Research Directions for Pushing Harnessing Human Computation to Mainstream Video Games

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Abstract

In this paper, we propose a research direction that will allow the harnessing of human computation to be included in mainstream video games. Human computing resources are vastly different and superior in some cases compared to traditional computing machines. Previous findings in this domain showed that humans playing FoldIt, a protein folding video game, created new solutions to the problem that were previously unknown. Successes like these suggest that harnessing human computation through games can provide the world with a new computation resource, but existing games in this domain tend to be built around the problem. This means a large population of game players remains unharnessed. We, however, hypothesize that focusing research efforts on the synergy of understanding isomorphing problems, identifying problem solving behavior in mainstream video games, and an understanding of real-world problems is a direction that will allow us to merge harnessing human computation into these mainstream games.

Introduction

In this paper, we examine existing research on harnessing human computation through video games and describe what we believe is a major research drive that must be explored to move harnessing human computation into mainstream video games. This harnessing would create new hybrid computation systems that are, hopefully, pleasurable activities for humans since it would be the play they already engage in during their free time.

Hybrid computation systems that can take advantage of computation (or problem solving) skills of both humans and computation machines have the potential to solve complex real-world problems that at present may be tedious human tasks, challenging unsolved problems, or are complex tasks that no computer algorithm has yet been created to solve. In the case of humans, we are able to make decisions based on observed patterns and understanding of the big picture, but we tire from monotonous tasks and are slow when dealing with low-level computational tasks. Computing machines, on the other hand, are

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tireless and accurate, but are hard to program/design to process high-level concepts. The challenge is merging these two entities so that humans enjoy the computation activity, and the overall system provides better solutions to the real-world problems compared to an algorithm or human alone. These types of blended systems will become more and more important as our economy goes through another shift from information technology to automation and higher order artificial intelligent systems (Brynjolfsson & McAfee, 2011). In some cases, when we can successfully design such systems people's jobs may evolve into playing video games.

Such systems, or Human Computing Games (HCGs) (Cusack, Largent, Alfuth, & Klask, 2010), have seen high research activity over the last few years, but one of the fundamental challenges is user participation. Similar to the challenge in attracting customers to buy video games, many harnessing human computing games have a tough time convincing players to play. We believe a major challenge to this extent is that the HCGs are built once a problem has been identified, and in this design process the problem is built with game mechanics and existing rules of the problem hoping that the gameplay will motivate the players. Still, these games tend to present the problem as is, and this presentation is far different from games created simply for entertainment.

Mainstream video games have a large population of players, and if these players could be tapped into a computational resource we might expect huge benefits due to the computational power of this hybrid system, the success of which will likely dwarf the early success of current HCGs. Therefore, there is a strong motivation to merge HCGs as part of mainstream video games. In this paper, we identify three synergistic areas that should be researched to help start this merging. Specifically, we believe that an understanding of isomorphing problems in the psychological sense, identifying existing mechanics and problem solving behavior in mainstream video games, and a breadth of understanding of real-world problems is necessary to find aspects of mainstream video games that could be harnessed.

The remainder of this paper looks at this problem. First, we introduce some definitions and existing HCGs in the *Background and Definitions* section. In the next section, *Successes in HCGs*, we describe some recent successes in HCGs and explain some theory on why these types of games can be successful. In the section *Research Directions in HCGs for Adoption in Mainstream Games*, we describe each of the major areas of research and understanding needed to push HCGs into mainstream video games, and finally, we conclude the paper.

Background and Definitions

The Human Cloud (HC) can be described as a network of intelligence, connected through existing systems like the Internet. Harnessing the HC has been done in a number of projects in a form of crowd-sourcing, which is defined in this paper as using the knowledge and effort of a large group of individuals. In particular, Human Computing Games (HCGs) have been used to harness the HC and include games such as protein folding (FoldIt, 2008), picture identification (ESP Game, 2008), and other types of human computation have been achieved without the game aspect such as security camera searches (Internet Eyes, 2009) and searching for space dust (Stradust@Home, 2009).

HCG's and other types of productive play fall under the greater domain of games with a purpose (GWAP) (defined by von Ahn) and the general and contested term serious games. Such games reverse the original notion of asking games to teach players, and instead often afford players the ability to teach or work with computers. One of the first of these games was the ESP Game (ESP Game, 2008), created by Luis von Ahn. Von Ahn and his colleagues and students have been very active in this field, and they have produced a number of games and research articles on GWAPs (Hacker & Ahn, 2009), (Law, Mityagin, & Chickering, 2009), (Law & Ahn, 2009), (Law, Ahn, & Mitchell, 2009), (Law, Ahn, Dannenberg, & Crawford, 2007), (Ahn, 2006), (Ahn & Dabbish, 2008), (Ahn, Ginosar, Kedia, & Blum, 2007), (Ahn, Ginosar, Kedia, Liu, & Blum, 2006), (Ahn, Kedia, & Blum, 2006), (Ahn, Liu, & Blum, 2006). Since von Ahn's original work, over 40 HCGs have been presented at conferences and in journals by a growing number of researchers. These games solve particular categories of problems and include:

- annotate images (ESP Game, 2008), (Ahn et al., 2007), (Ahn, Ginosar, et al., 2006), (Ho, Chang, & Hsu, 2007), (Gonçalves, Jesus, & Correia, 2008) (Ho, Chang, Lee, Hsu, & Chen, 2009) (Seneviratne & Izquierdo, 2010)
- annotate music (Law & Ahn, 2009), (Law et al., 2007), (Barrington, O'Malley, Turnbull, & Lanckriet, 2009), (Kim, Schmidt, & Emelle, 2008), (Mandel & Ellis, 2007), (Morton, Speck, Schmidt, & Kim, 2010), (Turnbull, Liu, Barrington, & Lanckriet, 2007)
- assist in improving search engines (Law, Mityagin, & Chickering, 2009), (Law, Ahn, & Mitchell, 2009), (Bennett, Chickering, & Mityagin, 2009), (Dasdan et al., 2009), (Ma, Chandrasekar, Quirk, & Gupta, 2009a), (Ma, Chandrasekar, Quirk, & Gupta, 2009b), (Pardo, 2007), (Shamma & Pardo, 2006)
- improve CAPTCHAs (Yan & Yu, 2009a), (Yan & Yu, 2009b)
- collect common sense facts (Ahn, Kedia, & Blum, 2006), (Kuo et al., 2009), (Lieberman, Smith, & Teeters, 2007), (Speer et al., 2009)
- produce useful geospatial data (Arase, Xie, Duan, Hara, & Nishio, 2009), (Bell et al., 2009), (Ferguson, Bell, & Chalmers, 2010), (Matyas, 2007), (Matyas et al., 2008)
- assist with various language processing tasks (Chamberlain, Poesio, & Kruschwitz, 2008a), (Chamberlain, Poesio, & Kruschwitz, 2008b), (Hladká, Mírovský, & Schlesinger, 2009), (Pearl & Steyvers, 2010), (Seemakurty, Chu, Ahn, & Tomasic, 2010), (Wang & Yu, 2010)
- help build the semantic web (Krause, Takhtamysheva, Wittstock, & Malaka, 2010), (Scharl, Weichselbraun, & Wohlgenannt, 2008), (Siorpaes & Hepp, 2007), (Siorpaes & Hepp, 2008)
- help predict protein structures (Cooper, Khatib, et al., 2010), (Cooper, Treuille, et al., 2010)
- help solve instances of various computationally difficult problems (Cusack et al., 2010), (DeOrio & Bertacco, 2009), (Lin & Dinda, 2009), (Terry et al., 2009)
- solve a variety of other problems (Bernstein, Tan, Smith, Czerwinski, & Horvitz, 2009), (Byron et al., 2009), (Chklovski, 2005), (Coelho, Wesselius, & Papakonstantinou, 2010), (Diakopoulos, Luther, & Essa, 2008), (Dugan et al., 2007), (Johnson & Do, 2009), (Kazai, Milic-Frayling, & Costello, 2009), (Kochhar, Mazzocchi, & Paritosh, 2010), (Krause & Aras, 2009), (Rafelsberger & Scharl, 2009), (Tuite, Snavely, Hsiao, Smith, & Popović, 2010), (Walsh & Golbeck, 2010), (Weng & Menczer, 2010)

There is a huge variety of HCGs, and we will look at a few of these games to understand how they motivate and present themselves to the user.

Foldit has had tremendous success (FoldIt, 2008), it is a game developed to allow players to interact with complex proteins, attempting to solve one of the problems facing biological science - how to predict protein structure. Foldit presents 3D abstraction of proteins and simplifies the chemistry behind protein folding by making the problem into a game. It is clear to the user that they are folding proteins as no abstraction is made, but users are rewarded for their efforts by a driving goal to get to the top of the leader board. Foldit develops solutions that are better than those produced by machines by encouraging competition between the 50,000+ players of the game and has been successful. The key here is the motivation to play comes from the challenge to be the first to solve the problem.

Another type of HCGs is related to an ongoing problem in the realm of computer vision and identifying and labeling images. This problem is simple for humans to solve, but challenging for machines. The Google Image Labeler (based on the ESP game (ESP Game, 2008)) tackles this image tagging problem by turning this menial task, for humans, into a game. The game is based on cooperative play between two players. Each player types what they believe describes the presented image and the aim of the game is for the two players to agree on the description by only communicating through the game interface. Players are driven to score well by matching words, and at the same time, these labels help solve the image tagging problem. The results obtained from the original version of the game showed that 5,000 players could label every image in Google image search in approximately two months. Motivation here is performance based with a timing mechanism to add excitement for the user.

Internet Eyes (Internet Eyes, 2009) and Stardust@Home (Stradust@Home, 2009) are examples of harnessing the HC, but these are not HCGs that humans play to solve problems, instead they call upon volunteers to look for criminals in closed circuit televisions and for space particles on microscope images. These projects motivate players with financial incentives in the case of Internet Eyes and academic incentives in the case of Stardust@Home.

In addition to using classic motivation techniques to play the games, all of these projects present the real-world problems in what we call the "direct form". Users are aware of the real-world problems since the game is presented in this manner, and the players are motivated to help by competing against others for status or other direct incentives such as money or recognition. The limitation of this approach is that only a specific problem can be solved in the direct approach, the game must be designed from the real-world problem, and the larger potential population of game players who just play for entertainment tends to be left untapped. Additionally, these games rely mainly on the game player to produce solutions at what could be considered a low granular level without the aid of computation (with the exception of basic visualization). These limitations are potential research avenues for pushing HCGs further into mainstream video games and would allow us to create a major computational resource that has significantly different qualities from traditional processors.

Successes in HCGs

Before identifying research avenues to push HCGs into main stream games, we will look at successes in HCGs that help motivate why we should spend time researching these ideas. The main drive of HCGs is that humans will play games regardless of whether they solve problems or not. If we do not harness this play, which is a form of computation, then we are wasting freely available computing cycles. Similarly, even if this human computation solves problems slowly, this computation comes for free and in essence is saving some of our worlds energy used for computation (glucose consumed by our brains) instead of just wasting it.

The HCG, Image Labeler (ESP game (ESP Game, 2008)), as described earlier is a major success based on its popularity. The simple idea of a timed game where two non-communicating players need to find matching words that will then be used to label an image was revolutionary for a serious problem. Because of the quality of this solution, Google bought a license for this game to help them deal with adding meta-data to their image search library.

A recent research paper from the Foldit researchers (Khatib et al., 2011) shows how their HCG was used to record user behavior in the game to discover new automated algorithms for protein folding. This result is of high importance since it suggests that HCGs will provide us with new algorithms for problem solving that are more efficient and discoverable through the interplay of humans and problems. This type of innovation is expected since scientists and engineers use canned algorithmic solutions and do not play with these algorithms to make them better for their problems. For example, meta-heuristic algorithms are one type of algorithm used to solve combinatorial optimization problems (Papadimitriou & Steiglitz, 1982) such as designing an optimal wing configuration for an airplane. A traditional algorithm that a designer might use to design the wing is *Genetic Algorithms* (Goldberg, 1989), but since there is little capability to play with the algorithm, then it is highly unlikely that the designer can come up with a new heuristic to solve this problem.

Crowd Wisdom and How HCGs are Successful

There are a number of underlying theories that help explain why crowd-sourcing, and the subgroup, HCGs, can be successful when solving problems. Two books which give nice overviews of how crowds solve problems are:

- Infotopia - How Many Minds Produce Knowledge (Sunstein, 2006)
- The Wisdom of Crowds (Surowiecki, 2005)

As described in both these books, our current understanding of how crowds solve problems is studied and researched, mainly, by psychologists and economists. In the case of psychology, a good starting point is Lorge *et. al.* and their review of the advantages and disadvantages of group solutions (Lorge, Fox, Davitz, & Brenner, 1958), and in the case of economics, Raymond reviews the idea of how wagering markets can help predict future outcomes (Sauer, 1998).

Of the theories that might be most relevant to HCGs under certain conditions is Condorcet's Jury Theorem (Condorcet, 1785). This is a theory for groups making a majority decision that states if the probability of individuals making the right decision is greater than $\frac{1}{2}$ then as the group size grows the probability of the group making the right decision approaches 1. With HCGs many of the problems are much more complex than a majority decision, but we might generalize this theory to state that if on average each person improves the existing solution by spending time on solving it then as the number of individuals grows and as the time spent on the problem increases, the solution tends toward being optimally solved.

This theory along with the idea that a diverse group of individuals playing an HCG brings varying knowledge and skills suggests that HCGs have the potential to be powerful computation resources.

Research Directions in HCGs for Adoption in Mainstream Games

The reality with existing HCGs is that the video games are designed around the problem they solve and game mechanics are mapped to the problem to try and motivate players to participate. This approach, however, means that mainstream games, and their associated mass playing population, remains untapped. One approach to tapping mainstream video games for real-world problem solving computation is to steal cycles on the actual devices that execute the video game. This approach would be similar to the SETI@home (Sullivan et al., 1997) where during slow periods of the game, the console or computer would be used to perform computation problems. This approach, however, is a traditional computing solution and our bigger goal is to benefit from human computation and utilize the energy that is currently wasted on problem solving that has no value other than pure play.

We believe that there are three major areas of investigation that must be examined to find where mainstream video games and HCGs will intersect. The following three subsections addresses each of these areas separately, but in reality these three areas are closely related and each will impact the other.

Isomorphs

Humans are able to make heuristic problem solving decisions based on observed patterns and an understanding of the big picture, but we tend to tire with monotonous tasks that are not motivated by intrinsic rewards, and we are slow when dealing with low-level computational tasks. One of the major challenges in incorporating HCG aspects into mainstream video games is how can we take a real-world computation problem and map it into the game. More, importantly, can this mapping be done in a way so that the problem being solved just seems part of the game.

To achieve this, we must address what is called an isomorph. More specifically, an isomorphic problem has multiple presentation formats at the surface level, but are the same problem underneath. For example, a problem like mowing the lawn requires that a mower be controlled to both efficiently cover the area that needs to be mowed and avoid any live obstacles that might enter the mowers path such as children or animals. An isomorph of the lawn mowing problems could be a coloring game where the goal is to draw in an area without lifting the crayon and avoiding random targets that might try to make you lift your crayon. A similar term to isomorphing in the field of computer science is reduction.

Isomorphic problems have been of interest to cognitive psychologists, and they have been used to help us understand strategical approaches people take to solving problems (Simon & Hayes, 1976), (Kotovsky, Hayes, & Simon, 1984). An equivalent problem example that illustrates the basic concept of an isomorph is for tic-tac-toe. Zhang *et. al.* (Zhang, Johnson, & Wang, 1998) show some common ways of presenting tic-tac-toe, and we have replicated one of these in Figure 1. In Figure 1, the number game is shown where players take turns at picking a number (by coloring in a circle) with the goal of picking three numbers to total fifteen exactly. This game is the same as tic-tac-toe, and the figure shows how these numbers can map to locations on the tic-tac-toe board.

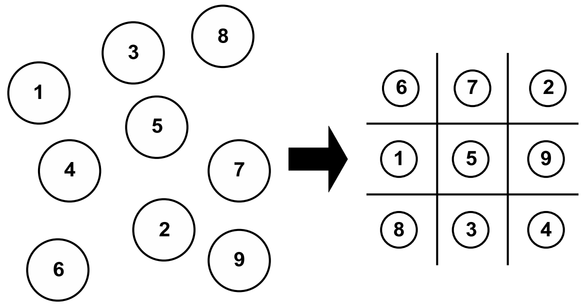

Figure 1. How a number game of picking 3 numbers that make 15 is an isomorph of tic-tac-toe board.

The different isomorphic representations of a problem affects the complexity of the task and the behavioral outcomes. For example, the tic-tac-toe problem represented as a number game is much more difficult for humans to play (Zhang et al., 1998). This phenomenon is called *representational effect* and was first studied by Zhang *et. al.* (Zhang & Norman, 1994).

The research challenge here is which real-world problems can be easily isomorphed into traditional problems within a game. Examining this research challenge will require expertise in both of the following sections - game mechanics and real-world problems.

Mechanics

Directly related to how to isomorph real-world problems for mainstream games is how existing game mechanics create surface problems. Game mechanics define the virtual worlds that players enter and interact with, and a subset of these mechanics might form a problem. For example, in first person shooters a capture mechanic and a particular map might be paired as a surface problem for finding shortest paths. By manipulating the map, where the starting point is, and where the goal capture point is we can isomorph certain shortest path problems into the first person shooter.

Mechanics, by themselves, help define how players can behave within the game, but the mechanics do not necessarily describe the underlying problems that the player will be solving. The previous example described a shortest path problem, but with one additional factor such as an opposing player protecting certain obvious paths towards the goal changes the problem from a shortest path problem to a reasonably short path with high probability of success problem.

The question with mechanics is which subset of mechanics, rules, and environment isomorph to particular real-world problems in terms of solutions generated. In the case of mainstream games, the most promising approach to this is to extract mechanics, observe player behavior in terms of what is the player solving during game play, and try to map this behavior to existing real-world problems. This is a similar approach to how engineers find real-world problems and then ask how nature solves these types of problems, which helps the engineer come up with a reasonable solution. The difference, however, is that we believe that we must look at how game players behave and solve problems in a mainstream game, and then ask the question: for which real-world problems is similar behavior displayed when being solved.

In reality, this approach will need to break player behavior to small granular parts of the game. This means that big problems such as winning the game or leveling up are player problems that probably don't isomorph well with any real-world problems. Instead, smaller granular problems, such as moving in a particular part of a map or using a particular skill will be the easiest problems to start isomorphing. In theory, a mainstream video game may have multiple human computation problems in it, and with large number of players, these problems will be solved more optimally.

It may even be possible to solve problems via suites of games by breaking the isomorphs into different game mechanics. For example, a game like "The Oregon Trail" had the game problems solved through 2 main mechanics buying supplies and hunting, and this approach may help prevent boredom produced by repetitive decision making.

Problems and Algorithms

The last aspect needed to merge HCGs into mainstream games is an understanding of problems and the existing algorithms that solve these problems. If we take the approach described in the previous section, we will set out to observe problem solving behavior of players and try to relate this to a type of real-world problem. This approach is the reverse of current approaches to HCGs, which take a problem and try to map it into a game. However, to tap the large human resource provided by mainstream games we need to reverse the approach, and to achieve this we must understand a large range of problems.

Due to the huge range of real-world problems, this will require a collective approach as opposed to the knowledge possessed by one individual or small group. The *wisdom of crowds* would be the best approach here, where a small group would identify behavior within a mainstream game, and then would release this behavior so that external experts might identify this behavior as part of a problem they are familiar with.

We hypothesize that only a few real-world problems will isomorph into mainstream games. The exception to this is graph problems which include combinatorial optimization problems since, in these cases, computer scientists actively work on transforming these problems into other problems to help them navigate and classify problems. For example, in complexity theory transforming problems into other problems can help classify a problem into the NP-complete class. Therefore, if we can isomorph a real-world problem that is in the NP-complete class into a mainstream video game, then it is theoretically possible that any NP-complete problem that is a real-world problem can also be solved in this HCG. Additionally, meta-heuristic algorithms are one type of algorithm used to solve combinatorial optimization problems. The no-free-lunch theorem (Wolpert & Macready, 1996), suggests that there does not exist an algorithm for solving all optimization problems that is on average better than competitors, and therefore, if we can isomorph one meta-heuristic algorithm into mainstream games, then all real-world problems solved by this algorithm can be solved by a mainstream video game with this type of HCG.

Recently, Viglietta *et. al.* (Viglietta, 2012) (Aloupis, Demaine, Guo, & Viglietta, 2012) have looked at classic video games and have shown how complex these algorithms are in terms of complexity theory. For example, they describe how a generalized form of a Pac-Man level is an NP-hard problem.

Regardless of the problem's complexity classification, we confidently hypothesize that meta-heuristic algorithms are an excellent interface point to think of as good game isomorphs that humans can work with computers to solve real-world problems. Meta-heuristics have been used to solve a number of classical problems such as the traveling salesman problem, the quadratic assignment problem, and the timetabling and scheduling problems. In terms of a tighter connection to real-world problems there are too many applications to list here. Recently, at CEC 2011 a report was prepared that lays out 15 problems to help evaluate evolutionary algorithms (Das & Suganthan, 2010), and these problems are in areas such as energy and power distribution, chemical production, economics, antenna design, and aerospace. Since meta-heuristic algorithms can be considered frameworks that will solve a huge range of problems, these types of algorithms will be highly beneficial if incorporated in mainstream video games.

Additionally, some meta-heuristic algorithms are classified as nature inspired versus non-nature inspired (Blum & Roli, 2003). We hypothesize that these nature inspired algorithms may be easier to use as interfaces for good isomorphs since there is a connection between human actions in nature, game enjoyment and its relationship to our basic needs as described by Falstein in his game design article, "Natural Funativity" (Falstein, 2004).

Conclusion

In this paper, we have identified a research direction, which includes understanding of isomorphing problems, identifying existing mechanics and problem solving behavior in mainstream video games, and an understanding of real-world problems, to help push HCGs into mainstream video games. The value of this work would be to create a hybrid human and machine computation system that can tap into the large number of players that play mainstream video games.

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