Towards a Taxonomy of AI in Hybrid Board Games

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ABSTRACT

With hybrid board games rising in popularity and game AI algorithms becoming more sophisticated, there is potential in involving AI to create novel game experiences and tools that can support developers. However, examples of hybrid board games that involve AI remain relatively sparse. In this work, we propose that creating a taxonomy of AI in hybrid board games can help the development of games that occupy as-of-yet unexplored areas of the design space. By mapping out different dimensions through which the involvement of AI in such games can be understood, we seek to encourage further academic discussions and applied explorations.

CCS CONCEPTS

• **Applied computing** → **Computer games**; • **Computing methodologies** → *Knowledge representation and reasoning*.

KEYWORDS

hybrid board games, video games, hybrid games, board games, game artificial intelligence, game ai

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1 INTRODUCTION

Over the past years, board games have been rising in popularity [11] in parallel to video games. Rather than standing in competition to one another, video games and board games offer different kind of experiences that are both in demand. Naturally, this also creates more interest for game systems that borrow from both modalities. The overlap between video games, a term that we use synonymously with 'computer games' and 'digital games' in this paper, and physical games is often referred to as 'hybrid board games'. Hybrid board games can be understood as part of a wider range of 'hybrid games' that generally involve multiple and different types of media without necessarily being defined by the involvement of analogue and digital game elements [3]. At the same time, in the area of video games, the importance of AI is steadily rising, as the necessary technology becomes increasingly more capable of sophisticated decision making and interpreting complex game states. This, in turn, allows for the creation of novel gameplay elements, as well as the development of systems that aid in the design and evaluation of video games [16, 23]. This trend is less pronounced in hybrid board games, where the use of AI appears to remain more rudimentary.

In this work, we present the first steps towards a taxonomy of AI in the area of hybrid board games with the purpose to aid the research and development of AI that can support such games. We see the creation of a taxonomy as a catalyst for generating new ideas by structuring existing knowledge and, perhaps even more importantly, emphasising areas that lack either practical or theoretical knowledge. Finding such design spaces can highlight interesting opportunities for future work that would otherwise remain unexplored. Our efforts should therefore be understood as a call for action to strengthen the presented structure through further critical discourse and empirical investigations.

The following section, '*Working Definitions*', provides our working definitions of hybrid board games, as well as what can be considered 'AI' in the context of such games. The section '*Taxonomic Lenses*' outlines a proposed taxonomy through different possible dimensions from which to attempt a differentiation of AI in hybrid board games. We conclude the paper with a discussion of the presented dimensions through illustrative examples.

2 WORKING DEFINITIONS

Before attempting to map out a taxonomy of AI in hybrid board games, we need to establish a definitional basis for the involved aspects. What forms of AI should be considered, and what do we mean when we talk about 'hybrid board games'? The focus here is less on arriving at indisputable demarcations (requiring considerably more argumentative writing space) than on outlining working definitions that provide a structure for further discussion.

In the context of this paper, we understand **hybrid board games as games that combine intentionally designed digital and physical modalities to create a game experience for players**

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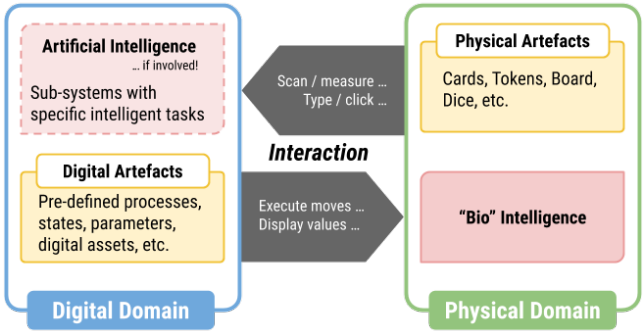

Figure 1: Illustration of high-level components involved in a hybrid board game. Both domains involve intentionally designed artefacts and interaction with the other domain. Typically, hybrid board games involve human, or 'bio' intelligence, but may also involve several AI sub-systems (which tend to be specific to the task)

within the boundaries of a defined physical space [3, 10]. The underlying games may be created for entertainment purposes, or fulfil additional purposes, such as to train players in a given task (often referred to as 'serious' games [1]). Under this definition, we exclude 'gamification', which is the use of individual game mechanics or aesthetics in otherwise non-gaming circumstances [8]. Our working definition further excludes games that lack physical or analogue artefacts that are explicitly designed for the purpose of facilitating a game session. We consider this an implicit aspect of the word 'board' in the term 'hybrid board games'. Augmented reality games such as *Pokémon GO* [14] may indeed involve the physical environment, but do not define specific game spaces and do not contain physical artefacts that are intentionally designed. The digital domain of the game adapts to the physical domain, while the reverse does not occur.

Augmented reality games or mixed reality games can certainly be described as hybrid games and the involvement of other domains might create hybrid games that are not defined by the use and interaction of both physical and digital components [3]. Likewise, any efforts of building a taxonomy may yield valuable insights for hybrid games of all sorts. However, we do see value in focusing on a specific sub-field, i.e. hybrid 'board' games, as it is also likely that some taxonomic dimensions that we will discuss do in fact not map to all hybrid games.

On the other hand, we consider the word 'board' a linguistic anchor that hints more at the involvement of physical artefacts, defined space and gameplay traditions than at the existence of a board in a strict sense. Card games or dice games, for example, may lack a physical board, but do involve intentionally designed physical artefacts and spaces. It would therefore perhaps be more accurate to talk about hybrid 'tabletop' games, as most of these games are traditionally played on a shared table. However, it should be noted that 'hybrid board games' is already an established and somewhat widely-used term that indeed appears to include physical games that lack a board. This is also where an excessive fragmentation of implementations is perhaps less useful in mapping out a potential design space.

In terms of what forms of AI should be considered for the taxonomic structure, we build on recent work in the field of game AI, which is focused on the use of AI for game purposes [16]. As a rough working definition, we are interested in mapping **any involvement of a computational system into a decision making process that is part of a hybrid board game.** This, just like for game AI, includes decision making processes before or after the game, as well as decisions that are more artistic than part of a game mechanic.

Figure 1 illustrates the conceptual components of a hybrid board game, as we understand it through the outlined working definitions. Components are separated between the digital and physical domain, both of which include artefacts that are intentionally designed to be part of the gameplay. Both domains further involve some degree of interaction with the other domain. The physical domain necessarily involves one or more intelligent entities[1] that usually take the form of human players (although the involvement of animal players is a possibility that fits perfectly well in this model). When AI is involved during the game session, the digital domain also involves one (or more) intelligent 'entities'. In contrast to human players, AI entities may not necessarily be featured as individualised agents, but can instead be constructed as compartmentalised sub-systems. Human players are generally capable of carrying out a wide range of decision making tasks that are very different from one another. AI systems are more likely to be designed to fulfil specific tasks, thus leading to a number of systems that can be at play in parallel even if they together only take control over a single game entity (if they represent an embodied agent at all).

We acknowledge that the presented working definitions likely leave questions open. For working towards a taxonomic structure we consider this both a practical necessity and an opportunity for encouraging a broader discussion in an effort to better map out potential uses of AI in hybrid board games.

3 TAXONOMIC LENSES

In this section, we outline dimensions on which examples of AI in hybrid board games either already exist, or could potentially exist. Each of these dimensions represents a 'lens' or perspective through which the involvement of AI in hybrid board games can be viewed and understood (see Table 1). The metaphor of different lenses follows a similar approach in efforts of outlining the wide range of interrelated dimensions in the practice of game design [18]. It is important to note that we choose this metaphor in part because it reflects the fact that individual dimensions are not necessarily separated as definitively as it is the case in other taxonomic models, such as the 'phylogenetic tree' or 'Linnaean taxonomy' in biology.

Throughout the following sub-sections we use chess as a case study to illustrate how it can be (and has been) modified to act as a hybrid board game with AI involvement. The point here is of course not that chess is the most suitable game for such efforts. However, it provides a widely known game example that is useful for illustration purposes.

[1] ignoring the more philosophical musings on the concept of zero-player games [5]

Taxonomic Lenses	→ Constituent Sub-dimensions
Embodiment	→ **Relationship** between agent(s) and players → **Believability** of interaction → **Amount** of agents
Physical Domain	→ **Awareness** of physical domain → **Interactivity** with physical domain
Temporal Domain	→ Temporal **involvement** within/outside a game session → Temporal **resolution**
Gameplay	→ **Centrality** to gameplay
Role	→ **Actor-Director** spectrum

Table 1: The left column lists the individual taxonomic lenses that are discussed in this paper. Each lens should be understood as an independent perspective on AI in hybrid board games. Each lens can be further deconstructed into constituent sub-dimensions. The table is not exhaustive and should be understood as structural foundation.

3.1 Embodiment

AI in games is perhaps most prominently represented by the involvement of intelligent agents that are embodied in some form. In video games, this embodiment happens in the digital domain, through 'bots' that compete with human players, or non-player characters ('NPCs') that give players the opportunity for diegetic interaction. Such agents also exist in hybrid board games, either as physical entities, or as virtual entities with varying degrees of defined embodiment. Early chess computers might require players to carry out turns for a computational agent on their behalf, but they still act as a virtually embodied entity (i.e. attributing any game interactions to an 'enemy' or opponent, rather than responding to unattributed changes in a game environment).

One dimension that falls under agent embodiment is **the relationship between AI agents and players**. AI agents may act fully collaborative, fully competitive, or somewhere in-between. This can extend to the expression of personalities through the way in which an AI agent plays. Competitive actions by a human player might trigger AI agents to respond in kind for the rest of a game session, thus giving the appearance of a resentful AI player. While the possibility for such behaviour depends in part on the underlying game, even fully competitive games can provide opportunities to display 'emotions', such as in the way that an agent responds to a loss (e.g., congratulating or antagonising). Many games do not necessarily feature a single, clearly superior strategy for competitive play, thus providing venues to express an agent's personality (e.g., through aggressive, risk-taking play). It is also worth noting that competitive play can originate fully from the rules of a game, without involving a model of competition in AI agents themselves.

The display of such 'emotions' ties into another sub-dimension: the **believability of any interaction with an AI agent**. Believability of agents is closely connected to what kind of embodiment is given to them by the design of the game. If they are given similar gameplay possibilities as human players, an agent AI will likely face a higher degree of scrutiny by players as to what is or is not believable. Here it is important to highlight that in the context of hybrid board games, the high end of the believability spectrum is less about the perfect simulation of human behavior[2], and more about maintaining a player's suspension of disbelief.

Another sub-dimension is **the amount of embodied agents**. A game might involve multiple AI agents with very rudimentary decision making that present an obstacle to other players simply by their existence. Such AI agents can be thought to have no relationship to the player at all, instead carrying out tasks without any considerations regarding other agents (human or otherwise).

Agents can also be classified according to their relative power compared to the player's. For example, we can have AI agents acting as opponents, limited by the same rules and driven by the same opportunities as the players but it is also possible to involve agents with different levels of advantages or limitations in their gameplay. This can be also moderated by the game settings, making the match more or less challenging for the human players.

The possibility of multiple AI agents brings up another dimension that is part of embodied AI involvement: **the number of agents that are controlled by an AI**. An AI system might be embodied as a single entity (whether fully virtual or with a physical representation), or consist of multiple, potentially infinite, embodied agents. Mapping an AI on this spectrum is not necessarily straight-forward. In the example of chess, one could argue that only two agents are involved, as it is played by two players moving pawns. On the other hand, the embodiment of each player within the game space can also be thought of as 16 agents that act through a hive mind. The question of how many agents are in a (hybrid board) game is thus dependent on whether the focus is on the actual embodiment, or on the intelligence that controls these embodiments. A hybrid version of chess could indeed be realised with multiple AI 'minds' that share the control of their 16 embodied agents, such as by developing competing strategies internally before settling on an externalised action. This form of hidden multi-agent setup is indeed used to treat the most difficult game playing AI tasks, such as beating professional human players in *StarCraft II* [6, 20].

3.2 Physical Domain

Given that we define AI as the involvement of computational systems with decision making capabilities, we can expect any AI to have easy access to any digital data that is kept as part of a hybrid board game. Such data might originate in the digital domain, but still require physical modalities to inform human players. The most straight-forward method is the involvement of additional devices such as smartphones or tablets to facilitate the communication between the AI and the physical environment. On the other hand, to register actions in the physical world and interact with it, a degree of physical awareness is required. The **dimension of awareness in the physical domain** thus describes to what extent a physical input or signal is digitalised. In addition to physical awareness, an AI can differ in the degree to which it is capable of acting in the

[2] Although, clearly, any progress towards solving 'AI-complete' problems are likely beneficial for the task of creating believable agents.

physical domain. **This dimension can be considered the interactivity of an AI in the physical domain.** Much of the existing academic work on hybrid board games focuses on how this translation between physical and digital states can be implemented [17].

However, for the purpose of building a taxonomy, the question of how awareness and interactivity with the physical domain is achieved might not be as important as to what extent it is involved at all. It is difficult to imagine examples in which an AI requires no degree of physical awareness, nor any form of interactivity with the physical domain. Early chess computers would require human players to provide information about the physical world (i.e., pawn movement), and to carry out AI movements correctly. While it may seem that full automation of such actions is always beneficial for human players, there is also some evidence that leaving some 'house-keeping' tasks to human players may be desirable [21].

3.3 Temporal Domain

Another lens to look at AI in hybrid board games is to consider the temporal domain: when is AI involved in the larger context of a game session, and at what temporal resolution does it operate?

The dimension of temporal involvement, or when AI is involved, seems less suitable for framing as a continuous spectrum than of distinctive ordinal categories, involving AI either: (1) before a gamesession, (2) during a game session, or (3) after a game session. It is conceivable that an AI is involved in some or all of these temporal categories, but it is more likely that this would involve different AI systems that target specific tasks within such a category.

The involvement of AI during a game session is perhaps the most apparent implementation and is exemplified by any AI agent that plays 'with' or 'against' players in a game. However, a taxonomy of AI in hybrid board games should also account for the use of AI in the preparation of a game session or even in the (co-)creation of the overall game [9, 13]. AI agents can, for example, be created not to act as opponents during a game session, but to serve as test 'participants' as part of the game development process [7]. Given that game development is often an iterative process, information about a play session will frequently be fed back into the design of a game. As such, post-play involvement may transition somewhat seamlessly into pre-play involvement. For the purpose of establishing a taxonomy, we may argue that the interpretation of gameplay data is more closely related to post-play involvement, while acting on that interpretation to improve a game is closer to pre-play involvement. As with (partly) automated play testing, a feedback loop encompassing in-play AI as replacement for the player, post-play game analysis and a pre-play game design angle happens in (partly) automated game balancing [15].

Another dimension related to temporal events is the resolution at which time is 'experienced' or processed. On the one end of the spectrum, actions can be expressed or perceived continuously in real-time. On the other side, actions and events may be regulated in discrete steps. This is not necessarily connected to the gameplay rules of a game. Taking chess as an example again, any moves take place in turns and can thus be said to happen in a discrete manner. However, an AI system could monitor the game state in real-time, using the idle time to consider possible moves, and immediately reacting to moves by the opponent as they occur. On the discrete side of this example, the same AI system could instead not have a concept of real-time and instead only evaluate game states after a specific event (e.g. when the opponent indicates that they have made their turn).

3.4 Gameplay

Understanding the involvement of AI through the lens of gameplay means to **establish how central an AI system or agent is to the game itself.** On one side of the spectrum, AI systems might be involved for convenience or aesthetic purposes, without having an impact on the way a game unfolds. This does not necessarily make the involvement less valuable for players, and might involve AI systems that are just as complex or even more so than those that are more central to the gameplay. An example can be found in computational systems that take care of board game 'chores', such as keeping track of game states [22].

On the other end of the spectrum, the involvement of AI might fundamentally shape the gameplay. This end of the spectrum is arguably harder to find among hybrid board games, as they often involve only incremental change over non-digital board games. However, returning once again to the example of chess, the involvement of an AI agent as opponent can make it central to the gameplay. While early implementations of artificial chess opponents may have only provided a trivial challenge, they have long since become real training partners that can inspire novel strategies.

While creating AI agents that can substitute for human players presents interesting research and development challenges, there is largely untapped potential in hybrid board games that are built around the involvement of AI. Such games could extend the design space with implementations that go beyond substitution.

3.5 Role

The final lens we propose is the role AI has within a hybrid board games. The actor-director dimension positions an AI on a spectrum between carrying out very narrowly defined actions on the one side, and directing all aspects of a game on the other.

This dimension is almost inseparably linked with how much information a computational system is given (or can access) about the state of game, as well as the extent to which it is permitted to modify it. Systems that generate aesthetic assets can, for example, function fully independent from the state of a game, and thus carry little information, but have a large effect on how the game progresses. The opposite would also be conceivable, e.g. by means of an AI driven assistant that analyses the complex state of the game in order to display it in simplified form to human players.

If an AI is given wide access to game state information as well as designed to actively modify such states, it can be compared more closely to the role of a 'game master' in pen-and-paper role-playing games. In this role, the system might be designed to find an optimum between challenge, relaxation, and diversity in order to provide a game experience that suits the idiosyncratic preferences of any participating player. Such balancing can be as simple as reducing difficulty of a challenge by modifying hidden parameters, or as complex as changing the game narrative based on interpreted player preferences.

Figure 2: Photograph of *Anki Overdrive*, a physical miniature racing hybrid board game that can be played against AI opponents.

One of the upcoming topics in game AI is 'human/computer collaboration', which may be seen as one side of 'team AI'. In our context, this could entail all possible roles between allowing competitive gameplay replacing missing human players with AI agents to just providing more interesting interactions for human players such that they do not feel lost. AI agents may have a 'digital life of their own' in an otherwise mostly physical game such that they neither have full access to the state of the game, nor do they have a large effect on the course of the game.

4 DISCUSSION AND CONCLUSION

In the previous sections we have outlined different taxonomic lenses through which AI in hybrid board games can be discussed and explored. Given that hybrid board games are a relatively 'young' medium, there is a limited number of widely-known examples. Before concluding this paper, we look at game examples that can be described along the aforementioned dimensions with the aim to provide a better understanding for the individual dimensions.

One example that can be helpful in expanding the view on how hybrid board games can look like is the racing game *Anki Overdrive* [2] (see Figure 2). In the game, players take control of physical miniature cars and race against opponents. Cars can combat each other with virtual weapons that create a simulated physical impact and feature simulated differences in terms of car characteristics (e.g. speed and defence). Looking at the game through the lens of 'Embodiment as Agent', it can be described as a game with a variable number of AI agents, including the possibility of letting AI agents race against each other by themselves. The relationship to the player is primarily competitive, with some game modes focusing on sabotaging other players, while others are more concerned with competing through flawless performance.

In terms of the 'Physical Domain', *Anki Overdrive* involves AI that has only limited awareness of the physical world. Cars in the game can only drive on specialised tracks and obstacles that may be present cannot be detected, with the exception of other cars. Interactivity with the physical world is fairly high, as all racing manoeuvres are physical actions. While weapons cannot be seen directly, they can be perceived through the simulation of their impact on other cars.

In regards to the 'Temporal Domain', AI is primarily involved 'in-play', i.e., during the game session. Given that the game involves a companion application for mobile devices, the game could potentially involve AI for pre-play purposes. Here, the application could automatically generate patterns as suggestions for the player while including pre-computed parameters such as the expected difficulty. The temporal resolution in which the AI operates within the game is necessarily in real-time given that any input by human players is carried out (almost) immediately. As such, any response needs to be processed and acted upon close to the reaction time of human players.

As long as players in the game lack another human player, the involvement of AI in the game is absolutely central to the gameplay. While players can race alone, the design of the game is built around competition, and thus, AI opponents in lieu of other human players.

Looking at the actor-director spectrum, i.e. the 'Role' AI plays within the game, we find that the game is closer to the midpoint than it might seem. While the individual AI-based opponents act as individual actor, their performance is actually in part dependent on how well human players perform. The developer at least claims that "the better you play, the better they become". Adjustments to the difficulty of a game, also known as 'rubber banding', fall closer to the 'director' side of the spectrum, as it suggests that weaker performance of a player also results in a less aggressive opponent. As such, the AI in the game is likely not only concerned with providing the best possible performance, but instead also considers what performance level results in the best player experience.

A complementary example case of a similar hybrid board game, both in its subject matter and its ability to inspire a broader view towards the medium, is *Room Racers* [19]. The game was developed as a research project and allows players to race with cars that are 'projection-mapped' onto an arbitrary surface. Instead of involving physical cars, it involves the physical environment and asks players to create a racing track out of a variety of objects. While *Room Racers* exists at the fringes of the definitions of a hybrid board game, it involves intentionally designed physical artefacts, even if they are provided ad-hoc by players. In this example, AI is involved primarily through computer vision, as the outline of the track is processed in real-time from the physical environment. In contrast to *Pokémon GO*, the physical domain involves physical artefacts, even if they are designed by players instead of the game designer.

These two examples are intentionally chosen as use cases that test the boundaries of our working definitions. A game such as *XCOM: the Board Game* [12] is perhaps more easily identifiable as a hybrid board games with AI involvement, as it features a physical board and a companion application that includes some degree of scenario generation. While such games undoubtedly provide entertainment to their players, there is value in exploring other implementations that push the boundaries of what game AI can potentially contribute.

A potentially contentious edge case that we have not discussed up to this point could be found in games that are fully digital, but use the digital domain to simulate physical board game elements. Such simulations can be as simple as using virtual cards and tokens (e.g. in *Tabletop Simulator* [4]) or involve a wider range of modalities

Figure 3: Photograph of *Room Racers*, a spatial augmented reality racing hybrid board game that involves AI as part of the racing track generation.

to invoke the feeling of a physical board game. At this point we will leave the classification of such games up to future discussions that we hope this paper will encourage.

Finally, we have not addressed all possible attributes that may describe an AI in this first presentation of the taxonomy. For example, we did not include the power or skill of AI systems, despite the reality that much of the work in game AI focuses on balancing such attributes. An argument could be made that a skilled AI system likely needs to operate at a lower skill level in order to give human players a fair chance. Within the taxonomy that is presented, we could consider this a factor that is represented in part by the believability of an agent (i.e. 'to what extent does the AI play as a human would?') and the role of an AI on the actor-director spectrum (i.e. 'to what extent does the AI facilitate an enjoyable game session?'). However, this challenge of classifying the quality of an AI system in hybrid games emphasises that more conceptual and argumentative work is required to strengthen the currently presented foundation.

Overall, we have presented the conceptual foundation for developing a taxonomy of AI in hybrid video games. Part of this effort has been the establishment of working definitions that focus the exploration of the design space. We believe that future work, both applied and academic, can build on these efforts. This will ultimately allow for the development of novel game mechanics and support systems that contribute to the enrichment of the medium of hybrid board games.

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