Online Algorithms for Matching Platforms with Multi-Channel Traffic

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Online platforms in both the private and nonprofit sectors have become increasingly prominent in facilitating social and economic connections. Many such platforms (including Etsy, DonorsChoose, and VolunteerMatch) attract traffic through multiple channels. Some users organically visit the platform and rely on the platform’s recommendation algorithm to find a desired product or donation/volunteering opportunity; we refer to these users as internal traffic. Other users, whom we refer to as external traffic, follow an external direct link to a particular page, thereby bypassing the platform’s recommendation algorithm. This external traffic is generated through a variety of off-platform outreach mechanisms, such as posts on social media or customized notifications.

We take VolunteerMatch—our industry partner—as a leading example. VolunteerMatch (VM) is the largest nationwide platform that connects nonprofits with volunteers: more than 130,000 nonprofits have posted volunteering opportunities on VM. In addition to relying on VM to attract volunteers, some of these nonprofits also generate sign-ups by publicizing direct links to their opportunities on other websites, such as LinkedIn or Facebook. Our analysis of VM data reveals that more than 30% of sign-ups on VM come from this external traffic, and there is substantial heterogeneity across opportunities in terms of the number of sign-ups from external traffic. In this work, we study the following question: how can platforms such as VM efficiently integrate internal and external traffic in order to maximize the number of successful transactions/connections?

A model for online matching with multi-channel traffic: To study the above question, we introduce a framework for making real-time recommendations in the presence of multi-channel traffic. We model the platform’s problem as a variant of online matching. For concreteness, we utilize terminology from the context of VM and refer to the two sides of the matching platform as...
“opportunities” and “volunteers.” In our setting, a fixed set of opportunities are posted on the platform, each requiring a certain number of volunteers which we refer to as its “capacity.” Volunteers arrive sequentially (in an arbitrary order) and are either external or internal traffic. External traffic directly views a specific opportunity’s page and signs up with their conversion probability for that opportunity (i.e., the probability that the volunteer signs up for that opportunity conditional on viewing it). By contrast, internal traffic can be influenced by the platform’s recommendation algorithm as follows: when an internal traffic volunteer arrives, the platform observes their conversion probabilities for each opportunity, and then must immediately and irrevocably recommend one such opportunity. The goal of the platform is to maximize the total number of “useful” sign-ups, i.e., the total number of sign-ups that do not exceed an opportunity’s capacity.

**Refining the notion of competitive ratio:** To evaluate the performance of different algorithms, we take a competitive analysis approach. In the absence of external traffic, the above problem can be viewed as an instance of the online bipartite B-matching problem with stochastic rewards and an adversarial arrival sequence. In this general framework, it has been shown that a simple myopic algorithm commonly-referred to as MSVV achieves the best-possible competitive ratio of $1 - 1/e$, at least asymptotically when all capacities are sufficiently large [3, 4]. We augment this framework by modeling external traffic as arrivals with only one possible edge (e.g., volunteers that only consider one opportunity). The presence of external traffic reduces the complexity of making real-time decisions: the platform cannot change what these volunteers will view, as they are only interested in one opportunity. Thus, in the extreme case where all traffic is external, the platform trivially maximizes the number of useful sign-ups. In light of this observation, we parameterize problem instances based on the amount of external traffic in order to study how the addition of external traffic impacts the achievable competitive ratio.

**Designing a new algorithm:** We find that existing algorithms that are optimal in the absence of external traffic (such as MSVV) fail to integrate such traffic efficiently. Thus, we develop a new algorithm—Adaptive Capacity (AC)—which accounts for matches differently based on whether they originate from internal or external traffic. For any amount of external traffic, we provide a lower bound on AC’s competitive ratio that is close to the parameterized upper bound we establish on the competitive ratio of any online algorithm, even though AC does not need to know the volume of external traffic in advance. Our analysis extends the path-based, pseudo-rewards approach in [1] and [2], which we further generalize to settings where the platform can recommend a ranked set of opportunities.

**Simulations based on VM data:** To complement our theoretical results, we evaluate the performance of AC on a problem instance constructed using a VM dataset that enables us to preserve real-life patterns of external traffic and heterogeneity in conversion probabilities. We show that our AC algorithm significantly outperforms a proxy for the current recommendation algorithm used on VM. It achieves this level of performance by reducing the number of sign-ups beyond an opportunity’s capacity, thereby utilizing internal traffic more efficiently.

**Link to full version of the paper:** https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4036904

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