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Bounded rationality can make parking search more efficient: The power of lexicographic heuristics

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ABSTRACT

The search for parking space in busy urban districts is one of those routine human activities that are expected to benefit from the widespread adoption of pervasive sensing and radio communication technologies. Proposed parking assistance solutions combine sensors, either as part of fixed infrastructure or onboard vehicles, wireless networking technologies and mobile social applications running on smartphones to collect, share and present to drivers real-time information about parking demand and availability.

One question that arises is how does (and should) the driver actually use such information to take parking decisions, *e.g.*, whether to search for on-street parking space or drive to a parking lot and, in the latter case, which one. The paper is, hence, a performance analysis study that seeks to capture the highly behavioral and heuristic dimension of drivers' decisions and its impact on the efficiency of the parking search process. To this end, and in sharp contrast with the existing literature, we model drivers as agents of *bounded rationality* and assume that their choices are directed by *lexicographic heuristics*, an instance of the fast and frugal heuristics developed in behavioral sciences such as psychology and biology. We analyze the performance of the search process under these heuristics and compare it against the predictions of normative game-theoretic models that assume fully rational strategically acting agents. We derive conditions under which the game-theoretic norms turn out to be more pessimistic than the simpler heuristic choice rules and show that these are fulfilled for a broad range of scenarios concerning the fees charged for the parking resources and their distance from the destinations of the drivers' trips. The practical implications of these results for parking assistance solutions are identified and thoroughly discussed.

1. Introduction

The increasing integration of advanced sensing and wireless technologies with urban infrastructures transforms dramatically the way citizens access and interact with them. At the same time, smartphones and other smart mobile devices turn their owners to potential mobile sensing platforms and engage them actively in the generation and distribution of various kinds of information. The two trends combined fuel the smart city concept, whereby fundamental daily activities and

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operations are carried out more efficiently in favor of individual citizens and the society as a whole (Zanella et al., 2014; Greenberg, 2015).

Parking space forms an instance of urban resource that is daily accessed and shared by multiple drivers. Often scarce in places such as shopping areas and business districts, it has to be properly managed to avoid congestion effects and the unfavorable consequences of cruising for parking such as the waste of time and fuel and the environmental burden (see, for instance, Shoup, 2006). Parking assistance systems seek to address the parking problem by expanding the reach of pervasive computing within the city roads and turning them to smart spaces. Combining sensors at the parking spots or onboard vehicles with radio communication technologies, and often involving the vehicular network as in Caliskan et al. (2006), they collect and distribute information about parking demand and supply to the vehicular nodes. More recent approaches to the assisted parking search[1] add a social media layer over the vehicular network. The drivers can use a mobile social application running on their smartphones to share their knowledge about parking space with other application users and even handover parking spots to save the overheads of parking search.

Despite the amount of work on the proposal and design of parking assistance systems, surprisingly little attention has been paid to their actual performance. Directly relevant to the performance issue is the amount of information that *can* or *should be* used when selecting parking resource, *e.g.*, on-street or parking lot(s), or searching for an on-street parking spot. The major assumption in our work is that these decisions involve, in one way or another, humans. The drivers are those who actually make choices when the parking assistance system only provides information about parking resources without making recommendations (although we discuss the implications for systems issuing recommendations in Section 7). But even when they are assisted by on-board mounted software agents, the human factor is present either indirectly, through offline configuring the agents with a profile of preferences, or, through its direct participation in the online search and selection processes.

The paper, thus, focuses on the decision-making task and the management of supplied information by the drivers. It seeks to answer how *efficient* is the parking search process when drivers employ psychologically *plausible* heuristics to choose between different parking resources. The efficiency of parking search is assessed by how much drivers end up paying in the aggregate to acquire parking spots, including the overhead costs due to needless cruising. The dominant modeling approach in literature is to view drivers as fully rational entities that process all information at hand and act strategically so as to minimize the cost of their search. In behavioral sciences such as economics and psychology, this kind of rationality is called *unbounded rationality*. In contrast, another kind of rationality is required for problems where there is not adequate time or computational resources in order to obtain all information and find an optimal solution, but nevertheless a good solution must be identified. This is referred to as *bounded rationality* and Herbert Simon is credited as its father (Simon, 1955).

However, Simon refrained from giving bounded rationality a precise definition and, as a result, multiple viewpoints to it have emerged over time (Rubinstein, 1998; Gigerenzer and Selten, 2001; Katsikopoulos, 2014). In the present work, we employ a view drawing on a family of simple mathematical models called *fast and frugal heuristics*, which are inspired by the actual behavior of people and other animals (Gigerenzer and Selten, 2001) and instantiate what Simon describes as procedural rationality in Simon (1986). Fast and frugal heuristics include the few pieces of information that people use and also specify the simple ways in which people process this information. *Lexicographic heuristics* are a specific type of fast and frugal heuristics, where pieces of information are inspected sequentially, and decisions are based on the first piece of information which satisfies a pre-determined criterion (such as exceeding a threshold value).

In our paper, which draws on and expands earlier work in Karaliopoulos et al. (2014), we study lexicographic heuristics for multi-attribute choice problems in the context of two representative instances of the parking resource selection problem. In the first one, drivers have to choose between the scarce but cheap on-street parking spots and the more expensive yet abundant space in parking lots. The second instance features two distinct (types of) parking lots that introduce a tradeoff between distance from the drivers' destinations and charged fee.

Methodologically, we follow the same steps in both problem instances: first, we formulate and analyze the games that emerge under strategic fully rational decision-making, then we analyze the performance of the parking search under activation of the cognitive heuristics and finally we compare the two cases. For the problem of risky choice, we derive analytically the conditions that let heuristics result in higher efficiency. Our results for most realistic scenarios suggest that should the drivers' behavior be more accurately characterized by these heuristics, then the parking search process would become more efficient than when drivers are modeled as fully rational strategic agents.

To the best of our knowledge, this is the first study that imports tools and modeling approaches from the field of cognitive psychology to the problem of parking search that has been extensively treated by transportation engineers, operational researchers, and computer scientists in the past. We strongly believe that putting the emphasis on the end-user decision-making process already is and will become all the more important for this problem in the future, as the combination of pervasive computing and social applications endows drivers with unprecedented amounts of information that could be exploited to engineer their choices. Section 3 summarizes the problem setting and existing results and provides background knowledge about the cognitive heuristics. Sections 4–6 contain the paper's main contributions. Section 4 devises and analyzes the priority heuristic for choosing between the cheap but scarce on-street parking and the spacious yet more expensive parking lot(s). It also compares it with those of the game-theoretic model in Kokolaki et al. (2013). Sections 5 and 6 con-

[1] Examples systems in this context include ParkingCarma (http://www.parkingcarma.com) and ParkShark(http://www.parkshark.mobi/www/).