Cognitive Modeling Of Video-Game Player User-Experience

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Abstract. This paper argues for the use of cognitive modeling to gain a detailed and dynamic look into user experience during game play. Applying cognitive models to game play data can help researchers understand a player's attentional focus, memory status, learning state, and decision strategies (among other things) as these cognitive processes occurred throughout game play. This is a stark contrast to the common approach of trying to assess the long-term impact of games on cognitive functioning after game play has ended. We describe what cognitive models are, what they can be used for and how game researchers could benefit by adopting these methods. We also provide details of a single model – based on decision field theory – that has been successfully applied to data sets from memory, perception, and decision making experiments, and has recently found application in real world scenarios. We examine possibilities for applying this model to game-play data.

1. INTRODUCTION

A major goal of video game research is to understand and influence what a player is thinking during game play, and perhaps to effect long term changes in the game player. One major theme in this research includes game impact on personality traits and emotional states – most famously, effects on player aggressiveness. This type of research is typically carried out via survey methods. Players answer a battery of questions before the game begins to assess their personal traits and current emotional state. After game play has completed, the player answers more questions and any changes are attributed to the effects of the intervening game play period. Another prominent theme is the effect of games on some aspect of cognition (e.g., spatial skills [5]). Although this second research theme is concerned with cognitive effects of games, it is often carried out by pretesting the participant using a standard laboratory task (e.g., a speeded search task) to assess the trait of interest (e.g., visual acuity), followed by a game play period, and then posttesting using the same standard laboratory task again to see if performance has changed.

These approaches take a bird's eye view of the cognitive phenomena underlying game play. They treat the mind like an impenetrable black box, observing or manipulating inputs to the cognitive system, and observing the concomitant outcomes. Although these research endeavors are valuable, they take an indirect route to understanding cognition during play. In both approaches outlined above, game play effects are measured after the fact. In the case of questionnaire methods, the data is subjective – participants give some indication of the game's effects through their answers to various questions. And although the second research approach aims at understanding something about cognition as it pertains to games, it too focuses on effects and measures indirectly by assessing changes after the fact.

What is needed is an approach that allows one to track cognitive effects of games *during* the game play session. As the player progresses through the game, seeking to accomplish various goals, making decisions, all manner of cognitive phenomena come to bear. Learning is required (e.g., what strategies worked before?). Attention has to be allocated. Memories of previous outcomes have to be accessed. Decisions have to be made. The outcome of these cognitive events translate into the player's observable performance in the game, their level of enjoyment or accomplishment, their learning. Understanding these dynamic events as they unfold throughout the course of play, rather than trying to infer something about them subjectively or indirectly after the game is over, would be of great value to the designer of games concerned with changing behavior, communicating messages, or just maximizing engagement and fun. In attempting to maximize game efficacy, the designer would likely benefit from knowing what a player is looking at when making decisions, what dimensions are most salient, which dimensions are routinely ignored, and when options are confusable.

In recent years, there have been efforts to peer into the inner workings of the mind during the game play events that cause them. Brain imaging techniques (e.g., fMRI) have been used to associate brain activity known to occur during aggressive thought with violent game content [8]. Other studies have tracked psychophysiological events (e.g., EEG) to infer mental states during play [1]. This approach to studying player cognition during game play is a welcome addition to the field. This research gives us valuable data synched in time to game events, and we can learn a lot by trying to interpret it. However, at this point in time, both imaging and psychophysiolical data are difficult and expensive to obtain, the measures are still relatively crude, and findings are often difficult to interpret. The degree to which one can relate the observed bodily states to aspects of cognition such as attention or executive function is an issue of lively (sometimes withering) debate [7].

Luckily, there is another approach to understanding cognitive phenomena at our disposal – cognitive modeling. For the past several decades, cognitive psychologists have devised and tested scores of detailed mathematical models that offer precise accounts of the cognitive underpinnings of behavior, and demonstrated their links to theoretical structures like memory and attention. Given the mature state of this field, as well as its widespread representation throughout academia, it is surprising to find that it has very little representation in the game studies literature (although some applications are noted below). The objective of this paper is to provide a basic understanding of what cognitive models can provide researchers, and to advocate their use in studying video games.

2. COGNITIVE MODELING

What, exactly, is a "cognitive model"? A cognitive model is a mathematical interpretation (i.e., specification) of the set of principles embodied in a theory of cognition. Cognitive models make specific assumptions about the information represented in the cognitive system (e.g., words and their meanings), along with the processes acting on this information to produce observable cognitive behavior (e.g., classifying an object). More concretely, a model receives inputs like a person in an experiment (e.g., size of objects on a screen), performs mental operations (e.g., like comparing perceived stimulus information to information stored in memory), and outputs a response (e.g., emits a classification of the object).

Models such as these are valuable for several reasons. First, they require a researcher to move past the initial stages of theorizing – often characterized by vague verbal descriptions of mental entities and their interactions – to taking a detailed, specific stance on these quantities and relationships. Doing this affords the research community a better opportunity to evaluate and criticize a theory's quality. Second, making detailed quantitative statements in a cognitive model allows a researcher to make precise, testable predictions. A third benefit is that simulating model behavior on a computer can lead to unexpected observations and insights that the researcher might not otherwise have reached. It is widely agreed in the modeling community that this is an important benefit of modeling.

There currently exists a wide array of cognitive models that have been vetted over the years by many experiments and data sets. These models elucidate a range of topics. Many models are designed to capture steady-state performance in cognitive tasks like recognition memory, discrimination ability, attention allocation, to name a few. These models are intended to account for specific, circumscribed aspects of cognition such as recognition, categorization, attention, etc. Another class of models – known as connectionist models (also called neural net or parallel distributed processing models) – mimic fundamental aspects of brain anatomy (i.e., populations of single processing units or artificial neurons communicating activation levels back and forth) and capture learning over the course of many training trials. A third class of models – known as cognitive architectures (e.g, ACT-R, EPIC, Soar) – attempt to capture several aspects of cognition in a single unified framework (e.g., attentional processes, memory, visual search tendencies), reflecting the fact that all these processes come into play simultaneously in the human cognitive system. Cognitive architectures have found wide application in human-computer interaction research and have even made their way into game research to some extent [4]. Existing applications of cognitive modeling in game research tends to take on a computer-science flavor. These models are valuable tools for making the game respond to the player in interesting ways or to create "smarter" non-player characters [3]. Our aim in this paper is to encourage much more widespread adoption of these techniques for gaining general understanding of the cognitive capacities invoked during video game play.

3. APPLYING COGNITIVE MODELS TO GAME STUDIES

The value of models for game research lies in the fact that models require inputs and produce outputs. In between they offer precise statements about attention, learning, decision strategies and biases, and so on. In doing so, a model often tells the researcher *why* performance looks as it does. Although a model can't tell the designer exactly how to craft a game environment that teaches or entertains, discovering that current inputs place unrealistic demands on attention might offer guidance by narrowing the range of necessary modifications to gain desired results. An important detail, of course, is how one goes about applying these models.

Within a cognitive model lie parameters that capture the modeled quantities (e.g., attention weights, learning rate, response biases). These values are indicators of the mental underpinnings of observable behavior. In order to make inferences about cognition, these models are often "fit" to a set of data. The computer takes the output of the model (i.e., predicted responses to events), compares it to player data (i.e., actual responses) and adjusts the internal parameter values (i.e., changes assumptions about attention, etc.) until the predicted responses are as close as possible to the data. The resulting adjusted parameter values indicate things like how confusable the stimuli were or which stimulus dimensions garnered the most attention. These parameter values can be used to make predictions for the player in later game sessions or scenarios.

It is also important to verify that what the model tells us is correct. In order to do this, researchers often attempt to fit a model to data using fixed parameter values gleaned from prior knowledge of the research participant. Achieving a good model fit (i.e., a good prediction of player performance) by setting parameter values *a priori* is a powerful demonstration that one understands the player's cognitive processes during play.

One way to obtain fixed parameter values for *a priori* prediction is to fit the model (by adjusting free parameters) to one data set, and then use the best-fitting parameter values to see if the model accounts for additional data sets (without re-adjusting the parameter values). Another way to demonstrate our understanding is to set the model parameters based on something else we already know about the player.

For example, one could take advantage of the kinds of data acquired through the survey methods described above. One recent (non-game) study used results from a survey designed to assess whether a person has an "action" orientation (tendency to accept risks to expedite achieving a goal) or a "state" orientation (tendency to be more deliberative in order to avoid risks). Scores on this questionnaire were converted into parameter values in a cognitive model and used to predict response probabilities and response time distributions in a sports-related task [6]. Such an approach grounds model parameters in knowledge about the participant even before experimental manipulation begins, and can still enable the model to make interesting predictions about behavior.

Another possibility would be for the researcher to set model parameters to reflect instructions given to the player (either before the game or inside the game). Instructing a player to pay attention only to RED enemies, for example, should be reflected in a model's attention weight parameters (assuming the model has them) and consequently in the model's predicted response probabilities (and hopefully lead to a good model fit). An important long-term goal of modeling is to find parameter values that can lead to valid predictions across several experimental conditions without the need to adjust parameters to account for each data set.

One challenge to applying cognitive models to data from video games is that events of interest must be operationally defined. For example, some agreement might need to be reached about what constitutes "fighting or fleeing" in a game scenario. Another example would be determining what qualitifies as a response option. Depending on the question under study, it may be wise to compare performance only in situations with a constant number of response options. Such apples-to-apples comparisions might be necessary when trying to determine response probabilities or response time distributions.

4. DECISION FIELD THEORY

Among the many aspects of cognition that can be modeled and examined in games, perhaps the most natural starting point is to look at decision making. One popular class of models that illuminates decision making is known as "sequential sampling" models. Sequential sampling models simulate the accumulation of information (i.e. sampling) over time in support of each choice alternative, leading to the eventual selection of one option over others. Decisions are triggered by internal choice thresholds – the first accumulation process to reach threshold wins, and the corresponding choice is made. Figure 1 depicts this sampling process for three choice options.

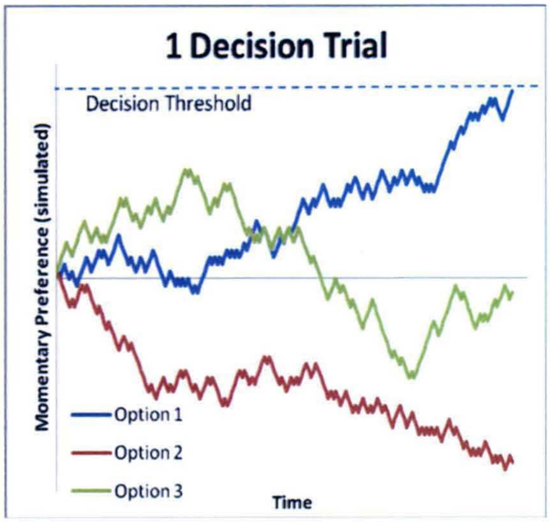

Figure 1: Information accumulation for three choice options

In this section, we describe a sequential sampling model based on Decision Field Theory [2]. Variants of this model have been successfully applied to a wide range of phenomena, including decision making, perception, and memory, among others. The model has mostly been applied to data from standard laboratory tasks, but has recently been used to explain decision making in a sports judgment task [6].

On a given experimental trial (in the context of games, an operationally defined recurring event), the model assumes that each set of choice options can be characterized by values along salient dimensions. For example, when trying to choose the best weapon for a fight, the player might consider three weapons along dimensions such as strength, range, and ammunition supply. Each weapon has its own set of values on these dimensions, and the player makes some assessment of these values. Table 1 illustrates some hypothetical values.

Table 1: Hypothetical dimension values for weapon choices

	Strength	Range	Ammo
Option 1	1.0	50	0.6
Option 2	0.5	150	0.8
Option 3	0.7	100	0.8

Also, each player is likely to display some difference in preference for the choice dimensions. For example, the player's decision might be most strongly influenced by the strength dimension 70% of the time. Range might be the most influential dimension 20% of the time, and ammo only 10% of the time. These values are model parameters. The model uses these values on each trial, along with other parameters representing initial biases, memory from trial to trial, and similarity between options, to produce a decision.

Figure 1 displays a characteristic example. The figure shows the (simulated) stochastic accumulation over time of evidence (to the cognitive system) in favor each of the three options. The first option to reach an internal decision threshold "wins" the race, and supplies the response. As the figure shows, not only is a choice determined from this process, but also the time to reach threshold. From trial to trial, responses and termination times will vary, and over trials the model will provide response probabilities and response time distributions that can be compared to a player's data. By adjusting the internal model parameters in order to fit the observed responses, the model tells a tale about the player's attention focus, memory, biases, and the confusability of the response alternatives.

This decision-field theoretic model could potentially answer many interesting questions. For example, how does action orientation predict game play? How does decision strategy change as a result of learning throughout the game? Which dimensions receive the most attention, and which the least?

5. DISCUSSION

We've argued in this paper that cognitive modeling provides a detailed and dynamic view into cognition – at the individual player level – as it unfolds during video game play. Currently, this powerful approach is seldom utilized in game research. This is a shame, since cognitive modeling is a mature field, and there are many useful models available that have been affirmed by decades of research in carefully controlled experiments.

Models can offer clues into the inputs required to produce the outputs desired. If a game is to have educational value, (or for communication or even just for fun), then variables that influence model behavior should be manipulated to moderate player behavior. Currently, most game design is guided by heuristics, prior experience, and flashes of insight.

Many of the cognitive models in existence today are ready for extension to new areas. In fact, the field of cognitive psychology is increasingly marked by attempts to extend the reach of cognitive theories to real-world scenarios. The application of these tools is especially timely considering the recent explosion of research into serious games (games designed to communicate and educate players). Designers of such games would likely benefit from a tool that can help foster a deeper understanding of what players focus on and are affected by during game play.

Finally, cognitive modeling dovetails well with the imaging and psychophysiological research mentioned above. The relatively recent emergence of the field of cognitive neuroscience attests to this. Cognitive models have become so powerful that competition between theories is often difficult to assess on the basis of behavioral data alone. Neuroscience data is now routinely used to place biological plausibility constraints on computational models. In turn, cognitive modeling imparts a deep level of meaning to neuroscience results. Models help neuroscientists understand the cognitive implications of their data.

In conclusion, cognitive modeling presents a powerful method for understanding what a player is thinking about while playing a video game. Research papers that describe cognitive models often report their model derivations in detail so that interested readers can adopt these methods. Our hope is that we've been able to convince readers of the allure of cognitive modeling for their own game research.

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