

Responsive Serious Games and Related Paths

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Abstract

Serious games are games whose primary purpose is something other than entertainment. A variety of domains have explored the use of serious games to achieve specific practical outcomes in players, including training and healthcare. In previous work, I have leveraged adversarial deep learning methods to create models that effectively and dynamically manage the experiences of users. I intend to develop this work further into serious games applications to adapt serious games during gameplay to support the desired outcome.

Previous Work

Automated planning is a process for abstract pathfinding that has a wide range of applications in different fields. In a classical planning problem, planners are given information about the initial problem state, actions that can be taken in the problem, and a set of requirements for the goal (McDermott 2000). The solution for a classical planning problem is a sequence of actions that, once executed from the initial state, lead to the goal requirements being met (McDermott 2000). Narrative planning emerged as an application of automated planning in plot generation (Rivera et al. 2024). When a story's setting is modeled as an initial state, and a story's desired ending is modeled as the goal requirements, the sequence of actions generated by a classical planner set upon such a problem can be considered a linear plot (Rivera et al. 2024). This made planning a popular method in linear story generation (Rivera et al. 2024). Because of this, planning also became a popular interactive story generation method, where a human player is also taking actions in a planning problem and a new plan is generated after every human action (Rivera et al. 2024). However, this introduces new problems. Given that player actions may not follow whatever plan was generated, they can take actions that directly disrupt or destroy the plan. They can cause world states from which the goals of the problem can never be completed, no matter what actions are taken by the player or other agents. These states are called dead-ends.

Experience management is the field of dynamically adapting a game to mediate between a player's actions in the game world and the game creator's design goals (Riedl and

Bulitko 2013). It is used in automatic narrative generation to balance player autonomy with the intended structure of the narrative. Narrative mediation is an experience management strategy where the planner identifies logical inconsistencies that the player can introduce and generates contingency plans (Riedl, Saretto, and Young 2003). The General Mediation Engine (GME) is a mediation experience management system that takes an additional measure to escape dead-ends. It does so by modeling player knowledge and allowing itself to change facts about the world that the player is not yet aware of (Robertson and Young 2014).

The Adversarial Experience Manager (AEM) was developed as an alternative experience management method for interactive games (Genoese-Zerbi and Robertson 2025). Instead of working with planners, AEM takes planning-style games that have been converted to python and trains adversarial agents designed to avoid dead-ends. AEM is modeled after AlphaZero, an adversarial deep-learning algorithm that trains game-playing models through self-play (Silver et al. 2018). Unlike AlphaZero, AEM trains one-sided models for asymmetrical games. Though AEM is adversarial, it is not necessarily the adversary of the other player. Rather, its adversary is dead-end states. In order to train games that fit this structure, additional modifications to the AlphaZero algorithm were required. In particular, AEM required support for asymmetrical and non-zero-sum games, which have in existing work been used in AlphaZero-like systems (Goldwasser and Thielscher 2020). In this context, an asymmetrical game is one where player do not have identical roles, actions, pay-offs, and mirrored positions, unlike chess, a symmetrical game. A non-zero-sum game is one where one player's is not necessarily an equal loss for another player. To allow for training of asymmetrical non-zero-sum games, AEM's process is as follows:

Step 1. The current experience manager model (CEM) and current player model (CP) play a set number of games against each other. The play data generated by these games is then used to train a new experience manager model (NEM) and a new player model (NP).

Step 2. The CEM and the NEM both play a set number of games against the CP. If the NEM wins more than 10% more of its games than the CEM, the NEM becomes the new CEM. This step is repeated using the CP and the NP playing against the CEM.

This process is repeated until performance goals are met. Using this framework, AEM was shown to be more effective at avoiding dead-ends than the plan-based GME.

Potential Future Work

This section details possible directions for further research and a dissertation. As a specific focus has yet to be chosen, multiple distinct paths are outlined for consideration. Some, while insufficient as a dissertation idea on their own, may be best suited when combined with another. In addition, once a theoretical framework for a concept has been established, the use of AI to enhance the application of that framework is a natural future research direction.

Expansion of AEM

AEM is a useful tool for flexible, planning-style games. However, there are many potential expansion directions that would give AEM more versatility in how it is applied. These should begin with the advancements other researchers have made with different AlphaZero-based systems. This includes aspects such as support for real-time gameplay (Vinyals et al. 2019), non-deterministic games (Hsueh et al. 2018), and multiple human players (Goldwasser and Thielscher 2020; Vinyals et al. 2019). These improvements would make AEM easier to apply to other domains.

Serious Games

AEM is able to adapt its behavior in response to user actions. It additionally has strengths in steering users towards desired outcomes and away from undesired outcomes. Given these features, it may be a useful tool to support human training. It is particularly well-suited for use with serious games, which are games whose primary purpose is not entertainment (Francillette et al. 2021).

There are several key research gaps in the current literature for serious games. One major gap is a lack of theoretical frameworks supporting the design of serious games (Damaševičius, Maskeliūnas, and Blažauskas 2023). An area that may help address this gap lies in neuroscience. There have been serious game studies in the field of neuroscience as well, but despite addressing the same topic, similar studies from a computer science perspective have not had significant overlap. This is a missed opportunity, as not every paper in this area uses techniques only possible by those with medical licenses. For example, Nouchi et al. found that using near-infrared spectroscopy (NIRS) to assess activity in the prefrontal cortex while playing a game once can predict cognitive developments from playing that game over 4 weeks (Nouchi et al. 2020). NIRS is sufficiently non-invasive as a technique to be accessible to those without medical licenses, though additional training is likely required. Additionally, games like *Brain Age*, which is a well-supported brain training game that improves performance in certain cognitive areas (Nouchi et al. 2020), go primarily unmentioned in computer science serious games papers. As a dissertation direction, more consideration would be required to apply something like AEM to the neuroscientific framing of cognitive training problems, as it has not been validated

that human modeling and self-play is sufficient to generate the kind of play data AEM needs to train a human to achieve mental outcomes. However, with data collected from humans playing test games with NIRS, it may be possible for a similar deep neural net to be used to train a model that adapts gameplay of a cognitive improvement game to induce higher positive activations in the dorsolateral prefrontal cortex and therefore better cognitive developments as found by Nouchi et al.'s prediction model (Nouchi et al. 2020).

Serious Games for Mental Health Mental health is a matter of global importance. A review study published in 2013 indicated that 1 in 5 people across 63 countries presented with a common mental disorder (Steel et al. 2014). Poor mental health can severely impact quality of life, yet healthcare systems are routinely under-equipped to handle issues of this nature as we face a growing shortage of mental health providers (Butryn et al. 2017). A thorough review of current literature shows that serious games have great potential to help address this problem by providing supplementary support (Damaševičius, Maskeliūnas, and Blažauskas 2023).

Current literature suggests many significantly disruptive symptoms of medical disorders stem from dysfunctions of specific parts of the brain (Hare and Duman 2020; Ahmari and Rauch 2022). The prefrontal cortex alone hosts symptoms of OCD (Ahmari and Rauch 2022), depression (Hare and Duman 2020), and anxiety (Hare and Duman 2020). While it is a leap in logic to assume that any game that produces significant activity in the prefrontal cortex will naturally have an effect on mental health symptoms, there is already evidence that serious games can be used as an effective treatment for OCD (Hong et al. 2018). If a correlation can be established between certain visible activity in the brain and alleviation of various mental health symptoms, it may be possible to more quickly develop beneficial serious games. At the very least, this avenue should be explored. In particular, whether it is possible to create a system that dynamically adapts a game as users play it to create a personalized experience that more effectively aids players. This system would use records of player gameplay and associated brain activity to train itself to recognize game patterns that trigger desired states. Once trained, it could shift game elements to more often encounter the gameplay states that it associates with better outcomes.

Compliance and Serious Game Efficacy There are mixed results on the relationship that enjoyment of serious games, anticipated and actual, has on positive outcomes (Iten and Petko 2016; Greene and Rougeau 2024). There is additionally not a consistent method of evaluating the somewhat abstract concept of fun in serious games literature (Tondorf and da Silva Hounsell 2022). The topic of fun in serious games has several open avenues for investigation, but how it relates to compliance, users' continued willingness to engage with the game, is particularly interesting.

The matter of compliance is an important one in various domains. In healthcare, poor compliance can render even a known effective technique unhelpful, as its benefits cannot be gained if the technique is not used (Courneya et al. 2025). Despite well-documented importance and benefits of exer-

cise (Greene and Rougeau 2024), for example, no more than 28% of US adults meet current muscle-strengthening and aerobic physical activity guidelines (Abildso 2023). Most current literature investigates the effects of serious games with regular use, where use is enforced by the parameters of the experiment (Franceschini and Rodà 2023). However, while this is useful for demonstrating the potential benefits of a serious game, it may also take for granted the users' desire to continue using the game and thereby reaping the benefits. Given that many people spend hours of their lives playing games for no other reason than enjoyment (Baumann, Lürig, and Engeser 2016), this area has great potential for furthering the positive effects of serious games. Developing methods to combine the benefits of serious games with the voluntary engagement of ordinary games without encouraging negative developments such as internet game addiction is an important research path.

Socialization Socialization is vital to maintaining one's health. Social isolation is associated with increased risk for cardiovascular disease mortality (Wang et al. 2023), cancer mortality (Wang et al. 2023), and suicide (Motillon-Toudic et al. 2022), as well as general decreased quality of life (Clair et al. 2021), and, in elderly populations, dementia (Shen et al. 2022). This last group is of great concern, as socially isolated elderly populations must contend with every prior risk in addition to increased risk of cognitive decline. In 2011, the prevalence of social isolation among older adults was found to be 24% (Cudjoe et al. 2020), and has only grown with the COVID-19 pandemic (Su et al. 2023). With such a large group suffering from these associated problems, effective interventions are sorely needed.

As older adults begin to face cognitive decline, their ability to recognize online threats like scams declines as well (Ueno et al. 2021). Due to this, straightforward social media becomes a risk. Given that this is a vulnerable group that needs additional protection online even as it may be desirable for them, cues may be taken from research on children, as many similar challenges can arise. Virtual play worlds designed for children are capable of fostering inner communities, despite the stringent restrictions in place to protect them (Reich, Black, and Korobkova 2014). Therefore, modeling serious games to combat social isolation in older adults after virtual play worlds for children merits consideration.

Non-Invasive Monitoring

Many HCI researchers leverage self-reporting methods or other survey-type data collection to understand the effects of their research on humans. While these methods certainly have their place, there are also drawbacks associated. There are often concerns around credibility and various biases, including primacy and recency effects, socially desirable responding, acquiescent responding, and extreme responding (Paulhus, Vazire et al. 2007). It can also cause inconsistent results across multicultural test populations, where different groups may tend to attribute different connotations to the questions or language used in them (Paulhus, Vazire et al. 2007). In related neuroscience fields, there are other methods that ought to be investigated for their viability. This

includes NIRS, which has been used to analyze the cognitive effects of an experience if repeated (Nouchi et al. 2020), which is not dissimilar to the electroencephalogram (EEG), another non-invasive method for recording brain waves. EEGs and other physiological sensors have been investigated for use in player modeling research (Anwar et al. 2017), but in serious games research, they're not often used as a tool for effect validation. Becoming an EEG technician requires training but not a full medical license, though the specific requirements may vary by location. The investigation of more detailed but still non-invasive techniques for human state analysis may have significant value in HCI.

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