Engineering emergence: applied theory for game design
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There is no single sentence describing what makes games attractive.


Introduction

Designing games is hard. Although games have been around for a very long time, it was the rise of the computer game industry over the past few decades that caused this problem to become prevalent. During its short history the computer game industry has grown from individual developers and small teams towards multi-million dollar projects involving hundreds of employees. In the contemporary game industry there is little room for mistakes: the financial stakes have grown too high. Today, more than any time before, there is a need for a better understanding of the process of designing a successful game in order to prevent such mistakes; there is a need for better applied theory and intellectual tools to aid game designers in their task.

At the same time, more people are playing video games than ever before. A wider audience means that there is an ever increasing demand for games with quality gameplay. As game players get more experienced they grow an appetite for ever more sophisticated games. Compared to other forms of art and media, computer games are a fairly recent invention. There is still plenty of room for development and innovation.

The general premise of this dissertation is that the difficulties in designing games lie within the nature of games as complex rule based systems that exhibit many emergent properties on the one hand, but must deliver a well-designed, natural flowing user experience on the other. In facing these difficulties, the game designer’s tool box is quite empty. The nature and emergent behavior of games is poorly understood. Level design has been one way to harness a game’s emergent behavior, by restricting the gameplay to a series of relatively simple tasks loosely strung together by a storyline. However, high-quality content is expensive to produce. Games with many hand-crafted levels are expensive to produce, and fail to exploit the true expressive power of open game worlds that emerge from rule systems.

This dissertation examines the nature of emergence in games in order to construct applied theory to deal with emergence in games head-on. This theory will enable the designer to get more grip on the elusive process of building quality games displaying emergent behavior. The theory developed in this dissertation applies to game mechanics and levels. However, where many scholars and designers treat levels and mechanics as two vastly different elements of game design,
this dissertation attempts to integrate the two: for both rules and levels, this
dissertation seeks to find formal, abstract representations through which the pro-
cess of designing these aspects of games might be elevated and unified. Through
these representations the material that game designers work with should become
more tangible. This leads to the central research question of this dissertation:
what structural qualities of game rules and game levels can be used in the cre-
ation of applied theory and game design tools to assist the design of emergent
gameplay?

The development of software tools to assist game designers in their task is
an important aspect of this dissertation. All too often, design theory has been
created in isolation from the practice of game design. The creation of software
tools that implement the theories presented here, means that these theories
have to be very concrete and applicable. In addition, it allows the automation
of certain parts of the design process. By automating these parts, designers will
be assisted in their work and can focus on those aspects of design that require
the most of human creativity and ingenuity.

This chapter introduces the central notions of this dissertation: games, game-
play, mechanics, levels, emergence, and progression. It also outlines the general
approach and the contents of the chapters that follow.

1.1 Games

What are games? Many people play them, but only a few stop to contemplate
their nature. The study of games, especially the study of games in its current
form, is very young. It was only in 2001 that Espen Aarseth declared that
year to be “year number one” of game studies (Aarseth, 2001). That year saw
the launch of the first peer-reviewed online journal and the first international
academic conference dedicated to games. Games were studied before, but it was
not until 2001 that game studies gained enough momentum to be recognized as
a separate academic discipline.

The study of games has been a multi-disciplinary affair from the beginning,
with researchers from different fields studying games from different perspec-
tives. The first few years of game studies were characterized by a fierce debate
between narratologists and ludologists. The former group comprised academics,	en often with a background in literature, who had been studying games from that
perspective for a while. They regarded games as a new medium for storytelling
and placed games in the context of literature and media studies (Laurel, 1986;
Murray, 1997; Ryan, 2001). The ludologists opposed this position, for them
games are rule-driven play experiences first and foremost. The story and visuals
are secondary to rules which are the most critical factor for game quality. Their
argument is that good rules with visuals and story of lesser quality still make
for a good game, whereas the opposite is not true (Eskelinen, 2001; Juul, 2005).

Today both positions are considered rather extreme. It is difficult to find
somebody who would maintain that the paradigms used to study stories in liter-
ature or cinema apply directly to games. You cannot ignore rules, interactivity
and gameplay in any study of games. On the other hand, the reskining of Tetris into the hypothetical “Mass Murderer Game” by Raph Koster (see figure 1.1) where the player tries to fill pits with awkwardly shaped dead bodies, clearly illustrates that story and visuals do affect the experience of play (Koster, 2005b, 166-169). The biting irony of a game like September 12 where the player is invited to shoot missiles at terrorists in an Arabic city and to explore the consequences of that action is only made possible by the sharp contrast between rules that support simple, typical gamelike shooting action and the game’s meaningful reference to a very real situation outside the game (see figure 1.2). Games do not exist in isolation but are part of a heterogeneous media landscape and the social structures from which stories derive their meaning. In this case it is worth noting that September 12’s developer, Gonzalo Frasca, is also a prominent ludologist and was in fact the first game researcher that coined the term ludology (Frasca, 1999).

The examples of the Mass Murderer Game and September 12 also illustrate nicely that in games, what matters most is what the player does. These actions are determined by rules on the one hand, but on the other a game’s art and story frame these actions and give them meaning. In a game, rules set up possible interactions, but through clever design of levels developers have some control over the order in which players encounter game elements and the challenges they pose. It is through levels that developers primarily control the sequence of actions.

The general consensus in game studies is that games are rule based artifacts designed to be experienced by one or more players, in which they strive to achieve some sort of goal. Without rules there would be no game, but the structured experience of the player is not unlike the structures and experience encountered in other media.

After close examination of eight different definitions of games, from histo-
rian Johan Huizinga to game designer Greg Costikyan, Katie Salen and Eric Zimmerman define games as follows:

“A game is a system in which players engage in artificial conflict, defined by rules, that results in a quantifiable outcome.” (2004, 80)

In their definition system, players, artificiality, conflict, rules and quantifiable outcome are the key notions. All games are systems consisting of many parts that form a complex whole (Salen & Zimmerman, 2004, 55). The system is defined by rules that determine what players can and cannot do. Following those rules, players engage in conflict against each other or against the game system. The conflict is artificial in the sense that the game is set apart from real life in both time and space, a space where the players submit to the rules of the game. In this sense, games are often said to take place within a “magic circle”, after the work of Johan Huizinga (1997). Finally, a game has a quantifiable outcome: players can win or lose, or measure their performance with some sort of score.

Salen and Zimmerman’s definition resembles many other definitions, even those not investigated by themselves. Mark J. P. Wolf uses the elements conflict, rules, player ability and valued outcome to define games (2001, 14). Alexander Galloway states that: “a game is an activity defined by rules in which players try to reach some sort of goal” (2006, 1). Ernest Adams and Andrew Rollings identify rules, play, goals and pretending as key elements of games. The latter element is linked to the magic circle and by extension to Salen and Zimmerman’s notion of artificiality (Adams & Rollings, 2007, 5-11). For Tracy Fullerton a game is “a closed, formal system that engages players in structured conflict and resolves its uncertainty in an unequal outcome” (2008, 43).

Jesper Juul examines many of the same definitions of games, including the definition of Salen and Zimmerman. He concludes that the following six features define games (Juul, 2005, 36):

1. Games are rule based,
2. and have variable, quantifiable outcomes,
3. which are affected by the effort of the player,
4. and which are assigned different values,
5. and to which the player is emotionally attached,
6. and which consequences are negotiable.

Of these six features only the first three are properties of the game as a formal system. The other three are either properties of the relation between the game and the player or the relation between the game and the rest of the world (Juul, 2005, 37).

Compared to Salen and Zimmerman, Juul’s definition incorporates a few extra elements. First, in Juul’s definition the outcomes of a game are not only
quantifiable, they are also variable. Games must have different outcomes to work as game. As soon as a game will always have the same outcome, there is little point in playing. This can happen when two players of vastly different levels are competing. When one of them is sure to win, when the outcome is known before the start, the game will cease to function as a game. Second, for Juul the player must be able to affect a game by putting in an effort. Without effort, the player’s actions are meaningless and the player will never become emotionally attached to the outcome of the game. For Juul this makes all games of pure chance, where players cannot affect the outcome in any way, borderline cases (Juul, 2005, 44). Thirdly, Juul pays more attention to the relation between the game and the player, and to the relation between the game and the world as is indicated by his last four points.

At the same time, Juul leaves out the artificiality of Salen and Zimmerman’s definition. In Salen and Zimmerman’s definition artificiality plays a similar role to Johan Huizinga’s concept of the ‘magic circle’ through which games create a reality outside real life (Huizinga, 1997). Although the magic circle is arguably porous (Copier, 2007) the artificial nature of games is without question. Game rules are made by designers and upheld by players to create an experience; players submit to these rules to experience the game. Games are also constrained by ‘rules’ that exist prior to the game, such as the law of gravity which constrains almost any sport (Juul, 2005, 58), but all games add rules to set up artificial goals, conflict and challenges. The game creates a space where the game is played, whether or not that space has clear boundaries.

For this dissertation I choose to build on Salen and Zimmerman’s definition of games, although I do add Juul’s player effort and ability to affect the variable outcome of the game. I choose to disregard Juul’s other additions as this dissertation focuses on games as formal systems and not on the relation between games and players. Thus, for this dissertation, games are defined as follows:

A game is a system in which players engage in artificial conflict, defined by rules, that results in a variable, quantifiable outcome affected by player effort and ability.

Gameplay, a key notion associated with the players actions’ and experience of play, is more difficult to define. Gameplay somehow consists of what the player does. At the same time, the term is used to describe a quality possessed by games themselves. Reviewers of games often talk about gameplay in this sense. Used in this way, “gameplay has become synonym with good gameplay” as Niels ’t Hooft once remarked.¹ That is to say, whether or not a game has gameplay, has become an assessment of its quality: good games have gameplay.

For this dissertation I will use gameplay in this sense. When designers are working to create gameplay, they are always working to create a compelling game experience. The game, as a product, is the prime source for this experience. What follows is that gameplay somehow emerges from the way a game is

¹Niels ’t Hooft is a freelance game journalist who works for Basher.nl and the Dutch newspaper NRC Next. He made this statement during a GameLab meeting on gameplay on February 2, 2011 in Pakhuis de Zwijger, Amsterdam.
constructed. It is these structural qualities of games as rule based systems that are the focal point of this dissertation.

1.2 Mechanics

When the game design community talks about game systems, they prefer the term “game mechanics” over “game rules”. “Game mechanics” is often used as a synonym for rules but the term implies more accuracy and is usually closer to an implementation. Although implementation here is still relatively independent from any platform or medium. Game designers Ernest Adams and Andrew Rollings explain the difference between the two with the following example: the rules of a game might dictate that in a game caterpillars move faster than snails, but the mechanics make the difference explicit; the mechanics specify how fast caterpillars move and how fast snails move. Mechanics need to be accurate enough for game programmers to turn them into code without confusion or for board game players to execute them without failure; mechanics specify all the required details (Adams & Rollings, 2007, 43).

In a similar vein, Morgan McGuire and Odest Chadwicke Jenkins state that “Mechanics are the mathematical machines that give rise to gameplay; they create the abstract game” (2009, 19). With that they point out that mechanics are media-independent: they are amongst those parts of games that are separable from images and sounds and might actually be transposed from one medium to another: a board game might be recreated as a computer game with different art and a different theme without altering the mechanics.

Game designers are perfectly comfortable talking about a “game mechanic” in the singular form (McGuire & Jenkins, 2009; Brathwaite, 2010). With this they are not referring to a person who is skilled in dealing with game mechanics, as the common use of the singular form “mechanic” would imply. Instead, they are referring to a single game mechanism that governs a certain game element. One such mechanism might include several rules. For example, the ‘mechanic’ of a moving platform in a side-scrolling platform game might include the speed of the platform’s movement, the fact that creatures can stand on it, the fact that when they do they are moved along with it, but also the fact that the platform’s velocity is reversed when it bounces into other game elements, or perhaps after it has traveled a particular distance. In this dissertation I prefer to use “mechanism” as the singular form indicating a single set of game rules associated with a single game element or interaction.

Some mechanics may be more central to a game than others. The term “core mechanics” is often used to indicate those mechanics that the player interacts with most frequently and have the biggest impact on the gameplay (Adams & Rollings, 2007; McGuire & Jenkins, 2009). Moving and jumping, for example, are core mechanics of most platform games. In contrast, the mechanics that specify that players gain one extra life for every hundred stars they collect, might or might not be considered to be the core of a game. For a game where

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2 The Oxford Advanced Learner’s Dictionary lists “a worker skilled in handling or repairing machines” as the sole meaning of the word mechanic.
the extra life is just a nice bonus, it probably is not a core mechanism, but for a game where stars are abundant and players lose lives easily it probably is. The distinction between core mechanics and non-core mechanics is not clear-cut; even for the same game, interpretation of what is core and what is not can vary between designers or even between different moments within the game.

Mechanics have come to indicate many different types of rules in games. The term sometimes denotes mechanics in the physics sense: the science of motion and force. In games characters commonly move, jump or drive vehicles. Knowing where a game element is, in what direction it is moving and whether or not it is intersecting or colliding with other elements make up the bulk of all calculations in many games. Here mechanics might be interpreted quite literally as the implementation of the physical laws that govern motion and force within the game. At the same time, games also include mechanics that have nothing to do with physics: for example, mechanics that specify how many coins need to be collected to gain an extra life. The mechanics that deal with power-ups, collectibles and other types of game resources constitute something that might be called an internal economy (Adams & Rollings, 2007, 331-340). The nature of economic mechanisms and game physics is different in a number of crucial ways. One problem of using the term mechanics for both is that it obscures these crucial differences.

Physics in modern games tends to be simulated with accurate mechanics that create near continuous game simulations. A game object might be positioned half a pixel more to the left or right and this might have a huge effect on the result of a jump. In contrast, the rules of an internal economy tend to be discrete; game elements and actions are a finite set that do not allow any gradual transitions: in a game you usually cannot pick up half a power-up. This continuous nature of game physics versus the discrete nature of game economies has consequences for the medium (in)dependence of games, the nature of the player interaction, and even for the opportunities for design and innovation. These effects are discussed below.

Due to its continuous nature, the implementation of physics tends to be much more closely tied to the medium or platform than a game economy is. Economic mechanics are indeed separable from a game’s medium, but physics not to the same extent. For example, a game that relies heavily on physics can not be easily mediated as a board game. Creating a board game for SUPER MARIO BROS. (see figure 1.3) where the gameplay originates from moving and jumping from platform to platform is very difficult. The continuous physics of a platform game translate poorly to the discrete nature of board games. A die only has so many sides, and to keep the game accessible overly complex calculations are best avoided. In platform games physical dexterity matters, just like a whole myriad of physical skills determine whether or not somebody is good at playing real-life football; those skills would be lost in a board game. SUPER MARIO BROS. is probably better mediated as a physical course testing players’ real running and jumping abilities. The point is, a rule that states you can jump twice as high after picking up a certain item, can be easily translated between different media, whereas rules that implement the physics of a jump cannot. The physical
mechanics of a game seem to be bound more closely to the medium than the
discrete rules that govern a game’s economy.

Interestingly, when we look back at the early history of platform games and
other early arcade games, physics were often handled quite differently, much
more discrete, one might say. The moves in Donkey Kong were much less
continuous than they were in Super Mario Bros.. In Boulder Dash (see
figure 1.4) gravity is simulated by moving boulders down at constant speed of
one tile every frame. It might play slowly, but it is possible to create a board
game for Boulder Dash. In those days the rules that created the game’s
mechanics (in the physical sense) were not that different from other types of
game rules. But times have changed. Today the physics in a platform game
have grown so accurate and detailed that they have become impossible, or at
least inconvenient, to represent with a board game.

With discrete rules it is possible to look ahead, to plan moves, create and
execute complex strategies. Although this does not need to be easy, it is possible
and players are encouraged to do so. Player interaction with this type of rules is
much more on a strategic level. On the other hand, once players grasp the physics
of a game (whether simulated or not), they can intuitively predict movements
and results, but with less certainty. Skill and dexterity become a more important
aspect of the interaction. This difference is crucial when you are using a game
to educate players. Angry Birds (see figure 1.5) won a serious game award for
teaching players a thing or two about physics in a fun way. While there is no
doubt that Angry Birds is fun and involves physics, I doubt that players really
learn about the application of forces, gravity or momentum in any conscience way
that is applicable to science education. Players of Angry Birds are involved
with those aspects mostly on the level of skill, rather than strategy; they might
develop an intuitive feel for the effects of forces, gravity and momentum, but that
is not quite the same thing as truly understanding them. Strategy in Angry
Birds involves those aspects of the game that are governed by discrete rules.
Players will have to plan how to use number and types of birds available to attack the pigs’ constructions most effectively. This requires identifying weak spots and to formulate a plan of attack, but the execution itself is based on skill and the effects can never be foreseen in great detail. Compare that to World of Goo (see figure 1.6) where players need to build constructions from a limited supply of goo balls. Physical notions such as gravity, momentum and center of mass play an important role in the mechanics of this game. Indeed, players might form an intuitive understanding of these notions from playing World of Goo. But more importantly, players learn how to manage their most important (and discrete) resource: goo balls, and use them to build effective constructions. The difference between Angry Birds and World of Goo becomes very clear when one considers the effects of continuous physics. Where in Angry Birds the difference of a single pixel can translate into a critical hit or complete miss, the effects are less felt in World of Goo. In the latter game, placement is not pixel precise: releasing a goo ball a little more to the left or right usually does not matter as the resulting construction is the same, and the spring forces push the ball into the same place. The game even visualizes what connections are going to be made before the player releases a ball (as can be seen in figure 1.6). Without trying to argue which game is more fun, I would say that players learn much more about construction in the World of Goo than they learn about physics in Angry Birds.

Physics and economy in games also affect design and innovation differently. One might say, that as games and genres evolve, the physical mechanics are all evolving into a handful of directions that correspond closely with game genres: most of the time there is little point in completely changing the physics of a first-person shooter.\footnote{Although certain games, like Portal, have successfully introduced innovative physics systems to established genres.} In fact, as games increasingly use physics engine middleware to handle these mechanics, there is less room to innovate in that department. On the other hand, every game is trying to create unique content, and many first person shooters do create an unique system of power-ups or economy of items to collect and consume to make their gameplay different from their competitors. If
there is room for creativity and innovation it is with the mechanics that govern these economies, and not with the physics of the game.

Still, looking back at four decades of computer game history, one must observe that physics has evolved much faster than any other type of mechanics in games. Physics is relatively easy to evolve because we have access to Newtonian mechanics and increasingly more computing power. The same solution does not apply to other types of mechanics. Calling all game rules ‘mechanics’ might distract developers from the fact that not all types of rules can be understood in the same way. Worse, developers might falsely assume that those other types of mechanics will turn out right, as long as we keep throwing more detailed rules and more processing power at it. The term mechanics is an unfortunate misnomer exactly because it might be holding back the development of proper understanding of different types of game rules. It might cause us to turn a blind eye to the artificial, discrete nature of those rules that are not part of the physical mechanics, but which are an equally important aspect of what makes games truly clever and unique. Without a solid theoretical framework for non-physical, discrete mechanics it is hard to evolve mechanics of that type beyond a certain point.

I will still use the term mechanics throughout this dissertation, as is customary within the game industry. However, in using the term, I will refer to the discrete mechanisms that generate a game economy more often than I will refer to continuous physical mechanics of motion. When appropriate I will differentiate between these and other types of rules, as mechanics do not impact all types of games equally.

1.3 Game Classification

What type of rules drives the gameplay of a particular game varies a lot between games and genres. Some games derive their gameplay mostly from their economy, others from physics, level progression, tactical maneuvering or social dynamics. Categorizations of games in different genres by the game industry and game journalists is usually based on the type of gameplay (Veugen, 2011, 42), and thus by extension on the different types of rules that feature more or less prominently in these genres. Figure 1.7 provides an overview of a typical game classification scheme and how these genres and their associated gameplay relate to different types of rule systems. Note, however, that this classification is one of many. There is a serious lack of consensus among the several classification schemes in use. The point here is not to present a definitive genre classification. Rather, it is to indicate how different types of rules correlate to different types of gameplay. There are many more genres and sub-genres that can be derived from this basic classification. For example, first-person shooters are a particular sub-genre of action games, whereas action-adventure games are common hybrids of the action and adventure game genres.

In figure 1.7 I distinguish between five different types of mechanics. The
Figure 1.7: Games genres taken from Adams & Rollings (2007) and correlated to five different types of game rules or structures. The thickness and darkness of the outlines indicate relative importance of those types of rules for most games in that genre.
boundaries between these types of mechanics are not very hard, and a single game can have multiple types of mechanics. The figure indicates typical configurations of these types of mechanics as they are frequently encountered across game genres, but it should be clear that each individual game can have its own, unique configuration of game mechanics. The mechanics of physics and economy were already discussed in detail in the previous section. Progression, tactical maneuvering and social interaction are new and will be discussed below.

Progression deals with those aspects of gameplay that stems from quality level design and mechanics that control player progress through these levels. In these games, designers have created levels in which players need to overcome a predefined set of challenges. Completing a particular challenge will often unlock other challenges, and this way players progress towards a particular goal. For most of these games, the goal is to reach a particular location (where usually the final challenge awaits in the form of a “boss fight”). For this type of game, careful lay-out of the levels creates a smooth experience. They tend to take longer to complete than games that do not rely on level progression, but once they are completed, they offer little replay value: many players play through this type of game only once. Because the play experience and progress through a progression-driven game can be tightly controlled by a designer, this type of game lends itself particular well to games that also deliver stories. Typical examples of level-driven games include action-adventure games such as *The Legend of Zelda* or *Assassins Creed*, first-person shooter games such as *Half-Life* or *Halo*, and role-playing games such as *Baldur’s Gate* or *The Elder Scrolls IV: Oblivion*.

Tactical maneuvering involves those mechanics that deal with the placement of game units on a map for offensive or defensive advantages. Tactical maneuvering is critical in most strategy games, but also features in certain role-playing games and simulation games. The mechanics that govern tactical maneuvering typically specify what strategic advantages units gain from being at a particular location. These mechanics might be continuous or discrete, but discrete, tile based mechanics still seem to be common. Tactical maneuvering is important in many board games such as *Chess* and *Go* but also computer strategy games such as *StarCraft* or *Command & Conquer: Red Alert*.

Much social interaction that emerges from playing a game is not captured with mechanics. As soon as a multiplayer game allows direct, in-game interaction, social interaction outside the rules emerges. Some games include mechanics that deal with that sort of interaction more explicitly. For example, role-playing games might have rules that guide the play-acting of a character, and a strategy game might include rules that govern the forming and breaking of alliances between players.

This dissertation mostly zooms in on the discrete mechanics of economy and progression. Three reasons for this are:

1. As should become clear from figure 1.7 these types of mechanics play a role in most game genres. They are more common than tactical maneuvering and social interaction.
2. As was discussed above, there is usually more freedom for design in those mechanics that are, to a certain extent, discrete. Continuous physics generally aim to accurately simulate a real or imagined setting, the required knowledge can be taken directly from real physics. For discrete mechanics and game economy, there exist far fewer off-the-shelf solutions. This dissertation aims to contribute to the development of applied theory to improve this.

3. In order to control the scope of this dissertation, not all types of mechanics can be discussed in equal detail. Tactical maneuvering and social interaction in games are both very large topics that would warrant independent, detailed study.

1.4 Emergence and Progression

Mechanics of progression correspond to what Jesper Juul calls “structures of progression” in games which he separates from “structures of emergence” (Juul, 2002). His classification is very influential within game studies and provides a relevant framework for the study of mechanics in this dissertation. Put simply, emergence indicates that relatively simple rules lead to much variation, whereas progression indicates that many predesigned challenges are ordered sequentially. According to Juul, “emergence is the primordial game structure” (Juul, 2002, 324) that is caused by the many possible combinations of rules in board games, card games, strategy games and most action games. Games of this type can be in many different configurations or states: all possible arrangements of playing pieces in a Chess constitute different game states as the displacement of a single pawn by even one square is a critical difference. The number of possible combinations of pieces on a Chess board is huge, yet the rules easily fit on a single page. Something similar can be said of the placements of residential zones in the simulation game SimCity or the placement of units in the strategy game StarCraft.

Progression, on the other hand, relies on a tightly controlled sequence of events. Basically, a game designer dictates what challenges a player encounters by designing levels in such a way that the player must encounter these events in a particular sequence. The use of computers to mediate games have made this form possible. Progression requires that the game is published with much content prepared in advance, for board games this is inconvenient. As such, progression is the newer structure, starting with the text-adventure games from the seventies. In its most extreme form, the player is ‘railroaded’ through a game, going from one challenge to the next or failing in the attempt. With progression the number of states is relatively small, and the designer has total

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5Published scenario’s for pen-and-paper role-playing games are examples of non-digital games of progression. They take the form of books specifying setting, characters and possible storylines. However, they cannot be considered to be older forms of progression in games than computer games, as pen-and-paper role-playing originate from the same period as computer games of progression.
control over what is put in the game. This makes games of progression well suited to games that tell stories.

In the original article Jesper Juul expresses a preference for games that include emergence: “On a theoretical level, emergence is the more interesting structure” (Juul, 2002, 328). He regards emergence as a structure that allows designers to create games where the freedom of the player is balanced with the control of the designer: with a game of emergence designers do not specify every event in detail before the game is published, though the rules may make certain events very likely. In fact, a game with an emergent structure often still follows fairly regular patterns. Juul discusses the gun fights that almost always erupt in a game of Counter-Strike (Juul, 2002, 327). Another example can be found in Risk where the players’ territories are initially scattered all over the map, but over the course of play their ownership changes and the players generally end up controlling one or a few areas of neighboring territories. Despite these emerging patterns Juul acknowledges that most games combine emergence and progression. The main example in Juul’s article, EverQuest, is “a game of emergence, with embedded progression structures” (Juul, 2002, 327).

In his book Half-Real, Juul is more nuanced in his discussion of emergence and progression (Juul, 2005). Most modern games fall somewhere between games of emergence and progression. Grand Theft Auto: San Andreas has a vast open world, but also a mission structure that introduces new elements and unlocks this world piece by piece. In the story-driven first-person shooter game Deus Ex the storyline dictates where the player needs to go next, but players have many different strategies and tactics available to deal with the problems they encounter on the way. It is possible to write a ‘walkthrough’ for Deus Ex, defining it as a game of progression according to Juul’s classification, but there are many possible walkthroughs for Deus Ex. Just as, at least in theory, it is possible to create a walkthrough for a particular map in SimCity, instructing the player to build certain zones or infrastructure at a particular time in order to build an effective city. It would be hard to follow such a walkthrough, but creating one is possible. Pure games of emergence and pure games of progression represent two extremes on a bi-polar scale, but most games have elements of both. Yet at the same time, emergence and progression are presented as two alternative modes of creating challenges in games, that might co-exists in a game, but are hard to integrate. This dissertation questions this perspective and seeks strategies to merge structured level design and emergent, rule-based play more effectively.

One trajectory towards an answer is that emergent behavior thrives somewhere on the border of chaos and order (cf. Salen & Zimmerman, 2004, 155). A true chaotic system will seem random and meaningless to most observers, whereas in games it helps if the player can make sense of what is going on. Where rules push games towards chaos by introducing dynamic behavior, levels pull games back towards order by imposing structure. If games are pulled too far back, they become games of progression where the spatial structure dominates the rules and little dynamic play remains.

This dissertation acknowledges that most games display complex, emergent
behavior. Many games structure this behavior through level design, but some games can do without. Many casual games, such as Bejeweled, are purely games of emergence. Many other casual games, such as Angry Birds, have many pre-designed levels that confront players with new challenges, but they are more puzzles than structured, story-like play experiences. For these games, once the mechanics are in place, many new puzzles and levels can be generated endlessly, not unlike the game of Tangram.

On the other hand, pure games of progression are quite rare. The most typical examples of these games are text-adventures such as Colossal Cave Adventure or Zork. But that game genre became almost extinct over two decades ago. Today adventure games are almost always action-adventure games; they almost always include some form of mechanics-driven, emergent action as part of the gameplay. So even though games can have both emergence and progression, it seems that modern games cannot do without the first, but can do without the latter.

So-called 'sandbox games' create an open, virtual world that is not designed to guide the player towards a particular goal. Sandbox games roughly correspond with the management simulation genre in figure 1.7. In this type of game, players are free to explore as they see fit, whether this is from a first person perspective as in Grand Theft Auto III or from the god-like perspective in a game like SimCity or Civilization (see figure 1.8). In a typical sandbox game there are few restrictions and many optional goals for the player to pursue, some of these goals are set by the player, not the game. Will Wright, the designer of SimCity and many other simulation games, is quoted to have stated that his games are more like toys as they do not dictate any goals (in Costikyan, 1994). These games do not define a variable, quantifiable outcome. Instead, players set and value their own goals.

As a medium for telling stories or delivering a concise play experience, vast open worlds are not always the best option. Worlds have gotten so large that
the player can easily lose track of the main storyline. Hunting down the story and making your way through yet another dungeon can be experienced as quite tedious. It is a flaw that large games such as *The Elder Scrolls IV: Oblivion* or *Fallout 3* suffer from. It is also the reason why Chris Crawford does not put too much faith in this structure for interactive storytelling (2003b, 261-262). Yet, the artificial worlds found in games seem to grow larger and more detailed with every new release, indicating that progression remains a relevant aspect of game design.

### 1.5 Emergence

The use of the term emergence in games, which predates Juul’s categories (for example see Smith, 2001), is often in reference to the use of the term within the sciences of complexity. There it refers to behavior of a system that cannot be derived (directly) from its constituent parts. At the same time Juul cautions us not to confuse emergent behavior with games that display behavior the designer simply did not foresee (Juul, 2002). In games, as in any complex system, the whole is more than the sum of its parts. While the active agents or active elements in a complex system can be quite sophisticated in themselves, they usually can be simulated as rather simple models. Even when the study is about the flow of pedestrians in different environments, great results have been achieved by simulating them with only a few behavioral rules and goals (Ball, 2004, 131-147). Similarly, the elements that make up games can be a lot more complex than the elements of a typical system studied by the science of complexity, but at least some games (such as *Go* and *Chess*) are famous for generating enormous depth of play with relatively simple elements and rules. The active substance of these games is not the complexity of individual parts, but the complexity that is the result of the many interactions between the parts.

The main assumption of this dissertation is that the particular configurations of elements into complex systems that contribute to emergence in other systems also cause interesting gameplay. In other words: gameplay is an emergent property of a game system defined by its rules. For game designers this means that understanding the structural characteristics of emergent systems in general, and in their games in particular, is essential knowledge.

One of the simplest systems that show emergent behavior is a particular class of cellular automata studied by Stephen Wolfram (2002). The cells of cellular automata are relatively simple machines that abide only to local rules. The algorithm that defines their behavior takes input only from its immediate surroundings. In this particular class of cellular automata, the cells are aligned on a line, the state or color of each cell is determined by the previous state of that cell and its two immediate neighbors. With only two possible colors, this creates eight possible combinations. Figure 1.9 displays one set of possible rules (on the bottom) and the resulting, surprisingly complex pattern (on top). This pattern is created because each iteration of the system is displayed on a new horizontal line below the previous iteration. Wolfram’s extensive study has revealed three critical qualities of systems that exhibit dynamic behaviors: 1)
They must consist of simple cells whose rules are defined locally, 2) the system must allow for long-range communication, and 3) the level of activity of the cells is a good indicator for the complexity of the behavior of the system. These qualities are discussed below.

The easiest way to implement a cellular automaton on a computer is to program a simple state-machine that takes its own state and the states of its immediate neighbors as input for the function that determines its new state after each iteration. This communication of each cell’s state plays an important role in the emerging behavior, without such input all cells would behave individually, and system-wide behavior would not be possible at all. In order to get more dynamic behavior communication between neighboring cells must lead to long-range communication in the system. This type of long-range communication is indirect and takes time to spread through the system. Systems that show pockets of communication with little or no communication between the pockets will show less complex behavior than systems in which such pockets do not occur or are less frequent (Wolfram, 2002, 252). Connectivity is a good indicator of long-range communication in the system. A special case of long-range communication is feedback: a cell or group of cells produce signals that ultimately feed back into its own state somewhere in the future. Long range communications travel over long distances through the system or, alternatively, through time and produce delayed effects. As we shall see throughout this dissertation, this sort of feedback is very important for games.

The number of cells that are active (cells that change their state) is important
for the behavior of the system as a whole. Complex behavior, that is behavior that is hard to predict but still seems to follow some sort of logic or hidden pattern, occurs mostly in systems with many active cells (Wolfram, 2002, 76).

Cellular automata show us that the threshold for complexity is surprisingly low. Relatively simple rules can give rise to complex behavior. Once this threshold is passed introducing extra rules does not affect the complexity of the behavior as much (Wolfram, 2002, 106).

In another study of emergence, Jochen Fromm builds a taxonomy of emergence that consists of four types of emergence (types I, II, III and IV). These types can be distinguished by the nature of communication, or feedback, within the system (Fromm, 2005). Feedback is created when a closed circuit of communication exists within a system: in effect, when a state change of a particular element directly or indirectly affects the state of the same element later on. Feedback is called positive when these effects strengthen themselves, as is the case with guitar feedback where strings are vibrated to produce sound, and amplification of the sound causes the strings to vibrate in turn. Feedback is called negative when the effect dampens itself. A thermostat is a typical example, a thermometer detects the temperature of the air, when it becomes too low it will activate a heater, the heater will then cause the temperature to rise which in turn will cause the thermostat to turn off the heater again. Negative feedback is often used in this way to maintain balance in a system.

In the simplest form of emergence, nominal or intentional emergence (type I), there is either no feedback or only feedback between agents on the same level of organization. Examples of such systems include most man-made machinery where the function of the machine is an intentional (and designed) emergent property of its components. The behavior of machines that exhibit intentional emergence is deterministic and predictable, but lacks flexibility or adaptability. Both the guitar feedback and the thermostat are examples of this type of predictable feedback.

Fromm’s second type of emergence, weak emergence (type II), introduces top-down feedback between different levels within the system. Flocking is an example he uses to illustrate this type of behavior. A flock-member reacts to the vicinity of other flock-members (agent-to-agent feedback) and at the same time perceives the flock as a group (group-to-agent feedback). The entire flock constitutes a different scale than the individual flock-members. A flock-member perceives and reacts to both.

One step up the complexity ladder from weakly emergent systems we find systems that exhibit multiple emergence (type III). In these systems multiple feedback traverses the different levels of organization. Fromm illustrates this category by explaining how interesting emergence can be found in systems that have short-range positive feedback and long-range negative feedback. It propels the appearance of stripes and spots in the coat of animals and the fluctuation of the stock-market. John Conway’s Game of Life is also an example of this type of emergence (Gardner, 1970). Although called the Game of Life, Conway’s cellular automaton does not fall in the category of games as defined earlier in this chapter. It does not have any quantifiable goal and
to include both positive feedback (the rule that governs the birth of cells) and negative feedback (the rules that govern the death of cells). The Game of Life also shows different scales of organization: at the lowest end there is the scale of the individuals cells, on a higher level of organization we can recognize persistent patterns and behaviors such as gliders and glider-guns.

Fromm’s last category is strong emergence (type IV). His two main examples are life as an emergent property of the genetic system and culture as the emergent property of language and writing.\textsuperscript{7} Strong emergence is attributed to the large difference between the scales on which the emergence operates and the existence of intermediate scales within the system. Strong emergence is multi-level emergence in which the outcome of the emergent behavior on the highest level can be separated from the agents on the lowest level in the system. For example, it is possible to set up a grid of the cellular automata used for the Game of Life in such a way that on a higher level it acts as a Turing Machine which in itself also displays emergent behavior. In this case causal dependency between the behavior displayed by the Turing Machine and the Game of Life itself is minimal.\textsuperscript{8}

From this brief discussion a number of important observations on the nature of emergence comes forward. Within this dissertation emergent behavior is attributed to feedback loops in the system, and preferably multiple feedback loops. Only one would only lead to nominal (type I) feedback. Therefore, emergent systems must consist of multiple elements that act more or less independently. A sufficient level of activity is required; a system with only a few active elements tends to be too stable and predictable to make for interesting games. Communication (or interaction) must exist between these elements at a local scale and this local communication must indirectly enable long range communication. Feedback, a form of communication where information and actions are fed back to the source, often causes emergent behavior, especially when more than one feedback loop affects the system. Finally, emergent systems often show different scales of organization, with communication and feedback traversing these scales.

1.6 Progression

Despite the importance of emergence in games, no professional game designer can turn a blind eye towards level design and mechanics of progression. To subject yourself to game rules is to cross the boundary into the magic circle and to immerse yourself in the game’s fictional space. Within that space the does not require any effort by the player. However, as we have seen with toys, players of the Game of Life can set goals themselves, such as finding configurations that will live for a very long time, or grow into stable systems. These goals are quantifiable and do require effort to reach.

\textsuperscript{7}One could question whether in both cases one follows from the other, or whether they have evolved in unison. Emergence might not be the best way to describe their mysteries. In fact, some researchers express serious doubts whether or not strong emergence can exist at all (Chalmers, 2006).

\textsuperscript{8}Although this is not the same as claiming that a Turing Machine could emerge from a particular, seemingly random, starting condition for the Game of Life.
player starts to explore the game and its possible states. The number of rules, interface element and gameplay options of a modern retail video game is usually larger than most players can grasp at once. Even smaller games found on the Internet frequently require the player to learn a multitude of rules, to recognize many different objects and to try out different strategies. Exposing a player to all these at the same time can result in an overwhelming experience, and players will quickly leave the game in favor of others. The best way to deal with these problems is to structure the game experience with clever level design that teaches the player the rules in easy-to-handle chunks. In many cases games include special tutorial levels to introduce a player to the core concepts, and even then they will introduce new concepts with extreme care.

The use of tutorials and level design to train the player is an illustration of one of the strengths of the medium of games: the use of game space to structure player experience. Unlike literature or cinema, which are well suited to depict events in time (histories), games are well suited to depict space. Henry Jenkins places games in the tradition of spatial stories, an honor they share with traditional myths and hero’s quests as well as modern works by J.R.R. Tolkien (Jenkins, 2004). Simply by traveling through the game space, a story is told. A similar sentiment is found in Ted Friedman’s essay on Civilization (1999) where the drama of that game directly stems from the player’s journey through and conquest of a virtual world.

Many games have utilized this capacity to great effect. The HALF-LIFE series stands out as a particular good example. The games from this series are first-person shooter action games in which the player traverses a virtual world that seems to be vast but which in reality is confined to a quite narrow path. The

Figure 1.10: In HALF-LIFE 2 the player arrives in the game by train, but never leaves the rails.
whole story of \textit{Half-Life} is told within the game, there are no cut-scenes that take the player out of the game, all dialog is performed by characters inside the game, and the player can choose to listen or ignore them altogether. \textit{Half-Life} has perfected the art of guiding the player through the game, creating a well-structured experience for the player. The practice is often referred to as ‘railroading’; in this light it is probably no coincidence that in \textit{Half-Life} and \textit{Half-Life 2} the player arrives in a train (see figure 1.10).

\section*{1.7 Approach and Dissertation Outline}

Designing games for emergent gameplay and coherent progression using discrete mechanics presents designers with many problems. Perhaps the biggest handicap for the game industry is the lack of formal, theoretical tools to deal with the complexity of emergent gameplay and to assist the design of games. Several prominent designers and academics have answered Doug Church’s call to develop “formal abstract design tools” (Church, 1999). This dissertation also answers that call. By developing applicable design theory for discrete game mechanics and level progression I hope to help designers understand the complex nature of game systems and to get a better grip on the elusive notion of gameplay and to create progression efficiently. In this respect this dissertation does not discriminate between board games and computer games, both are essentially rule-based artifacts and that can have emergent gameplay. The games discussed in this dissertation come from both categories in more or less equal measure.

The development of prototype software tools to assist or automate the design process is an important aspect of this dissertation. In many ways, the development of these prototypes was an important step in validation of the theory’s applicability. At the same time, implementation invariably led to further improvements of the theory in what turned out to be a highly iterative process.

In the next chapter I will explore games as rule based systems in more depth. Games share some relations with simulations, which are also rule based systems. However, where simulations aim to model a source system accurately, games have a different goal: they aim to create an interesting experience. This means that games can deal with rules differently.

Chapter 3 discusses game design theories from the game industry and from academia. Although all these theories have their own merits, no theory has emerged as an industry or academic standard. In fact, some people doubt that any theoretical or methodological approach to the design of games can work, as none of these can do justice to the creativity involved in designing games. Chapter 3 will also address the arguments put forward by the people who subscribe to this opinion.

In Chapter 4 I will present my Machinations framework as an alternative theory of game design focusing on internal economy and emergent gameplay. The design of this framework takes into account the concerns that have been discussed in Chapter 3. It utilizes an abstract, visual notation to represent discrete game mechanics. The digital version of these Machinations diagrams can be run in order to simulate a game. The Machinations framework aims
to foreground those structural qualities of game mechanics that contribute to (good) gameplay.

The Machinations framework focuses on game economy and neglects level design. In Chapter 5, game levels and mechanics of progression take center stage. In this chapter I will develop the Mission/Space framework, which offers a structural perspective on these elements of game design. As an illustration of how the Machinations framework and the Mission/Space framework can be used to inform game design on a theoretical level, I will leverage both frameworks in Chapter 6 to explore how emergence and progression might be, and occasionally have been, integrated in games.

In Chapter 7 I will unite the formal perspectives on games presented in Chapters 4 and 5 under the notion of game design as a series of model transformations. Model transformation, a concept taken from software engineering, describes how models, each representing a different perspective on the subject matter, can be transformed into other models through the use of formal grammars and rewrite systems. Model transformations for game design provide theoretical leverage to automate certain aspects of the design process, as will be illustrated with the discussion of some experimental software prototypes that generate game content.

In Chapter 8 I will evaluate the applied theory and the tools developed during this research and answer the main research question: what structural qualities of game rules and game levels can be used in the creation of applied theory and game design tools to assist the design of emergent gameplay? I will discuss the result of integrating them into the game development courses taught at the Hogeschool van Amsterdam (Amsterdam University of Applied Sciences) and the workshops I have hosted at several industrial and academic conferences. The reception of the tools and theory presented in this dissertation by students, industry veterans, and academic peers is an important aspect of its validation.

1.8 Terminology

The following terminology is used throughout this dissertation:

- A game is a system in which players engage in artificial conflict, defined by rules, that results in a variable, quantifiable outcome affected by player effort and ability.

- Gameplay is an emergent property of the game as defined by its rules. Gameplay is a qualitative measure of player actions and experience; good games are said to have gameplay.

- The mechanics of a game is a set of rules governing the behavior of a single game element. These rules are specific: for example, a mechanism specifies exactly how fast a character moves, how high a character jumps and how much energy this costs. In this dissertation I will prefer using “game mechanism” over the slightly awkward, but commonly used, singular form of “game mechanic”. This dissertation focuses on discrete game mechanics, not on continuous physics, as these mechanics generally offer
more design-freedom and are less well understood because the reference systems available to model discrete mechanics on are less established.

- The core mechanics of a game are those mechanics that players interact with most frequently and which affect the gameplay the strongest. The boundaries of this set are fuzzy.

- The internal economy of a game is constituted by the production, flow and consumption of game resources. These resources include, but are not restricted to, power-ups, collectibles, points, items, ammunition, currency, health and player lives. These resources can be tangible or abstract. The structure of the mechanics that determine the production, flow, and consumption play an important role in the emergent gameplay of the game.

- A level is a particular spatial and/or logistical structure in a game that dictates what challenges players encounter. Typically, a level contains a set of positioned game elements and/or scripts to control special events and players’ progress through the game.

- Emergence in games refers to the fact that the behavior of certain games is the result of a complex and dynamic system of rules. This means that for these games the number of possible states is huge: relatively few, and often discrete mechanics can create a large number, sometimes even infinite, of possible states. Emergence is an important source of gameplay and replay value, but it is also very hard to predict, design and control.

- Progression in games refers to the structures in games where a designer outlined the possible game states beforehand, usually through level design or through some form of game scripting. Progression offers much control of the play experience but has the disadvantage that it generates relatively low replay value.

- Feedback occurs when a change in the current state of a particular element in a system affects the state of the same element at a later time. Feedback requires that a closed circuit of causality causes the effects of the state change to ‘feed back’ into the new state. Feedback plays an important role in those structural qualities of game mechanics that contribute to emergence and emergent gameplay.