# Computationally Efficient Techniques for Economic Mechanisms

# (Doctoral Consortium)

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## ABSTRACT

My Ph.D. thesis is focused on the field of *mechanism design*, a branch of game theory that aims to study interaction mechanisms for rational agents. The basic goal is the design of direct–revelation mechanisms that are stable. Given the valuations reported by the agents, a mechanism determines the outcome of the interaction by means of an objective function. In some contexts, such objective function cannot lead to a stable mechanism or finding an optimal solution is $\mathcal{NP}$–hard. The goal of my studies is the development of techniques to deal with these situations. The basic idea is to design a new objective function that approximates at best the original one, but, at the same time can be used to build a stable mechanism computable in polynomial time. During my Ph.D., I will extend the techniques currently available in the state of the art to more general situations and I will apply such techniques to the important field of ad auctions.

## Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Multi–agent systems

## Keywords

Auction and mechanism design

## 1. INTRODUCTION

Mechanism design is a field of game theory extensively used in microeconomics, but recently applied also to modeling and solving problems in many branches of engineering, included computer science. Known applications are selfish routing, cryptography, *ad hoc* wireless networks and electronic commerce [7]. Two desirable properties for the applicability of the mechanisms are the *stability* of the outcome (no agent aims to change the outcome misreporting his preferences) and that the different elements of the mechanism can be computed in *efficient time*. Thus, literature and my research activity focus on the design of stable mechanisms computable in polynomial time in the size of the problem.

The application that I have studied most is Sponsored search auctions (SSAs), one of the most successful economic mechanism. The framework of SSA consists in a publisher that selects ads to be placed in a number of slots on a web page and an advertiser that pays the publisher only when his ad is clicked. The importance of SSAs is due to the fact that they play a central role in Internet monetization, e.g., in the first half of 2010, revenue from online advertising totalled $12.1 billion in the U.S. alone, of which search revenue accounted for 47%, dominating display ads, the second–largest revenue source. Finding the optimal placement of ads into slots with the model most largely used in literature is an $\mathcal{NP}$–hard task and my goal is to develop mechanisms that can approximate the outcome at best in an efficient way.

**Appears in:** *Proceedings of the 12th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2013)*, Ito, Jonker, Gini, and Shehory (eds.), May, 6–10, 2013, Saint Paul, Minnesota, USA.


## 2. STATE OF THE ART

The aim of mechanism design consists in designing rules that handle the interaction among rational agents (e.g. humans, computers, etc.) in order to achieve outcomes with desired properties (e.g. stability of the interaction).

Mechanism design defines the policy of a social planner that aggregates the preferences of the agents and produces a social decision. The preferences of the agents are *private information*, and the mechanism acts in order to elicit them.

A generic direct–revelation mechanism $M$ is composed of six elements $M = (A, O, \Theta, f, P, U)$:

- $A = \{1, \ldots, n\}$: the set of rational agents,
- $O$: the set of possible outcomes of the interaction,
- $\Theta = \{\Theta_1, \ldots, \Theta_n\}$: $\Theta_i$ is the set of types of agent $i$, where the type represents the private information,
- $f$: the social choice function $f : \Theta \to O$ that, given the declarations of the agents, produces the outcome, i.e. the social choice,
- $P = \{p_1, \ldots, p_n\}$: the payment rule $p_i : \Theta \to \mathbb{R}$ for agent $i$ determines how much an agent has to pay or is paid on the basis of the agents' declarations.
- $U = \{u_1, \ldots, u_n\}$: the utility function $u_i : \Theta_i \times O \to \mathbb{R}$ of agent $i$, that defines how good is an outcome for $i$, considering also the payments.

A mechanism where the optimal strategy for each agent is to declare his true type is stable, and is said to be *incentive compatible* (or truthful). Mechanisms of this kind are attractive for real–world applications also because the computational effort for the agents is very low. Given that there is no need for acting strategically to gain more utility, they have only to declare their true types.

The social choice function $f$ is usually defined as an optimization problem. One of the objective functions most used in literature is the maximization of the social welfare. In this particular case a well known payment scheme (VGC) allows to design incentive compatible mechanisms. When the mechanism is single–parameter, i.e. the type of an agent

has only one dimension, and the utility function is linear, it is possible to produce a more general characterization of incentive compatibility property, even for objective functions different from the social welfare. In this case, notions like maximal in its range [8] or the more general contribution of [2] are used. The latter states that it is possible to design an incentive compatible mechanism if and only if the property of monotonicity described in [2] is satisfied.

However, in some environments, $f$ is $\mathcal{NP}$–hard. Moreover, even in the case $f$ can be computed in polynomial time, there is no guarantee that the payments [2] can be computed in polynomial time too. This prevents the application of these mechanisms in some contexts of real life.

A branch of research consists in the study of approximation mechanisms that do not find the optimal solution of $f$, but can be computed in polynomial time and possibly are incentive compatible. These mechanisms allow the application of mechanism design even when the optimal mechanism is not tractable and are usually provided lower bounds on the ratio between the value of the optimal outcome and the one returned by the approximation mechanism. My research activity focuses on this topic.

# 3. THE OBJECTIVE OF THE THESIS

The objectives of the Ph.D. thesis can be separated in two distinct parts: theoretical and application oriented.

Theory presented in [2] applies only to a restrict group of environments, the single–parameter ones with linear utility. Thus, in this context, it is possible to reason on approximation incentive–compatible mechanisms, while in the more general setting of multi–parameter mechanism a complete characterization of the incentive compatibility property is still missing. The solution of this problem is preliminary to the discussion on approximation incentive compatible mechanisms. Thus, I would like to generalize the results of [2] in the more general setting of multi–parameter mechanisms.

At the same time multi–parameter mechanisms open a new problems related to interdependencies, that I want to explore. Interdependencies characterize situations where the values of the agents depends on parameters of other agents.

Then I want to extend my studies to situations where the information arrives gradually over time and decision are made over multiple periods. These contexts can be handled through dynamic mechanism design. In this case it is more difficult to guarantee the incentive compatibility of the mechanisms, indeed an agent can declare a type conditioned to the previous observations.

From the point of view of application oriented contributions, I have identified the setting of ad auctions as my field of study. In particular I will focus on SSAs and a new potential application, mobile geo–location advertising [9].

In the environment of SSAs the problem is that the most common (in literature) user model (*cascade model* [6]) is not applied in reality, due to the fact that finding the best allocation of ads into slots is an $\mathcal{NP}$–hard problem. Hence I would like to develop approximation mechanisms that allow the real application of this model that better represent the user's behaviour respect to the other ones currently used.

On the other hand, the idea of mobile geo–location advertising is that mobile ads can be targeted on the bases of a user's location (e.g., streets or squares within a city or a district). Mobile geo–location advertising has been identified as a key growth factor for the mobile market. Growing at a compound annual growth rate of 31 percent, the mobile ad market is forecasted to be worth 19.7 billion Euro in 2017—corresponding to 15.5 percent of the total digital advertising market. A crucial ingredient for its success is be the development of effective economic mechanisms.

# 4. PROGRESS

In the first year of my Ph.D. I focused my attention on the problem of SSAs. I have shown that the constant approximation algorithm proposed in literature is not monotone, thus, due to the characterization developed in [2], it cannot be used to develop an incentive compatible mechanism. I proposed a new monotone approximation algorithm that provides, at least, an approximation of $\frac{1-\epsilon}{4}$ respect to the optimal solution. Adapting to the case of SSAs the payment techniques described in [1] and [3], it is possible to obtain mechanisms incentive compatible in expectation. I also provided experimental results that compare the optimal allocation algorithm with the approximation one. These results are based on data from *Yahoo! Webscope A3* [5].

A non–secondary problem in SSAs is the estimation of parameters of the economic mechanism that are usually considered known by the auctioneer, but that in reality are not. Machine learning techniques are useful for this goal. The unknown quantities can be estimated preserving the incentive compatibility of the mechanism [3, 4] and I am working to complete the dissertation of [4].

I am also focusing on the mobile geo–location advertising problem, developing a model of the *users' behaviour*, and designing *tractable algorithms* that avoid *advertisers' strategic manipulation*. The idea is to compute an advertising policy (that consists in sending coupons to the mobile device of the user) based on the route followed by the user. The payment scheme should be based on a *pay–per–visit* fashion.

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