Physics Simulation in Games

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Abstract

The aim of this paper is to investigate the principles and effects of simulation in digital games, in particular simulation of the laws of physics. Building on the assumption that all games can be framed as the "play of simulation", physics simulation is regarded to be present in the majority of games, but in widely varying forms and for different purposes. To illustrate this, a theoretical part, a design-centered part and a practical look at some gameswill be used to help to construct schemes by which games may be categorised according to the physics simulation involved.

First, a range of theories is considered, of simulation in general, of its relation to representation and reality and of its place in games. This is followed by an outline of important characteristics of such simulations in games. The common technical principles of physics simulation are reviewed, reasons why the laws of physics (or a subset thereof) play a major role in many digital games are investigated and design issues are discussed. Finally, a number of games are studied with respect to the role of representation and simulation of laws of physics.

Das Ziel dieser Arbeit ist die Untersuchung der Prinzipien und Effekte von Simulation in digitalen Spielen, insbesondere von Simulation physikalischer Gesetze. Ausgehend von der Annahme, dass alle Spiele als "Play of Simulation" aufgefasst werden können, kann die Gegenwart von Physiksimulation in der Mehrheit aller Spiele beobachtet werden, allerdings mit starken Unterschieden in Form und Zweck. Ein theoretischer Teil, ein designorientierter Teil und eine praktische Studie einiger Spiele sollen das verdeutlichen und bei der Konstruktion von Klassifikationsschemata für Spiele hinsichtlich der involvierten Physiksimulation helfen.

Dazu wird zunächst auf eine Reihe von Theorien eingegangen, von Simulation generell, von ihrer Beziehung zu Repräsentation und Realität und von ihrem Platz in Spielen. Darauf folgt ein Überblick über wichtige Charakteristika solcher Simulationen in Spielen. Übliche technische Prinzipien der Physiksimulation werden vorgestellt, Gründe für die Relevanz von physikalischen Gesetzen (oder einer Teilmenge davon) in vielen digitalen Spielen werden untersucht und Designprobleme werden diskutiert. Schließlich werden einige Spiele hinsichtlich der Rolle von Repräsentation und Simulation von Physik untersucht.

Table of Contents

Introduction

Still from a trailer on the official website of the game *Fracture* (www.lucasarts.com/games/fracture). The player has just used one of the terrain-transforming special weapons.

You are looking down on a muscular guy equipped with futuristic-looking armour and a soldier-style haircut, who is roaming a desolate landscape. At first glance, the trailer you are watching seems to depict a third-person shooter game, similar in style to the *Quake* or *Unreal* series. The next second, however, the protagonist throws a grenade at a flat, empty area in front of him – and what follows is certainly not what one would expect: The grenade does not simply burst in an explosion, it *raises a complete hill from the ground,* similar to the way in which a level designer would create a hill in a visual terrain editor. What was a flat field a second ago is now cover from enemy attacks.

The trailer you are watching is for the game *Fracture*, to be released for two major console platforms in 2008. Its central feature is that the player can choose from a number of weapons that directly manipulate the terrain. While such manipulations used to be limited to pushing crates around and destroying certain types of objects in shooter games, *Fracture* promises to enable manipulation of the ground the player walks on in unforeseen ways – through *physics simulation*.

Go back thirty-two years. Atari releases the arcade game *Breakout*. The player controls a paddle at the bottom of the screen and has to use it to keep bouncing a ball back to the top. There, several rows of bricks have to be cleared, i.e. they have to be hit with the ball. The bricks are the only elements that can be destroyed in the game and the only way the player can influence the ball is by deciding with which of the paddle's ends to hit it, for this determines the angle at which it is deflected. As simple as this is compared to the transformable environment in *Fracture*, the bouncing of the ball is, again, *physics simulation*.

What do the simulated laws of physics in both examples have in common? What is fundamentally different? In this paper the inner structure of phyics simulation, its relation to what it references and the design strategies that might be employed shall be examined. Some games will be analysed with respect to their way of representing laws of physics and integrating them into the play experience.

The paper is not intended to discuss advantages and disadvantages of various technologies used for physics simulation. Neither is it a philosophical investigation of such ambiguous terms as representation, abstraction, meaning and simulation. The possible interpretations and implications of these terms, however, have to be presented in order to gain a vocabulary to describe design strategies. Likewise, some technical issues are adressed to illustrate what is possible and what is commonly put into practice.

Chapter Outline

The central questions are:

- What is simulation, how can digital games be framed as simulations and how does simulation relate to other aspects of digital games?
- What are the characteristic goals, effects and fallacies in designing digital games involving some simulation of physics?
- How do these elements contribute to the play experience in existing games?

The text is divided into the following major parts:

- Chapter one, “Defining Simulation”, collects a basic vocabulary to talk about games and explores the meaning of simulation in general and in games.
- Chapter two, “Designing Physics”, discusses game design problems faced when framing games as simulations and specifically when incorporating simulated physics in games.
- Chapter three, “Playing Games”, looks at a number of games and examines the way in which physics simulation contributes to the game play.
- Finally, the main points will be summarised and possible applications of the insights gained pointed out.

Defining Simulation

> In any case, there is no escape from this race to the real and to realistic hallucination since, when an object is exactly like another, *it is not exactly like it, it is a bit more exact.* There is never similitude, any more than there is exactitude. What is exact is already too exact, what is exact is only what approaches the truth without trying.
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> -- Jean Baudrillard, "Holograms", in: *Simulacra and Simulation*

Simulation in games is usually associated with "simulation games" such as flight simulators or simulated cities. Most theoretical texts on games, however, agree that simulation is rather something that can be observed in all games, although the mentioned games do take a special place. So what is simulation? The concept is, of course, in no way limited to games. What, then, is specific to simulation in games?

In this chapter, definitions of core terms of all theory of digital games are given (or rather adopted, since a discussion is beyond the scope of it) in order to provide a theoretical foundation. After that, simulations are examined in their possible general meanings, followed by more specific observations about simulations in games and their relation to reality. The aim is to show similarities and differences in major theories on this topic and to gather knowledge on which the more design-oriented chapter to follow can build.

Defining Games

Compared to other forms of cultural expression, games have enjoyed surprisingly sparse coverage by scholars of arts and humanities. While the study of literature has its own academic branch in every possible language and even newer media such as film have claimed their place in the academic world, games, although they have a history older than that of literature, have hardly been studied, at least not with a focus on their structure and inner mechanics.

The spreading of the personal computer and, with it, that of digital games has resulted in a game industry larger than ever before. Digital games have become an essential part of the "multi-medial" culture which surrounds us. This has not only raised new questions concerning the causes and effects of playing (digital) games, but also a sudden interest in their design. Any comprehensive study of games and their design must first define its basic terms and categories, since, as has been mentioned, the field in which it operates is not a well-established field of research and lacks common ground.

One highly ambitious and successful attempt to analyse games, especially digital games, in their entirety (in order to gain insights as to what good game design practice should comprise) is *Rules of Play*[1] , written by game designers and scholars Katie Salen and Eric Zimmerman. Published for the first time in 2004, this effort has quickly become somewhat of a standard textbook in game design. This is why the definition of central terms such as "game" and "play" as used in the following text are taken directly from or built on the ones given in this book.

What constitutes a game? Salen and Zimmerman review a number of definitions, among them one given by Johan Huizinga in his essential work *Homo Ludens,* first published in 1938, in which he examines "Play" as the origin of culture:

> [Play is] a free activity standing quite consciously outside "ordinary" life as being "not serious", but at the same time absorbing the player intensely and utterly. It is an activity connected with no material interest, and no profit can be gained by it. It proceeds within its own proper boundaries of time and space according to fixed rules and in an orderly manner. It promotes the formation of social groupings, which tend to surround themselves with secrecy and to stress their difference from the common world by disguise or other means.
> (Huizinga, cited in RP, p. 75) [2]

An analysis of games that is more concerned with their inner structure than *Homo Ludens* is Roger Caillois' *Les jeux et les hommes*, first published in 1958. His definition, also reviewed by Salen and Zimmerman, is similar, but differs in some essential aspects, such as the uncertainty of the outcome of a game and its fictional character (see Caillois 1982, p. 16). In *Rules of Play*, these and other definitions of what a game is are all considered, but ultimately a new one is given:

> A *game* is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.
> (RP, p. 81)

By this definition, the various forms of "informal" play, where goal and rules do not necessarily exist, are excluded. Note also that the fictonal aspect explicitly claimed by Caillois is not part of the definition.

An important term introduced in *Rules of Play* is the "magic circle" (RP, p. 93ff), inspired by what has been translated to "Zauberkreis" in the german edition of Huizinga's *Homo*

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[1] *Rules of Play* is subsequently cited as "RP".

[2] The according passage in the German translation of the text cited by Salen and Zimmerman can be found in Huizinga 2006, p. 22.

Ludens. There, this term is mentioned when the author explains the special place within which games take place (Huizinga 2006, p. 18) and later compared to similar special places created by "sacred" rituals. Salen and Zimmerman essentially adopt this, and their "magic circle" as a separate place (and time, both possibly in an abstract way) where special rules apply becomes a central concept in their further explanations.

Another idea central to *Rules of Play* is that for a game to be fun, it must involve "meaningful play":

> *Meaningful play* occurs when the relationships between actions and outcomes in a game
> are both *discernable* and *integrated* into the larger context of the game.
> (RP, p. 34)

Discernable means that a player‘s action must be perceivably communicated, integrated means that it affects the play experience later in the game.

Salen and Zimmerman frame games within three "schemas": "Rules", "Play" and "Culture". The first schema, "Rules", examines the logical inner structure of games as closed systems and the various kinds of rules related to it. "Culture" places games in a larger context and regards them as open systems interacting with a larger cultural environment. The "Play" schema regards games either as open or closed systems and is the "experiential" analysis of playing games. The authors' general definition of play is the following:

> Play is free movement within a more rigid structure.
> (RP, p. 304).

Within the schema of Play, the authors look at games from various perspectives, among them some that directly address the problem of representation in and by games. These chapters, especially "Games as The Play of Meaning" (RP, p. 364ff) and "Games as the Play of Simulation" (RP, p. 421ff), shall be reviewed and related to other concepts in the following sections.

Meaning and Representation in Games

In the introductory chapters of *Rules of Play,* Salen and Zimmerman quickly review the basics of semiotics (referring, among others, to Peirce and Saussure) to establish the following:

> 1. A sign represents something other than itself.
> 2. Signs are interpreted.
> 3. Meaning results when a sign is interpreted.
> 4. Context shapes interpretation.
>
> (RP, p. 43)

The authors bring examples of games such as Tic-Tac-Toe, where the signs "X" and "O" represent the player's actions and the capturing of the grid's squares. Another important claim shall be added, stated by semiologist Umberto Eco:

> [...] daß das Zeichen nicht die Totalität des Gegenstandes repräsentiert, sondern ihn - vermittels unterschiedlicher Abstraktionen - *nur von einem bestimmten Gesichtspunkt aus* oder *im Hinblick auf einen bestimmten praktischen Zweck* vertritt.
> (Eco 1977, p. 31)

> [...] that the sign does not represent the totality of the object but that it represents the object – by means of various abstractions – only from a certain point of view or to a specific end.
> (Ibid., my translation)

Here, the concept of abstraction is introduced. Abstraction is essential for all forms of representation and simulation, since the referents - in the basic semiotic triangle as reviewed by Eco (Ibid., p. 28) - can never be represented in their "entirety".

When they examine games as the "Play of Meaning" (RP, p. 364ff), Salen and Zimmerman identify two kinds of representation:

> First, games can represent.
> Second, games are representations.
> (RP, p. 364)

Although these attributes depend on each other, they are of different qualities. Both, however, are constituted by: 1. a system of meaning that consists of defined relationships between representations and 2. the play context, from which a "vast space of representational possibility" (RP, p. 365) emerges. This is based on two other concepts examined earlier in the book: Emergence, the manifestation of complexity in a system of possibly quite simple rules (see RP, p. 158ff), and a general definition of "play" as given above.

Approaches to Simulation

Before dealing with the simulation of physics in digital games a definition of simulation in general should first be established - and then especially in the context of games. Here, a survey of possible definitions shall be presented while avoiding epistemological implications.

Starting with the etymology of the word, it can be observed that traditionally, "to simulate" means to deceive. The entry for "Simulation" in the dictionary *Ästhetische Grundbegriffe. Historisches Wörterbuch in sieben Bänden*[3] (indirectly) cites Thomas Aquinas, who "asserit: Simulationem esse, cum quis per exteriora signa factorum, vel rerum significat contrarium eius, quod credit"[4] (ÄG, p. 512). It is further pointed out that the term dissimulation is somewhat complementary: simulo means "affirmo id quod non est"[5] whereas dissimulo means "nego id quod est"[6].

This meaning of simulation is linked with the notion of "mimesis", imitation in a system of a clear dichotomy of original and copy. This link has only been broken in the 20th century, the age that Jean Baudrillard calls "l'ere de la simulation" (ÄG, p. 515). The "mimetic" meaning of simulation was connected to the Platonic criticism of images (as according to this point of view, they are mere copies striving to be like the original); this meaning has changed, mainly due to the rise of computer technology, but the connection with the old one can be clearly seen: A simulator is now a mechanism with the achievement of the same result as the only analogy to the given mechanism (ÄG, p. 516), simulation is the "process of representing the dynamic behavior of one system by the behavior of another system" (ÄG, p. 516), the "resemblance in behavior of systems without identity of the inner systems" (ÄG, p. 518).

Simulation is further a term central to theories of "postmodern" theorists such as Jean Baudrillard, who frames our whole culture as a system of simulation. It entails an invertion of the platonism which means "denier le primat d'un original sur la copie, d'un modèle sur l'image" (Deleuze, cited in ÄG, p. 523) and finally leads to a "liquidation of all referentials" and their "artificial resurrection in the system of signs" (Baudrillard 1994, p. 2). While these theories are certainly related to simulation in games and other digital media, they cannot be considered in detail in the scope of this paper. Nonetheless, a short summary of some of Baudrillard's concepts shall be cited:

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[3] *Ästhetische Grundbegriffe. Historisches Wörterbuch in sieben Bänden* is subsequently cited as "ÄG".

[4] "[he] claims: It is simulation if someone signifies with the outer signs of deeds or things the contrary of what they believe." (my translation)

[5] "to confirm what is not" (my translation)

[6] "to deny what is" (my translation)

> In his reading, such culture [of simulation] has three inter-related features. The first is that computer modelling can be used to design and 'crash-test' objects or ideas by running them through different imaginary scenarios, which in turn predict and perhaps shape events before they take place. The second is that reality is giving way to hyperreality – that which is more real than the real. Baudrillard, for example, talks of the 'hyperrealism of simulation', and suggests that technologies, in particular digital media, increasingly shape our capacity to know the world (including key events such as the Gulf War), and with this blur the boundaries between what is 'real' and what is virtual or mere 'appearance'. [...].
> (Gane 2006)

The first part is particularly noteworthy, although it is not in the least specific for Baudrillard's theory but rather points out the meaning of simulation for the sciences: Simulation is used to explore situations and infer predictions that could not be arrived at via analytical methods because of the sheer complexity of the simulated system. Although this is the purpose of non-game simulations, it has implications for the systemic character and the resulting possibilities of forming complexity; this will be addressed in chapter 3.

Regarding the second point, Baudrillard explains this as the process of "substituting the signs of the real for the real" and of "deterring every real process via its operational double, a programmatic, metastable, perfectly descriptive machine that offers all the signs of the real and short-circuits all its vicissitudes" (Baudrillard 1994). He further proposes that dissimulation as simple masking "leaves the principle of reality intact" (Ibid., p3). Simulation, however, may produce symptoms that are "true" and this production blurs the line between the real and the imaginary. This view of simulation bears some similarity to psychosomatic processes. Baudrillard claims that this concept of deterrence can (now probably amplified by the Turing Machine as a manifestation of the "perfectly descriptive machine") be extended to all areas (with grave consequences: "What if God himself can be simulated, [...] reduced to the signs that constitute faith?") (Ibid., p. 5).

Simulation is therefore also the function of sign processes which are not about representation or pretense of things external to them but in which this pretense itself replaces the things (ÄG, p. 509). These theories shall not be discussed any further here, but hopefully a hint at the large debate surrounding the term "simulation" has been given.

Simulation in Digital Media

Having outlined the possible meanings of simulation in a general context and explored representation in games, how is simulation related to representation? Lev Manovich, in his famous work *The Language of New Media,* examines the relationship between the screen as a medium for the visual display of information and the user. By analysing the relation of screen and body he arrives at the topic of virtual reality; he finds that the difference between VR (in a narrower sense) and the screen is rooted in the one between simulation and representation:

> The alternative tradition of which VR is a part can be found whenever the scale of a representation is the same as the scale of our human world so that the two spaces are continuous. This is the tradition of simulation rather than that of representation bound to a screen. The simulation tradition aims to blend virtual and physical space rather than to separate them.
> (Manovich 2001, p. 112)

Soon thereafter he explains that there is also a difference between this "simulation tradition" and VR: "In VR, either there is no connection between the two spaces (for instance, I am in a physical room while the virtual space is one of an underwater landscape) or, on the contrary, the two completely coincide (i.e., the Super Cockpit project). " (Ibid., p. 113) From this perspective, simulation has (analogously to the change of the mimetic tradition of the term illustrated above) transformed from a "simulo" ("affirmo id quod non est") linked to a certain physical environment to a "VR where the physical space is totally disregarded and all the 'real' actions take place in virtual space" (Ibid., p. 113) - a concept bearing remarkable similarity to Baudrillard's liquidation of referentials.

Manovich's description of simulation seems to imply that there is some principle of immersion or "suspension of disbelief" underlying the aims of simulations. This issue shall be returned to in a moment.

Simulation in Games

Having defined and examined the core terms "Simulation" and "Games", several concepts of how games can be or include simulations shall be given.

For the authors of *Rules of Play*, all games can be regarded as some kind of simulation; simulation is not something that is contained in a game or not, but rather a way of understanding games. They define simulation as "a procedural representation of aspects of 'reality'" (RP, 423). The procedurality is the central feature of the interaction between player and game: In a game, "reality" (the quotation marks are put there by the authors to avoid a clash with metaphysical debates) is not merely (or not at all) represented by, for example, visual abstractions, but centrally by the play possible within its rules.

A similar approach is taken by digital game theorist Gonzalo Frasca. In his article "Simulation 101" (2001), he points out the difference between viewing games as representations and viewing them as simulations. He argues that in simulations, rules are shown by (interactive) models, whereas in classical "representation", rules are narrated in one way or the other. He further points out that "because for an external observer, the outcome of a simulation is a narration" (Ibid., p. 2), digital games are often interpreted as narratives. This, however, has to be the wrong approach "because in many simulations, particularly in videogames, the player does not feel like she is being told a story by a narrator, but rather experiencing events as a personal experience“ (Ibid., p. 2).

For him, the difference between "narrative" representation and simulations is exemplified by the difference between the painting of a city and the game Sim City: "The key concept here is **behavioral rules**. Sim City is a dynamic system that *behaves* like a city and also has many characteristics of a city, while the painting [of a city] only provides the characteristics." (Ibid., p. 3) He also gives an interesting comment on the different uses in teaching and learning:

> Usually, narrative works in a bottom-up sequence: it describes a particular event from which we can generalize and infer rules (this is why narrative is used so much in education). On the other hand, simulation is usually top-down: it focusses on general rules, which then we can apply to particular cases (this is why simulation also works great as a tool for teaching complex rules because, unlike narrative, it allows **experimentation**). (Ibid., p. 3)

While the term "representation" appears to be used in a slightly different way by Frasca, his point is very close to the one made by Salen and Zimmerman: In simulations, the referents are not merely depicted (mimetically), but modelled through "procedural representation" or "behavioral rules". A depiction draws its dynamics from its relation to its referent (as a painting does), a procedural representation draws its dynamics from its possible interactions with the other procedural representations, forming an emergent system and leading to a complexity that is (hopefully) fun to play.

Consider a third analysis of computer games as simulations, given in Myers' *The Nature of Computer Games: Play as Semiosis* (2003) and founded in semiotics. According to him, simulations signify the the semiotic relationships (of signifieds and signifiers) in some other semiotic system. He thinks that there are two modes for simulations to do so:

First, through a denotative signification process, as in *Microsoft Flight Simulator*, which "is similar to that of an action game in all respects but its intended signified" (Ibid., p. 22). Myers argues that action games are constituted by first-order signs, usually determined in pre-existing visceral/sensory contexts, although initially they were often intended to simulate real-world processes; only over time would they dispose of the relationship to the signified outside and benefit play in doing so. This first kind of simulation procedurally signifies the semiotic "engine" of some other semiotic system; it *models* the other system. This procedural character is something the other definitions reviewed so far include as well.

The second type of simulation uses a contextual signification process generating semiotic systems similar to the one referenced. Connotation replaces denotation - the simulation *mimics,* rather than models, its signified (Ibid., p. 33). For the first kind, the "algorithmic simulation" *Microsoft Flight Simulator* serves as an example, for the second kind, the "experiential simulation", Myers mentions *Sim City* and similar games. This *mimicking* is related to the *mimesis* discussed earlier, I would argue, because it draws from the connotation rather than from a modelling of the behaviour.

Simulation and Reality

How is a simulation related to the "reality" it represents (procedurally), not in semiotic terms but in terms of player experience? According to *Rules of Play*, metacommunication guarantees that while the actions undertaken in a game represent the respective actions in "reality", they also represent the fact that they are not real, but only "played". This conscious partaking in an artificial conflict (which is part of the accepted definition of games) can be immersive. Immersiveness is often associated with the degree of "suspension of disbelief", and a highly accurate representation (of all kinds, visual as behavioral) of "reality" is commonly believed to heighten it. But this is identified by Salen and Zimmerman as "The Immersive Fallacy" (RP, p. 450). They argue that the immersiveness games should strive for is one of meaning, only possible by maintaining the layer of metacommunication. In this way, one can experience immersion with *Crysis* as much as with *Tetris*. Framed from another perspective, the relation between metacommunication and the magic circle of the game can be compared to the concepts of hypermediacy and immediacy introduced in *Remediation* by Bolter and Grusin

(1999): Immediacy is the principle underlying a "transparent" interface that "erases itself" (Ibid., p.24), hypermediacy the one exemplified in the multiple windows of today's operating systems, creating a interface to a heterogenous space of different media that does not attempt to "erase itself" at all. This duality is apparently as necessary for other forms of "new media" as it is for games.

A similar, very good point about realism in digital games is made in a very different way by Hanna Sommerseth (2007). She employs a phenomenological methodology to claim the following:

> Here I propose that Merleau-Ponty's notion of the bodysubject as an alternative to the Cartesian cogito provides a means for arguing that our experience of realism in video games is not tied to the perceptive process, understood as the passive reception of visual stimuli, but to the enactive process, to movement and bodily sensation.
> (Sommerseth 2007, p. 3)

"Movement and bodily sensation" does not imply that VR equipment is required for a realistic experience - this would only further feed the immersive fallacy. Rather, a simple joypad can become the extension of the player's body if it works properly: Heidegger (whose ideas are never far when phenomenology is mentioned) would say: A good game transforms the joypad from "vorhanden" to "zuhanden". Thus, "video games may be seen as a subset of the player's experienced reality." (Ibid., p. 4). Sommerseth's central point appears to be that realism depends on how much the results yielded by actions conform to the expectations the player has. Following this proposition, realism directly relates to the player's experience of control within the game. The expectations, however, are derived from a player's experience with "reality" (including other representations and games as well). Seth Giddings and Helen W. Kennedy (2006, p. 141f), looking at "Digital Games as New Media", come to the same conclusion about control as a central aspect for the quality of a game, but do not hold its effects responsible for the felt realism, but for immersion, which they relate to pyschologist Czikszentmihalyi's notion of "deep flow", a concept also taken into account in *Rules of Play* (see RP, p. 336ff). This experience of control is also recognised by Kücklich (2006, p. 109), who references Espen Aarseth's scheme of *aporia* and *epiphany,* the former constituting what has to be overcome to (re-)gain control, the latter the solution to this impediment, forming a dialectic process of struggle and pleasure. If the player was in control all the time, no pleasure could be derived from the game.

That this objection to the "immersive fallacy" is plausible is further confirmed by an anecdote cited in *Rules of Play* (RP, p. 448f), where a racing game prototype is described which simulated the experience of the real driving it referenced so accurately that only a real professional race driver could play it well. In this case, the simulation of the laws of physics were so precise that to properly drive the car would have required specialist tricks rather than common knowledge and experience with existing representations and driving games. The feeling of control was diminished and, following Sommerseth's reasoning, many players would neither have perceived this game to be particularly realistic nor would they have enjoyed it. This whole issue of "realism" is addressed again in a more design-related context in chapter two.

Staying on a more general level of simulation, the next question is: Framing games as a "play of simulation", which characteristics of the simulation make them fun to play?

Simulation between Rules and Fiction

To tackle this question, a look at one last concept of simulation in games shall be taken before the more concrete design aspects are approached. Jesper Juul (2007) argues that one can view games as having two complementary parts: rules and fiction. Games such as chess rely purely on rules, whereas the backstory of a game would be an example of pure fiction. Often, of course, rules are motivated by fiction and Juul (referencing Espen Aarseth) calls this area where the two parts overlap "*virtual* or *simulation*" (Ibid., p. 510). Here, this "virtual" system of the game relates, as established in the previous chapter, to "reality" with some degree of abstraction. Abstraction from what? The physical laws simulated in racing games or the social and economic processes simulated in "Sim City" provide abstractions so clear that these games are, depending on their accuracy, labelled "simulation games". Accepting Myers' definitions given above it could be said that one is rather "algorithmic" and one rather "experiential", but essentially they are understood as simulations. What does a game like "StarCraft" abstract from?Its world is wholly fictional. The processes simulated and abstracted from in StarCraft are processes resembling "real" ones (gathering resources, producing, developing new technologies, commanding military units), applied to the fictional world in which they are embedded in a way that is consistent with common sense. Myers locates the difference between strategy games and simulations in the lack of another semiotic process that is mimicked or modelled; no values are fixed prior to the play (Myers 2003, p. 41). Juul points out that the closer the fiction is to our "reality", the more easily we can deduct the inner mechanics of the rule system from the fiction. In "StarCraft", the fictional world is so unfamiliar to a player who does not have experience with similar games that they cannot approach the system intuitively - as they can, for example, in "Age of Empires", because the fiction that inspired the rules and the simulated processes in this case (ancient history) is well-known to most people. Juul (2007, p. 514): "The player must identify the genre and the fiction, and then begin to explore the abstraction of the game". This theory is picked up again in the next chapter when the systemic character of simulations and its relation to fiction and narrative are outlined.

Summary

In this chapter, a very brief overview of theories of games and play was given, mostly in accordance with *Rules of Play*. It was argued that a game can be viewed as a play of meaning, a system of representations that forms a representation itself. A game can also be framed as a play of simulation, where simulation represents some "reality" by means of procedural or behavioral rules that can cause complexity to emerge from the system of their relationships. Since we know that all representations abstract from what they represent and that simulation is a form of representation we conclude that rules underlying a simulation are abstractions, too, and that the way the rules are discovered by the player depend on the player's experience with the part of a simulation not constituted by rules, identified by Jesper Juul as fiction. The "immersive fallacy" was explained as the belief that realism or immersion in games is an effect of the degree of "suspension of disbelief". This is only true to a certain extent, for the main factor on which realism or immersion depends is our feeling of control or of consistency in the play of meaning; this is only possible if we maintain a layer of metacommunication (or hypermediacy) on which we constantly signify that we are within the game's magic circle.

Taking into account the various ways one can talk about simulation, the next chapter shall highlight game design issues related to simulation and, specifically, physics simulation.

Designing Physics

> Sims are not people. They are images. [...] But even though the images are meaningless, the algorithm still functions. It assigns, if not meaning, if not veracity, if not necessity, then at least a score to representations.
>
> -- McKenzie Wark on *The Sims*, in: *Gamer Theory*

In the previous chapter, general aspects of games and play, meaning, representation, abstraction, simulation and immersion were discussed. Now it shall be attempted to create the basis for “formal abstract design tools”, a term proposed by Church (1999), from these observations. These tools should help analyse aspects of certain games and articulate descriptions applicable to a large range of heterogenous games. After that, some common practices in simulating physics in games are outlined and finally the question why physics simulation is such a central element of so many games is adressed.

In their chapter on simulation, Salen and Zimmerman outline central guidelines for designing the simulation aspects of games (see RP, p. 439f), which shall be used as points of reference to take a look at some design problems.

Simulations are Abstractions

Simulations are necessarily abstract. But what do they abstract from and how much? Abstract too much and the player will not understand the game, as seen in Juul’s example of a game representing psychological conflicts in a marriage by geometric shapes (Juul 2007, p. 512). Abstract too little and you will strive to model reality so accurately that all play is lost, as seen in the example of the too “realistic” driving simulation given in the previous chapter. Abstract in obscure ways and the player will not be able to grasp the rules because they appear to contradict what Juul identifies as fiction. The amount and the ways to abstract are a matter of balance.

But which processes should the game designer choose to abstract from in the first place? In his book *Half-Real: Video Games between Real Rules and Fictional Worlds*, Jesper Juul likens this abstraction to the one found in comics and calls such simulations “*stylized simulations*”: “The simulation is oriented toward the perceived interesting aspects of soccer, tennis, or being a criminal in a contemporary city.” (Juul 2005, p. 172). Chris Crawford highlights this (and also reminds us of the fundamental difference between game and non-game simulations) in his book *The Art of Computer Game Design,* first published in 1982:

> The simulations designer simplifies reluctantly and only as a concession to material and intellectual limitations. The game designer simplifies deliberately in order to focus the player's attention on those factors the designer judges to be important.
> (Crawford 1982)

Salen and Zimmerman find that due to their definition of games containing the element of "artificial conflict", this element must also be central to simulations. They further distinguish between general types of conflict commonly simulated (and therefore abstracted from): Territorial conflict, economic conflict (in its broadest sense of some "value") and conflict over knowledge (which is strongly tied to the cultural environment outside the magic circle) but do not exclude the possibility of other conflicts being modelled (RP, p. 431).

Simulations are Systems

Complexity can emerge from comparatively simple, clear, abstracted rules as they interrelate. "An apparent paradox is that chaos is deterministic, generated by fixed rules which do not themselves involve any elements of change" (Peitgen et al. 2004, p. 11). Chaos (random games) is undesirable, as is its opposite, complete predictability (tic-tac-toe played by adults), but complexity, located on the border of chaos and also creatable by such fixed rules, is necessary in some aspects of a game to create meaningful play, as explained in the chapter on "Games as Emergent Systems" in *Rules of Play* (RP, p. 154ff). Where the non-game computer simulation of complex systems is used to gain empiric evidence of relations on which future predictions to be used for scientific or economic purposes can be based, simulation of complex systems makes games interesting because it is the player who has to constantly form and revise their predictions, which they can then put to economical use, that is in the economy in which the goal is to win the game.

The simulation system is essential - the referents in "reality" from which the abstractions were made or which inspired the fiction are far less important than the way the system works.[7] This point shall be given some consideration because it touches the concept of fiction and narrative in games. Jesper Juul's definition of simulation and abstraction achieves something essential in showing that the simulation aspect of games abstracts from "reality" and that the nature of these abstractions has to be explored by the player in order to gain control over the game. Control, as discussed earlier, is directly related to quality characteristics

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[7] Some relation of this to the postmodern theories presented earlier is apparent, although the implications for culture as a whole are not of concern to this text.

such as realism, immersion or “deep flow”. By giving the player control over certain mechanisms within a simulation, their actions become meaningful. Just how important the fictional part remains depends on the game. Juul points out that players of some games may, as they get better, reduce the information provided by the game fiction (e.g. by turning down the graphics level of detail in a first-person shooter) and successively ignore the fiction in order to be able to focus on the rules (Juul 2007, p. 513). If they do so, they forget about the meaning of the simulation as a whole and concentrate on its internals. In *Quake III Arena*, of course, this might be more common - and more intrinsic to the game - than in an adventure game. But no matter what type of game, “the player is aware that it is optional to imagine the fictional world of the game” (Juul 2005, p. 141). This possible disposal of the fiction does not mean that narrative elements are reduced to the same extent as the systemic character of a simulation grows in importance. First of all, narrative is hard to define but if we accept the (still somewhat fuzzy) notion of narrative used in *Rules of Play,* it can also be generated by the “dramatic” order of events in a chess game (although Salen and Zimmerman use the example of a basketball game) - so narrative is not the same as ficton, although the concepts are related. Furthermore, narrative can be tightly interwoven with what Salen and Zimmerman call “procedural character”, the modelling of elements so that narrative can emerge from the interaction of elements within the simulation system - they use the behavioural simulation of Deus Ex non-player characters as a prime example (RP, p. 435ff).

A different point of view is offered by McKenzie Wark in *Gamer Theory,* an ambitious, if rather theoretical, attempt to generate ideas about the meaning of gaming. During his observations regarding the abstract “rail-shooter” *Rez* he remarks:

> The storyline is the gamer’s alibi. [...] You are not in the topographic space where storyline opens a moral flaw between self and other, us and them, good and evil. You are in an amoral space where lines merge and converge everywhere [...] A storyline is the bad faith of the game. Read it as if it were a novel or a movie and it seems ridiculous. [...] Games are not morality tales. But their storyline can be read as allegories. The storyline provides a key to the relation between the effective enclosure of signs within the game as a system of values and the ineffective enclosure of signs within gamespace [the outside of the game], caught between values and meanings.
> (Wark 2007, p. 142)

This does not outright contradict Juul’s observations, but forces, again, to think of digital games as something very different to other forms of media. There is no place to further investigate these matters here, especially since narrative and fiction in games has been subject to much discussion, but it can be concluded that for many digital games, there is an intricate connection between “reality” and the game’s play of simulation through fiction, and that the systemic character of simulation is what remains even if all fiction is subtracted.

Simulations are Numerical / Simulations are Limited

For rules to work unambiguously (something that is demanded for any game in *Rules of Play*), a numerical representation in the game medium is necessary. In the case of digital games, the numerical quality is inherent to the medium anyway. Thus, processes calculable (to some extent) in reality are easier to simulate than those that are not: It is, with all technical complexity, much easier to simulate the laws of physics than to simulate emotions and social relationships.

Since simulations are abstractions and have to be represented numerically, they are naturally limited. This, however, enables meaningful play rather than hindering it; for a game, we need a limited set of unambiguous rules forming a system from which the right amount of complexity can emerge. Unlimited simulation would introduce the ambiguity of reality into the game. Radically spoken from within the magic circle: “The world outside [of the game] is a gamespace that appears as an imperfect form of the computer game” (Wark 2007, p. 22).

Another important distinction made in *Rules of Play* is that between emulation and simulation (RP, p. 446f). Although this dichotomy only works with a narrower concept of simulation (the generalised design approach) it is useful to consider. Emulation, in this context, is a simple cause-effect relation of certain game elements, such as switches that open a door when touched. Emulation is necessary because simulations are limited and a balancing between these two modes of relating player action to game effects is necessary exactly for the same reasons for which the inherent limitation of simulations benefits the play.

Physics Simulation

The features and design implications of simulations also apply to physics simulations, but there are several other aspects to be considered as well in this case. As mentioned before, physics can (in theory) be simulated far more accurately than many other aspects of reality: Numerical and thus mathematical representation is possible because mathematics is the method by which the science of physics operates, whereas psychology, for example, must largely rely on other methods. In practice, a simulation of a substantial subset of the laws of physics has only become possible in recent years with the improvement of processor power, since the CPU is where physics simulations in games are most commonly calculated, although this might change in the near future.

Before it is attempted to apply the concepts established so far to physics simulation in concrete games, a brief overview of what can be subsumed as physics simulation shall be given. The first step is to exclude what could be, but is not regarded as physics simulation: The graphics of a game. Optics is a sub-discipline of physics and the simulation of light and shadow, of rough and smooth surfaces as found in today's 3D-games is commonly addressed as real-time graphics rather than physics simulation, although, for example, shaders often calculate the way light is reflected according to simplified models of the laws of optics. Acoustics are excluded as well, as are all more advanced topics. When we say physics simulation we usually mean the simulation of classical mechanics.

This distinction is also mentioned by Millington (2007, p. 2) in his book *Game Physics Engine Development*. He gives a short introduction to physics engines in games and points out that the development of separate specialised code for each needed effect has been replaced by a generalised approach resulting in physics engines. These engines can be commercial or not and vary in what they simulate, but the basic concept is that bodies are represented in the physics engine in certain ways and the engine provides methods to apply forces that yield results according to internally simulated laws of mechanics. The game designers and game developers have to provide properties for the objects they want to be part of the simulation. The advantages of a physics engine over developing the various processes separately are reusability and consistent quality in the interaction of multiple processes. These benefits are usually weighed against the increased hardware demands and the integration effort.

Set Lasers to Fun

But why simulate physics in a game in the first place? How does that contribute to the fun, or, as Salen and Zimmerman would put it, to meaningful play? Steven Poole confirms what we know about the possibilities of simulation: “Physical modeling [...] synthesizes movement from the inside, from the interaction of fundamental parts, and so allows a theoretically infinite range of character movement.” (Poole 2000, p. 91) Physics simulation allows complex interaction to emerge from simple, fundamental rules representing the laws of physics. But why is the play with this kind of simulation particularly fun, how can it generate the right amount of challenge? Poole proposes the following reason:

> We are used to handling objects with mass, bounce and velocity in the real world, and we can predict their everyday interactions pretty well. [...] Appreciation of dynamic properties is hard-wired into the species—it's essential for survival. This, then, is one of the most basic ways in which videogames speak to us as the real world does, directly to the visceral, animal brain— even as they tease the higher imagination by building a universe that could never exist.
> (Poole 2000, p. 92f)

Poole relates the fun in physics simulation to our daily navigation through a dynamic three-dimensional space governed by the laws of physics. But why is this, a necessity in real life, fun when simulated? We remember: Simulaton is procedural representation with a certain level of abstraction. The play of simulation is the free movement within more rigid, clearly defined rules constructed by the simulation. Fun emerges from participating in an artificial conflict that takes place within this structure, knowing (through metacommunication) that it is just a game and knowing that the rules are clear and fair for everyone. This means: Our skills in mastering the laws of physics in real life and of adapting to new and unforeseen circumstances as well as in developing stategies to perform better than our opponents can be playfully tested in the fair environment of the game. Apart from that, it should also be noted that the term "visceral", attributed to our interaction with simulated physics by Poole, is also described as characteristic for action games or "algorithmic" / denotative simulations by Myers (2003, p. 10 and p. 32) – this indicates that some games involve this "visceral" part more than others.

There is more to the compelling character of physics-centered games: At the end of the quotation above, Poole says that games "tease the imagination by building a universe that could never exist." In the chapter the quoation is taken from, he generally argues that "unrealistic" properties are essential to any simulation of physics. This appears contradictory at first glance, but fits well with the balancing of rules and fiction, of "realism" and limitations, of simulation and emulation demanded earlier. As Poole puts it, if the lasers in spaceship fighting games behaved like real lasers, the challenge of predicting the enemy's movement would be lost. After all, "[w]e don't want absolutely real situations in videogames. We can get that at home." (Poole 2000, p. 93f). This is why the most accurate flight simulator can, although it already abstracts a great deal from reality, hardly be called a game, whereas *Wipeout* can. The necessary "unrealism" is, for example, subtly present in the tuned physics of first-person shooters. Millington reports a common practice in designing games based on 3D physics:

> Games are intended to be more exciting than the real world: things happen more quickly and at a higher intensity. Creating simulations with a g [= gravity] value of 10 m/s^2 can look dull and insipid. Most developers use higher values, from around 15 m/s^2 for shooters (to avoid projectiles being accelerated into the ground too quickly) to 20 m/s^2, which is typical of driving games.
> (Millington 2007, p. 50)

Other measures undertaken in such a game to keep using a "realistic" physics engine while modelling the mechanics in a way that benefits game play might include a radical tuning of the properties of the projectiles fired by the player so that they travel more slowly, but with the same impact and the same course as if they had properties more akin to those of their "real" counterparts. Such a case is examined in the next chapter.

The previously addressed "playful testing" of the player's skills fits well with this take on "unrealism". In *A Theory of Fun for Game Design,* Raph Koster argues that games have always been a chance to practice certain competencies one might need in real life and also explains why the "unrealism" mentioned by Poole is so prevalent in games - because it adds an unexplored space, a new environment to which we must adapt, like we often encounter new situations we have to adapt to in our life: "Exploring conceptual spaces is critical to our success in life. [...] We also need to understand how it [the conceptual space] will react to change to exercise power over it" (Koster 2004, p. 56). This insight is shared by many other game theorists.

Ninja Worms

Following the considerations just taken, I propose that games "realistically" simulating a certain subset of real physics (tuned to a pace that feels appropriate for a game) but bending these and introducing "impossible" mechanics in some places can generate systems that, in addition to the conflict aspect, also provide space for experimentation. These games may prove very popular, because this experimentation not only creates potential for developing custom strategies (among them many unforeseen by the game designers) but also enables informal play within the game system.

A good example for this is the "ninja rope" tool in *Worms Armageddon*, a game very much based on abstracted physics. In this game, players compete against each other or AI-controlled opponents. Each player controls a team of anthropomorphic worms in a destructible cartoonish 2D-landscape and strives to destroy all opponents' worms. Turn after turn, each player has a certain amount of time to act with one of their worms: They can move, jump, use tools such as a parachute or attack once per turn with one of a large number of collectible and restockable weapons, often projectiles affected by wind and gravity so that the players must carefully choose the strength with which they fire them. This way of centering game play around simulated physics is a good example of the theories proposed in the last section on its own, but there is a particularly interesting element included in the game: One of the tools for movement is the ninja rope which a worm can fire to any robust part of the landscape to swing from one place to another. The player will typically fire the rope, swing back and forth and when the worm has gathered enough momentum they will let go of the rope to catapult the worm to the desired place. However, the rope can also be fired again when the worm is still in the air - and again after the next swing-and-release. In this way, with some practice it is possible to quickly navigate to improbable places if the terrain allows it (essentially if there is some kind of ceiling). Not only does this add a whole range of strategies to prevail in the game's artificial conflict, it is arguably also fun in and by itself, comparable to the irrational pleasure achievable by, for example, juggling – it allows informal play within the larger conflict. While the ninja rope simulates the way such a tool could work in "reality", it is quite clear that even if the actor wasn't a worm the movements possible in the game would never be possible in "reality". This impossibility of the rope's mechanics in "reality" also open up room for discovery; what is important here is that some mechanics we infer from what we know from "reality" should also apply within this "impossible" system, for if they do not, its rules will appear arbitrary to the player.

The player knows all of this, of course, but this enhances the play rather than impairing it. What would disrupt the experience, however, is internal inconsistency. Poole points out that the very free interpretation of the laws of nature is hardly a problem, but he identifies three kinds of critical internal incoherence that can negatively influence the felt realism (notice the lacking quotation marks, this is not what the "immersive fallacy" suggests it to be): Incoherence in causality (e.g. rockets that cannot destroy simple wooden doors), in function (e.g. items usable only in one situation while there are countless others where they could also reasonably be applied) and spatial management (e.g. items that cannot simply be dropped on the floor) (see Poole 2000, p. 95ff). Maintaining such coherence throughout is hard - a design strategy could be to skip it where there is no reason the player could logically expect it. This logic, however, does not follow the logic of "reality" but might be quite different; we accept, for example, that Mario has three lives in *Donkey Kong*, as pointed out by Juul (2005, p. 141) while explaining the concept of "*Incoherent Worlds",* fictional worlds the gaps of which we cannot easily fill. This does not strike us as incoherent, though, since we accept this as a necessary part of the rules.

Summary

Rules and fiction create a simulation. Players infer the rules from the “rules” underlying the processes related to what the fiction refers to. Games can manage with minimal fiction, but not without rules. Those aspects of reality that could become interesting when formalised through rules are abstracted to form stylised simulations; one example is the abstraction of different types of conflict. Fictional worlds can be coherent or incoherent; incoherence can sometimes be accepted as part of the rules, sometimes it disrupts the play experience.

Simulations form systems from which complexity can emerge; this is required for meaningful play and possible immersion. The rules are represented numerically, they are limited and unambiguous. To maintain this unambiguity, “accurate” simulation is balanced against “emulation”.

Physics simulation almost exclusively means simulation of classical mechanics. The simulation of certain effects of physics has been complemented by generalised systems such as physics engines. One of the reasons why physics contribute to the fun in games is that the environment in which the player moves everyday is abstracted, structured by fair rules and enhanced with unrealistic elements in the simulation and the player can compete against other players (or the game “itself”) within this structure. The unrealistic elements balance the challenge and add space for exploring strategies for adaptation to and mastery of unforeseen circumstances; they might also allow experimental, informal play.

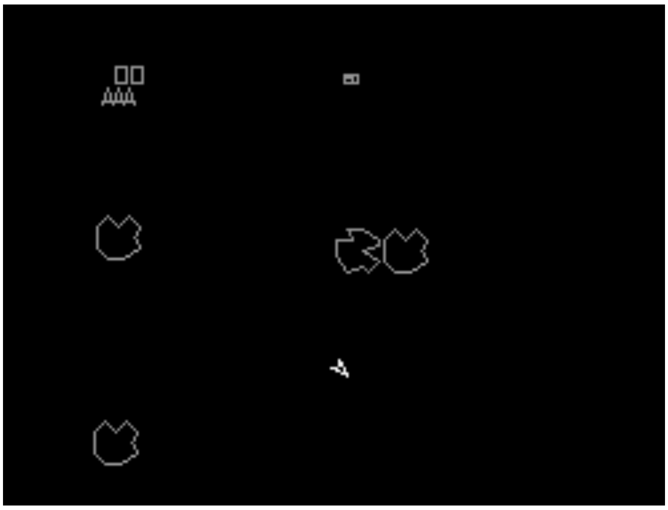
Playing Games

> Fun from games arises out of mastery. It arises out of comprehension. It is the act of solving puzzles that makes games fun.
>
> In other words, with games, learning is the drug.
>
> -- Raph Koster, *A Theory of Fun for Game Design*

So far, games, simulation and physics simulation have been defined and discussed and important design aspects adressed. Now a number of games shall be examined and hopefully common design strategies and differences can be found. The main focus is the place that the physics simulation takes in relation to the whole of the game.

Abstract Asteroids

In *Asteroids*, the "reality" the game refers to is a spaceship flying through fields of asteroids, occasionally encountering enemy spaceships. The player steers the spaceship through a two-dimensional space with a toroid topology, i.e. if the ship (or an asteroid) crosses any screen boundary it appears on the corresponding opposite edge at the same point, keeping speed and orientation as if the facing edges were glued together (if the plane was embedded in a three-dimensional space and bent accordingly). This mapping enables infinite movement in any direction (as long as no obstacles are encountered) and thus abstracts from the (supposed) spatial infinity of the "real" three-dimensional space of the universe. The difference, however, is that while we are not certain about the "shape" of the universe, the shape of the world of Asteroids can be easily imagined, as mentioned above. The therefore possible infinite movement of the player's spaceship forms the core of the simulated physics in the game: The player can essentially only accelerate and turn the ship and shoot. Since, as in "real" outer space, there is no drag or friction, the challange for the player is to predict the effects of the cumulative forces exerted on the ship in order to steer it where desired while turning and shooting in the direction the ship is currently facing (but not necessarily moving) to destroy the obstacles. The asteroids shatter into four smaller pieces when hit; this is another abstraction of how we would imagine "real" asteroids to behave under fire. Not only does it simulate a shattering body - albeit in a radically simplified manner -, it also adds the strategical



Asteroids. The player's ship is represented by the white arrow, the large outlined shapes are the asteroids.

challenge of constantly deciding whether the multiplied danger of four smaller obstacles instead of one larger one is temporarily accepatble in the player's current situation in order to be able to completely eliminate the asteroid in the near future (thus, the player's actions are discernable and integrated, as demanded in *Rules of Play* (RP, p. 34f)). In addition to the asteroids, the player also faces the danger of enemy spaceships attacking. Here, the simulation of the simplest conflict imaginable appears clearly: Shoot the enemy or be shot. The remarkable thing about this is that the simulated physics of the rest of the game are somewhat suspended in this case: The enemy spaceship does not shatter when shot, it cannot move beyond the screen edges and it does not seem to navigate in the same way as the player or the asteroids. Here the effect of balancing simulation against what was called emulation is apparent: The game designers seem to have decided that an exclusion of this certain aspect from the system of simulated physics would benefit the play experience. Of course this was the core concern. Myers compares Asteroids to its probably even more famous predecessor *Spacewar*:

> The realistic ship movement of *Spacewar* [...] was streamlined and redesigned in *Asteroids* to take advantage of higher resolution display. The result, however, was not a more realistic representation of movement in space; rather, the more sophisticated displays used chunky, cartoonlike symbols that were more easily discerned and manipulated by human players.
> (Myers 2003, p. 5)

It is, however, easy to imagine a variation in which the AI-controlled enemy struggles with the navigation in the same way the player does or one in which the their ship explodes and destroys nearby asteroids when hit.

Another feature not mentioned yet is the “hyperspace” action: When a special button is pressed, the player’s ship’s position is randomly reset to an arbitraty point on the screen. Concerning the core meachanics of the game, this adds an additional option of risk to the game. Salen/Zimmerman (RP, p. 189): “A **risk** is an outcome with a known probability of happening.” “Known” here means that the player can roughly estimate the probability to be reset to a position that leads to immediate destruction and can weigh this against the imminent danger faced in the current position. In terms of simulated physics, this feature can be regarded as a very free abstraction from what is still not entirely known to physicists. This unknown, this potential, is exactly what most science fiction draws its power from and can become an interesting design device. It is also a part of the experimental play and joy of discovery.

On the whole, Asteroids uses a minimal fictional universe (you control a spaceship in outer space - survive as long as possible) and radically abstracts those features of the mechanics that would or could apply in this setting if it were real to their essence, which is largely constituted by the fundamental difference to our immediate surroundings: No friction, no boundaries. In this case, the laws of physics and the way the player must interact with the simulated environment via simple controls is a major part of the challenge of the game.

Mushroom Physics

This is also true for one of the oldest and most important genres in the history of digital games: Jump’n’Runs. In *Asteroids* the basic play of inertia and applicable forces in a space, wheregravity is abstracted away because it is neglectible in the reality referenced, constituted the movement of the object controllable by the player. In *Super Mario Bros.* it is a comical abstraction of the human movement on a globe that exerts gravitational force on all objects. Again, the space is reduced to two dimensions but it is no more infinite and the movement of the player-controllable subject (Mario) is not simulated by a rigid body on which a force can be applied by pressing a button. Instead, Mario’s body is something that produces force by itself, it is the player’s task to act as Mario’s brain rather than an invisible power applying forces to his body. This is a different kind of play within simulated physics and we would probably expect it to be rather close to how we move our own bodies. But it is not. As discussed in the last chapter, we would not want a Mario restricted to moves that we can perform in real life. In fact, the very genre of jump’n’runs is built on exagerrations: Mario can jump higher than multiple times his own height, he can, to a certain extent, change the direction of his jump mid-air and he can run blazingly fast. Yet somehow these loosely interpreted physics projected on a plane appear coherent and consistent with the whole game. Why? Perhaps because Mario’s world is strange in other ways too: The task given to an italian plumber of rescuing a

Super Mario Bros. Here it would be possible to jump and steer Mario to the left while still in the air, in order to land on the platform.

princess from the claws of an evil anthropomorphic turtle by defeating evil mushrooms (by jumping on their heads) and collecting good ones already makes us suspect that the game mechanics are probably inspired by a very unusual fictional framework. The whole thing reminds us of Disney or Warner comics that are ever-present in our culture so that certain abstractions and exaggerations are already familiar to us. If the game was set in a more realistic environment, we might not tolerate the deviations from “real” physics as easily. The main reason why we accept the deviated physics is the plausibility and consistency of the core mechanics within the fictional universe. The high jumps and the turning in mid-air might be accepted as part of the comic environment. Other laws of physics, however, are simulated in an essentially correct way: When the player decides to stop running, inertia carries Mario a couple of steps further; if the player presses “B” while moving (signifying running mode) and then presses “A” to jump, Mario jumps higher and further, just like in “reality” one can jump higher and further when running. This concept has been taken further in *Super Mario Bros. 3*, where under certain circumstances Mario can take off and fly when the “speed meter” is full. Altogether, a plausible system is created; technically, however, most of the game’s effects can probably be classified as emulation rather than simulation. True contingency, true complexity and unforeseen activities within Mario’s universe are impossible.

Coherent Rocket-Jumps

The approach to physics simulation underlying most first-person shooters is somewhat different: The space is now three-dimensional, the player looks through the eyes of the characer they control and depending on the setting the relation to real-life physics is closer. In order to create games instead of simulators, the physics are tuned: As mentioned in the last chapter, the speed at which the characters move is high, as is their jump height, although the gravity is probably increased as well. In *Quake III Arena*, the rockets you fire with your rocket launcher are ridiculously slow, so that the rocket launcher, while highly damaging, requires you to predict the enemy's movement - the Railgun, on the other hand, hits instantly, but must be aimed precisely (because it lacks "splash" damage) and reloads slowly. The measures taken to create a "rock-paper-scissors"-like balance impose restrictions on the physics simulation. If the rockets travel slowly, the law that gravity exerts an equal force on all objects must be broken to prevent them from falling to the ground after a short distance. If the rockets' damage was modelled via a closed physics engine as well, their mass property would have to be increased enormously to keep the energy (= damage) product in the equation "energy = mass × speed^2" high enough with a lowered speed (these relations are explained by Millington 2007, p. 56f). With all restrictions, the simulated physics form a complete layer where in *Super Mario Bros.* only the central characteristics were simulated. The coherence of this system is illustrated by Poole:

> [...] Quake III incorporates the hilarious but highly coherent idea of "rocketjumping." You've got a rocket-launcher. If you point it at the floor and then fire as you jump, you'll be catapulted much higher into the air by the recoil of your foolishly potent weapon. Eminently reasonable.
> (Poole 2000, p. 96)

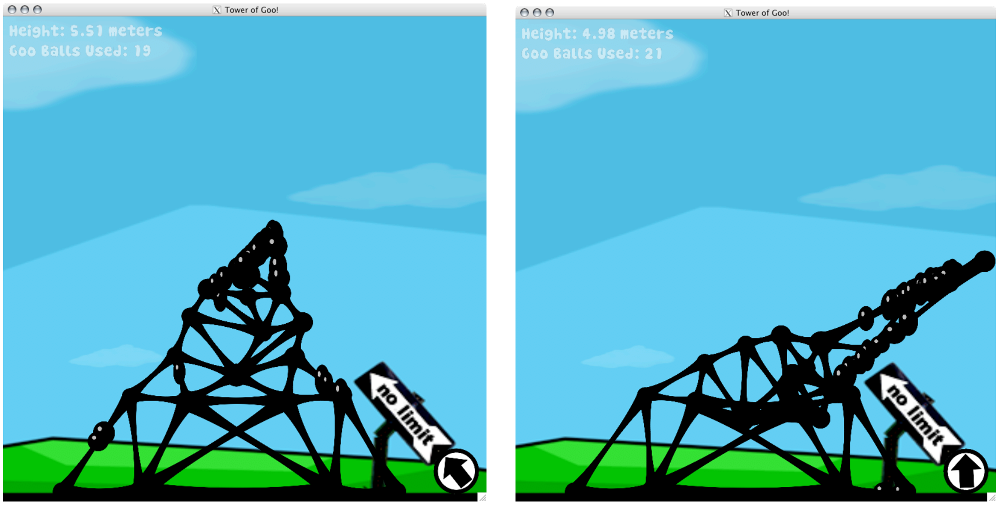
Crucial to his point is that, although blatantly "unrealistic", this is something that makes sense within the game because it fits, for example, with the fact that a direct hit by a rocket launcher in *Quake III Arena* does not kill a player at full health and that a rocket launcher causes "splash damage". It is hardly possible to give precise guidelines of which features are accepted as coherent and which ones disrupt this coherence, but by analysing specific games with respect to this problem at least the concept should become clear.

Quake III Arena. Firing a rocket at the own feet and pressing the jump button at the same time results in a particularly high jump.

Working with Myers' dichotomy of simulations (Myers 2003, p. 31ff), *Quake III Arena* is also a good example of the different kinds of simulations that work together to form a whole: While the physics simulation is arguably a model of "real" physics and the movement within this environment is structured by a semiosis of denotative signs (and oppositional character), the simulated conflict between the opposing teams (in team deathmatch or capture the flag modes), that of all against all (in the regular deathmatch mode) or that of a one-on-one (in tournament mode) instead creates a semiotic system mimicking other possible semiotic systems of conflict.

Exploring the Goo

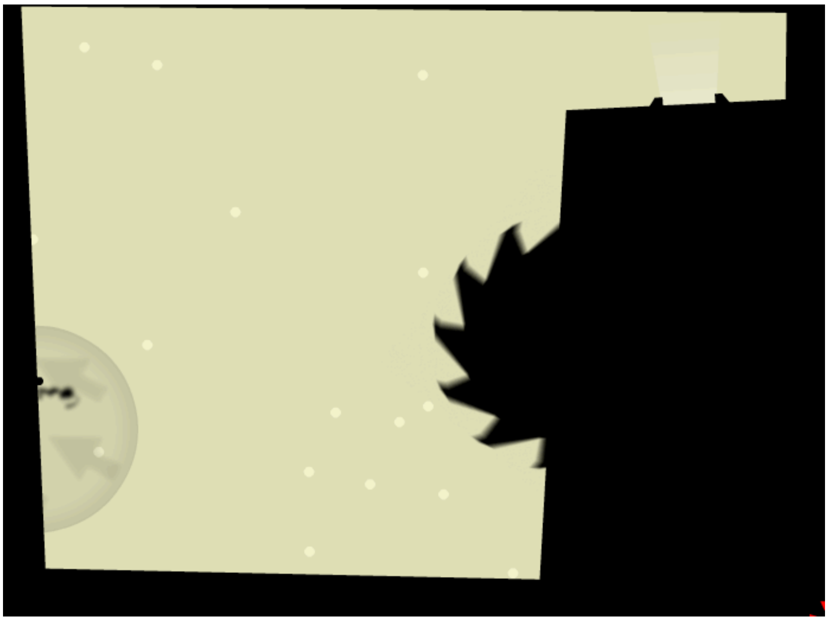
While in *Super Mario Brothers, Quake III Arena* and even in *Asteroids* physics simulation forms an environment to be mastered to win in the game conflict (surviving, defeating enemies, making it to the end of the level alive), in some games the player actually engages in a conflict against the laws of physics. *Tower of Goo Unlimited* is such a game. In this rather minimalistic 2D-Flash-game the player has to construct a tower by forming its structure out of a “gooey” material. To achieve this, the existing structure is buzzing with goo knobs that, when dragged to a position near the edges of the tower built so far, automatically connect to the tower and expand its frame. The goal is to build a tower as high as possible - and this is pretty much the only conflict there is, since there is no apparent limit of time or resources to be considered. The problem is that no matter how carefully and densely the knobs are placed, at some point the elastic structure will usually lose balance and slump down. Behind this, a strongly abstracted simulation of gravity and statics must be at work. The challenge for the player is to learn to predict the laws of these unusual “goo statics” and to overcome their pitfalls. Here, the fun lies in learning the twisted physics system of the game. This can be explained with the notion of “conceptual spaces” introduced in the last chapter. The unusual physics system is to be explored experimentally, by building a tower, watching it collapse and guessing what was done wrong. The difference to the physics simulated in *Quake III Arena* is that there, the physics system can be mastered by taking one’s existing capability of navigating and quickly reacting in 3D space and adapting it to the tuned comical version of the game - while the main part of the “conceptual space” is a space of possibilities when to use which weapon, when to use which strategy in teamplay etc. In *Tower of Goo Unlimited*, however, the simulated physics form the whole conceptual space.



Tower of Goo Unlimited. On the left, the tower is still standing.
After a few more additions to the structure, it falls over.

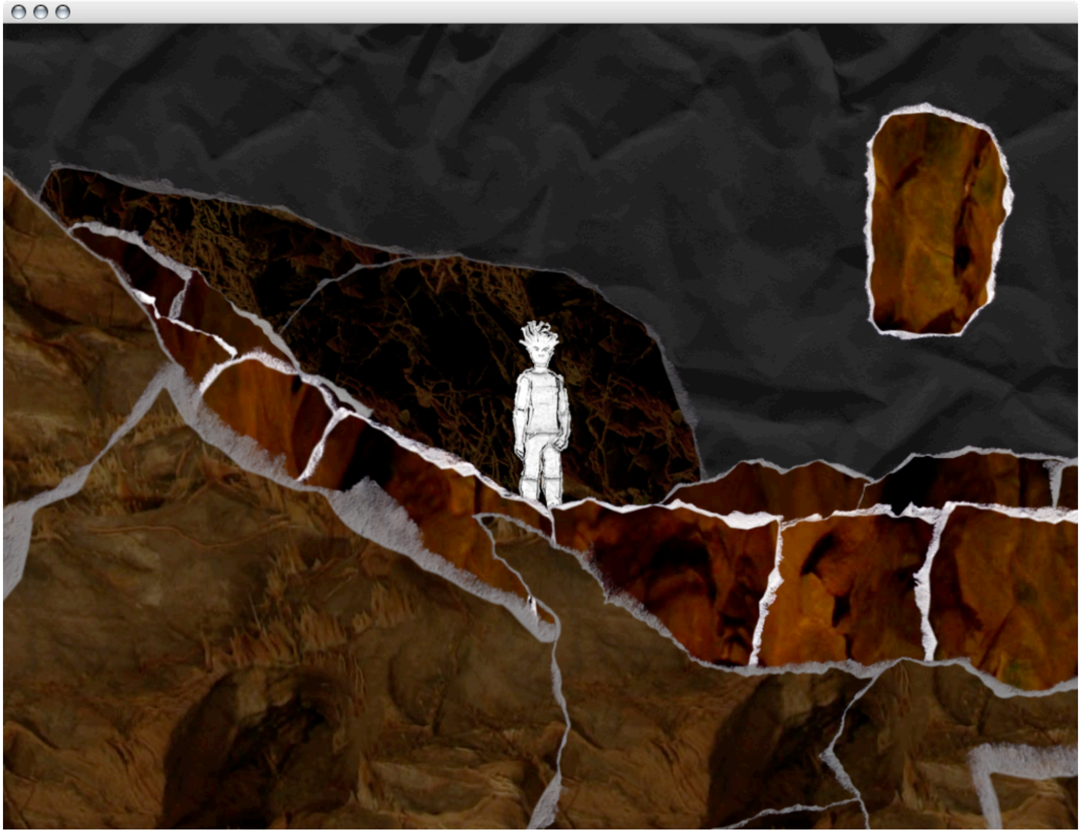
DIY Gravity

All the games considered so far have one thing in common: They use physics simulation to create an evironment the player has to adapt to in order to succeed. Recently, increasing numbers of games have been released that employ a different strategy: They require the player to manipulate the laws of physics themselves to win – within certain rules, of course. A good example is *Manifold*. In this flash game, the player controls an ant-like creature trying to get to the exit of each of the few (single-screen) levels. The usual jump'n'run movement is possible, but in most levels the exit is in a place unreachable with simple running and jumping. But the player has another tool at hand: A gun with which a projectile can be fired that on impact creates a circular field of altered gravity. The direction of this gravitational force is determined by the direction in which the player drags the cursor when firing the gun. Any created field can be removed and re-added as ammunition: The player has either one or two projectiles at their disposal in every level. When the character enters one of these gravity fields, the regular gravity is suspended and only that of the field applies. By cleverly using this tool, the player can let the character walk on walls or ceilings or have it catapulted somewhere. The challenge is to constantly overcome the automatic prediction of movement derived from “reality” where gravity never changes. The player is required to visualise and estimate forces working in a space made up of multiple “correct” simulations of physics forming one apparently incoherent whole.



Manifold. In this level, the player has two units of „ammunition“ and must fire them alternatingly to climb the wall and walk along the ceiling to the goal while avoiding the spiky trap.

A similar idea lies at the core of the game *And Yet It Moves*: The player controls a nameless character in paper-cut aesthetics, again in a very classic jump'n'run manner. Here, too, to reach the end of the level it is necessary to manipulate gravity, but in a very different way: By simply pressing a button, the whole world (except the player) can be rotated clockwise or counterclockwise by 90 degrees. All calculations of the physics simulation engine are suspended and recommenced in the new world state. Not only does this device allow the player to "climb" walls by simply rotating the world and walking along them, it also needs to be used to solve various puzzles. An example: Rocks resting on the ground and blocking the entrance to a tunnel may be moved by rotating the world so that the ground becomes a wall and the rock falls into the void. Like *Manifold*, this game simulates simplified 2D-physics the way one would expect but adds an "impossible" element, the mental integration of which with the "real" physics system is the player's challenge. And it is quite a challenge - consider the following: The player has to keep in mind that forces can be generated which are accumulations of gravitational forces of different directions (because they affected the player in different world states). One cannot simply jump down along the right side of a wall and rotate the world counterclockwise while falling and expect to safely land on the wall (which is now the ground) - the accumulated speed will render the impact lethal. When I was invited by



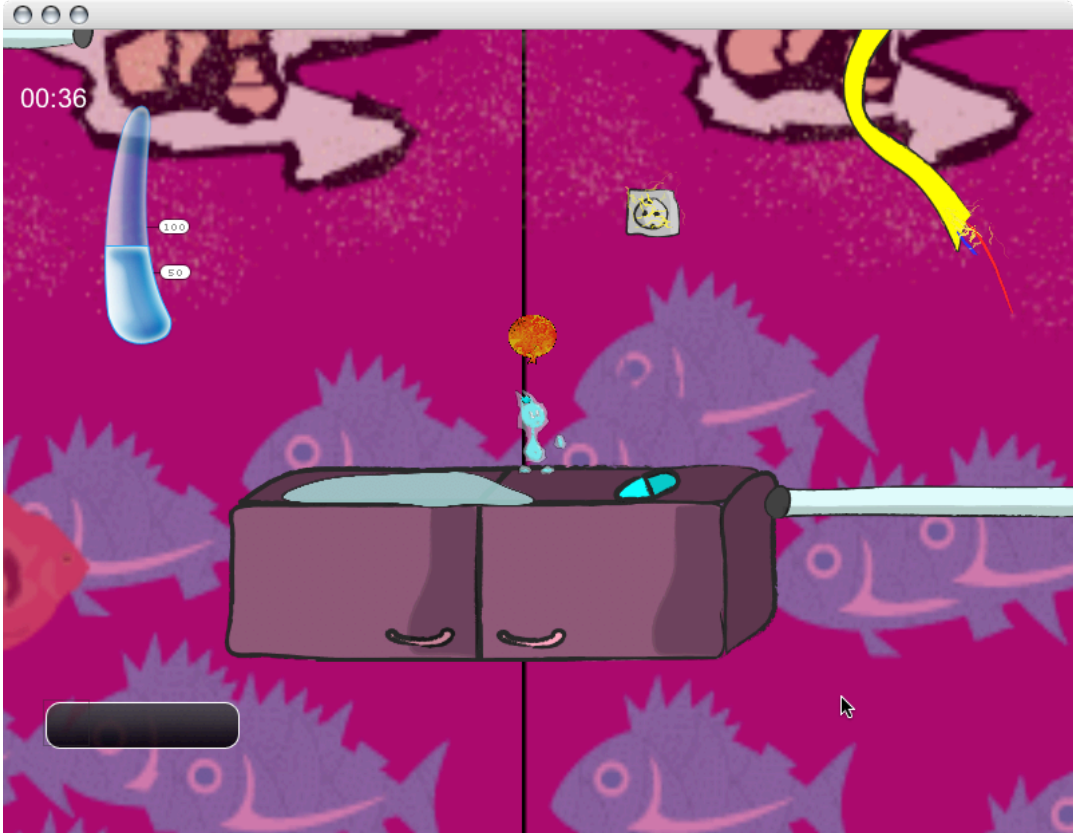
And Yet It Moves. If the player rotates the world by 90 degrees, the ground turns into a wall and the obstacle to the right into a platform.

the game designers to a playtesting session and I played that version of the game for the first time I was initially quite frustrated by this because I somehow did not expect the simulation to behave this way and found it counter-intuitive. It is impossible to say whether I was wrong because a situation such as the one modelled in the game is strictly impossible in "reality". The decision the designers had to make here was not one between more or less accordance with real-world physics. It was one of a balance between game mechanics, difficulty and what the designer expects the player to expect. From the difficulty point of view is is obvious that this restriction (which was kept in the end) prevents players from using a particular kind of exploit, namely the replacement of running by rotating, falling and rotating back. From this problem it can be seen that the introduction of strong "unrealism" can, while opening a wide space of possibilities for innovative gameplay, impose serious design difficulties that have to be handled carefully.

Another thing common to both games is that they hardly involve any recognisable fiction. Most of the rules are derived from standard jump'n'run games and are quickly grasped by players. The essential difference that constitutes the core mechanic is not founded in any fiction either. In regular jump'n'runs, the distinctive element is often the fiction. Here, it is the promise of "experimental" game play and a breaking of the rules of both "reality" abstracted in a usual way and the conventions and mechanics of regular jump'n'runs.

WIMPS

As this paper was created in the context of a game design bachelor's project, I will now relate what has been said so far to the game I developed with two fellow participants in this project. It is called *WIMPS* (working title) and was developed with GarageGames' *Torque Game Builder*, a 2D game development platform with a graphics and physics engine, its own scripting language and an IDE. *WIMPS* is a 2D jump'n'run game in which the player controls a small alien who has crash-landed in a house on earth, in its kitchen, to be exact. The task is to find a way through increasingly dangerous and unlikely household environments to some device via which the alien can send a message to outer space for his/her people to get him/her back. The central idea of the game, however, was not the setting but the "core mechanic": The alien uses a balloon to aid it in its movement. There are two distinct modes of moving: Walking and flying. When the alien walks, the balloon is dragged behind on a cord held in one hand. When the alien stands still, the balloon hovers straight above its head. When the alien walks, the balloon follows according to a (tricked) simulation of inertia. However, the longer the alien keeps running in one direction, the faster it gets and the lower the balloon flies (up to a certain limit). By doing so, it is possible to avoid sharp obstacles above the alien's head;



WIMPS. The protagonist is currently in walking mode and the balloon is idly hovering above.
The player has also stepped into cold water and is now in a frozen state slowing the movement.

touching these with the balloon would subtract life energy. To fly, it is necessary to pump gas into the balloon; the gas is measured in units and one "pump" costs 10 units. When pumped, the balloon is sent upward with a certain force and the alien follows, hanging down on the cord. While in the air, the alien can lean left or right to steer the balloon in one direction. The gas vanishes quickly from the balloon, however, and gravity pulls the alien down again. The gas resources are replenished automatically, but slowly. The levels also contain gas capsules throughout for a quicker replenishment. If the balloon touches a sharp obstacle in flying mode, a hole is torn into the hull, the life energy is diminished and the recoil of the escaping gas causes alien and balloon to race around randomly (but still somewhat steerable) for a few seconds.

The movement modes should demand a constant decision whether to fly or to walk. Walking is free and can be faster, flying is required in some parts and useful in others. The player can also choose to consciously touch a sharp obstacle while flying to reach the desired destination much faster, but less accurately in the uncontrolled flying mode, at the expense of some life energy and more possible collisions. The physics simulation is partly based on the built-in physics engine, which takes care of gravity and collision and allows forces to be applied to objects as well as the velocity or the position of objects to be set directly. The force-methods were mostly ignored since the simulation engine did not appear capable of providing a really stable behaviour if they are used. The balloon physics forming the core "novel" component of the game were mostly simulated in a less general way and were tuned at all ends until they felt right.

I realise that most of what was just described does not sound very "realistic", but neither does a crash-landed alien. The aim was, on the one hand, to approach the established jump'n'run control paradigm and alter it slightly; the player should be given choices over the modes of movement that have clear consequences; they should therefore be *interesting* choices:

> 1. No single option should be the best.
> 2. The options should not be equally good.
> 3. The player must be able to make an informed choice.
>
> (Sid Meier, cited by Richard Rouse, cited by Juul 2005, p. 92).

A constant weighing of the modes of movement against each other and a mastering of these modes of movement and of the obstacles should keep the player engaged. Another aspect was the pure desire to experiment with the laws of physics. Although these laws were strongly abstracted and twisted for the game, the point was to create a method of control that invites the player to literally play with it.

PhysX

Most of the games considered so far implement their own physics; *And Yet It Moves* and *WIMPS* builds on the Torque Game Engine which includes a considerable amount of 2D physics simulation, but their core mechanics are built on custom physics features. However, in the last few years, commercial and non-commercial physics engines have been appearing in an increasing number of games, similar to the way in which the use of complete graphics engines became widespread a few years earlier. Especially in the 3D action genre that builds on some common ground of "realistic" simulation of physics and "realistic" visual depiction, the use of pre-existing graphics and physics engines allows developers to focus on the original aspects of their games without "reinventing the wheel" while keeping pace with technical advances.

As physics engines are becoming more common in games, the way in which the physics simulations abstract from the laws of physics in "reality" increasingly share common traits. This development has been taking place for a longer time in 3D-graphics. In "Does it have to be 3D?", the author Dennis Ray Vollmer likens the advent of 3D graphics in computer games to the adoption of the central perspective in painting in that it unites the formerly subjective perspective (or, likewise, the two-dimensional visual abstractions of older games) with visual consistency and an objective measure of "reality" by simulating the visible through a (albeit simplified) model instead of employing techniques from two-dimensional animation (see Vollmer 2003). Such a consistency is also introduced by physics engines that build the game's realities on a common ground of certain standardised abstractions.

This is a good reason to examine one of the most popular commercial physics engines, the *Ageia PhysX*, and try to find game design decisions implemented in it. The engine works as follows: The game developer has to connect every rigid-body object that should be included in the physics simulation calculations to an "Actor" representing it within a "Scene". The common way to influence these Actors is to apply forces to them via methods provided by the PhysX API. The developer has to include an instruction to advance the engine state regularly in the game code to have the calculations performed. The results of the calculations (the Actors' positions and orientiations) are read from the Actors before each frame is displayed so that the associated objects can be rendered in the correct positions. Apart from rigid bodies, PhysX also allows the simulation of more complex phenomena such as fluids or cloth.

Remarkable and essential for game design, however, is the engine's "Character Controller" which replaces the Actor as an internal representation of objects participating in the simulation that are controlled directly by the player. The following is the passage from the official documentation explaining the need for this class of objects:

> In the past, games didn't use “real” physics engines. However, they still used a character controller to move a player in a level. These games, such as *Quake* or even *Doom*, had a dedicated, customized piece of code to implement *collision detection and response*, which was often the only piece of physics in the whole game. It actually had little physics, but a lot of carefully tweaked values to provide a good *feeling* while controlling the player. The particular behavior it implemented is often called the *“collide and slide”* algorithm, and it has been tweaked for more than a decade. The result is that players expect to find the same well-known behavior in new games, and providing them with anything else is often dangerous (a few games come to mind but I'm not sure it's appropriate to name them). This is especially true if provided behavior is not as robust and stable as before, which is exactly what happens if you use a typical physics engine directly to control players.
> (PhysX Documentation 2006, Chapter “Character Controller”)

If the player character was represented as a regular Actor, a number of unwanted effects could ensue, as the documentation further explains:

- **(Lack Of) Continuous Collision Detection:** “Tunnelling” and “jittering”.
- **No Direct Control:** We do not “push” our own bodies as we would push a trolley. We do not expect to have to “push” our avatar.
- **Trouble with Friction:** Especially on ramps, “regular” friction usually does not feel right.
- **Trouble with Restitution**
- **Undesired Jumps**
- **Undesired Rotations**

In general, the problems result from the fact that the player generally assumes the character they control to respond like their own body (in an abstracted way) and to automatically keep balance and avoid sliding down a ramp. If the player-controlled character is an Actor, however, the player has to apply singular forces to it and predict its movement. This difference was already observed in the two games discussed at the beginning of this chapter: In *Asteroids*, the spaceship is similar to an Actor and the player's challenge is to apply a force to it and correctly predict its movement. In *Super Mario Bros.*, Mario is more like a Character Controller, moved by itself (or by the player's “command” to do so) rather than by a force.

It is now clear that while physics engines are usually meant to be applicable to a wide range of games (and other applications), they might already include design mechanisms that break the laws of physics and stray from “realism” (accuracy of the model) to benefit the realism (possible felt immersion and control).

Summary

Several games using physics as a central element of game play were briefly analysed:

The first part focussed on games in which mastering abstracted, simulated physics is essential, but serves the purpose of succeeding in another conflict. The first gae examined was *Asteroids* which is built on a strongly abstracted physics simulation forming a system to be mastered by predicting the results of forces applied to objects in infinite 2D-space. *Super Mario Brothers* was considered next, where physics apply that are most coherent with those implied in certain kinds of comics and where the player's relation to the controlled object is somewhat more direct. Finally *Quake III Arena* was discussed *which simulates* physics much more "realistically", but is still highly tuned and with surprisingly coherent "unrealistic" elements.

The second part was devoted to games with a very conscious approach to physics simulation. *Tower of Goo,* making the player struggle for control in an unknown conceptual space of twisted statics. *Manifold* and *And Yet It Moves,* putting the player in charge of manipulating the physics simulation in order to change the laws of physics to let them work in their own favour. *WIMPS,* involving more fiction, but still placing its emphasis on abstracted, twisted simulated physics and on the required decisions when to employ which of the features.

Finally, design measures implemented in a commercial physics engine forming a basis for many current digital games were highlighted. These measures do not necessarily result in games that all feel similar; such physics engine will hopefully rather provide an elaborate foundation that can be used to create more games that make creative and experimental use of simulated physics and challenge established conventions.

Conclusions

Review

The analysis of how physics simulation is intertwined with design problems in digital games could be continued for much longer, but for now conclusions will be drawn.

In the beginning, possible definitions of simulation were outlined, from the original use of the term to its meaning in the computer age and poststructuralist problems. This allowedbetter understanding of four definitions of simulation in (digital) games, given by Salen and Zimmerman, Frasca, Myers and Juul, respectively. The first two are subsumable into one: Simulation is a procedural/behavioral representation of aspects of 'reality'. The third: Simulations signify the the semiotic relationships of signifieds and signifiers in some other semiotic system. The fourth: Simulation is where rules and fiction overlap. This caused considerable problems: It was necessary to define representation and consider abstraction, fiction and narrative. Though a more thorough investigation of these key concepts was beyond the scope of this paper, some understanding for the related problems was gained.

The "immersive fallacy" was rejected by arguing that an intricate process of feeling in and out of control is responsible for creating immersion or realism and that a game cannot erase all metacommunication because it is constituted by it. Control is also a way of describing a predictable relationship of action and outcome, which is necessary for meaningful play. Looking at various characteristics of simulations in games, we identified that the creation of a coherent system through abstraction, limitation and the balance of simulation and emulation is the central task for a game designer framing a game as a play of simulation.

When physics simulation was finally addressed, a number of new questions appeared. Why simulate physics? How do simulated physics add to the play experience? How do games simulate physics? It was argued that adapting to the laws of physics is part of our basic survival skills and that in a game these skills can be tested under unambiguous and fair rules. In addition, by adding "unrealistic" elements games make us constantly explore and master new conceptual spaces and may also provide some room for informal, experimental play within them.

By analysing a number of games regarding the way they simulate physics and how this simulation affects the play experience, design strategies were pointed out: Games may have the player adapt to physics abstracted to various degrees in order to engage in another conflict, they may have the player engage in a conflict against the physics simulation itself or they may require the player to imaginatively use devices that can directly change rules in the simulation. Every strategy involves difficult design problems to be solved by the game designer; a problem often encountered is the maintenance of coherence, especially in “unrealistic” simulations or, on the other hand, ones that stick rather closely to “reality” and are faced with all the more serious limitations. Of course, only a small set of possible uses of physics simulation in games could be dealt with. Recent developments have shown a tendency to allow the player to directly influence the laws of physics. The more game designers have potent hardware and large standardised physics simulation systems at their disposal, the larger the space of possibility grows.

Purposes, Means and Problems of Physics Simulation

I will try to give another summary of physics simulation in games in terms of purposes, means and problems.

The fun in games lies in meaningful play within an artificial conflict. Physics simulation can contribute to this in the following ways:

1. Physics simulation forms a system from which complexity emerges which is necessary to create a space of possibilities that lets the player make informed choices and develop strategies in order to gain more control, resulting in pleasure and possible immersion.

2. Mastering this complexity connects to a “visceral” part of the player’s thinking because it is related to the skills needed for basic survival. This is opposed to more connotative simulations concerning other areas than physics.

3. The referenced reality and the game fiction are relevant for inferring initial relationships within the simulated system. The addition of elements impossible in this reality enhances the play experience as long as it is internally coherent. This is because it creates a hypothetical conceptual space the player is challenged to adapt to and to master. The simulated system is autonomous and not bound to its referent.

4. Due to their strong relation to a very fundamental understanding of our environment and possible alterations to their laws when simulated in a game, physics can also be used in a game to create situations that invite the player to experiment and play informally within the larger game context.

Some means employed to put these strategies into practice are the following:

1. Physics simulation can be used to form either an environment for meaningful play mainly resting on other decisions or to constitute the opposition itself.

2. The simulated system can either abstract, tune and bend the laws of physics and force the player to explore it and adapt to it or it can afford the player to manipulate its basic mechanisms within clear rules – this should not be seen as an exclusive binary opposition but rather as complementary uses that are often combined.

3. Not all parts of a game are included in the simulation system. “Emulation” of many aspects is necessary to give the game designer control over the structure of the game. This balancing sets games apart from “mere” simulations striving to be as close to reality as possible.

The problems faced during design can include:

1. The simulation can strive for too much “realism”. Since it is still limited compared to reality, the limits are in this case not controlled by the game designer via “emulation”. The result is the injection of ambiguity into the magic circle, causing the feeling of too much randomness and rendering meaningful play impossible.

2. Wrong use of “emulation” can entail the feeling of incoherence of various sorts. The game designer has to predict player expectations and behaviour to ensure coherence where needed.

3. When strongly “unrealistic” elements are introduced, guaranteeing coherence can be highly problematic since player expectations may diverge more than usually.

Perspectives

Returning to the example of *Fracture* mentioned in the introduction, it is apparent that more than ever before, experimentation is currently taking place in physics simulation. Advances in hardware and software technology and the growing recognition of game design as a veritable discipline integral to the creation of digital games seem to nourish the development of new ideas. It is hard to say what can be expected, but, as *Fracture* and the more experimental games mentioned in chapter three demonstrate, giving the player the chance to bend the laws of physics modelled in the simulation (within rules) and actually requiring them to be creative in doing so in order to succeed in the conflict can be a design strategy leading to highly pleasurable game experiences. Similar trends can be found in other kinds of simulations, such as the evolutionary and genetic processes modelled in the upcoming game *Spore*. Nevertheless, physics are central to most games and I think that much innovation can be expected in this field in the very near future.

Bibliography

AGEIA PhysX SDK Documentation. AGEIA Technologies Inc., 2006.

Baudrillard, Jean: *Simulacra and Simulation*. University of Michigan Press, February 1995.

Bolter, J. D. and Grusin, R.: *Remediation: Understanding New Media*. The MIT Press, 2000.

Caillois, R.: *Die Spiele und die Menschen: Maske und Rausch*. Frankfurt/M; Berlin; Wien: Ullstein, 1982.

Church, D. (1999): “Formal Abstract Design Tools”. http://www.gamasutra.com/features/19990716/design_tools_01.htm (accessed 01/2008)

Crawford, C. (1982): *The Art of Computer Game Design* http://www.vancouver.wsu.edu/fac/peabody/game-book/Coverpage.html (original version is out of print, free online version accessed 02/2008)

Dotzler, B.: “Simulation”, in: Barck, K. et al., eds.: *Ästhetische Grundbegriffe. Historisches Wörterbuch in sieben Bänden*. vol. 5. Stuttgart/Weimar: J.B. Metzler, 1992ff., pp. 509–535. Cited as “ÄG”.

Eco, U.: *Zeichen. Einführung in einen Begriff und seine Geschichte*. Frankfurt am Main: Suhrkamp, 1977.

Frasca, G. (2001): “Simulation 101: Simulation versus representation.” http://www.ludology.org/articles/sim1/simulation101.html (accessed 01/2008)

Gane, N.: “Simulation”, in: *Theory, Culture & Society*, no. 23, 2006, p. 282f.

Giddings, S. and Kennedy, H. W.: “Digital games as new media”, in: J. Rutter and J. Bryce, eds.: *Understanding Digital Games*. SAGE, 2006.

Huizinga, J.: *Homo Ludens: Vom Ursprung der Kultur im Spiel*. Reinbek bei Hamburg: Rowohlt-Taschenbuch-Verlag, 2006^{20}.

Juul, J.: “A certain level of abstraction”, in: B. Akira, ed.: *Situated Play*. Tokyo: The University of Tokyo, September 2007, pp. 510–515.

Juul, J.: *Half-Real: Video Games between Real Rules and Fictional Worlds*. The MIT Press, 2005.

Koster, R.: *A Theory of Fun for Game Design.* Paraglyph, 2004.

Kücklich, J.: "Literary theory and digital games," in: J. Rutter and J. Bryce, eds.: *Understanding Digital Games*. SAGE, 2006.

Manovich, L.: *The Language of New Media*. The MIT Press, 2002.

Millington, I.: *Game Physics Engine Development*. Elsevier, 2007.

Myers, D.: *The Nature of Computer Games: Play As Semiosis.* Peter Lang Publishing, 2003.

Peitgen, H.-O., Jürgens, H. and Saupe, D.: *Chaos and Fractals*. Springer, February 2004.

Poole, S.: *Trigger Happy: Videogames and the Entertainment Revolution*.
Arcade Publishing, 2000.

Salen, K. and Zimmerman, E.: *Rules of Play: Game Design Fundamentals.* The MIT Press, 2003.
Cited as "RP".

Sommerseth, H.: "'Gamic Realism': Player, Perception and Action in Video Game Play",
in: Akira, B. ed.: *Situated Play.* Tokyo: The University of Tokyo, September 2007,
pp. 765–768.

Vollmer, D.: "Does it have to be 3D?
Überlegungen zur Beziehung von 3D-Hardware, -Software und User",
http://www.playability.de/1/vollmer_p.html (accessed 01/2008)

Wark, M.: *Gamer Theory.* Harvard University Press, 2007.

List of Games Cited

And Yet It Moves

C. Binder / F. Bohatsch / J. Hackl / P. Vorlaufer, www.andyetitmoves.at, 2007

Asteroids

Atari, 1979

Breakout

Atari, 1976

Crysis

Crytek, 2007

Fracture

Day 1 Studios, unpublished at time of writing

Manifold

J. Esler, http://www.kongregate.com/games/joelesler/manifold, 2007

Quake III Arena

id Software, 1999

Rez

United Game Artists / Q Entertainment, 2001

Spacewar!

S. Russell et al., 1962

Spore

Maxis, unpublished at time of writing

Super Mario Bros.

Nintendo, 1985

Super Mario Bros. 3

Nintendo, 1988

Tetris

V. Gerasimov / A. Pajitnov, 1985

Tower of Goo Unlimited

Kyle Gabler, http://www.experimentalgameplay.com/game.php?g=17

WIMPS (working title)

P. Holzkorn / A. Lenzhofer / P. Ollram, unpublished at time of writing

Wipeout

Psygnosis, 1995

Worms Armageddon

Team 17, 1999