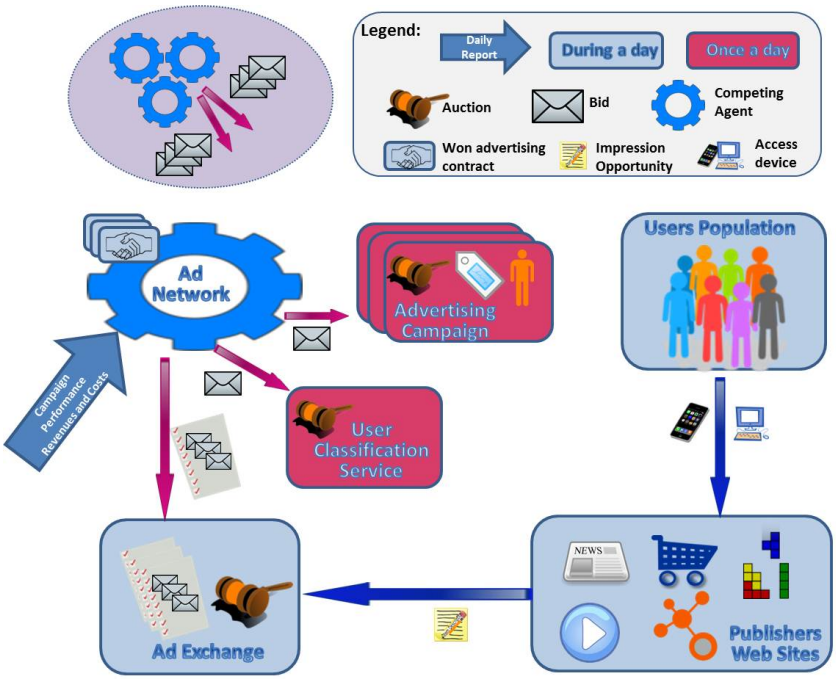

Figure 2: AdX game entities: *Users* visits to *Publisher's* web sites result in impression opportunities that are auctioned by the *Ad Exchange*. Bids for the impression opportunities are submitted by competing *Ad Networks* in order to execute their contracted *Advertising Campaigns*. The Ad Networks also bid daily to win advertising campaigns and for the cost and level of a *user classification service* that determines the ability of the Ad Network to identify the market segment of the potential user to be impressed. The competing agents base their bids on daily reports detailing their specific contract execution figures and overall user and web sites statistics.

At the beginning of the game each competing Ad Network is assigned an advertising campaign, and additional advertising campaigns are auctioned daily among the Ad Networks. Each advertising campaign auctioned results in a contract in which the winning Ad Network commits to win a fixed number of targeted user impressions at a price per impression (the amount to be earned by the Ad Network) that is set through the daily auction. The actual bid for a user impression may also depends on the access device used by the user to access the web sites (desktop or mobile) and the type of ad chosen by the publisher (video or text).

A performance rating is maintained for each Ad Network. The performance rating is taken into account in the daily advertising campaign auction (it influences the ability to win new advertising campaigns and the associated revenue) and is updated upon the expiration of each campaign based on the success level of the Ad Network in fulfilling the contract. Therefore, in order to maximize its profits (The ultimate goal of the game), it is key for the Ad Network to balance the performance rating and the actual

costs of bidding for impression opportunities at the Ad Exchange. The game setting is illustrated in Figure 2 and further detailed:

- *Audience*: The user population visiting the publishers' web sites. The users population is based on Age, Gender, and Income, where each attribute has a small set of possible values (e.g., *male* and *female* for Gender, *25-34*, *35-44*, ... for Age). Each day every user may visit one or more web sites: After each visit of a user to a web site, a continuation parameter determines whether the user continues to visit web sites or stops until the next day.

- *Publishers*: The web sites submitting impression opportunities to the Ad Exchange upon users' visits. Web sites differ by the service they provide to the users: News, Shopping, Social interaction, Media consumption (e.g. music, video, books, etc'), and Games. Accordingly, each web site has a predefined orientation level toward the audience attributes, which is reflected in the probability of a user with certain attributes visiting each web site. With every user visit, the *publisher* submits one or more Ad Requests (each reflecting an impression opportunity) to the AdX, accompanied with a user identification reference and a reserve price (the requested minimal price to be paid by a winning Ad Network).

- *Ad Exchange*: Auction platform for the impression opportunities. Upon an Ad Request from a publisher, the AdX solicits the competing Ad Networks to bid for the potential impression. Together with the Bid Request indication, the AdX passes the related publisher and user details. The amount of user details disclosed to each Ad Network depends on the Ad Network's *User Classification Service* level, as determined through a dedicated daily auction. The AdX implements the mechanism for selecting the winning bid and related price and facilitates the display of the ad from the allocated campaign.

- *User Classification Service*: Using cookie matching technologies, the user classification service provider allows the ad networks to target the required audience for their contracted advertising campaigns. The price of the service and its accuracy are set by a dedicated daily auction.

Finally, *Ad Networks* are implemented (each) by a competing agent. The competing agents bid daily for new advertising campaign's budget and for user classification service level. The agents also submit daily bid strategies as follows: As an approximation to real-time-bidding, a bidding strategy maps the context of an impression opportunity (user, publisher, access device, and ad type) to a bid amount and a distribution over advertising campaigns. During each simulated day, impression opportunities are auctioned and allocated to the winning Ad-Networks' campaigns according to the submitted bidding strategies. The Ad Networks may update their strategies based on daily reports that include web sites' popularity statistics and campaigns' revenues and costs.

3 Game Elements

A compete specification of each game element is provided in this section:

3.1 Users

A user is characterized by a value from each of three attribute sets: *Age* (One of six possible ranges: 18-24, 25-34, 35-44, 45-54,55-64,65+), *Gender* (One of the two values: Male, Female), and *Income* (One of four ranges: \$0-\$30K, \$30-\$60K, \$60-\$100K, \$100K+). A population of 10000 users (the total audience) is created at the beginning of each game by sampling [12] according to the probabilities detailed in Table 2.

3.2 Publisher's Web Sites

Every day every user visits one or more of a predetermined set of web sites [13], chosen randomly at game start out of web sites of the following categories *News*, *Shopping*, and *Information*[14]. Each web site w is characterized as follows:

- Relative popularity $P_W(w)$ - the probability of an arbitrary user visiting w.
- User Orientation $P_{\text{Age}}(\cdot|w)$, $P_{\text{Gender}}(\cdot|w)$, and $P_{\text{Income}}(\cdot|w)$
- Access Device probability $P_{\text{Device}}(\cdot|w)$ - over the set $\{$*Desktop*, *Mobile*$\}$ of access device types used by visiting users.
- Ad Type probability $P_{\text{Adtype}}(\cdot|w)$ - over the set $\{$*Video* or *Text*$\}$ of ad types that may be presented to visiting users.

Every day, every user of attributes $Age = a$, $Gender = g$, and $Income = i$, visits web site w with a probability that is proportional to [15]

$$Pr([a, g, i] \text{ visits } w) \propto P_{\text{Age}}(\text{a}|w)P_{\text{Gender}}(\text{g}|w)P_{\text{Income}}(\text{i}|w)P_W(w).$$

The probabilities that characterize the web sites' popularity and user and access device orientation are chosen based on real data that is available through web information services: Figures available for six leading web sites in each category (see Table 3) are used, and two from each category are chosen at the beginning of every game and communicated to the competing agents. The Ad-Type probability is not disclosed to the competing agents up front, as it may be adaptively set by the web site during a game.

Every day, upon visiting a web site, a user may continue visiting web sites that day with probability P_{Continue} up to a maximum of $N_{\text{ContinueMax}}$ visits per day.

[12] Available statistical data e.g., from web information services such as www.alexa.com is used to set the probabilities detailed in Table 2 upfront

[13] For simplicity, we use web sites visits to model other methods (e.g dedicated mobile applications) through which users may get a service that is funded by advertisers paying to get their ad displayed to the user.

[14] See Table 3

[15] This results from Bayes rule and a conditional independence assumption over attributes given the web site

3.3 Impression Opportunities and Reserve Prices

Upon every visit of a user to a web site, one or more impression opportunities are announced to the Ad Exchange [16]. A reserve price is set by each publisher for each impression opportunity using one[17] of the following adaptive methods:

A The initial average reserve price $b_1(u,a)$ for each user type u and impression type a (where a is one of the four combinations of Mobile / Desktop and Video / Text) is randomly chosen uniformly between 0 and $R_{\text{ReserveInit}}$, and reserve prices in subsequent days are adaptively set to maximize the publisher's profits. This is done by randomly varying reserve prices $r_t^i(u,a)$ during day t around the daily baseline average $b_t(u,a)$ and updating the baseline for the next day in the direction of the reserve price $b_t^{\max}(u,a)$ that resulted in the highest average profits during the day[18]:

$$r_t^i(u,a) = b_t(u,a) + \epsilon_i$$
$$b_{t+1}(u,a) = \eta b_t(u,a) + (1-\eta) b_t^{\max}(u,a) \ ,$$

where the perturbation ϵ_i is normally distributed with zero mean and R_{Variance} variance, and the learning rate η is fixed to $R_{\text{LearnRate}}$.

B Along the lines of the algorithm proposed in [3], the reserve price is set as a linear function of the user and impression attributes, where the constant coefficients are learned (namely, optimized) from previous games's data.

C No reserve price (that is, reserve price set to 0).

3.4 Market Segments

A set of partitions of the users population is defined by partitioning each attribute range to two (that is, the user's Age range to *Younger* $= \{44-\}$ and *Older* $= \{45+\}$ and the user's income range to *Low* $= \{60-\}$ and *High* $= \{60+\}$). Now, a market segment is any intersection of partitions (at most one partition per attribute). For example, if we designate each partition by its initial letter (e.g. Female by F and Younger by Y) we get the following 12 market segments of double partitions: FY, FO, MY, MO, YL, YH, OL, OH, FL, FH, ML, MH. Market segments of single partitions (e.g. M) or triple partitions (e.g. MYH) are also valid (and there are 6 and 8 such segments, respectively). Note that the segments may overlap (i.e., a user may belong to multiple segments). The segments serve as the key elements of defining the advertising campaign targeting goals, as detailed below.

[16] The number of impression opportunities is uniformly chosen from $\{1, \ldots, N_{impsmax}\}$. Since Ad Networks are rewarded by *unique* impressions (as detailed in Section 3.6), the multiple appearance of the same ad in a web page is avoided by excluding the winning agent from subsequent auctions related to the same web page visit.

[17] The specific method to be used by each publisher is announced to the competing agents at game start.

[18] Taking into account the estimated probability of at least one bid reaching or passing the reserve price. In case of no won impressions $b_t^{\max}(u,a)$ is set to 0.

3.5 The Ad Exchange

For each announced impression opportunity, the Ad Exchange operates a second-price auction among the Ad Networks [19] where each Ad Network submits a bid that depends on the context accompanying the bid request:

- The web site id
- The ad type (either *Video* or *Text*$\}$)
- The access device used (either *Mobile* or *Desktop*$\}$)
- The user's market segment (Note, matching depends on the User Classification Service level in effect for the Ad Network).

If the winning bid is below the reserve price indicated by the publisher, the impression opportunity is lost. Otherwise, the impression is allocated to the highest bidder and a targeted advertising campaign's ad gets displayed to user u.

3.6 Marketing Campaigns

A marketing campaign is auctioned daily among the competing Ad Networks. A marketing campaign's contract C is characterized by the required *reach* C_R (the size of total audience impressed - the total effective number of daily-unique user impressions), the duration in days C_L, the targeted marketing segment C_S, an ad type preference factor C_V (A unique *Video* impression is counted as C_V effective impressions. A *Text* impression is counted as one effective impression), and access device preference factor C_M (A unique *Mobile* impression is counted as C_M effective impressions. A *Desktop* impression is counted as one effective impression). [20]

The campaign parameters are set as follows: C_L is uniformly chosen to be one of $C_{\text{CampaignL1}}$, $C_{\text{CampaignL2}}$, $C_{\text{CampaignL3}}$. C_S is uniformly chosen over the 26 possible market segment combinations (see section 3.4). Finally, a reach level C_{RL} is uniformly chosen over $C_{\text{CampaignLowReach}}$, $C_{\text{CampaignMediumReach}}$, $C_{\text{CampaignHighReach}}$ and C_R is set

$$C_R = C_{RL} \cdot |C_S| \cdot C_L \ ,$$

where $|C_S|$ is the average size of the chosen target segment C_S.

Each Ad Network n bids B_n for the total campaign budget, and with probability $1 - P_{\text{RandomCampaign}}$ the campaign is allocated to the Ad Network of highest quality per dollar ratio [21]. That is, the campaign is allocated to the Ad Network with highest effective bid $e_n = \frac{Q_n}{B_n}$, where Q_n is the quality rating of Ad Network n as defined by (3). Reserve maximal and minimal cost per impression ($R_{\text{CampaignMax}}$ and $R_{\text{CampaignMin}}$

[19] Actually, to approximate real-time bidding while keeping the messaging load of the game reasonable, the Ad Exchange consults the daily bidding strategy submitted by each competing agents instead of interacting with each agent upon every impression opportunity.

[20] A user that is impressed more than once during a period is counted according to the highest effective value of the impressions.

[21] Alternatively, with probability $P_{\text{RandomCampaign}}$ the campaign is allocated uniformly at random to one of the bidding Ad Networks at the bid budget (as long as within the reserve limitations).

respectively) are used in all campaign auctions, the former to bound the price to be paid by advertisers for campaigns of little demand and the latter to preclude Ad Networks from committing to execute campaigns at unreasonable loss. The quality rating is taken into account in the reserve prices by only considering bids that satisfy $B_n Q_n > C_R R_{\text{CampaignMin}}$ and $\frac{B_n}{Q_n} < C_R R_{\text{CampaignMax}}$. The campaign's budget C_B is set to the maximum campaign budget the winning Ad Network could have had bid and still win: $C_B = \frac{Q_{\text{win}}}{b_{\text{second}}}$ where Q_{win} is the quality rating of the winning Ad Network and $b_{\text{second}} = \max\{e_{\text{second}}, \frac{1}{R_{\text{Campaign}} C_R}\}$ is the highest of the effective bid of the Ad Network reaching the auction's second place and the reserve effective value.

For an impression on user u, let $C(u)$ be the contract chosen by the ad network for the potential impression on u and let $D_C(u)$ be $C(u)_M$ if u is using a mobile device and 1 otherwise. Similarly, let $T_C(u)$ be $C(u)_V$ if u is being impressed by video and 1 otherwise.

The effective number of unique impressions w.r.t. contract C achieved by Ad Network n is

$$I_n(C) = \sum_{u: C(u)=C \text{ and } C_S \in s(u)} D_C(u) \cdot T_C(u) \ , \tag{1}$$

where $s(u)$ indicates the actual[22] set of segments to which user u belongs, and the sum is over all daily-unique impressions on users u that belong to segment s.

Now, to encourage ad networks achieving the required reach levels of the contract, the effective reach ratio $\text{ERR}_n(C)$ of contract C is set as a function of the effective number of unique impressions $I_n(C)$:

$$\text{ERR}_n(C) = \frac{2}{a}\big[\arctan(a\frac{I_n(C)}{C_R} - b) - \arctan(-b)\big] \ ,$$

where a and b are set[23] such that when $I_n(C) = C_R$ we have $\text{ERR}_n(C) = 1$ and the marginal effective reach per unique impression is $\frac{1}{C_R}$. This monotone relation is illustrated in Figure 3.

Finally, the payment $E_n(C)$ to Ad Network n for impressions on users allocated to contract C is set

$$E_n(C) = \text{ERR}_n(C) \cdot C_B \ . \tag{2}$$

At the expiration of every contract, the quality rating Q_n of the relevamt Ad Network is updated using $\eta = L_{\text{Rating}}$ learning rate:

$$Q_n^{\text{new}} = (1-\eta)Q_n + \eta \text{ERR}_n(C) \ . \tag{3}$$

[22]Note that the ad network may not have complete information to exactly compute $I_n(C)$. The game server computes this value, mimicking a marketing survey that may take place in reality upon the conclusion of a campaign. After all, the actual segment to which the user belongs carries the true marketing value for the advertiser!

[23]For any nonzero k, take the unique b satisfying $\frac{\arctan(k)-\arctan(-b)}{1+b} = \frac{1}{1+k^2}$, and set $a = b + k$. We use $k = 1$ resulting in $a = 4.08577$ and $b = 3.08577$.

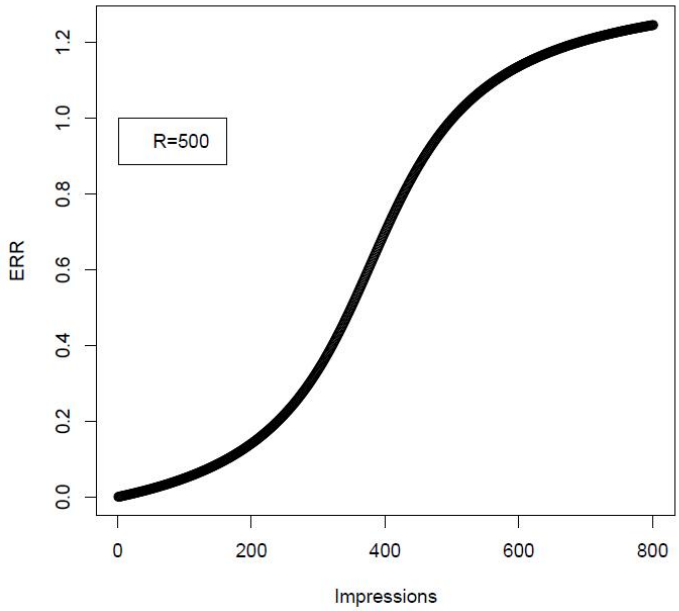

Figure 3: The Effective Reach Ratio (ERR) as a function of the effective number of unique impressions achieved by the ad network, for a contract requiring a reach $C_R = 500$.

3.7 User Classification Service

When a potential impression is announced to an ad network, the actual attributes of the associated user are only provided with a probability that depends on a prepaid user classification service[24]. The quality of the matching (i.e., the probability of the Ad Network getting the true value of the attributes) depends on the service level purchased. The probability and cost are determined by a Generalized Second Price (GSP) auction that is conducted daily. The highest bidder will get 100% revelation, the second a lower probability $P_{\text{UserRevelation}}$, the third $P^2_{\text{UserRevelation}}$, and so on[25]. The outcome of the auction (quality and cost of the service to the ad networks) is determined in the following manner: Denote by $c_{i_1}, .., c_{i_m}$ the ordering of the bids of the ad networks from high to low. As a result of the auction, the ad network n in the k^{th} position will receive the true value of a user's attributes with probability $p_k = P^{k-1}_{\text{UserRevelation}}$, and will pay for the service the amount of,

$$K_n = p_k \cdot c_{i_{k+1}} \ . \tag{4}$$

[24]This reflects the situation in which the user reference (i.e., cookie) provided by the Ad Exchange has to be matched to a real user, using a dedicated third-party service provider

[25]Otherwise, an "unknown attributes" value is indicated

The normalization by p_k above ensures that the actual price paid is the average price for correct user classification.

3.8 Ad Networks

The Ad Networks, implemented by the competing agents, bid daily for advertising campaign contracts and for user classification service level. To overcome the intensive communication rate required to implement real-time bidding in our game, every Ad Network n submits to the AdX upfront a daily bid bundle. The bid bundle is used by the AdX throughout the day to map bid requests to ad networks' bid/contract pairs by indicating the following information for each market segment s [26], site w, access device, and ad type combination:

- Contract weight p_n: The weight associated to the contract induces a probability distribution over all the contracts associated with entries that match a certain impression opportunity [27].
- Bid b_n: The bid level, upon assignment of the impression opportunity to contract C.

The way the game server simulates the daily real-time bidding on behalf of the Ad Networks is as follows: Upon a bid request as a result of user u visiting web site w, the matching Bid Bundle entries are set according to actual user attributes and the user classification service level in effect [28]. The contract C_n to use for Ad Network n is randomly selected according to probability induced by p_n and the bid amount is set according to the chosen entry's b_n. The daily bid bundle of an Ad Network may also indicate for each assigned campaign a budget constraint on the daily spending for impressions and an impressions-won constraint (and also similar total campaign constraints). Once the spending or impressions limit is reached for contract C no more bids are placed on behalf Ad Network n w.r.t. contract C.

Now, set $c_n(u)$ to be the price paid by Ad Network n for an impression won on user u (the outcome of the second-price auction conducted by the AdX). The net earnings $N_n(C)$ of ad network n on contract C are therefore:

$$N_n(C) = E_n(C) - \sum_{u:C(u)=C} c_n(u) \ , \tag{5}$$

where $E_n(C)$, Ad Network's n income related to contract C, is according to (2).

[26] an "unknown" segment is also included - to be used when the user classification service fails to reveal the visiting user's segment.

[27] An impression opportunity matches an entry if the user to be impressed belongs to the market segment of the entry. The "unknown"-segment entry matches impressions for which the user classification service fails to recover the user attributes.

[28] Multiple segments may apply - resulting in more than one matching bid-bundle entry.

4 Game Flow

The game consists of at most T_{Gamedays} simulated days in which up to 8 competing ad networks aim to maximize their total accumulated profits (6). Throughout the game each ad network executes one or more campaigns, where its competitiveness in winning campaign contracts [29] depends on the targeting effectiveness achieved by executing its past campaigns (3).

4.1 Daily sequence of actions and events

To achieve its goals, each Ad Network bids daily for users' impression opportunities and selects for each impression which of its contracts to serve. The ad networks base their decisions on daily reports. In what follows, the daiy sequence of actions and events is detailed for a typical day d (from the point of view of an agent implementing the Ad Network functionality). Note that a day in game-time is executed in $T_{\text{Dayseconds}}$ real-time seconds. The sequence is illustrated conceptually in Figure 4 and specifically in Figure 1.

4.1.1 Reports

After the game server simulates the users visits to publisher's web sites during day $d-1$ and related AdX auctions, each agent n receives during day d reports summarizing the preceding day $d-1$.

- Publishers-Report: A public report that details user visiting statistics for each web site (popularity and orientation frequencies, out of total user visits during the day), and impressions statistics by campaign.
- AdNet-Report: A private report that details the Ad Network bidding totals for each bid-bundle entry[30]: bids, wins, and cost.
- Campaigns-Report: A private report that details accumulated statistics for each AdNet's campaign: targeted impressions, non-targeted impressions, and cost.

4.1.2 Notifications

A Daily-Notification message is sent on day d to notify the Ad Networks regarding the results of the following developments of fay $d-1$:

- Campaign-Auction-Result: The Ad Networks are announced regarding the winner of the campaign auctioned on day $d-1$. The campaign is scheduled to start on day $d+1$ and last until day $d+C_L$. The winner is also announced regarding the resulting budget C_B (this figure is not disclosed to non-winners).

[29] Reflected by a squashing value applied to its bids

[30] For convenience, the key includes the campaign id.

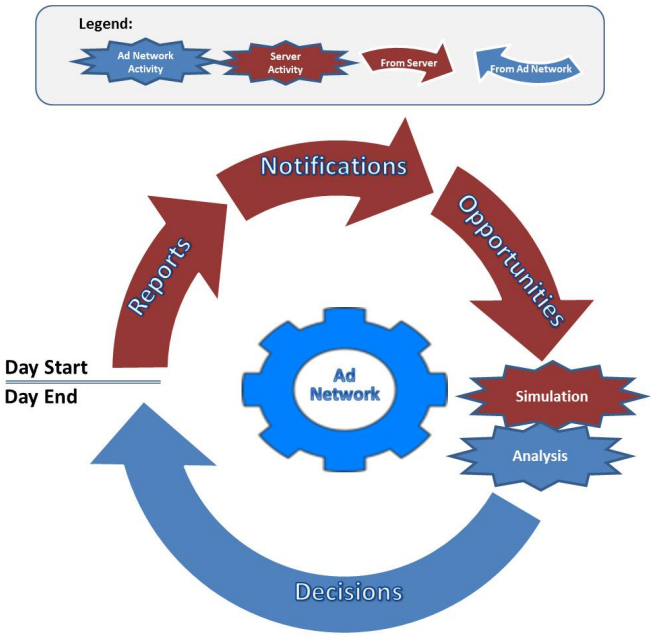

Figure 4: AdX game daily flow: Day d starts with the server sending to the Ad Network the reports regarding day $d-1$. Notifications about the campaign contract and user classification service level to be in effect during day $d+1$ are sent next, followed by details regarding day $d+2$ campaign opportunities. Based on the information, the Ad Network may conduct an analysis toward decisions regarding its bidding strategy during day $d+1$ while the server simulates the impressions and related AdX auctions of day d.

- UCS-Auction-Result: The Ad Networks are notified (each) regarding their user classification servide level and cost to be in effect during day $d+1$ as auctioned according to the bids submitted during day $d-1$.
- Quality-Rating-Update: Each Ad Network is notified regarding its updated Quality-Rating, as a result of campaigns ending during day $d-1$. This rating is in effect for the Campaign-Opportunity auctions to take place during day d.

4.1.3 Contract Opportunity

The details of the advertising campaign to start on day $d+2$ are provided to the Ad Networks. The Ad Networks' bids (to be sent to the game server during day d as detailed below in 4.1.4) will be considered and the winner will be announced (as detailed above in 4.1.2) during day $d+1$.

4.1.4 Ad Networks Decisions

After the Ad Networks consider the reports, notifications, and opportunities, they submit their decisions to the game server: First, the Ad Networks submit their bids for the advertising campaign opportunity just announced (see Section 4.1.3) and the user classification service level to be in effect during day $d + 2$. The results of the user classification service level auction will be reported during day $d + 1$ (as in Section 4.1.2). Finally, each Ad Network submits a Bid-Bundle message reflecting its bidding strategy to be used by the Ad Exchange upon impression opportunities resulting from users visits to web sites during day $d + 1$. As described in section 3.8, the strategy is conveyed in a bid bundle that maps the context of the impression opportunity to a bid level and a distribution over campaign contracts.

4.2 The First And Last Days

During day 0 the agents are notified regarding their first campaign contarct (each Ad Network is allocated one campaign) to start on day 1. All initial campaigns have $C_{\text{CampaignL2}}$ duration, $C_{\text{CampaignMediumReach}}$ reach level, and double partition target segment C_S. The Busget of each initial campaigns is set to 1\$ CPM.

During day 1 the user classification service is provided to all agents at no cost and at accuracy level ($Z_{\text{UCSaccuracy}}$). As the last simulation day approaches, campaigns whose end day are beyond the last day are not announced. Whenever this happens an empty campaign is indicated in the Campaign-Opportunity message.

4.3 Game Results

Upon game termination each ad network score is its net accumulated profits (5) over all executed contracts, less the cost of the user classification service over all periods.

The overall score of Ad Network n is therefore

$$N_n = \sum_C N_n(C) - \sum_d K_n(d) \ , \tag{6}$$

where $K_n(d)$ is the price paid by Ad Network n for the user classification service on day d as set by (4).

Acknowledgments

We thank Tomer Greenwald, for his key role in implementing the AdX Game server. We are also very grateful to Amy Greenwald and her team from Brown University, for the valuable feedback and suggestions provided during the early specification and implementation stages.

References

[1] Muthukrishnan, S., *Ad exchanges: Research issues*. In Proc. of 5th Workshop on Internet and Economics(WINE), 2009

[2] Tanmoy Chakraborty, Eyal Even-Dar, Sudipto Guha, Yishay Mansour, and S. Muthukrishnan, *Selective call out and Real-time Bidding*. In Proc. of 6th Workshop on Internet and Economics(WINE), 2010

[3] Mehryar Mohri and Andres Muñoz Medina, *Learning Theory and Algorithms for Revenue Optimization in Second-Price Auctions with Reserve*. Proceedings of the 31st International Conference on Machine Learning, 2014

[4] Santiago Balseiro, Jon Feldman, Vahab Mirrokni, and S. Muthukrishnan, *Yield Optimization of Display Advertising with Ad Exchange*. ACM Conference on Electronic Commerce, 2011

[5] Jon Feldman , Vahab Mirrokni , S. Muthukrishnan , and Mallesh M. Pai, *Auctions with intermediaries*. Proceedings of the 11th ACM conference on Electronic commerce, 2010

[6] Magna Global, *2011 ADVERTISING FORECAST*. www.magnaglobal.com, 2011

[7] Patrick Jordan and Michael Wellman, *Designing an ad auctions game for the trading agent competition*. In Workshop on Trading Agent Design and Analysis, 2009

[8] *Current Population Survey, Annual Social and Economic Supplement, 2013*. U.S. CENSUS BUREAU

[9] www.alexa.com

[10] www.quantcast.com

A Game Parameters

Table 1 details the game parameters and their standard values. The game setting also depends on the user population distribution (Table 2) and the web site's orientation (Table 3), which are based on real figures from [8], [9]. Note that in Table 2 the income is in \$1000 units and the probabilities are in 0.001 units.

Table 1: Parameters

Parameter	Symbol	Standard Game Setting
User Continuation Probability	P_{Continue}	0.3
Random Campaign Allocation Probability	$P_{\text{RandomCampaign}}$	0.36
Max User Daily Impressions	$N_{\text{ContinueMax}}$	6
Publisher's Initial Reserve Price	$R_{\text{ReserveInit}}$	0.005
Reserve Price Variance	R_{Variance}	0.02
Reserve Price Learning Rate	$R_{\text{LearnRate}}$	0.2
Short Campaign Duration (Days)	$C_{\text{CampaignL1}}$	3
Medium Campaign Duration (Days)	$C_{\text{CampaignL2}}$	5
Long Campaign Duration (Days)	$C_{\text{CampaignL3}}$	10
Low Campaign Reach Factor	$C_{\text{CampaignLowReach}}$	0.2
Medium Campaign Reach Factor	$C_{\text{CampaignMediumReach}}$	0.5
High Campaign Reach Factor	$C_{\text{CampaignHighReach}}$	0.8
Max Campaign Cost Per Impression	$R_{\text{CampaignMax}}$	0.001
Min Campaign Cost Per Impression	$R_{\text{CampaignMin}}$	0.0001
Quality Rating Learning Rate	L_{Rating}	0.6
Game Length	T_{Gamedays}	60
Real Time Seconds per Simulated Day	$T_{\text{Dayseconds}}$	10
User Classification Service Revelation Probability	$P_{\text{UserRevelation}}$	0.9
Initial Days Classification Service Accuracy	$Z_{\text{UCSaccuracy}}$	0.9

Table 2: User Population Probabilities

Age	Gender	Income	Probability	Age	Gender	Income	Probability
18-24	M	0-30	526	25-34	M	0-30	371
35-44	M	0-30	263	45-54	M	0-30	290
55-64	M	0-30	284	65+	M	0-30	461
18-24	F	0-30	546	25-34	F	0-30	460
35-44	F	0-30	403	45-54	F	0-30	457
55-64	F	0-30	450	65+	F	0-30	827
18-24	M	30-60	71	25-34	M	30-60	322
35-44	M	30-60	283	45-54	M	30-60	280
55-64	M	30-60	245	65+	M	30-60	235
18-24	F	30-60	52	25-34	F	30-60	264
35-44	F	30-60	255	45-54	F	30-60	275
55-64	F	30-60	228	65+	F	30-60	164
18-24	M	60-100	11	25-34	M	60-100	140
35-44	M	60-100	185	45-54	M	60-100	197
55-64	M	60-100	157	65+	M	60-100	103
18-24	F	60-100	6	25-34	F	60-100	75
35-44	F	60-100	104	45-54	F	60-100	122
55-64	F	60-100	109	65+	F	60-100	53
18-24	M	100+	5	25-34	M	100+	51
35-44	M	100+	125	45-54	M	100+	163
55-64	M	100+	121	65+	M	100+	67
18-24	F	100+	3	25-34	F	100+	21
35-44	F	100+	47	45-54	F	100+	57
55-64	F	100+	48	65+	F	100+	18

Table 3: Publisher's audience orientation, access device ratios and popularity, for news, shopping, and web information services

Name	18-24	25-34	35-44	45-54	55-64	0-30	36-60	60-100	Male	Mobile	Popularity
Yahoo	12.2	17.1	16.7	18.4	16.4	53	27	13	49.6	26	16
CNN	10.2	16.1	16.7	19.4	17.4	48	27	16	48.6	24	2.2
NY Times	9.2	15.1	16.7	19.4	17.4	47	26	17	47.6	23	3.1
Hfngtn	10.2	16.1	16.7	19.4	17.4	47	27	17	46.6	22	8.1
MSN	10.2	16.1	16.7	19.4	17.4	49	27	16	47.6	25	18.2
Fox	9.2	15.1	16.7	19.4	18.4	46	26	18	48.6	24	3.1
Amazon	9.2	15.1	16.7	19.4	18.4	50	27	15	47.6	21	12.8
Ebay	9.2	16.1	15.7	19.4	17.4	50	27	15	48.6	22	8.5
Wal-Mart	7.2	15.1	16.7	20.4	18.4	47	28	19	45.6	18	3.8
Target	9.2	17.1	17.7	18.4	17.4	45	27	19	45.6	19	2.0
BestBuy	10.2	14.1	16.7	20.4	17.4	46.5	26	18	47.6	20	1.6
Sears	9.2	12.1	16.7	20.4	18.4	45	25	20	46.6	19	1.6
WebMD	9.2	15.1	15.7	19.4	18.4	46	26.5	18.5	45.6	24	2.5
EHow	10.2	15.1	15.7	19.4	17.4	50	27	15	47.6	28	2.5
Ask	10.2	13.1	15.7	20.4	18.4	50	28	15	48.6	28	5.0
TripAdvisor	8.2	16.1	17.7	20.4	17.4	46.5	26	17.5	46.6	30	1.6
CNet	12.2	15.1	15.7	18.4	17.4	48	26.5	16.5	50.6	27	1.7
Weather	9.2	15.1	16.7	20.4	18.4	45.5	26.5	18.5	47.6	31	5.8