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Interdependence: A Mathematical Approach to the Autonomy of Human-Machine Systems

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ABSTRACT

We update our theory of interdependence for autonomous human-machine teams operating in open systems (A-HMT-S). In closed systems, desired outcomes can be easily obtained with rational models (e.g., game theory); there, uncertainty can only be studied as part of a system's internal complexity. In hindsight, the problems with closed system models are obvious: they are fragile, hard to replicate, and not generalizable, the latter being the fatal flaw for autonomous human-machine teams and systems. Surprisingly, no amount or aggregation of data from individuals can be recombined to replicate social data. In contrast, with open systems, interdependence theory is state dependent, reactive to every situation and change, especially the environmental and social uncertainty caused by competition or conflict. More important, in contrast to social science's reliance on the independent and identically distributed (i.i.d.) data derived from individuals, interdependence theory is generalizable. But before we start, we acknowledge that machine learning is a closed system model, context dependent, and that existing artificial intelligence (AI) models are insufficient to produce autonomy today. Thus, we built a mathematical model based on first principles around interdependence and applicable to intelligent autonomous teams of any sort. With our model of interdependence, among the results we have found: reactiveness to bistable information requires intelligence, and boundaries as a barrier to impede its unwanted flow; independent information cannot replicate teammate dependence, effects, nor performance; interdependence creates tradeoffs between the structure and performance of autonomous systems, that, as byproducts, affords metrics, deception, suppression, and vulnerability, the latter being a new field of research that we have discovered and that is the motivation for innovation, mergers and acquisitions. We close with a brief review of future research opportunities.

Keywords: Human machine teams, Autonomy, Interdependence, Systems

INTRODUCTION

In this chapter, we briefly review our findings to provide an update of our theory of interdependence for application to autonomous human-machine teams operating in open systems (A-HMT-S).

CLOSED SYSTEM MODELS

In closed systems, desired outcomes can be easily obtained with rational models (e.g., game theory); specifically, by using games, uncertainty can only be studied as a part of a system's internal complexity.

Wargaming, however, is considered to be a crucial step for military planning processes (Guyer et al., 2021). When done thoroughly, these games are supposed to allow a commander and staff to identify their strengths, weaknesses, opportunities and threats in their plan. This wargaming planning step is believed to be critical in testing the fighting products that synchronize an operation in time and space across all warfighting functions and domains. The time invested is thought to be well spent and to allow commanders to understand their unit's decisions against the enemy that is being faced. From a war gamer's perspective, its outputs supposedly build the foundation for the targeting process and the assessment cycle that follows.

Wargames are, however, associated with closed system models, confounding their traditional use. Considering closed systems, retired U.S. General Zinni (Augier & Barrett, 2021) complained that the use of war games results in "preordained proofs"; that is, by choosing a game's context, a war gamer can obtain any outcome desired.

Surprisingly, no amount or aggregation of data from individuals can be recombined to replicate social data. That lack of generalizability to intelligent systems of any sort is directly related to the use of independent data, known as i.i.d. data (Schölkopf et al. 2021) .

In hindsight, the problem with closed system models are obvious: they are fragile, hard to replicate, and not generalizable to systems confronting uncertainty or conflict (e.g., Mann, 2018), the latter being the fatal flaw for an application to autonomous human-machine teams and systems.

OPEN SYSTEM MODELS

In contrast, with open systems, interdependence theory is state dependent, reactive to every situation, especially the environmental and social uncertainty caused by competition or conflict (Lawless, 2020). More important, in contrast to social science's reliance on the independent and identically distributed (i.i.d.) data derived from individuals, interdependence theory is generalizable. But before we start, we acknowledge that machine learning is context dependent (Peterson et al., 2021), and that existing artificial intelligence (AI) models are insufficient to study autonomy today. Thus, we are building a mathematical model based on first principles applicable to intelligent autonomous teams or systems of any sort.

Applied to intelligent systems, the chief characteristic in response to uncertainty is an interdependent reactivity to the perceived risks that may arise if these perceptions have not been suppressed (e.g., with authoritarian rule or where minority rules known as consensus seeking control decisions; in (Lawless, 2019; 2020). For an open-system model of teams, we propose that a trade-off exists between uncertainty in the structure of an autonomous human-machine system and uncertainty in its performance (for details, see Lawless, 2020):

$$\Delta(structure) * \Delta(performance) \approx C. \tag{1}$$

The predictions for entropy production with Equation (1) are counterintuitive. Applying it to concepts and actions results in the following tradeoffs that we have discovered up until now: as uncertainty in a concept reaches a minimum, the gold standard of social scientists, however, uncertainty in the behavioral actions covered by that concept increase exponentially, rendering the concept invalid, a result that has been found for self-esteem (Baumeister et al., 2005); implicit attitudes (Blanton et al., 2009); or ego-depletion (Hagger et al., 2016). These problems with concepts have led to the widespread demand for replication (Nosek, 2015). But the demand for replication more or less overlooks the larger problem with the lack of generalizability to intelligent systems arising from the use of strictly independent data (Schölkopf et al., 2021).

Findings

With our model of interdependence, here is what we have also found: the minimum reactiveness to uncertainty explains why the best teams are highly interdependent, outperforming the same members for a team that act independently even in the same roles as individuals (Lawless, 2019); the most effective members of a team perform in orthogonal or complementary roles, reducing a team's entropy by reducing its degrees of freedom (e.g., for a 3-person restaurant: a cook, a waiter and a cashier).

Metrics

Related to metrics, we have found in a series of tradeoffs with Equation 1 that boundaries minimize the transmission of value (bistable) information; that the whole is greater than the sum of its parts only if the parts are dependent on each other; and that internal suppression across a system (censorship) can deceive observers into believing that an organization is well-run, but one that is unable to innovate, motivating its need to steal secrets.

Regarding the need by systems to steal secrets, after it had been confirmed that the Chinese had stolen millions of records from federal employees for the innovativeness that had so far eluded China, General M. Hayden, the former Central Intelligence Agency and National Security Administration chief, told his Chinese counterparts (Baker, 2015),

> "You can't get your game to the next level by just stealing our stuff. You're going to have to innovate."

Stealing occurs by monopolies, too. From the Wall Street Journal, Amazon has been charged with stealing the designs of the companies it markets (Mattioli, 2020):

> "Amazon.com Inc. … employees have used data about independent sellers on the company's platform to develop competing products, a practice at odds with the company's stated policies."

With Equation 1, we have also learned that spies operate best as insider threats by appearing to be compliant and complaisant until opportunity for an exploitation arises (Lawless et al., 2020); that the likelihood of innovation increases in markets sufficiently free to seek the optimum fit of the best partners available (Lawless, 2020); and that least entropy production, LEP, in a team or system's structure promotes maximum entropy production, MEP.

Vulnerability: A New Discovery

We also review the discovery with Equation (1) of a new field of research by the mathematical identification of structural vulnerability in teams, organizations and systems; how pursuing the natural motivation to reduce structural vulnerability unexpectedly produces organizational resilience to social shocks; and how the seeking of structural vulnerability in opponents motivates decisions in opposing interdependent (e.g., social) forces that lead to mergers and alliances to create more order in a system in accordance with the second law of thermodynamics (Lawless, 2019; 2020).

The search for vulnerability by "red teams" is important to establish trust in a machine system (Avin et al., 2021). After the erroneous drone attack that killed 10 civilians in Afghanistan by the U.S. military in the summer of 2021, the investigation report by the Department of Defense recommended the use of red teams to test the decisions made by human teams before they used armed drones in combat (DoD, 2021).

The search for vulnerability leads to political positions that explore moral positions in the search for a global or national advantage. From Friedman (2021),

> "The question of the proper relationship of the United States to the rest of the world has been a central issue since America was founded. Thomas Jefferson warned against entangling alliances, while George Washington and Benjamin Franklin were maneuvering to try to get France engaged in the American Revolution. America was founded as an alternative to Europe and a new order of the ages. … Since the 1930s, there has been a debate in the United States over a foreign policy based on "America First," a nationalistic policy that prioritizes U.S. objectives over others'. It's an idea that has at different times been central to Democrats and Republicans alike. The positions have ranged from the right urging that the U.S. not take responsibility for the fate of other nations, and the left condemning the United States for acting as the world police. The left has supported a strategy that the United States must remain enmeshed in the world through alliances. On the right, there has been the belief that the U.S. must remain enmeshed in the world in order, for example, to defeat communism. It has taken on the character of a moral principle and prudent action in both ideological tendencies, and as a moral obligation in both as well."

Government, however, often operates as a command decision (authoritarian) operation; if it is not careful, it can gravely subdue the forces of innovation. Specifically, it should not be involved as a direct regulator of free trade. From Boudreaux (2021), the value of free markets is that,

> "Under a policy of free trade, all producers must earn their livings honestly – that is, by supplying genuine value to consumers *as consumers judge that value and not according to what that value is asserted to be by producers themselves, or by their cronies in government*. Under a policy of free trade government does not deny any of its citizens, either as consumers or as producers, the opportunity to get the most for their money in voluntary exchange with others – nor, however, does government artificially inflate the incomes of the politically potent by forcibly transferring income away from the politically impotent."

Equation 1 predicts that systems operate best when they are able to freely choose teammates and to freely pursue opportunities legally available, wherever these opportunities exist (Lawless, 2019). Regarding free choice, government control reduces free choice, but it also depends on the rationality of economics. However, economic theory is contingent on independent data derived from closed system models. This state has led to the controversial first sentence by Rudd (2021),

> "Mainstream economics is replete with ideas that "everyone knows" to be true, but that are actually arrant nonsense."

Moreover, Mann (2018) has found that rational models fail when facing conflict or uncertainty.

CONCLUSION

We close with a brief comment for further future research that Equation 1 applies to factoring risk into two parts: calculable or actual risk, and subjective risk perception (Lawless & Sofge, 2022). In closing, interdependence offers a rich vein of opportunity for the science of autonomy for teams and systems.

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