Note on Adversarial and Stochastic Elements in Autonomous Systems

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1 Problem Domain Overview

Autonomous Systems is an area of high interest for the USAF. To be precise, one should refer to the class of systems of interest as semi-autonomous, as the human presence in the loop, at a supervisory level, is typically essential. However the term autonomous is simpler, and emphasizes the general goal. It is implicit here is that we are not speaking of subsystems in a single vehicle, or even single vehicle control. Instead, we are discussing command and control at the operational and tactical levels. Further, we are often dealing with the actions of multiple entities, both friendly and otherwise, operating in a potentially adversarial environment.

Although for some problem classes, the controls may be at the vehicle-trajectory planning level, for others they may be at the tasking level, or sometimes simply at the communication planning level. In particular, for some problems, the state and controls may lie in the continuum, while in other problems, one, both or some combination of these may be discrete, possibly even taking values in a finite set. The systems may be purely observational, engaged in combat operations, or some mix of both. They may operate purely independently, or they may be working in tandem with human teams.

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One aspect is critical. This is the stochastic and adversarial nature of the overall systems in which the autonomous entities operate. Although one can imagine very large systems, such as those typically envisioned as swarms, there are difficult and deep problems induced by the stochastic and adversarial elements which must be resolved even for systems consisting of only a *very* small number of entities.

2 Some Sample Problem Classes

A few possible problem domains are indicated below. This list should not be taken as a complete, or even nearly complete, catalog. There are undoubtedly many important problems which we have not even considered. The list merely indicates a few points in a very large space of problem classes. Suggestions for problems that AFOSR should be aware of are absolutely welcome.

1. Air supremacy in future conflicts cannot be taken as a given. With the advent of UAVs, the pursuit-evasion problem for autonomous vehicles becomes of interest. With the relative low cost of some UAVs, the problem could also be generalized to cases where more than two vehicles are involved. On a slightly different front, one can consider a problem where a piloted vehicle is under threat from another vehicle (possible a missile), and deploys a defending missile. Lastly, pursuit-evasion problems for motion in a potential field, with finite L_1-norm controls might be an interesting problem class as well.

2. The theory of discrete-time games under full-state feedback is relatively well-understood. However, game problems in the defense arena seldom fall within the domain where full state knowledge can reasonably be assumed. This includes problems in command and control, where the state model may also be discrete, and often finite. For many of these problems, the certainty equivalence principle may not be a reasonable approach. The problems may also have significant stochastic elements as well as adversarial elements. In addition to the stochastic/deterministic division, there are subclasses within this class of problems which are worthy of mention. Problems where one assumes that the information pattern is nested may be substantially more amenable

to solution than non-nested problems. (Here, we say that the information is nested if one player's information is a subset of the other player's information.)

3. It is clear that stochasticity is a critical component of problems in the defense domain. For decades, certain models of stochastic processes have been heavily employed simply because they are more amenable to computational solutions. It has become clear that the classical models are often (although not always!) inappropriate, and that estimators and controllers built on them are significantly suboptimal. If one can develop computationally tractable algorithms for more appropriate noise models where this leads to substantially improved results, that would provide an obvious benefit.

4. Deception is a critical component of real-world games in complex and imperfectly observed environments. However, even the basic mathematical definitions of issues in deception are not complete. This an important practical problem, which is natural to humans, but presents deep difficulties.

5. Nonlinear games are computationally difficult. This include deterministic, stochastic, continuous, discrete, full information and imperfect information problems. As always, nonlinear stochastic control and estimation problems are also difficult as well.

6. In networked systems, communication links may be intermittent because of physical barriers, random dropouts and adversarially induced disruptions. The development of controllers which are robust to such effects will be invaluable.

7. If an opponent can invade a network, introducing random or intentionally deleterious inputs, tremendously poor system behavior could result. Developing means for making networked systems robust to such masqueraders would be invaluable.

8. Any of the adversarial problems above can be considered from both sides. For example, in addition to being robust to deception, one might wish to employ deception to reduce losses.

3 ASEAS Workshop

On March 24 and 25, a small workshop was held in Arlington, Virginia, USA. This was the Adversarial and Stochastic Elements in Autonomous Systems (ASEAS) Workshop. As part of this workshop, several DoD representatives described some sample problems in the defense arena. There were also presentations by a number of academic and industrial representatives. A number of these presentations will be posted elsewhere on this website.

A second component of the workshop consisted of discussions of problems in the domain indicated by the workshop title. Some of these discussions inform the above problem class descriptions. Further details of a portion of the small-group discussions will also be posted elsewhere on the website.