From single planning agents to planning with multi-agent adversarial networks

Planning agents have been described as those agents which consider anticipated future situations, possibly as a result of their own actions, to decide a best course of action [1]. These agents' actions contrast with *reactive agents*, which base decisions on sensory input [2]. The existence of these planning agents dates to the initial development of the autonomous planning robot *Shakey* in the Stanford Research Institute during the mid 1960s, and the STRIPs representational model which since has become the model upon which much of the language around planning has been constructed. The basic idea of the STRIPs representation is built on the concepts of states, goals, and actions, with actions being a construct based on the satisfaction of preconditions and the execution of which produce effects [6]. To achieve certain goals, an agent generally must pass through various states produced by the execution of a variety of actions.

In multiagent planning, goals are allocated amongst multiple agents, with the goals being refined into subtasks which are scheduled via resource allocation and timing constraints [2]. The assignment of tasks may occur through either centralized or distributed means depending on the application of the system. An interesting element of multi-agent systems is the necessity for communication among the agents and the necessity for an additional level of planning on the group level as well as the individual level. This generates several challenges which are not common to single agent systems, however when managed effectively, allow for much greater efficiency and increased complexity in the tasks approached. The use of multi-agent systems has been found to be a valid approach for a range of planning problems from the management of "smart grid" technologies to transportation planning [3, 4].

The use of multi-agent systems as applied to adversarial networks is also not a new topic of study, with a significant amount of research coming out of labs focused on game theory and video game development. Studies such as those done by Georgeff [8] demonstrated the potential for plan synchronization among agents with individual plans, which showed the potential for two agents with competing goals to help one another. Significant planning work involving multiple adversarial agents was also focused in this area with advancements leading to improvement in simulation scenarios such as those found in real time strategy video games [5].

Recently, with the advent of deep learning, the development of General Adversarial Networks(GANs) has taken the limelight as being an effective means of both training new models in difficult tasks such as image generation and in the exploitation of security vulnerabilities in networks defended by machine learning models utilizing techniques such as regression. A generative model used for planning can learn a conditional distribution over future states of the world, given the current state of the world and hypothetical actions an agent might take as input [7]. Multi-agent GANs are now being explored to solve problems involving image generation and cooperation in conceptual learning among agents applied to language [9]

We are finally reaching a point in which much of the research from disparate areas is able to be explored in depth using computational power which was not previously at hand. The potential implications of these developments is significant and it will be interesting to see what developments arise from the confluence of these technologies.

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