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Basis Construction and Utilization for Markov Decision Processes Using Graphs

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Abstract
The ease or difficulty in solving a problem strongly depends on the way it is represented. For example, consider the task of multiplying the numbers 12 and 24. Now imagine multiplying XII and XXIV. Both tasks can be solved, but it is clearly more difficult to use the Roman numeral representations of twelve and twenty-four. Humans excel at finding appropriate representations for solving complex problems. This is not true for artificial systems, which have largely relied on humans to provide appropriate representations. The ability to autonomously construct useful representations and to efficiently exploit them is an important challenge for artificial intelligence. This dissertation builds on a recently introduced graph-based approach to learning representations for sequential decision-making problems modeled as Markov decision processes (MDPs). Representations, or basis functions, for MDPs are abstractions of the problem's state space and are used to approximate value functions, which quantify the expected long-term utility obtained by following a policy. The

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graph-based approach generates basis functions capturing the structure of the environment. Handling large environments requires efficiently constructing and utilizing these functions. We address two issues with this approach: (1) scaling basis construction and value function approximation to large graphs/data sets, and (2) tailoring the approximation to a specific policy's value function. We introduce two algorithms for computing basis functions from large graphs. Both algorithms work by decomposing the basis construction problem into smaller, more manageable subproblems. One method determines the subproblems by enforcing block structure, or groupings of states. The other method uses recursion to solve subproblems which are then used for approximating the original problem. Both algorithms result in a set of basis functions from which we employ basis selection algorithms. The selection algorithms represent the value function with as few basis functions as possible, thereby reducing the computational complexity of value function approximation and preventing overfitting. The use of basis selection algorithms not only addresses the scaling problem but also allows for tailoring the approximation to a specific policy. This results in a more accurate representation than obtained when using the same subset of basis functions irrespective of the policy being evaluated. To make effective use of the data, we develop a hybrid leastsquares algorithm for setting basis function coefficients. This algorithm is a parametric combination of two common least-squares methods used for MDPs. We provide a geometric and analytical interpretation of these methods and demonstrate the hybrid algorithm's ability to discover improved policies. We also show how the algorithm can include graphbased regularization to help with sparse samples from stochastic environments. This work investigates all aspects of linear value function approximation: constructing a dictionary of basis functions, selecting a subset of basis functions from the dictionary, and setting the coefficients on the selected basis functions. We empirically evaluate each of these contributions in isolation and in one combined architecture.

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