ESSAY

MULTI-LEVEL ABSTRACT GAMES FOR POLICY, STRATEGY AND TECHNOLOGY DEVELOPMENT

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The scope of military simulations expands well beyond the traditional type of war games that focus on organised violent conflict. Defence scientist Dr Darryn Reid argues that the approaches and models used in modern 'wargaming' can inform better decision making in uncertain and fast-moving environments, such as economic planning.

When John Maynard Keynes outlined a notion of inherent uncertainty arising through the complex interdependent interactions between agents in a competitive investment environment,[1] he might just as well have been analysing the core observation of Carl von Clausewitz, one of the main founders of military theory as the field of philosophy examining the nature of war and battle.[2,3] Both effectively described precursors to discoveries of extreme impact in pure mathematics and right at the foundation of computer science, which would be developed starting about a decade later by Kurt Gödel, Alan Turing and others.[4] The implications are still being unravelled to this day.

It is common for modern defence organisations to develop and play various kinds of games, but what might be less widely recognised is that the scope of such activities expands well beyond just the war games that are directly focused on organised violent conflict. Their focus may sometimes not include any

1. Keynes, 2017
2. Von Clausewitz et al., 2001
3. Beyerchen, 1992
4. Copeland et al., 2015

direct warfare at all. Through its Modelling Complex Warfighting (MCW) initiative, the Defence Science and Technology Group is engaging with multiple research partners to build national capability in artificial intelligence for defence and national security, where, perhaps surprisingly, game models and analysis are also crucially important. Indeed, games are, somewhat counter-intuitively, the central focus in these efforts; this is because the focus is not directly on algorithm development as such, but on systematic problem-solving in problem domains that have tended to defy adequate resolution by current methods because of their intrinsic difficulty. Specifically, these problems are deeply 'wicked' – to use traditional Operations Analysis terminology – because they are high in inherent uncertainty, ambiguity, complexity and asymmetry. Games have central importance because they provide concise representations of wicked problems that capture core structural properties while washing out the mess of unnecessary and often seductively misleading details.

Games thus amount to empirically testable scientific decision-making theories in target wicked problem environments. Note that they are defined by decision-making purpose as by the problem environment itself, so there may be many distinct yet equally valid game representations possible for any given problem environment. This perspective on decision making motivates using game representations in the first place and defines the various actors in a game. Sides in a conflict are generally not monolithic. Instead of comprising multiple interacting actors, the list of actors may also include changing environmental features. Actors in games can even themselves be subordinate games.

The critical insight is that analysis has typically relied on, and hence been limited by, narrow and rigidly prescriptive models that do not fully represent decision making in realistic target problem domains.[5] Worse, a great deal of the time, models have been largely or entirely implicit, which means they naturally embody what often turn out to be overly strong assumptions that may reflect various biases, especially in obtaining ready pathways for developing solutions. Consequently, we seek to utilise explicit, immersive and well-situated models through analysis to establish them as reliable decision-making theories in a target problem environment to provide realistic yet abstract living embodiments of pivotal features. These features comprise the various modes of uncertainty, ambiguity and various kinds of asymmetries, particularly those set up by the potential for terminal failure.

Games, in this context, constitute decision-making theories in target problem environments designed to capture modes of self-reference in their logical structures. Any game model boils down to a system of invariant conditions that describe underlying symmetry properties in the problem domain, under which agents interact via a conflict, competition, cooperation, or all three. Unlike many narrowly prescriptive models oriented around a high degree of predictability in the target environment, these game models are about defining wide spans of possible evolution paths that may develop through the complex interactions between actors under the game's rules.[6] Because of this possibility of self-reference in the game structure, which leads to the presence of logical paradoxes, game models can generate environments manifesting fundamental uncertainty.

5. Reid, 2018
6. Samarasinghe et al., 2021

A prominent example of paradoxical self-reference can be seen at the heart of the military theory, which explains the nature of war and battle and applies to adversarial or competitive environments more broadly. What constitutes a good choice of action for a player is often heavily dependent on opponent action choices, so each player must develop expectations about each other players' future actions to make a good choice of action. What constitutes a good action to choose is thus dependent on what actions everyone is choosing, which means the quality of action choices is not a fixed function. This is also why deception takes such a central position: successfully distorting an adversary's theory about future actions by appropriate action choices changes – often radically – the goodness of future action choices to favourable effect.

Estimating opponents' capabilities within context is a crucial part of forming beliefs about their future actions. This is how uncertainty and ambiguity – both natural and deliberately created by disguising capability and its present arrangement – blend in formulating effective game strategy dynamically. Uncertainty occurs even in the presence of complete information, but realistic adversarial problems also involve creating ambiguity to disguise intent actively.

We can contrast paradoxical self-reference in game models with more familiar kinds of self-reference in which there is a stepwise reduction towards a base case (inductive) or generalisation away from a base case (co-inductive). In either of these situations, the self-referential structure ultimately reduces to an answer; the self-reference is just a way of compactly specifying a computation consisting of repeated steps. Most extant models, in contrast, have acyclic causal structures, or the cycles they do reduce away in this manner to a logically acyclic equivalent. Any time we have paradoxical self-reference, however, we will have a system that manifests inherent uncertainty because paradoxes in the formal logical sense do not reduce to simple answers, but to some properties of the system being unknowable within the context of the system.

There is a powerful emphasis on the systematic composition of game models in which actions can change the game itself. Such games are non-ergodic self-evolving systems, and this course of game evolution is generally unpredictable in detail – the game model's overall invariant conditions are outer bounds on what this evolution in terms of changing rules can produce. These bounds are typically at different levels of abstraction: they may be concrete for properties that are conveniently statistically predictable and successively more abstract for describing properties around which there is inherent uncertainty. Strategy, in military theory, is not about solving a given problem as such, but rather about shaping it over time towards eventually realising the kind of problem one is better to set up to solve.

A particular area of the current focus is simultaneously representing event sequences at different temporal granularities in game models;[7] many of the crucial properties in conflict involve self-reinforcing or self-denying feedback loops yielding paradoxical effects that play out across vastly different time scales. For instance, tactical events amount to relatively fine temporal granules but can generate solid strategic consequences at much coarser temporal scales, much as microeconomic activity might relate to macroeconomic policy formulation. It generally is not feasible to play a game entirely representing every time step at the finest temporal granularity

7. Cohen-Solal et al., 2015

– mainly when humans play as actors within the game – so the ability to represent only relevant events smoothly across dynamically changeable temporal scales is crucially important.

Usable invariant conditions – properties that remain constant – need be global. Systems subject to fundamental uncertainty typically undergo periods of relative stability concerning their various properties of interest in between rapid phase shifts, and these patterns can be different relative to different properties. There is often a fractal nature whereby equilibria and mode changes occur frequently but at different levels of abstraction. Temporal granules at different scales form a sliding kind of hierarchy against which more localised invariant conditions might be detected and exploited – in the case of artificial intelligence, the emphasis is on doing this dynamically, either with machine assistance or entirely within the machine – for the duration for which they hold before they dissolve when the problem environment undergoes mode shift. Invariant properties that last for only short periods are generally much harder to exploit; decision making is only reliable if it is possible to detect and respond to the potential collapse of temporary properties, and the detection and response often must occur at a finer temporal granularity than that at which the invariant property holds.

Given a game model, obtaining reliable decision making then boils down to finding invariant properties that are maximally concrete operating at the lowest practical time scales yet that are nonetheless still supported by the environment for the duration of their utilisation – as concrete as possible but no more – because using weaker invariant properties at higher abstraction yield unwarranted robustness at potentially unnecessary efficiency costs and loss of opportunity. Obtaining relative advantage over an opponent who also understands how to ground decision making in this way amounts to walking closer to the line than they can without crossing it, forming a theoretically endless competition.

The overriding observation here is that we have uncertainty everywhere, but that uncertainty is always bounded, never absolute: paradoxical effects are unknowability, within the context, of specific properties generated by an underlying paradoxical structure; that is, questions that just cannot be reliably answered within the game even with complete information. Understanding what can and cannot be answered within the decision-making context means obtaining reliable decision making within known limits. This recognition that wherever there is an unpredictable property, there is also a weaker and more abstract predictable one to utilise in its place was what was missing when Robert Lucas[8] described the axioms of economics as patently unreal yet also defended them as the only way to do economics scientifically.

Joseph Stiglitz has also reflected the sentiment in maintaining that although economic phenomena are manifestly not ergodic, using ergodic assumptions in economic analysis is necessary for us to have ourselves an economic science at all.[9] That economic phenomenon, like adversarial systems in war and battle, is generally not ergodic should be obvious and universally endorsed; yet it does not follow that analytical necessity of ergodicity means we cannot have science. It means instead that concrete predictability conditions may often need to be supplanted in analysis and technology development with abstract properties that describe weaker invariant conditions. This amounts to mapping non-stationary systems into stationary systems to which conventional methods can then be applied reliably, through abstraction.

8. Lucas et al., 1981
9. Davidson, 2003

In conclusion, theorists of war and battle emphasise this as a dynamic process because of the unpredictability of these inherently non-stationary problems. Planning in problem environments featuring uncertainty is not so much about producing plans as it is about detecting and responding – with an acute emphasis on doing so proactively – to their impending failure. Utilising invariant properties that hold for some limited time means that failure to produce credible plans requires folding back to higher levels of abstraction, typically operating at longer time scales.

Utilising game models to penetrate wicked adversarial problem domains involves two processes of abstraction. First, the game model is composed of game mechanisms to give testable decision-making theories in the target problem environment. Second, exploitable invariant conditions are extracted to base policy determination, strategy formulation, or technology development at potentially different temporal granularities. These exploitable invariant conditions may be enduring or temporary; in the latter case, solutions must handle mode switching dynamically. I warrant that economics might significantly advance in its ability to deal with wicked policy problems by adopting the same approach. Indeed, it seems doing so would be the realisation of science addressing the core problem of economics as set out by Keynes when he described his notion of fundamental uncertainty, distinct from stochastic chance, and the belief formation of economic investors.

REFERENCES

Beyerchen, A. (1992), Clausewitz, Nonlinearity, and the Unpredictability of War, *International Security,* 17(3), 59–90, https://doi.org/10.2307/2539130

Cohen-Solal, Q., Bouzid, M. and Niveau, A. (2015), An Algebra of Granular Temporal Relations for Qualitative Reasoning, Proceedings of the 24th International Joint Conference on Artificial Intelligence (IJCAI)

Copeland, B.J., Posy, C.J. and Shagrir, O. (2015), Computability: Turing, Gödel, Church, and Beyond, The MIT Press (Reprint Edition), ISBN: 0262527480, 978-0262527484

Davidson, P. (2003), Financial Markets, Money, and the Real World, Edward Elgar Publishing, ISBN: 1843765586, 9781843765585

Keynes, J.M. (2017), The general theory of employment, interest and money, Wordsworth Editions

Lucas, R.E. and Sargent, T.J. (1981), Rational Expectations and Econometric Practice, Minneapolis: University of Minnesota Press

Reid, D.J. (2018), An Autonomy Interrogative, in Abbass, H.A., Scholz, J., Reid D.J. (2018), Foundations of Trusted Autonomy, Springer, ISBN: 978-3-319-87879-9

Samarasinghe, D., Barlow, M., Lakshika, E., Lynar T.M., Moustafa, N., Townsend, T. and Turnbull, B.P. (2021), A Data Driven Review of Board Game Design and Interactions of Their Mechanics, IEEE Access 9: 114051-114069

von Clausewitz, C., von Oetinger, B. and Bassford, C. (2001), Clausewitz on Strategy: Inspiration and Insight from a Master Strategist, John Wiley & Sons, ISBN: 0471415138, 9780471415138

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