On The Foundations of Digital Games

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ABSTRACT

Computers have lead to a revolution in the games we play, and, following this, an interest for computer-based games has been sparked in research communities. However, this easily leads to the perception of a one-way direction of influence between that the field of game research and computer science. This historical investigation points towards a deep and intertwined relationship between research on games and the development of computers, giving a richer picture of both fields. While doing so, an overview of early game research is presented and an argument made that the distinction between digital games and non-digital games may be counter-productive to game research as a whole.

Categories and Subject Descriptors

K.8.0 [**Computing Millieux**]: Personal Computing – *games.*

General Terms

Theory.

Keywords

Games, Computers, Digital

1. INTRODUCTION

Games have increasingly become a popular form of entertainment. While the diversity of traditional board games and roleplaying games is large, these types of games cannot compete with the attention given to those played on personal computers, video game consoles, and increasingly also smart phones and computer tablets. The possible causes for this preference are many: the ability of computers to handle complex sets of rules and game states, their capability to provide captivating audio and video, being able to play with people in other cities or countries but also being able to play against the computer rather than a person. The ubiquity of computers has clearly had a strong impact on which games are possible to make, and how these games are played.

But how much influence have games had on computers? Taking an alternative – but arguably a more literal – meaning of digital games, this paper does an initial exploration of this question. By doing so, it aims to show that there exists an intertwined relationship between research on computer and on games, and by extension, that separating between games classified as digital and those classified as non-digital may hinder research opportunities.

2. THE CONCEPT OF DIGITAL

In common usage, digital is typically attributed to something that makes use of computer technology, i.e. digital games refer to games that are played or mediated by computers. This usage is unproblematic for everyday and commercial purposes, but poses some problems to research due to some inherent ambiguities it creates. First, some of the electronic or video games used analog computers or circuitry (e.g. Tennis for Two[1] and the unnamed game patented as "cathode ray tube amusement device" [16]). Are these games examples of video and computer games but not digital games even if this is assumed to mean computer games? Second, many classic and modern board games (e.g. Go, Chess, Tic-Tac-Toe, Settlers of Catan, Neuroshima Hex, etc.) exist both in "normal" and "computerized" versions - does this mean that they are both analog and digital games? Are they a ludic version of Schrödinger's Cat (the metaphorical cat in Physics whose state as being dead or alive is undetermined until it is observed), and therefore has to be assumed to be both initially?

The original meaning of digital refers to the usage of discrete values, e.g. integers such as 0, 1, and 42, to represent data. These numbers in themselves can of course be represented exactly digitally, but so can fractions, characters, and algorithms. Irrational numbers, e.g. π, the golden ratio φ, and $\sqrt{2}$, are examples of values that can only be approximated digitally. So while digital typically today means electronic or computerized, discrete values are found in many technologies predating computers, e.g. alphabets, the Antikythera mechanism [53], the abacus, and Morse code. Further, many of the early computers, e.g. the Fermiac [35] and the Moniac [42], were analog since they made use of electrical, mechanical, or hydraulic quantities directly instead of using these to represent values symbolically and then manipulate these symbols.

These objections may seem to be nitpicking on definitions. The common usage of "digital games" refers to the medium that allows specific instantiations of a game. While this logically implies a support for Juul's [20] argument that games are trans-medial, i.e. that they can be moved from one medium to another while still being recognized as being the same thing, in practice the concept of digital games are used to cause a dichotomy between different categories of games. Not problematic in itself, the dichotomy is however used to value what game are worthy of studying, and this is often done while simultaneously claiming to be inclusive for all types of games.

Looking at games, one of their characteristics is that they have a state consisting of values. These values can either be represented in a digital or analog way. Chess is digital in the meaning that each Chess piece is in one specific squares on the board or have been removed from play; they are not partly between two or more

[1] http://www.bnl.gov/bnlweb/history/higinbotham.asp

squares. The pieces are actually a representation of the game state rather than the game state, so if a piece by mistake has moved slightly over to another square it is not a game action to correct this. In contrast, Soccer is analog in that players' positions is their actual physical position and measurement issues make referees needed to impartially interpret what the game state actually is. In this paper, digital games are simply seen as those having states that are described through discrete values. Besides all (digital) computer games, examples of such games include the traditional games of Chess, Go (圍棋), Backgammon, and more modern examples such as Settlers of Catan and Pandemic.

3. HISTORICAL FIGURES WITHIN THE DEVOLOPMENT OF COMPUTERS

Given that academic research is a continuously developing area where fields emerge, develop, and splinter into new fields it is unproductive to judge the relevance of a specific contribution from how it positioned itself with its contemporaries. Instead, the following exploration highlights researchers that in hindsight have contributed to both game research as well as computer research.

3.1 Blaise Pascal (1623-1662)

The French mathematician and philosopher, Blaise Pascal, is the first person that can reliably be linked to works related to both computers and games. Computers in that he – inspired by a wish to help his father in the calculations needed for his work as tax commissioner – invented a mechanical calculator in 1642 [13]. These did not sell but sparked an interest in perpetual motion machines, and an early form of the roulette wheel has been accredited to him due to this[2].

His game studies sprung out of an issue in gambling: how to fairly divide stakes in interrupted dice games. While discussing this with Pierre de Fermat in a series of letters in 1654, they developed the basis for probability [46]. However, after having a mystical experience in the same year, he shifted focus from mathematics to philosophy and theology, but this did not stop his from using probability in what is known as Pascal's Wager: to argue that one has more to win by waging on the existence of god than on the non-existence [40].

3.2 Gottfried Wilhelm Leibniz (1646-1716)

While Liebniz may be most well-known for having developed infinitesimal calculus results (using the groundwork created by Pascal and Fermat in probability) independently of Isaac Newton, and having a fierce rivalry with him, he was a polymath. One of his notes [28] is an early study of games where he looked at four different games. In it, he does a comparative analysis of Chess and Ludo Latrunculorum and concludes that the former is not an evolved version of the latter due to having different core gameplay; as evidence he points out that Ludo Latrunculorum used what Parlett calls the mechanic Custodianship [39], p. 235] to capture pieces while Chess uses a distinctly different mechanic, Displacement in the parlance of Parlett [39], p. 232]. Further, he discusses various ways of playing Solitaire, mentions a new naval game in passing, and speculates on the rules of Go based on second-hand accounts and puts forth a hypotheses that some Brahmin invented the latter because pieces are not "killed" while playing it.

Two other results of Leibniz are relevant for this paper. First, he described the binary number system [12] (with possible inspiration from the Chinese I Ching hexagrams). Second, he improved Pascal's mechanical calculator by adding support for multiplication and division, and contributed to the field of mechanical calculating by inventing the Leibniz wheel and describing pinwheel calculators [27].

3.3 Charles Babbage (1791-1871)

The Englishman Charles Babbage is most famous for inventing the first proper mechanical computer in the 19th century, although his Difference and Analytical engines were not completed beyond prototype stages.

Although not directly connected to gameplay, Babbage did write on a Euler's solution to moving a Knight over all squares of a Chess board [1] (the original text states the author as an "correspondent", but Babbage lists the text as his own in a later collection [4]). He also wrote texts on the expected outcome when a gamester would bet multiple times while having the same chance on each bet [2].

Babbage and Ada Lovelace (see below) considered building tic-tac-toe machines as a way of funding their development of the Analytical Engine [31], p. 84]. More specifically, he stated:

> "[A]fter I had made many drawing of the Analytical Engine and all its parts, [I] dwelt with satisfaction upon the power which I possessed over mechanism through the aid of the Mechanical Notation. I felt, however, that it would be more satisfactory to the minds of others, and even in some measure to my own, that I should try the power of such principles as I had laid down, by assuming some question of an entirely new kind, and endeavouring to solve it by the aid of those principles [...] After much consideration I selected for my test the contrivance of a machine that should be able to play a game of purely intellectual skill successfully; such as tit-tat-to [sic], drafts, chess, &c." [3], pp. 465-468]

After this, he looked at tic-tac-toe and developed what in principle are trees of possible game events. He then noted that manufacturing mechanisms that could play games in this way would offer him a way to "acquire the funds necessary to complete the Analytical Engine." [3], p. 468].

3.4 Ada Lovelace (1815-1852)

Hailing from Great Britain, Ada Lovelace is recognized as the first programmer, as she in her note G from 1843 [32] describes an algorithm for producing Bernoulli numbers using Babbage's analytical engine. Of interest to this paper, the Bernoulli numbers [5] were developed as part of work done in calculating the expected outcomes of games of chance.

As mentioned above, Lovelace and Babbage developed a tic-tac-toe machine but gave up on this on the advice that the market for travelling novelties was filled [43]. They then moved on to using a small version of the difference engine to run a system for betting on horses; this was unsuccessful and Lovelace had to pawn her husband's family jewels to pay the bookies [43].

3.5 Alan Turing (1912-1954)

Initially a mathematician, Alan Turing is recognized as one of the founders of computer science and artificial intelligence. He developed the conceptual computer model known as a Universal Turing Machine while reformulating Kurt Gödel's solution to the *Entscheidungsproblem*, [56], and did more applied work during the Second World War when he designed electro-mechanical machines to decipher German encryptions.

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[2] http://web.mit.edu/invent/iow/pascal.html

Turing's work on computers and computation continued after the war. He developed a program – Turochamp – for playing Chess together with Chapernowne in 1948 [Copeland, p. 563], but since there were no computer powerful enough to run the program, Turing manually did the calculations. Although a game against Champernowne's wife has not been recorded, one against Alick Glennie in 1950 has been recorded[3]:

1.e4 e5 2.Nc3 Nf6 3.d4 Bb4 4.Nf3 d6 5.Bd2 Nc6 6.d5 Nd4 7.h4 Bg4 8.a4 Nxf3+ 9.gxf3 Bh5 10.Bb5+ c6 11.dxc6 O-O 12.cxb7 Rb8 13.Ba6 Qa5 14.Qe2 Nd7 15.Rg1 Nc5 16.Rg5 Bg6 17.Bb5 Nxb7 18.O-O-O Nc5 19.Bc6 Rfc8 20.Bd5 Bxc3 21.Bxc3 Qxa4 22.Kd2 Ne6 23.Rg4 Nd4 24.Qd3 Nb5 25.Bb3 Qa6 26.Bc4 Bh5 27.Rg3 Qa4 28.Bxb5 Qxb5 29.Qxd6 Rd8 0-1

Turing developed another type of game, the Imagination Game, in 1950 [58]. The idea behind the game is to test whether a computer program is intelligent or not - a "player" is set to communicate with a human and computer through a mediating system which masks physical characteristics. The goal is to guess who the human is. Turing's argument is that we should recognize computers that manage to trick the player as intelligent in the same way we view other humans. While this game has later been "simplified" to Turing Test where a computer tries to trick a human in one-to-one conversations, there are two points to make about his original text. The first is that Turing is explicit in talking about "digital computers" compared to others (not analog computers in this case but rather human computers – the term computer originally designated a profession). The second is that a precursor of the Imagination Game is a version where the human and computer play Chess against the "player" [57], p. 431] and Turing most likely refers to his experience with Turochamp when he states "(This is a rather idealized form of an experiment I have actually done.)" [57], p. 431]

3.6 John von Neumann (1903-1957)

John von Neumann was born 1903 in Budapest. He distinguished himself early as a mathematician – contributing to operator theory and ergodic theory – but also made important contributions to quantum physics [61]. After moving to the USA, he became involved in practical applications of mathematics and physics as part of the Manhattan project (and later the Intercontinental Ballistic Missile committee. During this work, he made important contributions to the construction of both the atom and hydrogen bomb.

One of the early works by von Neumann, published in 1928, introduces what is now knows as the minimax theorem [60]. This shows that for games with perfect information (such as Chess or Go) there exists strategies for both sides to ensure that both will minimize their losses. While his work proved the theorem mathematically, the idea of game trees with all movements as nodes had been used by Babbage in his concept for a Tic-Tac-Toe machine nearly 100 years earlier. Von Neumann's work was specifically directed at parlor games (Gesellschaftsspiele) although he pointed out that national economics looks at similar problems. It would be until 1944 when, under the encouragement of Oskar Morgenstern, the book *Theory of Games and Economic Behavior* was published [62]. While this book is the primary contribution to the field known as game theory (and applied in first economics and then biology), von Neumann himself published papers purely related to games later (e.g. [6][15]). His work on game theory and nuclear weapons intertwined when he developed the Mutually Assured Destruction (MAD) strategy for how to defend the USA against the USSR in the Cold War.

Von Neumann's interest in computers grew out of the need for calculations related to the development of the hydrogen bomb. His later consultancy work on the EDVAC and ENIAC computers resulted in what is known as the von Neumann architecture and is the basis for current computer designs. Besides this, he contributed to the field of computer science with work on pseudorandom numbers, stochastic computing, cellular automata, and sort algorithms.

While von Neumann himself did not implement any programs that could play games, Stanislaw Ulam and some other researchers that developed the hydrogen bomb (with some input from von Neumann himself) used his computer Maniac I to implement a program for a simplified version of Chess [21]. It is unlikely that von Neumann was unaware of this, as they worked together on computer programs for the same computer and they have been documented as close friends [59].

3.7 Edward Condon (1902-1974)

Neither a computer scientist nor a game researcher, the American physicist Edward Condon managed to connect computer development and game design in 1939. While he is mainly known for his work in quantum mechanics, resigning after working 6 weeks on the Manhattan project, being targeted by the House Un-American Activities Committee[4], and debunking UFO sightings [9], Condon also developed a machine – the Nimatron – that was exhibited at the New York World's Fair in 1940 and let the public play the game of Nim against it; some 50,000 people played against it but only ~10% won. Condon himself provides frank information about this in an interview: "[...] this was a good four or five years before Johnnie von Neumann and Eckart and Mockley and all this digital computer business, and [I] never thought of it in serious terms; I just thought of it as this gag thing, yet the circuitry and all that was exactly what was later used for computers, for programmed computers." [63]

The Nimatron made use of circuits to represent numbers digitally, and this was something which had not been done previously; Condon and his collaborators applied and received a patent for the invention [8], but they failed to make commercial use of it. In hindsight, Condon realized the importance this patent could have had on the development of computers: "None of us had sense enough to do anything with it, so the patent just never amounted to anything. But if we had had sense enough with our postwar planning to think of automatic computers, I might have amounted to something; IBM might not be what..." [63]

3.8 Claude Shannon (1916-2001)

Claude Shannon first played an important role in the development of computers when he in 1937 wrote a master thesis showing that Boolean algebra could be applied to electrical system design and thereby construct and resolve any logical, numerical relationship - something which is critical if one actually wanted to construct a digital computer.

While working on as a national research fellow in 1939 at the Institute for Advanced Study in Princeton, USA, he began research on understanding the limits of signal processing which

[3] http://chessprogramming.wikispaces.com/Turochamp

[4] One line of attack went: 'quantum mechanics. It strikes this hearing that if you could be at the forefront of one revolutionary movement. . . you could be at the forefront of another.' [44], p. 236]

later became the field of Information Theory. In his publication from 1948 [47], Shannon introduced the concepts of information entropy, redundancy, and the bit. Entropy was explained with the help of Bernoulli trials [5] and the name entropy was suggested by John von Neumann; the argumentation was that the underlying idea of uncertainty had already been called entropy in the field of thermodynamics which von Neumann had been involved in [55].

The collaboration between the US and the UK during WWII meant that Shannon met with Alan Turing in 1943 to share information of breaking German ciphers. Here Shannon became aware of Turing's work on his Turing Machine but also described to Turing general strategies for playing Chess. Shannon took this knowledge further when in 1950 he published an early paper on programs that could play Chess [48]. Building on some arguments from von Neumann and Morgenstern, he created a program that unfortunately would be "both slow and a weak player" [48], p. 12] but described ways to improve its strategy as well as potential alternative strategies. Shannon also constructed a device to play the game *Hex*, and pointed out that it is "curious that the Hex-player reversed the usual computing procedure in that it solved a basically digital problem by an anlog [sic] machine." [49], p. 1237]

Shannon is credited with inventing one game, the Shannon switching game (see [29] for a description and analysis of the game). This is an abstract two-player graph game where one player is trying to connect two nodes by coloring edges and the one player is trying to hinder this by deleting non-colored edges. Shannon is also one of the first people that developed wearable computers. Together with Edward Thorp, he in secret developed a small analog computer that helped them predict results when playing roulette [54].

3.9 Donald Michie (1923-2007)

Like Alan Turing, Donald Michie worked on cracking German codes (specifically the Lorenz cipher) during the Second World War. While this involved the development of computer hardware, he later turned his attention to artificial intelligence (e.g. [38]) and became director of the University of Edinburgh's Department of Machine Intelligence and Perception.

In 1947-48, he and Shaun Wylie developed the Chess-playing computer program Machiavelli. This was developed at the same time Turing and Chapernowne was developing Turochamp and they were aware of each other; a planned match was however never arranged (one reason was probably that no computers were available that could run the programs) [52]. In 1960, Michie began developing techniques for machine learning by developing the tic-tac-toe machine MENACE (Machine Educable Noughts And Crosses Engine) [36].

Michie has published one game. This unnamed party game was developed together with Christopher Longuet-Higgins as a way of providing the minimal specification for the information transactions that need to be performed to replicate information [37]. While this does not directly sound like it has relations to computers, the paper was written to study the similarities in information processing between biological cells and digital computers.

3.10 Donald E. Knuth (1938-)

An American that worked as a professor in computer science at Stanford University, Donald Knuth is most famous as the author of *The Art of Computer Programming*, a series of volumes describing and analyzing computer algorithms. The first book was published in 1968, and four installments have been published as of 2011. He is also well-known within the field of computer science for inventing the TeX typesetting system.

Most of his work on games and puzzles have been collected in the book *Selected Papers on Fun & Games* [25]. Texts included using computer to support coaching a basketball team in 1958 [25], p. 199], analysis of three-sided shootouts as a game [25], p. 209], an analysis of Master Mind [25], p. 219], and the introduction of variant of Chess [25], p. 231]. A full 160 pages of the book is devoted to a translation of the game *Adventure* to C in the literary programming style Knuth advocated to support human readability [25], pp. 235-395]; Knuth perceives the game as a good tool to "improve your programming skills by reading code" [25], p. xii].

4. AN INTERPLAY OF CONCEPTS

The previous section has shown that many people, fundamentally involved in the core development of computers as we know them today, also were interested in games. This in itself does not have to signify any particular relation between them: the interest in both may be random coincident and there are of course many people that have made important contributions to the development of computers without doing research on games and vice versa. A possible connection between the work on games and computers requires a closer inspection.

A first observation is that the people mentioned did not work in isolation; many were aware of each other's work and build upon each other's result. Leibnitz has references to Pascal [27], Lovelace mentions Pascal's machine [32] and so one can assumed that Babbage also was aware of it. Von Neumann is said to have referred to Pascal's wager when asking for the last sacraments while dying of cancer in 1957 [33], p. 379]. Turing is a somewhat of a hub in this. Von Neumann and Turing had many recorded interaction [11], p. 21] including von Neumann offering him a position as his assistant [11], p. 134] and attributing Turing with the concepts of the digital computer not already anticipated by Babbage, Lovelace, or others [11], p. 22]. Further, Turing is reported as having "enthusiastically discussed the mechanization of chess with Donald Michie"[11], p. 353], and Turing tells of Shannon describing to him the rules of thumb for winning Chess [11], p. 393] while Shannon was impressed with the ideas behind the Universal Turing Machine when they met in 1943 [18], p. 251]. Then again, there is no clear indication that Turing was aware of Babbage’s work [11], p. 29]. While Turing might be directly connected to many of the other researchers mentioned, there are many independent links between the other researchers. For example, Michie references Shannon in his paper on MENACE, the "engine" that could learn to play better Tic-Tac-Toe [36], and Shannon in turn refers to Condon's Nim-played machine and von Neumann game theory book when describing how to progress computers to play Chess [50].

Shannon has published a paper on von Neumann's work on automata theory [51] and mentions both Turing and von Neumann in his 1954 paper on computers and automata where he among other things describes his own maze-solving device that learns mazes using a circuit of 110 relays organized "somewhat after that of a digital computer [49], p. 1238]. That Shannon, Turing, and von Neumann were aware of each other is not particularly surprising since they spent time at Princeton University or the nearby Institute for Advanced Study. Likewise, Condon and von Neumann (and Ulam) worked together on the Manhattan Project in Los Alamos.

Knuth was aware of Babbage's work on Tic-Tac-Toe, quoting him in an exercise regarding that game in volume 4A of The Art of

Computer Programming [26], pp. 19-20], but also refers to von Neumann in an early book [24], p. 159].

That the researchers investigated are aware of each other points to direct or circumstantial evidence that they may be aware of each others' interests in both games and computers, but does not actually create tangible links between the two fields. To do this we need to look more at the actual content of their work. That computers could do the calculations necessary for making moves in games is the easiest observation to do: Babbage, Condon, Michie, Shannon, and Turing all did this. This of course is the reason why a digital game today signifies a game that is possible to play by running a program on a computer.

But what about how games influencing computer development? There is no direct use of Pascal and Leibnitz's results on gambling research (i.e. probability) and the calculating machines they built. A first possible intertwining occurs with Ada Lovelace; she chose the calculation of *the Numbers of Bernoulli* as her example in her Note G [32], which has become known as the first algorithm specifically constructed to be run on a computer. These numbers are interesting since they were developed as part of the exploration by Bernoulli on games of chance in *Ars Conjectandi* [5] which "generalized the doctrine of chances previously developed by Pascal and Huygens" [17], p. 224]. It seems very unlikely that Lovelace – someone associated with gambling – would not be aware of the context of Bernoulli's work, so the choice of first computer program was most likely one of calculating numbers developed to understand games. In addition, Babbage and her tic-toe-toe machine and the use of small scale versions of the differential machine for betting on horses can be seen examples of dedicated gaming machines.

Turing's machine is not a game but he did construct a game that is still used today, the imagination game, to test whether or not a computer program could be perceived as being intelligent. One aspect of this test – in fact the original one – was having the ability to be able to play Chess. Wanting people to be able to play this game, he (and Michie) worked on developing Chess programs, so some of the pioneers of computers developed game programs to be able to let people play a game to judge the intelligence of computers.

Knuth apparently considers reading code for running computer games, or at least Adventure, as a good way of learning to code by including it in his book *Selected Papers on Fun & Games*. This is however not a one-time occurrence, he has argued for the benefits of well-chosen puzzles and games both in *The Art of Computer Programming* [26], pp. 7-9] and in the essay "Are toy problems useful?" [23] Taking it one step further, he states that "I've never been able to see any boundary between scientific research and game-playing." [25], p. ix]

This last statement by Knuth may point to another way research on computers and games may be connected. Regardless of if they affect each other, they may be expressions of a certain frame of mind or curiosity. Indeed, many of the researchers mentioned above also contributed to mathematics and one can find mathematicians doing research on games, with John Horton Conway as a prime example. Not only has he published the book *On Numbers and Games* [10], he credits the discovery of the Surreal numbers from a desire to study the game Go[5], and he developed Conway's Game of Life [14]. It can be pointed out that Conway's game is a cellular automaton, a concept John von Neumann and Stanislaw Ulam (one of the physicist that made the simplified Chess program for the Maniac I) developed in the 1940s, something which points to connections between these fields as well.

[5] But it was Donald E. Knuth that gave them their name [22].

The above paragraphs have pointed out different ways in which the development of computers and various results from research on games can be connected to each other. However, the claim of interaction between the research fields can be objected to in a couple of ways. The following sections address some of these.

4.1 Objection #1: That isn't Game Research!

The first objection is simply that the work that has been described as being on games is in fact on some other field. Game theory is for example regarded as a branch of economics and the games being studied do not have to be run on computers to be played. One might as well use the same objection to computers; that is, much of the research described above does not relate to the computers built from silicon that ubiquitously surround us today. Turing had to 'run' his computer program manually to be able to let it play against somebody and Michie resorted to manipulating large amounts of matchboxes and physical tokens to represent the state of his MENACE system. In doing so, they were not using what we see as computer today but rather made use of – or, more correctly, took the role of – *human* computers. While this may seem strange or quaint to us now, it does actually point to the historical basis for the concept of computers. Originally, a computer was a person that was employed to do calculations (computations), and Pascal's and Babbage's inspiration for developing mechanical computers was to remove humans (partly to increase speed, partly to avoid human errors; Babbage [4], p. 139] comments on the latter himself). While we typically think of personal computers or laptops when hearing the word computer, within theoretical computer science anything that can systematically follow a rule of instructions in accordance with a program is a computer (more formally, something is Turing complete if it can simulate a Turing machine). While the physical capabilities of a computer are important for speed and presentation, programs can be studied independently. Likewise, the medium supporting a gameplay experience is influence by that medium, but one can study games such as Chess, Go, Poker, etc. without references to a specific medium.

References to von Neumann and Morgenstern's work on game theory are typically not given in modern game research texts. This probably reflects the theoretical background of the current research community; the mathematical terminology used is not part of the scientific tools used within social science, media theory, etc. The claim that the theory only applies to economics and not really to games is simply false. First, von Neumann's work in 1928 has no reference whatsoever to economics. Second, in his and Morgenstern's book they explicitly reference this issue:

> "In studying it as a problem in its own right, our point of view most of necessity undergo a serious shift [...] we shall have to treat the games as games. Therefore we shall not mind if some points taken up have no economic connections whatever, - it would not be possible to do full justice to the subject otherwise." [62], p. 46].

Third, the central concept of von Neumann's 1928 paper, min-maxing, has spread among gamers of role-playing games, wargames, and video games although with a specific and derogatory meaning [34]. Further, von Neumann has publications dating after the original publication of the game theory book in 1944 which focused exclusively on games ([6][15]).

4.2 Objection #2: That isn't playing!

Another object comes from the stance that game research needs to study people playing games. This is based on the two ideas that gameplay only occurs when an activity is ongoing, and that game research is concerned with the experience of gameplay. Since no computers have convincingly passed Turing's Imagination Game or any other test for being intelligent, computers playing games are outside the domain of game research.

This objection faces problems when one looks closer at the actual work reported above. While early work on probability can easily be misinterpreted to be aimed at providing advantages to gamblers, the original issue that sparked the whole field of probability was how to divide pots in a fair and civilized fashion when gambling sessions had to be interrupted [46], p. 546]. Both the machines of Babbage and Lovelace and the one by Condon were built to be played by (or maybe to play against) people. The Chess programs by Michie, Shannon, and Turing were part of the early research in artificial intelligence so they can be seen as early (and maybe naïve) attempts at replicating or understanding human intelligence. The game theory by von Neumann and Morgenstern was developed to study decision making where bluffing and deceptions have roles (it is for this reason that von Neumann could state "Chess is not a game. Chess is a well-defined form of computation" [41]). All these examples point to that the research was interested in the human dimension of games and gaming.

4.3 Objection #3: These are only games that are not computer-based!

While this objection might seem trivial given that the starting point for the study was explicitly to look at games with a digital game state, the objection is that none of the examples are possible to play *only* through computer mediation. However, all examples are actually games that can be played without computers (except for the peripheral examples of *Adventure* and Conway's Game of Life), so one could argue that the study has only looked at games that do not *need* computer mediation; that Turing could run his program by hand and Michie could simulate his program with matchboxes show that even these programs did not need computer mediation. The problem with this argument is that it points back to the difference between what we call computers and computation; computation can be done through many different means, including but not limited to the silicon-based integrated chips that are the core of what we commonly refer to as computers. A more reasonable counter-argument might be based on the fact that no examples make use of electricity-based display devices, i.e. no examples are *video games*. Linderoth [30] discusses this issue but points out that using a display that is a boundary between player and the game content as a distinction between different categories of games would put pinball machines and claw machines in the same category as video games.

5. The Risk of a Digital Dichotomy

This paper has explored the relation between studies of games and the development of computers. It has done so by looking at computer pioneers and their work on both computers and games, where games have been digital in the sense that they have game states consisting of discrete values (making measuring unnecessary or trivial to do). While this may have a value in itself from a historical perspective, are there other reasons why awareness of the intertwined relationship between games and computers?

One may be found by looking at the recently developed research communities that are dedicated to studying games. These represent interests from research disciplines varying from computer science through media studies and social sciences to philosophy and history. While specialization of topics is common in research, a closer inspection of the conferences and journal show that computer or digital games are actually meant; ISAGA - The International Simulation And Gaming Association is the clearest exception. For example, the call for papers to "The History of Games International Conference 1st edition" states "We invite proposals on the history of games at large, as long as it is tied with the electro-mechanical / digital development of the phenomenon."[6] Similarly, the Game Studies journal describes its purpose in general terms regarding what types of games are in its scope ("Our Mission - To explore the rich cultural genre of games; to give scholars a peer-reviewed forum for their ideas and theories; to provide an academic channel for the ongoing discussions on games and gaming."[7]) but at the same time the journal has the subtitle "the international journal of computer game research". Explicitly or – perhaps even worse – implicitly restricting game research to being about only that subset of games that qualify as digital risks creating a digital dichotomy.

A consistent rejection of games and computers that are not digital in the current meaning of the word would limit research possibilities. For example, looking at the development or nature of role-playing games would not be possible to do since the first role-playing games were not computer-based and both tabletop and live action role-playing is still developing in parallel to the computer-based ones. While one could claim that such works still are about "digital" games since some of the games are such, this raises the question how many percentages of the games or the text need to be specifically allocated to the acceptable games for the research to become tolerable. A second limitation is that all theory about "digital" games would have to be created without reference to other types of games, effectively demanding that the research field should begin without any theory. This is not what is done currently, research is often built upon the works of Caillois [7] and Huizinga [19]; both of which studied games before "digital" games had emerged as a phenomena. Permitting such references while not allowing actual research to look at the same games that the reference did creates paradoxes. One is that Caillois' and Huizinga's work would not be publishable and another is that while existing work can be used doing similar studies are no longer permissible.

There are, however, examples of research which makes no clear distinction between games that make use of computers and those that do not [20][30][45]. These stress the commonalities between digital (or computer) games and other games and point to observations made possible by having a more inclusive stance. This paper adds to this list of observations by studying the relation between digital games and the development of computers. While using the everyday usage of digital games would have repeated a tale told in the introduction of many papers and books in game research, another approach was taken here. Digital games in the original meaning of digital are instead used, and by doing so, the paper shows a more complex dynamic between the fields of computer research and game research. While not denying that computers have greatly influenced today's games, it also shows that games and game research have greatly influenced today's

[6] https://depts.washington.edu/critgame/wordpress/2012/09/cfp-the-history-of-games-international-conference-montreal-canada-621-623-2013/

[7] http://gamestudies.org/

computers. This is an argument that would have been impossible to do if restricted to the everyday meaning of digital games (although one could have done more restricted explorations, e.g. how the development of first-person shooters drove the development of graphics cards for PCs).

This is not to say that the medium a game is conveyed through does not affect the experience of playing it, nor of what games are possible to play, but this is not the only way to categorize games. Examining the role computers have on games is an important area in game research, and banning studies of what these differences are would be as problematic as not considering "non-digital" games part of the subject area for game research. What to do then? One approach could be to sharpen the descriptions of statements and call-for-participations in journal and conferences, and then enforce these. This would partition game research into separate subfields which would probably not be beneficial to such a complex phenomena as games (the partitioning in one sense already exists since there is little crossover between e.g. the game research presented above in the paper, the research within ISAGA, and newly established conferences primarily studying computer-based games). An alternative approach would be to be explicitly more inclusive in descriptions of what types of research topics are invited. This would make finding relevant reviewers more challenging and cause friction until a common vocabulary has been developed, but the reward would be to create a research community where games can be studied from many perspectives, e.g. as rule-based systems, as technology, as activities, or as mediated experiences.

The computer pioneers described in this paper did not make a distinction between games being played on computers and those being played without them; if anything, they tried to make it possible to use computers as a new medium to play games played elsewhere earlier. In doing so, they were increasing the possibilities for gaming and gameplay experiences rather than partitioning off this new way of playing as a separate phenomenon.

6. CONCLUSIONS

This paper has looked at work done by researchers central to the development of computer in the shape and form we have them today. Besides the theoretical and practical work on developing computers, these researchers have in various ways researched games as well. Not only that, but the game-related work have in various ways influenced the work on computers – and vice versa – which creates a complex tapestry of interrelationships between the two fields of research. This advocates a view that the two fields have symbiotic relations that might not be perceived if game research is limited to being about games that are only playable through computer mediation.

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8. REFERENCES

[1] Babbage, C., 1817. An Account of Euler's Method of Solving a Problem Relative to the Move of the Knight at the Game of Chess" Journal of Science and the Arts, published by John Murray for the Royal Institution, London, 1817-18; vol.3, art.5, pp.72-77.

[2] Babbage, C., 1821. An Examination of Some Questions Connected with Games of Chance. In Transaction of the Royal Society of Edinburgh, Vol. IX, pp. 153-177.

[3] Babbage, C., 2011. Games of Skill can be played by an automaton. In Babbage, C., 2011. Passages from the Life of a Philosopher. Cambridge University Press, pp. 465-468.

[4] Babbage, C., 2011. Passages from the Life of a Philosopher. Cambridge University Press.

[5] Bernoulli, J., 1713. Ars Conjectandi. Impensis Thurnisiorum, fratrum. Available in full text from Google books.

[6] Brown, G.W. & von Neumann, J., 1950. Solutions of Games by Differential Equations. In *Contributions to the Theory of Games*, Vol. 1, 1950, pp. 73-79.

[7] Caillois, R., 1961. Man, Play and Games. University of Illinois Press.

[8] Condon, E.U., Tawney, G.I. & Derr, W.A., 1940. Machine to play game of Nim. Patent Number: US002215544.

[9] Condon, E.U. & Gillmor, D.S., 1968. Final Report of the Scientific Study of Unidentified Flying Objects. Bantam Books. Available at http://files.ncas.org/condon/

[10] Conway, J.H., 2000. On Numbers and Games. AK Peters.

[11] Copeland., B.J. (ed.), 2007. *The Essential Turing: Seminal Writings in Computing, Logic, Philosophy, Artificial Intelligence, and Artificial Life plus The Secrets of Enigma*. Oxford University Press.

[12] Couturat, L., 1901. La Logique de Leibniz - D'après des documents inédits, pp. 473–78.

[13] d'Ocagne, M., 1893 Annales du Conservatoire national des arts et métier, 2e série, tome 5, Le calcul simplifié. Paris: Gauthiers-Villars et files, Imprimeurs-Libraires. Available online from cnum.cnam.fr/CGI/fpage.cgi?8KU54-2.5/249/150/369/363/369.

[14] Gardner, M., 1970. Mathematical Games - The fantastic combinations of John Conway's new solitaire game "life". No. 223, pp. 120–123.

[15] Gillies, D.B., Mayberry, J. P. & von Neumann, J., 1953. Two variants of poker, Contributions to the theory of games, vol. 2, Annals of Mathematics Studies, no. 28, Princeton University Press, Princeton, N. J., 1953, pp. 13–50.

[16] Goldsmith, T.T. Jr., Mann, E.R., 1948. Cathode-Ray Tube Amusement Device. Patent Number: US 2455992.

[17] Hald, A., 1990. *A History of Probability & Statistics - and their applications before 1750*. John Wiley & Sons, Inc.

[18] Hodges, A., 1992. Alan Turing: The Enigma. Vintage.

[19] Huizinga, J., 1955. Homo Ludens: a study of the play element in culture. Beacon Press.

[20] Juul, J., 2005. Half-Real: Video Games between Real Rules and Fictional Worlds. MIT Press.

[21] Kister, J., Stein, P., Ulam, S., Walden, W. & Wells, M., 1957. Experiments in Chess. J. ACM 4, 2 (April 1957), 174-177. DOI=10.1145/320868.320877 http://doi.acm.org/10.1145/320868.32087

[22] Knuth, D.E., 1974. Surreal Numbers: How Two Ex-Students Turned on to Pure Mathematics and Found Total Happiness. Addison-Wesley.

[23] Knuth, D.E., 1996. Are toy problems useful. In Selected Papers on Computer Science. CSLI. chapter 10, 169–183. Originally published in Popular Computing.

[24] Knuth, D.E., 1998. The Art of Computer Programming: Volume 3: Sorting and Searching. Boston: Addison–Wesley. p. 159.

[25] Knuth, D.E., 2011. Selected Papers on Fun & Games. CSLI Publications.

[26] Knuth, D.E., 2011. The Art of Computer Programming. Volume 4A: Combinatorial Algorithms, Part 1. First Edition. Addison-Wesley. ISBN 0-201-03804-8.

[27] Leibniz (1685). Translated by Kormes, M. as part of Leibniz on His Calculating Machine. In Smith, D.E. (1929). A Source Book in Mathematics, pp. 173-181. McGraw-Hill Book Company, Inc.

[28] Leibniz, G.W., 1710. Annotatio de quibusdam ludis, in primis de ludo quodam Sinico, differentiaque Scachici et Latruncolorum, et novo genere lui navalis. Miscellanea Berolinensia, pp. 22-26. English translation by Pulskamp, R.J. available online at http://www.cs.xu.edu/math/Sources/Leibniz/sinico-alliey.pdf.

[29] Lehman, A., 1964. A Solution of the Shannon Switching Game. Journal of the Society for Industrial and Applied Mathematics, 1964, Vol. 12, No. 4, pp. 687-725.

[30] Linderoth, J., 2011. Beyond the digital divide: An ecological approach to gameplay. Procedings for Think, design, play. The DiGRA conference on games and play, Utrecht (September 2011).

[31] Logsdon, T., 2000. The Robot Revolution. iUniverse.

[32] Lovelace, A., 1843. Notes. In Menabrea, L.F. Sketch of the Analytical Engine invented by Charles Babbage Esq (translated by Lovelace, A.). In Taylor, R. (ed.) Scientific Memoirs, Selections from The Transactions of Foreign Academies and Learned Societies and from Foreign Journals, F.S.A.,Vol III London: 1843.

[33] MacRae, N., 1992. John Von Neumann: The Scientific Genius Who Pioneered the Modern Computer, Game Theory, Nuclear Deterrence, and Much More (2 ed.). American Mathematical Soc., p. 379.

[34] Masters, P., 1994. The Vocabulary of Role-Playing. Interactive Fantasy (2).

[35] Metropolis, N., 1987. The Beginning of the Monte Carlo Method. Los Alamos Science, No. 15, p. 125.

[36] Michie, D., 1961. Trial and error. Science Survey, part 2, Harmondsworth: Penguin, pp. 129-145.

[37] Michie, D. & Longuet-Higgins, C., 1966. Party Game Model of Biological Replication. Nature, Vol. 212, pp. 10-12.

[38] Michie, D., 1986. On Machine Intelligence. Ellis Horwood Ltd.

[39] Parlett, D.,1999. The Oxford History of Board Games. Oxford University Press.

[40] Pascal, B., 1699. Pensées, section III, note 233. English translation by Trotter, W.F. and available from project Gutenberg: http://www.gutenberg.org/files/18269/18269-h/18269-h.htm.

[41] Poundstone, W., 1992. Prisoner's dilemma: John von Neumann, game theory, and the puzzle of the bomb. New York: Anchor Books.

[42] Reserve Bank of New Zealand Museum. A. W. H. Phillips, MBE and the MONIAC. Available at http://www.rbnz.govt.nz/about/museum/3121411.pdf

[43] Rheingold, H., 2000. Tools for Thought: The History and Future of Mind-expanding Technology. MIT Press.

[44] Sagan, C., 1997. The Demon-Haunted World - Science as a Candle in the Dark. Headline Book Publishing.

[45] Salen, K. & Zimmerman, E., 2004. Rules of Play: Game Design Fundamentals. MIT Press.

[46] Sanford, V. (translator). Fermat and Pascal on Probability. In Smith, D.E., 1929. A Source Book in Mathematics, pp. 546-565. McGraw-Hill Book Company, Inc.

[47] Shannon, C.E., 1948. A Mathematical Theory of Communication. Bell System Technical Journal 27 (3): 379–423.

[48] Shannon, C., 1950. Programming a Computer for Playing Chess. *Philosophical Magazine*, Ser.7, Vol. 41, No. 314, pp. 256-75.

[49] Shannon, C.E., 1953. Computers and Automata. Proceedings of the Institute of Radio Engineers Vol. 41, No. 10, pp. 1234-1241.

[50] Shannon, C. E., 1955. Games-playing Machines. Journal of the Franklin Institute, Vol. 260, pp. 447-54.

[51] Shannon, C.E., 1958. Von Neumann's contributions to automata theory. Source: Bull. Amer. Math. Soc. Volume 64, Number 3, Part 2 (1958), 123-129.

[52] Smith, J.M. & Michie, D., 1961. *Machines that play games*, New Scientist, 12.

[53] Spinellis, D., 2008. The Antikythera Mechanism: A Computer Science Perspective. Computer 41, 5, pp. 22-27.

[54] Thorp, E.O., 1998. The Invention of the First Wearable Computer. In Proceedings of the 2nd IEEE International Symposium on Wearable Computers (ISWC '98). IEEE Computer Society, Washington, DC, USA, 4-.

[55] Tribus, M. & McIrvine, E.C., 1971. Energy and information, Scientific American, No. 224.

[56] Turing, A.M., 1936. On Computable Numbers, with an Application to the Entscheidungsproblem. Proceedings of the London Mathematical Society, 2 42, pp. 230–65.

[57] Turing, A.M., 1948. Intelligent Machinery. In Copeland., B.J. (ed.) (2007). *The Essential Turing: Seminal Writings in Computing, Logic, Philosophy, Artificial Intelligence, and Artificial Life plus The Secrets of Enigma*. Oxford University Press.

[58] Turing, A.M., 1950. Computing machinery and intelligence. *Mind*, Vol. 59, pp. 433-460.

[59] Ulam, S.M., 1991. Adventures of a Mathematician. University of California Press.

[60] von Neumann, J., 1928. Zur Theorie der Gesellschaftsspiele. *Mathematische Annalen 1*, Vol. 1 (1928), pp. 295-320.

[61] von Neumann, J. 1932. Mathematische Grundlagen der Quantenmechanik. Springer.

[62] von Neumann, J. & Morgenstern, O., 1990. *Theory of Games and Economic Behavior*. Princeton University Press. First edition 1944.

[63] Weiner, C., 1968. Interview with Dr. Edward U. Condon. Transcript available at http://www.aip.org/history/ohilist/4997_2.html.