Real-time Analysis of Skin Conductance for Affective Dynamic Difficulty Adjustment in Video Games

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Abstract

As video games continue to penetrate the mainstream, their target audiences expand and diversify. For this reason, it is unreasonable to expect a video game with static difficulty levels to cater to an audience with a variety of skills and emotional traits. *Affective dynamic difficulty adjustment*, one of the many areas of exploration within the nascent field of *affective gaming*, is a high-level design concept that is intended to leverage the player's indicators of emotion (often physiological) to manipulate the difficulty of a video game in real-time. A review of two dozen studies reveals that skin conductance – the most widely used physiological response system in the history of psychophysiology – can be used to modify the difficulty of a video game, but it is most effective when paired with other psychological indicators of emotion, such as heart rate. Overall, a cross-disciplinary review of over 90 publications provides readers with a comprehensive view of the history, current works, future challenges, and design issues pertaining to *psychophysiology, affective gaming,* and other related fields. To illustrate one way in which skin conductance can be used to inform an *affective dynamic difficulty adjustment* algorithm, a top-down shooter titled *Electroderma* is created. A performant emotion-sensing algorithm, titled *data subset analysis*, is developed by the author as part of the game. Initial results for both the game and algorithm are promising, but usability testing must be conducted to formally validate the author's work.

Chapter I: Introduction

Valued at over $100 billion [1], the video game industry is the largest entertainment industry in the world, eclipsing film and music. Perhaps the greatest reason video games are so popular is because of the level of interactivity they offer versus other forms of digital entertainment; interaction with a video game and its core systems fulfills a number of basic psychological needs, namely that of competence, autonomy, and relatedness [2]. However, the dynamicity of video games introduces some design aspects unique to the medium. Of particular relevance to this thesis is the design concept of video game difficulty balancing. To be entertaining, a video game must neither be too easy or too hard [3], [4]; furthermore, the design and the difficulty level of the video game must be able to accommodate different players with different skill levels. Today, there exist two accepted methods for modulating the degree of challenge offered by a video game: *difficulty selection* and *dynamic difficulty adjustment* (DDA).

1.1 Problem Definition

The aforementioned game difficulty adjustment methods, difficulty selection and dynamic difficulty adjustment are commonplace in the video games industry, but they are subject to a number of limitations. The *difficulty selection* model provides a fixed degree of challenge based on the difficulty level chosen by the player (typically easy, medium, or hard). As such, the experience offered by the video game does not dynamically adapt to the player and their skills. On the other hand, implementation of dynamic difficulty adjustment algorithms *does* allow a game to tailor the experience to the player based on their in-game performance, but since the variability of these algorithms strip a considerable amount of control out of designers' hands and introduce unique, non-trivial design issues, very few commercial developers have implemented DDA systems for their games [3]. Furthermore, both difficulty selection and DDA share an inherent disadvantage in that they are bound to the "virtual world"; neither design approach takes into account players' physiological indicators of stress, such as their heart rate or skin conductivity.

1.2 Objective

The core objectives of this thesis are: a) to provide a comprehensive evaluation of current methods of modulating difficulty in video games, b) to evaluate the reliability of *electrodermal activity* (defined in chapter 2) as a measure of stress and cognitive load, c) to identify a correlation between gameplay and these responses, and d) to discuss a new method of real-time difficulty adjustment that works by adjusting in-game factors based on the player's electrodermal activity measurement. To provide a real-world case for the use of physiological responses as a means of dynamically adjusting video game difficulty, an electrodermal activity-sensing game will be created in the Unity game engine. Exploration of objectives b) and c) will consequently determine if electrodermal activity is a suitable variable for modulating the difficulty of a video game.

1.3 Thesis Overview

Chapters 2, 3, and 4 introduce, discuss and provide historical perspectives on topics that form the core of this thesis. More specifically:

Chapter 2 serves as a primer on the psychophysiological concepts that are referred to throughout the document; it introduces the *arousal-valence* theory of emotion and relates it to the physiological process of *electrodermal activity*.

Chapter 3 delves into the domain of game design and discusses two topics of particular relevance: difficulty adjustment and *flow*.

Chapter 4 introduces the concept of affective gaming, which bridges the topics discussed in previous chapters. Namely, it discusses how players' physiology can be utilized to dynamically adjust the difficulty of a video game.

The latter four chapters evaluate more contemporary information:

Chapter 5 assesses the state of difficulty adjustment and affective gaming in academia and the mainstream. A wide variety of studies, research projects, and commercial applications are analyzed for the purpose of providing further support for claims made throughout the thesis.

Chapter 6 speculates about the future of affective gaming and dynamic difficulty adjustment.

Chapter 7 offers readers a detailed deconstruction of the workings of *Electroderma*, a game built specifically for this thesis.

Chapter 8 briefly summarizes the assertions, findings, and implications of the thesis with an eye on the future of video games and computing.

Chapter II: Psychophysiology

The human body is in a constant state of activity. Whether we are in a state of motion or in rest, incessant biological processes occur within the body, all of which seek to aid in healthy functioning and survival. However, it would be foolish to assume that the internal workings of the human body occur autonomously, with no influence from stimuli, internal or external. In fact, the processes that occur within us affect and are affected by the workings of our minds. *Psychophysiology*, a branch of psychology, seeks to affirm such a link; a primary focus of the field is to explore the way that the mind and the body interact [5]. Within this diverse, ever-growing field of research, two concepts particularly pertain to this discussion: *emotions* and *electrodermal activity*.

2.1 Emotions

Emotions – also known as affects[1] – form a hugely important part of the human identity. They color our social interactions, behavior, decision-making processes and otherwise shape the way that we perceive and interact with the world around us [6]. A widely-accepted theory developed Lang [7] suggests that emotions are best classified based on two interrelated components: *arousal* and *valence*. In layman's terms, *arousal* describes the intensity of a felt emotion, ranging from calmness to excitement. *Valence* identifies the inherent positivity or negativity of an emotion; low valence is associated with unpleasant emotions such as sadness or depression, whereas happiness and elation are examples of emotions with high valences [8]. These two components do not exist independently of one another. To accurately describe an emotional state, one needs to identify both the arousal and valence of the felt emotion. As such, there is a relationship between the two concepts such that different combinations of valence and arousal produce different emotions (Fig. 1) [9].

Of course, emotions are not simply abstract, invisible states of mind; changes in emotion manifest themselves through physiological changes in the human body. Some of these changes are clearly visible to the naked eye: sweating, cutaneous blood flow (blushing or turning pale),

[1] The psychology community emphasizes that there is a distinction between affect and emotion, but this difference is pedantic in the context of this thesis.

and piloerection (involuntary raising of hairs on the body) can all be observed through sight alone, albeit informally. Other responses, such as changes in heart rate and skin conductance occur within the human body and can only be assessed through empirical analysis of measurements from specialized devices and sensors. Readily observable or not, all physiological manifestations of emotion are triggered by the autonomic nervous system, a branch of the nervous system that is responsible for controlling the body's flight-or-fight response and involuntary bodily functions, such as respiration and heart rate [10], [11]. As such, it is widely accepted that one's emotional state can be inferred through measurement of physiological changes in the body [12]–[16]. Emotions are also a vital part of our experiences with interactive entertainment, helping shape decisions made during gameplay [17].

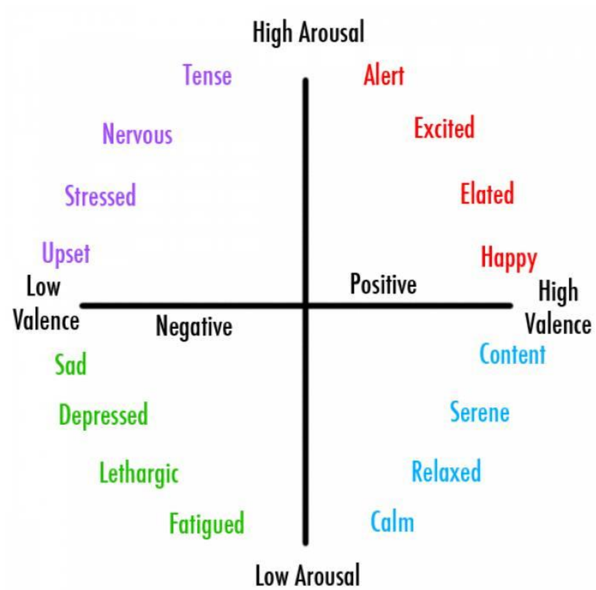

Figure 1. As per Lang's theory of emotion, different combinations of arousal and valence produce different emotions [9]

2.2 Electrodermal Activity

Electrodermal activity (EDA) is a broad term that describes changes in electrical properties of the skin based on exposure to either internal or external stimuli. The most widely-studied (and most relevant) facet of EDA is *skin conductance* (SC), which is a measure of how electrically conductive the skin is. When an individual is exposed to certain types of events or stimuli, the electrical conductivity of the skin changes momentarily, which in turn can be measured by passing a small electrical current through the skin. Events that are of a novel, intense or significant nature typically trigger a sharp increase in skin conductivity [18]. SC has also been shown to be a reliable indicator of cognitive activity [19]–[22] and an individual's emotional state [13], [23]. Most importantly, individuals are generally unable to explicitly control their levels of SC, meaning that it can be almost guaranteed that all changes in conductance result from unconscious processes in the body [24].

Generally speaking, SC is arguably the most useful indicator of arousal within the autonomic nervous system because it is not affected by the normal, at-rest functions of the human body [20]. Thus, when an individual is taking a math test, for instance, their skin would become more conductive as an indication of the additional cognitive load imposed by taking the test. As a similar example, one's SC is different when one is relaxed versus when one is elated. It is worth noting that changes in SC are best observed and measured via an individual's palms, fingers, forearm, or the soles of their feet [25]. The Galvactivator (Fig. 2), a glove-like instrument, is an example of a device that measures the wearer's skin conductivity via their palm. Chiefly due to its trivial measurement and the low cost of associated sensors, EDA is one of the most widely used physiological measures and has seen application in a wide variety of domains, including affective computing and video games [26].

The notion of skin conductance is nothing new in the psychophysiological community. In fact, research on the matter dates back to 1878, when Hermann and Luchsinger noted a connection between sweat gland activity and electrical current in the skin. Since then, electrodermal activity has been widely observed and studied by members of a number of scientific communities. In older literature, EDA has been referred to as *galvanic skin response*, *skin conductance*, *electrodermal response* and a myriad of other terms. For the sake of reducing ambiguity and redundancy, the term *electrodermal activity* has been standardized as a descriptor for all electrical phenomena in the skin [27]. However, the older terminology persists in current literature. Hence, some diagrams referenced throughout this thesis refer to electrodermal activity as galvanic skin response – GSR.

Figure 2. The Galvactivator, a glove-like instrument that measures the wearer's skin conductivity [18].

2.2.2 How Skin Conductance Works

The skin serves many functions: it prevents entry of foreign materials in the body, aids in the regulation of body temperature, and is a key instrument in the maintenance of the body's water balance. The latter two functions, temperature and water regulation, are accomplished through the production of sweat. In turn, sweat production is regulated by the body's sweat glands, of which there are two types: the eccrine and the apocrine. Up until this point, perspiration-related research has focused on the function of the eccrine sweat glands, largely due to their novelty. These glands cover the majority of the human body but are densest on the palms and the soles of the feet. Although their primary function is to assist in the regulation of body temperature, findings have revealed that eccrine glands on the palms respond more to emotional stimuli than to thermal stimuli. Such emotionally arousing stimuli, positive or negative in nature, activate the body's autonomic nervous system. In response to this, the autonomic nervous system orders the eccrine glands to produce sweat. This increase in perspiration changes the skin's moisture content, which ultimately affects how electrically conductive the skin is. It is worth mentioning that sweat is initially released far below the skin's external layer; as such, changes in skin conductance can be observed even if a person is not visibly sweating. Readers interested in further exploring the physiological processes behind skin conductance can consult [27], [28].

2.2.3 The Components of Skin Conductance

Thanks to its dynamicity and intricacy, the human body is full of data that can be measured, analyzed and leveraged for different purposes. Even in the case of skin conductance, different methods of measurement can reveal different patterns and trends of electrical conductivity. There are two major of components of skin conductance, each of which corresponds to different processes within the body: *skin conductance responses* and *skin conductance level*.

Skin conductance responses (SCRs) are the body's physiological responses to discrete stimuli – sights, smells, sounds – and cognitive processes. Such responses are typically sudden in nature and manifest themselves in abrupt, short-lived increases in skin conductance. On the other hand, *skin conductance level* (SCL) can be thought of as a smooth, slow-changing process. It is typically used as a measure of one's overall skin conductance, absent from the influence of particular events or stimuli. Measurement of SCL can be accomplished by computing an average of one's skin conductance over an extended period of time – typically from a few seconds to a few minutes. Of course, since SCL and SCR represent inherently different things, each should be measured for a different purpose. If a researcher seeks to identify small, minute physiological responses to particular stimuli (a frightening image, for example), he or she should measure participants' SCRs. Conversely, measurement of SCL would be most appropriate in situations where researchers wish to assess participants' overall levels of physiological arousal over an extended period of time. Fig 3 helps illustrate the distinction between the two concepts; the red line represents SCRs (the circled regions represent the largest responses), and the white line represents the underlying SCL [29].

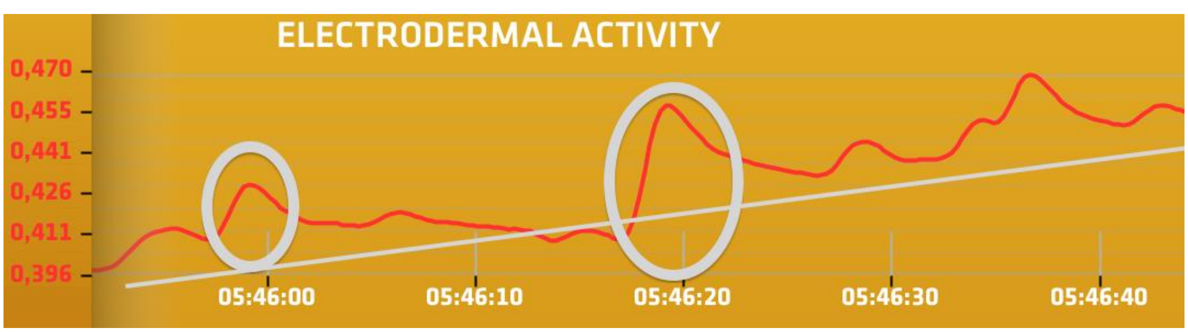

Figure 3. Skin conductance responses and level [29].

Chapter III: Game Design

3.1 Methods of Adjusting Difficulty in Games

Video games serve a wealth of purposes and use cases, but their general function is to entertain players [30]. Obviously, there is no predefined, prescribed way to make a video game “fun”; during the process of game development, an enormous number of design aspects must be considered. An especially important design consideration is that of difficulty. A game is boring when it is too easy, and frustrating when it is too difficult [3], [4], and the concepts of “easy” and “difficult” are subjective and vary based on the player and their skill level. Generally speaking, there are two ways that a video game can modulate the degree of challenge that it offers to the player: via *difficulty selection*, or through *dynamic difficulty adjustment* (DDA).

The difficulty selection method works by presenting players with a number of difficulty options (e.g. easy, medium, hard) before entering gameplay; at this point, the player chooses the difficulty level that they believe most closely corresponds to their skill level. The number of difficulty levels and the challenge they offer are pre-determined by designers during a game’s development process. As such, subsequent replayings of the game at the same difficulty level will produce largely the same play experience.

As video games continue to penetrate the mainstream, their target audiences expand and diversify. For this reason, it is unreasonable to expect a video game with static difficulty levels to cater to an audience with a variety of skills and emotional traits [31]. In addition, the use of the aforementioned static method may cause undue stress or boredom in players because the game has no way of assessing the challenge level that best matches the player’s skills. To address the rigidity of fixed difficulty levels, a growing body of research has been developing on dynamic difficulty adjustment (DDA), which, above all, seeks to dynamically adapt the difficulty of a difficulty of a video game to the current player’s skill level. At a basic level, DDA works by adjusting in-game factors and variables in real-time in response to well or how poorly the player is performing in the game. To help fulfill this task, DDA implementations typically make use of three interconnected modules [3], [30]:

- A *monitoring engine* that records raw player performance metrics (e.g. level completion times, player health, number of deaths), and passes them along to the analysis engine. The monitoring engine may also collect data from specialized physiological sensors to help determine the player's stress level, among other things.
- An *analysis engine*, which runs computations on raw data it receives to determine which elements of the game should be adjusted to provide a better experience for the player.
- Finally, a *game engine/control engine* that adjusts the game components as dictated by the analysis engine.

If designed correctly, a large portion of a game's elements can be adjusted dynamically. These elements are classified into three core groups [30]:

- *Player character attributes*; e.g. health, jump height, damage inflicted to enemies.
- *Non-player character (esp. enemy) attributes*. Since non-player characters are controlled directly by the game, a larger number of factors can be adjusted dynamically. These include not only fundamental attributes, such as health, but also decision-making processes, such as path-finding algorithms. Thus, the better the player plays, the smarter enemies appear to become.
- *Game world and level attributes.* The structure and design of game levels have been proven to have an impact on a game's difficulty [32]. With this in mind, developers can design their games so that the world shifts in subtle, transparent ways to aid the player along their journey. For example, in a platforming game that relies heavily on jumping puzzles, the distance between platforms could be adjusted to reduce the emphasis on jumping dexterity and precise timing.

Bailey and Katchabaw [30] also argued that the ability to adjust the difficulty of puzzles should also be a consideration when designing a DDA system, but due to the static nature of puzzles in video games, this may not be feasible [33]. Ideally, a DDA system should be subtle, invisible to the player during gameplay, and should optimally allow the player to disable or mitigate the dynamic changes made by the game [4], [33], [34].

Although DDA systems have seen a surge in both academic and commercial use in recent years, the concept is nothing new: examples of dynamic difficulty in games can be dated back to as early as the 1980s. *Astrosmash*, a 1981 Intellivision clone of the hit game *Asteroids*, assisted players by reducing the game's difficulty whenever it noticed that the player was running low on lives [33] (for an evaluation of recent titles that use DDA, consult chapter 3). More recently, some academic publications have affirmed the value of DDA systems in games. For one, an experiment conducted in 2005 by Robin Hunicke showed that integration of even a crude, shallow DDA system into a game can improve player performance [4]. However, "traditional" DDA systems share an inherent flaw: they rely exclusively on player performance metrics to determine what kind of alterations to make to the game. Pagulayan, Keeker, Wixon, Romero and Fuller noted that a player's affective (i.e. emotional) experience is a better indicator of an overall game experience than raw performance stats [35]. This seems like a logical conclusion: just because a player is slow to complete a level, for instance, that does not mean that they are bored or incompetent. The player may simply achieve more enjoyment from exploring the game's levels than from completing required objectives. Other research has supported Pagulayan et al.'s claims, emphasizing the importance of affective experience over performance metrics in determining overall player enjoyment [35], [36]. Based on this information, Liu, Agrawal, Sarkar and Chen have stated that the next generation of DDA mechanics should take into account both the player's performance and affective state [31]. Relatedly, recent literature has proposed the concept of *affective gaming*, which focuses on how emotions can influence and be impacted by gameplay and game design. Discussion on affective gaming is continued in chapter 4.

The aforementioned difficulty selection options are not mutually exclusive: some titles allow players to select their desired difficulty level but use DDA algorithms to fine-tune certain aspects of the play experience in real-time. Other games provide the option to disable their DDA components entirely [33], [37].

3.2 The Concept of Flow in Games

One of the most important roles of difficulty adjustment techniques in games is to optimize the difficulty for the player. This core objective may produce and closely relates to the concept of *flow*, which represents an intrinsic and energized focus in an activity, with a high level of enjoyment and productivity. Enjoyment in games has been closely linked to the concept of flow [38]. The term was originally coined in the 1990s by Hungarian psychologist Mihaly Csikszentmihalyi, who identified the eight components necessary to achieving flow in any activity [3]:

- A challenging activity requiring skill
- A merging of action and awareness
- Clear goals
- Direct and immediate feedback
- Concentration on the task at hand
- A sense of control
- A loss of self-consciousness
- An altered sense of time

When some or all of these criteria are fulfilled, the player enters a state of flow; they become wholly immersed in the game and lose track of time. In the domain of video games, flow is perhaps best visually represented as a balance of the relationship between challenge and activity (Fig. 4); to be wholly immersed in a game, the challenge provided by the game must match the skills of the player [38]. Otherwise, if the game is too difficult, the player will become anxious – or, if the game is too easy, it will likely produce boredom. A notable design issue with flow is that it

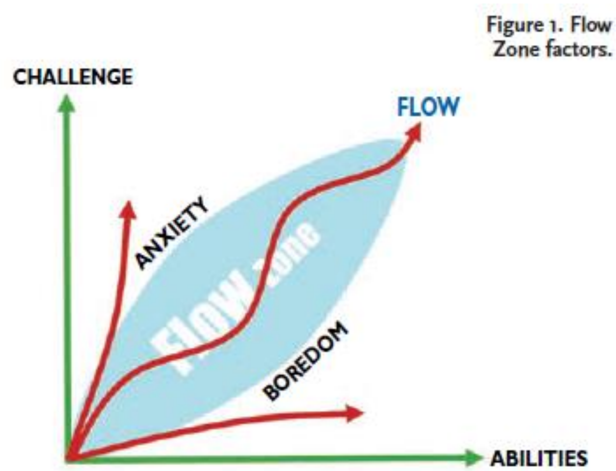

Figure 4. If the challenge provided by a game matches the player's abilities, the player enters the flow zone [3]

has to accommodate improvements (or any other changes) in the player's skill level over time as they play the game. Otherwise, the player will fall out of the so-called "flow zone" and their sense of fun will begin to falter. To help remedy this fact, a developer may choose to implement a DDA system in their video game that dynamically tailors the difficulty of the game to the skill level of the current player. In fact, renowned game developer Jenova Chen suggests that utilization of DDA is a key component for enhancing the flow of a game [3]. However, as will be soon revealed, DDA algorithms alone typically are not enough to provide a satisfactory flow experience for the player.

3.2.1 Implementation and adjustment of flow in games

A considerable portion of the game design process should focus on tweaking flow in a game. Unfortunately, proper integration of flow in a game is not a trivial task: different people have different skill levels, and, on top of that, the entire experience of flow is abstract and subjective – what one person considers entertaining and immersive may be off-putting for someone else. The subjective nature of flow makes in a difficult game design component to evaluate during playtesting [3]. Instead of focusing on implementing a static, "one-size-fits-all" form of flow in a game, developers should instead consider the concept of *dynamic flow*, which allows the game to dynamically tailor its experience to each player's unique interests and skill level. We will discuss two methods of accomplishing the aforementioned design task: *passive flow adjustment* and *active flow adjustment*.

Passive flow adjustment

This method of dynamically altering the flow of a game makes use of DDA techniques to generate a feedback loop of sorts. At a basic level, it works as follows: the player plays the game as normal while the monitoring system records raw data about how the player is doing (examples of such data in a first-person shooter include total kills, accuracy, and health). The monitoring system then runs a number of computations and passes flow-relevant data over to the analysis system. Upon receiving this data, the analysis system assesses the player's current flow state and lets the game system know what factors or variables to modify. The aforementioned factors are then modified by the game system, which in turn modifies the player's game experience. This cyclic sequence of steps runs continually throughout gameplay [3].

Theoretically, such a system should be able to keep the player within the flow zone by constantly reacting to the player's feedback, but evaluation of this model from the perspective of real-world use has revealed a number of potential issues [3], [30]. Namely: the raw stats collected by the monitoring system do not represent the "big picture" of fun and flow and thus can't accurately indicate if the player is having a positive or negative experience. This issue could potentially be resolved by feeding the player's real-time physiological data into the monitoring system, instead of just in-game statistics. This will be further explored in coming chapters.

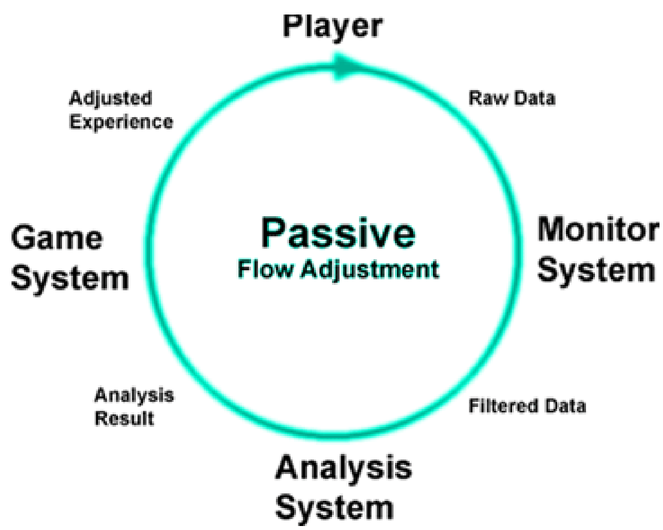

Figure 5. Passive flow adjustment [3]

Active flow adjustment

Active flow adjustment can be implemented in a game by embedding a network of choices and activities into the core of the game design; here, no central DDA system governs the flow experience. Instead, the game empowers the player to experience the game in their own way. If the player becomes bored, for instance, they could choose to play harder by selecting a choice that provides a greater challenge. In essence, this approach allows the player to control the flow of the game instead of passively consuming the flow experience offered by a DDA algorithm.

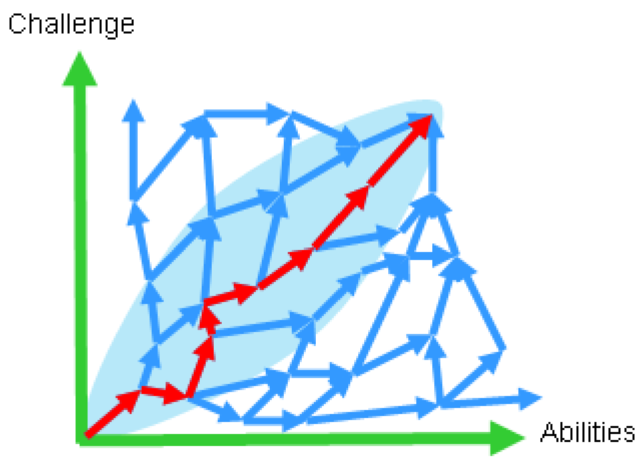

Figure 6. Active flow adjustment [3]

Because there is some overlap between flow and DDA, the concept of flow was taken into consideration when designing the project portion of this thesis (for more information, consult chapter 7).

3.3 Summary

Video games and their audiences are diverse in nature. There exist two design strategies that game developers can implement to accommodate different skill levels and ultimately make their games more enjoyable: *difficulty selection* and *dynamic difficulty adjustment*. The former is static in nature, requiring the player to explicitly select their desired level of difficulty before entering the game; the latter allows the game to fine-tune the degree of challenge it offers by assessing the player's level of performance in real-time. The concept of dynamic difficulty adjustment is certainly enticing and its validity has been affirmed by the academic community. At the same time, its reliance on raw player performance statistics means that it cannot see the "big picture" of the user's overall experience and that it can only make assumptions based on the limited amount of data it has. In response, some studies have suggested that the player's emotions are a far better indicator of their overall experience than statistics alone. Any difficulty adjustment approach should seek to achieve *flow*, an intrinsic and energized focus in an activity.

Chapter IV: Affective Gaming - the Integration of Emotion and Physiology in Games

The previous two chapters have respectively examined psychophysiology and game design, two concepts that, on the surface, have no apparent connection to one another. This chapter introduces the concept of *affective gaming*, which bridges the topics discussed up until this point.

4.1 What is Affective Gaming?

Humans are inherently emotional creatures. Emotions govern every aspect of our lives, from the way we make decisions, to how we interact with others, to the way that we perceive the world around us. Thus, for a game to be truly engaging, it must appeal to our emotional capacity in some way; it has to make us cheer, laugh, cry, or otherwise *feel* something. Thanks to ongoing technological advances, current video games can be made sophisticated enough to elicit emotion from players. However, modern games ignore the other side of this affective equation: they do not respond to players' emotions in any way, and as such are best considered as static entities that respond only to the listless, hollow input from game controllers. At its core, the field of *affective gaming* seeks to improve the coupling and relationship between our emotions and video games; it aims to develop a loop of interaction in which both the player and the video game can understand and respond to affective signals of one another [39].

In short, a major focus of research in affective gaming is to instill some kind of emotional intelligence in machines [34], [39]. Obviously, for a video game to understand and respond to the emotional signals of players, it needs to have some way of reading emotions. This feat can be accomplished by measuring certain physiological factors, such as one's EDA or heart rate [14], because, as discussed in previous sections, changes in emotion can elicit physiological changes in the body that are invisible to the naked eye. These physiological signals can be obtained through a number of means other than EDA, including electrocardiography [40], respiration [41], movement of facial muscles [42], and pupil size variation [43]. In addition to physiology, a game may evaluate the player's facial expression [44] or speech patterns [45]. A more unconventional approach, suggested by Skyes and Brown, involves inferring the player's affect by measuring the pressure at which the they depress buttons on the gamepad; testing conducted on the game *Space Invader* showed that the intensity of players' button presses increased with the difficulty of the game [46].

A particularly interesting example of an affective game that leverages players' physiological signals is *Affquake* [47], an experimental modification of first-person shooter *Quake II* developed in the late 1990s at the Massachusetts Institute of Technology. The Galvactivator skin conductance sensor was used to transduce skin conductance responses, which in turn modified minute aspects of the player's avatar. If the player became startled as noted by a sharp peak in skin conductivity, their avatar would mirror the reaction by quickly jumping back. Avatars also changed in accordance with the player's level of emotional arousal; the more excited the player became, the larger their avatar turned, which consequently made the player an easier target for enemies. *Affquake* certainly isn't the earliest example of an affective game; the active integration of human physiology and emotion in games dates back to the 1980s [39].

4.2 What makes a Game Affective?

Creating an affective game involves far more than simply shoehorning the concepts of physiology and emotion into the game's design. For a game to be considered *affective*, it needs to disseminate *affective feedback*, which in itself has two major criteria. First, the game needs to use emotions as a means of interaction. To illustrate this, consider a racing game which measures the player's excitement level to influence the speed of the car; the more excited the player is, the faster their car moves. Second, physiological responses from the player need to be uncontrolled. If the game requires the player to explicitly and consciously manipulate their physiology, then the second criterion is not met and the game becomes a *biofeedback* game. In games of this type, the player is aware of how their physiological responses affect the game and is thus able to consciously control their physiology. Conversely, affective games work with uncontrolled or "organic" emotions and physiological responses; in fact, the player may not even know that their physiology is being used to control certain aspects of the game [39]. Biofeedback games are often designed for medical or therapeutic purposes [39], [48]. Such games make players (i.e. patients) consciously aware of the biological processes occurring inside of them. Then, through gameplay, patients slowly learn to control physiological responses relating to their condition, with the ultimate intention of mitigating or eradicating the medical issue.

It is worth noting that not all genres of games can benefit from affective components. Gilleade and Allanson identified the action, adventure, puzzle and sports genres as suitable for affective gaming. Games of other genres, such as strategy and role-playing, are typically played at a slower pace and are more long-winded in nature, meaning that physiological measures of arousal are less likely to change substantially during gameplay [34].

4.2.1 Affect as a Method of Adjusting Difficulty

In a later paper, Gilleade, Dix, and Allanson proposed two general design heuristics that pertain to affective difficulty adjustment in games: *assist me* and *challenge me* [39]. The former heuristic focuses on reducing stress experienced by players during gameplay by providing assistance or cues for particularly difficult challenges, in a sense making the game more "sympathetic". To detect when to intervene, the game would need to analyze both the current context of the game and the player's frustration level as reported by physiological sensors. For example, consider a scenario in an RPG game where the player is fighting a boss (i.e. a powerful enemy character). If, for instance, the game detects that attempts to do damage to the boss have been largely futile and that the player's level of frustration has been rising, the game could provide hints as to the enemy's weak points, suggesting where to hit to inflict maximal damage. However, the use of this approach might not benefit experienced players, who see frustration as a crucial part of the gaming experience [49]. For this reason, the *challenge me* heuristic was designed with a wider range of player types and skill levels in mind. As part of this design approach, Gilleade et al. suggest creating what is essentially a DDA system that uses unconscious, automatic affective signals from the player to make adjustments to a game's difficulty. Boredom has been correlated with low levels of physiological arousal [15], [16]; with this in mind, one can develop an affective game that ramps up the level of difficulty when it detects low levels of arousal, and reduces the amount of challenge or stimuli when arousal exceeds an acceptable threshold. Affective games can go far beyond simply adjusting a game's difficulty, but this topic is beyond the scope of this thesis. For further reading on this subject, see [39], [50].

At this point in the document, it is important to create a distinction between two types of DDA:

- *Performance-based DDA*, which exists solely in the "virtual world"; such DDA implementations only assess performance metrics generated by the player's interactions with the game to determine how to best adjust the game to meet the player's skill level.
- *Affective DDA*, which uses the player's indicators of emotion, often physiological, to manipulate components pertaining to the difficulty of a video game.

Tijs, Brokken, and IJsselsteijn created a diagram that serves as a visual complement to the definition of affective DDA (Fig. 7) [51]. The depiction shows an affective loop in which the game analyzes data from physiological indicators of emotion and accordingly makes changes to the game state for the purpose of establishing an optimal level of difficulty.

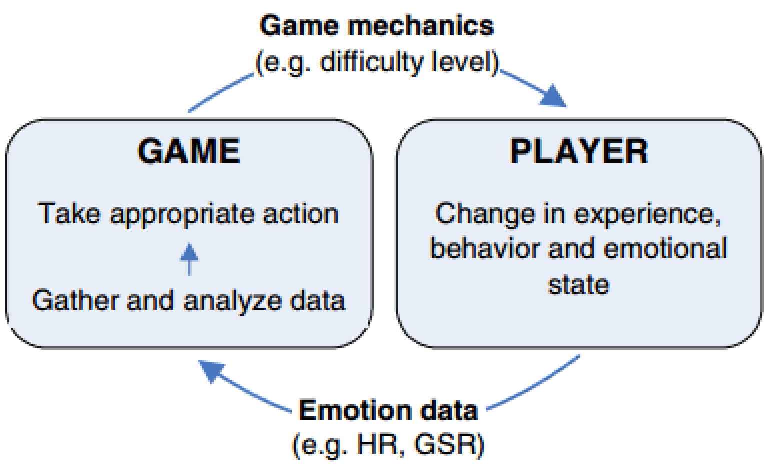

Figure 7. An affective loop between the player and game [51]

Just like the overarching concepts of difficulty levels and DDA, affective and performance-based DDA can coexist; some affective DDA implementations also use in-game performance metrics to help inform their decisions [39]. However, in commercial games, performance-based DDA is far more popular than its affective counterpart, likely because it requires no specialized devices to implement. From this point on, the author will distinguish between performance-based DDA and affective DDA when necessary.

4.3 Techniques for Emotion Detection and Modelling

As discussed in section 4.1, players' affect can be measured by a number of devices to varying degrees of effectiveness. No matter which devices are employed, software algorithms and techniques are required to deduce the player's emotions and otherwise make sense of the data. Because the field of affective gaming is still in the process of coming to fruition, there exist very few standardized software solutions for accomplishing such a task. In an attempt to taxonomize certain components of affective gaming, Yannakis and Paiva identified two high-level approaches for detecting and modeling emotions in games: *model-based* and *model-free* [52].

Model-based approaches are perhaps the more trivial to implement of the two. In these approaches, researchers and developers design their software algorithms around well-known theories of emotion, such as the theory of cognitive appraisal [53] or the circumplex model of affect [16]. In essence, use of these theories acts as a guideline when developing emotion-measurement algorithms. For instance, if a developer chose to utilize the previously-mentioned circumplex model of affect, in which physiological manifestations of emotions are mapped to distinct emotional states, the developer could implement logic to tell the game that the player is excited if his or her heart rate is elevated. At the same time, one must be careful when applying theories of emotion to the domain of video games, since the majority of them have not been tested for use in interactive media.

Although model-based approaches provide a simplistic way to integrate emotion into a game, they rely on rigid models and theories of emotion, which may not be suitable for use in a medium as dynamic as video games. Conversely, *model-free* approaches use no hard-coded rules for emotion recognition; instead, they employ machine learning techniques (e.g. fuzzy logic, artificial neural networks) or statistical analysis to derive players' emotional states based on raw data from both the game and biometric sensors. The process by which the model-free approach is implemented is intricate and lengthy. In most cases, participants are tasked with playing a traditional, non-affective game for a particular period of time while connected to specialized sensors. Researchers and developers then use one of many machine learning or statistical analysis techniques to derive a computational model that can effectively transduce physiological signals to affective states in real-time.

In practice, most emotion detection techniques used in video games and research projects contain elements of both model-based and model-free approaches. A considerable number of experiments have used various machine learning techniques to classify emotions based on Lang's arousal-valence theory [7], [13], [54]–[56].

4.4 Research Supporting the Use of Skin Conductance in Games

Thanks to crucial technological advances and an uptick in the popularity of affective computing [57], affective gaming too has seen a notable increase in interest from research communities and commercial game developers [34], [39], [42], [46], [58], [59]. With this has come a considerable of new information on the relationship between human physiological factors and emotions experienced during gameplay. This section will discuss studies and research related to physiology (specifically skin conductance) and games, affirming the link between the two concepts.

In 2006, a study performed by Mandryk, Inkpen, and Calvert found a statistically significant correlation between skin conductance response and subjective measures of fun in adult participants playing video games [14] (Fig. 8). Results from this study also show that participants' skin conductance levels (and subjective scores of fun) were higher when playing against a friend instead of a computer-controller opponent. Other measures of experience evaluated in the study, such as boredom, challenge, and frustration, were not found to have a significant correlation with skin conductance. Other research supports the correlation between skin conductance and fun in games [60], [61]. Relatedly, low levels of physiological arousal have been linked to boredom [14]–[16].

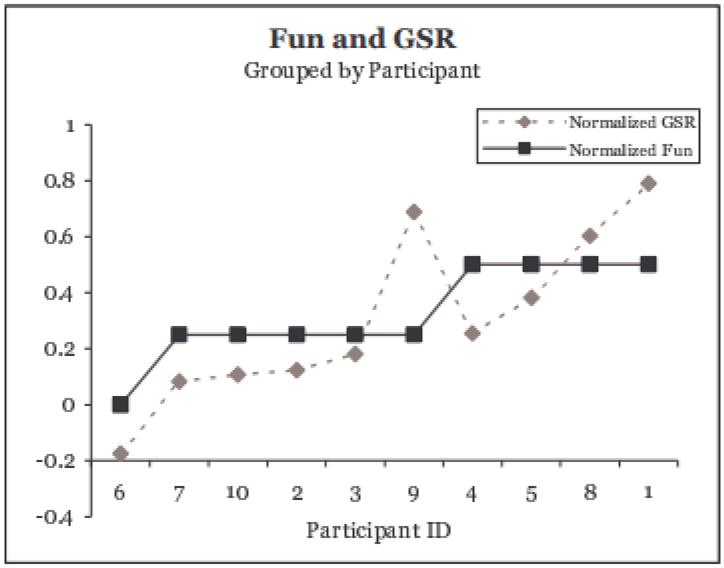

Figure 8. Correlation between users' skin conductance levels and subjective measures of fun [14]

More relevant to this thesis, however, is the relationship between frustration and electrodermal activity, since a game utilizing affective DDA could use measures of frustration to determine when to adjust game difficulty. In another study, Mandryk et al. noted a correlation between high EDA values and high levels of arousal, concluding that high EDA measurements can be indicative of challenge, frustration, and/or excitement, depending on the context of the gameplay scenario [13]. This conclusion is supported by earlier work by Frijda, who indicated that skin conductance levels rise in accordance to the difficulty of given tasks [53]. Others exploring this avenue of research have reached similar conclusions. Attempting to identify a correlation between video game difficulty and skin conductance, Singh found that the number of challenges encountered by players during gameplay had a direct impact on the number of GSR arousals, and the difficulty associated with completing the challenges foretold the magnitude of the arousal [62]. Tijs, Brokken, and IJsselsteijn discovered that players' skin conductance levels differed significantly when playing Pac-Man at different levels of difficulty [51]. Furthermore, Drachen et al. established a statistical correlation between high levels of skin conductance and frustration during gameplay [40].

Amalgamation and analysis of results of the aforementioned studies paints an incomplete picture: some associate fun with changes in skin conductance levels while others emphasize a relationship with frustration. Despite this, one can draw a few substantial conclusions. Most importantly, skin conductance can be used as an indicator of an individual's level of emotional arousal, since both enjoyment and frustration (both of which are emotional states that occur with high arousal) elicit high levels of skin conductance. This statement is supported by studies from the psychological community; it is generally accepted that skin conductance is a linear correlate with emotional arousal [7], [27], [63]. On the other hand, determining the valence of felt emotions based on skin conductance is not possible, since emotional arousal alone cannot indicate whether an emotion is of a positive nature (e.g. happiness) or a negative nature (e.g. frustration) [64]. This is not to say that skin conductance has no place in affective DDA systems. In fact, a number of experimental games using affect-based DDA implementations have shown that skin conductance is appropriate for use in dynamic difficulty adjustment when used in conjunction with other physiological measures, such as heart rate and muscular tension [31], [65]. There are two situations in which an affective DDA system may be able to solely use skin conductance to inform its decision-making processes: if the only affective goal of the system is to maintain an optimal level of arousal (section 4.2.1), or if the signal of arousal is coupled with the context of the game (section 4.5). Additional research on skin conductance in games is continued in chapter 5. Chapter 7 proposes a trivial (albeit somewhat naïve) method developing an affective DDA system solely based on skin conductance measurements.

4.5 Issues and Considerations Related to Physiology and Affective Gaming

There exist several design issues unique to affective games, especially those that incorporate real-time analysis of human physiology. There are three that are particularly pertinent to the discussion on skin conductance analysis: the *baseline problem*, timing-related issues, and the distinction of different emotional valences.

As the name suggests, the *baseline problem* refers to finding a neutral point of reference (a *baseline*) which changes in skin conductance can later be compared to. Simply designating a period of relaxation before gameplay is not sufficient because rest does not guarantee emotional equilibration [66]. In addition, due to the individual nature of skin conductance, it is impossible to designate a fixed baseline for all players [20]. To properly establish a physiological baseline, Levenson suggests presenting participants (players, in this case) with carefully-selected stimuli that generate a moderate level of activity in the autonomic nervous system [66]. So, for instance, before entering gameplay, a player could be shown a relaxation sequence consisting of soothing colors accompanied by calm music. An EDA measurement guide published by the University of Birmingham suggests that the baseline acquisition period be between 2 – 4 minutes [20]. At the same time, such a period may not be necessary for real-time computing applications. Chapter 7 discusses a trivial algorithm that organically classifies and normalizes skin conductance data.

Once a proper baseline is established, another issue to consider is that of timing, or, *how often should the game measure the user's physiological state*? This is an especially important question to address since some emotions manifest themselves in brief physiological arousals while others build up over time [66]. For most usage scenarios, the polling rate for skin conductance can be as low as 5 - 50 samples per second [67]. In cases where researchers seek to identify specific, minute correlations between particular stimuli and changes in skin conductivity, the polling rate is recommended to be set to at least 2000 samples per second [20]. In addition, changes in skin conductance in response to a stimulus are not instant; the latency period is typically between 1 - 4 seconds in length [28], [68].

Equally important to take into account is the valence associated with emotions. In other words, we need to consider if emotions experienced by the player are of a positive or negative nature. By itself, measurement of skin conductance cannot detect if a felt emotion has a positive or negative valence; in most cases, a spike in skin conductivity could equally indicate stress or elation [64]. It is only an accurate indicator of one's level of emotional arousal [7], [40], [63]. Thus, as indicated in section 4.5, accurate, thorough classification of emotions via physiology requires simultaneous measurement of multiple physiological factors. A number of machine learning techniques have been implemented to classify emotions and their valence, including fuzzy logic [13], auto-associative neural networks [69], and discriminant function analysis [70]. At the same time, some argue that in certain situations, explicitly capturing valence via physiology may not be required to infer one's emotional state. According to famed game developer Erin Reynolds, the player's feeling can be deduced by coupling their level of emotional arousal with the current context of the game. For instance, if an affective game detects that the player is in a state of high emotional arousal but their character's health is low, it would assume stress or frustration. Conversely, a combination of high health and high emotional arousal could be used to imply enjoyment or excitement. Biofeedback horror game *Nevermind* used a similar arousal-context coupling technique to good effect [48].

A few less substantive issues may need to be considered as well. In the 2003 paper *Affective Gaming: Measuring Emotion Through the Gamepad* [46], Sykes et al. argue that the very act of playing a game may corrupt or interfere with the player's physiological signals. They assert that this is particularly true for fast-paced games, where the arousal imposed by constant sensory information may cause excess perspiration and in turn alter the player's level of skin conductance. For instance: while playing *Doom*, an abrasive, violent first-person shooter, the player is likely to be in a constant state of elevated emotional arousal, so measuring the player's skin conductance (or any other physiological factor, for that matter) may not provide data that can be usefully leveraged in any way. However, it would be foolish to use this argument to wholly dismiss the concept of affective gaming. Just like not every game mechanic or feature is suitable for incorporation in every video game genre (it would not make sense to incorporate shooting mechanics into a *Super Mario* game, for example), not every game can be made affective. In fact, Sykes et al.'s pessimistic view serves to reinforce Gilleade et al.'s reasonable assertion that some genres and styles of games cannot benefit from affective components [34].

Chapter V: The State of Difficulty Adjustment and Affect in Games

5.1 Performance-based DDA in Games

5.1.1 Recent Examples of Performance-based DDA in Commercial Titles

DDA is a broad design concept and has thus been implemented differently in different games. Below are some examples of high-profile commercial titles that have integrated performance-based DDA in their design.

Left 4 Dead (Valve, 2008)

Although Left 4 Dead's developers insist that the game's algorithms modify the pacing of the gameplay, *not* its difficulty [71], the game is nevertheless a compelling example of a commercial release that assesses and manipulates in-game variables with the ultimate intention of providing a more entertaining play experience. The co-operative shooter is most notable for its incorporation of a so-called "AI Director", a software module designed in-house by game developer Valve that adjusts the quantity and location of pertinent game elements (such as enemies, health packs, and ammo pick-ups) by analyzing a number of player performance metrics, such as the player's health [72]. Not only does the implementation of such a system promote replayability, but it also generates "dramatic pacing", that is to say, algorithmically-generated pacing that seeks to maximize intensity and player excitement. Valve president Gabe Newell largely attributed Left 4 Dead's success to the custom-tailored gameplay made possible by the Director.

The game's 2009 sequel further expanded on the sense of dynamicity by featuring a revamped version of the AI director that procedurally adjusts weather effects, lighting, and pathways in levels to match the player's performance [73].

The Elder Scrolls IV: Oblivion (Bethesda Softworks, 2006)

Not all commercial implementations of DDA are wholly successful. Released in 2006 to universal critical acclaim [74], *The Elder Scrolls IV: Oblivion* is an open-world RPG that allows players to explore and interact with their surroundings as they wish. As players progress through the game, their character increases in level and is accordingly granted new skills and abilities. One facet of the game's design that has received some criticism over the years is its implementation of DDA. Essentially, the game's difficulty adjustment systems work by assessing the player's current stats (more specifically, the level of their character) to make adjustments to the state of the world; factors that are dynamically modified by the game include the how and when enemies spawn, the types of armor and weapons worn by friendly and non-friendly non-player characters (NPCs), and even the prices of items in the game's shops. An unfortunate side effect of the dynamic nature of the game's world is that in some cases, completing certain objectives were made unfairly difficult – if the player's character reaches a certain level, some items required for completion of particular quests will not spawn as originally intended by the game's logic [75]. One could also argue that the adaptive nature of the enemies also diminishes the game's sense of progression; since the game's enemies constantly evolve to closely match the player's level, the player may feel that they are merely catching up to enemies in terms of skill, and not gaining an advantage over them throughout the course of the game.

Mario Kart Series (Nintendo, 1992 – present)

Titles from Nintendo's Mario Kart series are just a few of many racing games that use a controversial form of DDA called *rubber banding* to provide the illusion of fairness. If the player gets too far ahead of AI-controlled racers, the system ratchets up the speed of opponents. Similarly, if the player falls behind the pack, enemies will drive slower to provide the player an opportunity to catch up. In the particular case of Mario Kart, the game is also more likely to provide more powerful items the closer the player is to last place [72].

5.1.2 DDA in Research and Academia

Robin Hunicke's oft-cited paper, *The Case for Dynamic Difficulty Adjustment in Games*, provides a sound case for the effectiveness of "traditional" DDA that solely modifies game parameters. As part of the research, a DDA system, dubbed *Hamlet*, was created and integrated into *Case Closed*, a custom game built upon Valve Software's *Half-Life* engine. The custom-made system assessed a number of in-game factors, such as damage taken by the player over a period of time, to determine the player's chance of death. If the calculated chance of death is high, Hamlet intervenes, placing down additional health kits or adjusting enemy health to gradually decrease the difficulty of the game. Testing affirmed the effectiveness of this particular DDA approach; participants that played the “dynamic” version of the game experienced fewer in-game deaths than those who played the “standard” version of the game. Furthermore, there was a small correlation between the perception and actuality of game adjustment, implying that the adjustments made by Hamlet were transparent to the users. Hunicke concludes that even simple, crude adjustment algorithms can improve player performance in games [4].

As discussed in chapter 2, one of the facets of a game that can be modified by a DDA system is level design. Jennings-Teats, Smith, and Wardrip-Fruin show a real-world application of this idea with *Polymorph* [76], a 2D side-scroller that collects and uses data from players to aid in the procedural generation of its levels. For the purpose of the project, the researchers created a web-based tool that asked users to complete multiple short (10-second-long) level segments and rate them based on difficulty, on a scale of 1 (easy) through 6 (hard). This data, along with other statistics collected during gameplay, were then used train a multilayer perceptron, which classified the level segments based on difficulty. In turn, the game component of Polymorph dynamically pieced together the aforementioned segments during gameplay to create full levels, using the perceptron-computed data to help determine the order and sequencing of the segments. It is important to note that Polymorph’s form of DDA does not completely bend over backward to accommodate the player’s skill level. Instead, the game follows a difficulty curve to gradually increase the level of challenge, only adjusting the curve when the player’s performance drastically declines as marked by a substantial increase in the number of character deaths. To the best knowledge of the author, Polymorph is no longer available for play online.

In 2006, Spronk et al. proposed a novel DDA technique, entitled dynamic scripting, as a means of modifying enemy behaviors in accordance with player skill [77]. This approach is able to generate sets of behavioral rules (*scripts*) from predefined rulebases to control NPC behaviors. Scripts are created dynamically by assessing weight values associated with rules in the rulebase; the higher the weight, the more likely the rule is to be selected. These weights are continually adjusted according to their success rate in the game (success is measured by a number of factors, including how much the execution of the rule affects the player’s performance). To demonstrate the applicability of dynamic scripting in large-scale commercial games, Spronk et al. implemented the system in the existing role-playing game *Neverwinter Nights*. Not only did the dynamically-scripted AI implementation provide a better play experience than the standard AI, testing showed that Spronk et al.'s implementation easily met requirements for efficiency and scalability.

5.2 Flow in Games

Created by previously-mentioned game designer Jenova Chen, *FlOw* [3] is arguably a seminal example of flow integration in games. In it, players control an organism swimming around an ocean; the game's main objective is to grow the organism by consuming other creatures floating in the depths of the ocean. The game was designed to use active flow adjustment so that players are always in control of their play experience. For instance, if at any point the player is intimidated or overwhelmed by the difficulty of any one of the game's 20 levels, they can eat a special pellet to return to the previous, easier level; similarly, levels can be skipped altogether. The web-based game was downloaded over 350,000 times within the first two weeks of release and received a warm reception from players.

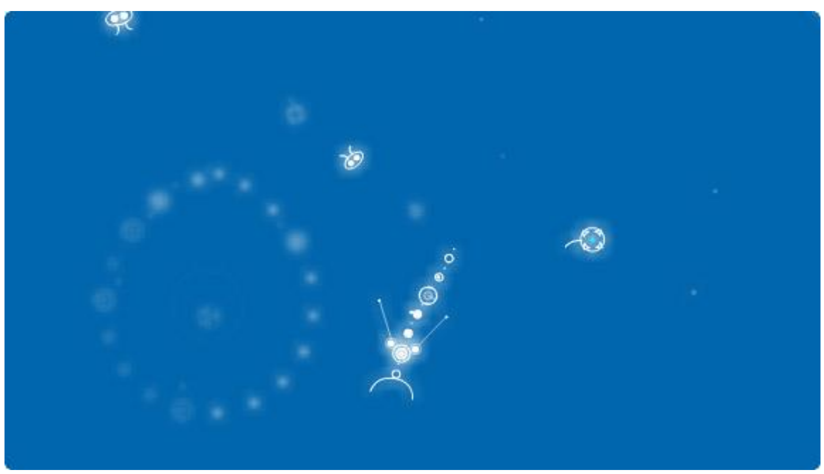

Figure 9. Scene from FlOw, a game by Jenova Chen [78].

5.3 Affective and Biofeedback Gaming

5.3.1 Affective and Biofeedback Games in the Mainstream

At this point, the marriage between physiology and games is in a nascent stage, so commercial examples of affective games are few and far between. The unfortunate truth is that the majority of commercial affective and biofeedback games, save for a few exceptions, fall into the category of "gimmicks"; they do not fully exploit the wealth of capabilities offered by physiological input and instead rely on novelty as a selling point. Even such inconsequential examples are worth discussing solely for the sake of illustrating how biometrics-based games have evolved over the past few decades.

In as early as the 1980s, companies were already experimenting with biofeedback in interactive media. At the 1983 Consumer Electronics Show, Atari demonstrated *Bionic Breakthrough*, a clone of arcade hit *Breakout* in which players controlled their on-screen ping-pong paddle by flexing their forehead muscles. This method of interaction was made possible by Atari's MindLink, a headband-like device measured electrical conductance in the wearer's forehead to control some facet of the game. The MindLink was slated for launch the following year but was scrapped after testing revealed that players frequently got headaches from having to continually tense and relax their forehead muscles [39]. However, the abortion of Atari's device did not mean that 1984 was a fruitless year for physiology-based games; that year, Canadian biofeedback equipment manufacturer Thought Technologies released the GSR2, a version of the Apple Mouse II embedded with skin conductance-measuring electrodes. A few applications and games were released alongside the GSR2, ranging from a stress-relief solution to a racing game in which the player's skin conductivity level influenced the speed of their car. Later, in 1998, Nintendo released a version of Tetris packed in with a heart rate monitor; the game assessed the user's heart rate to optimize the speed and difficulty of the game [79].

As the body of research on affective gaming has grown, companies have begun to take the concept more seriously. A 2013 interview with PlayStation lead architect Mark Cerny revealed that Sony had trialed EDA sensors in prototype versions of the PlayStation 4 controller to detect players' stress levels [58]. Ultimately, the feature was left out of the final version of the controller.

Cerny never disclosed why this was, but one can imagine that costs associated with integrating such a sensor might have steered the company away from the idea.

Valve Software, another major force in the gaming industry, has shown a great interest in affective gaming, going as far as creating prototype versions of games that leverage players' physiological measurements. Company president Gabe Newell has gone on record to affirm his support for the integration of physiology and emotion analysis in games, suggesting that even simple proxies of player state, such as skin conductance and heart rate, can be used to provide more interesting and compelling play experiences. This claim has been supported by internal testing within Valve; the company experimented with biometrics by integrating them into an internal version of the aforementioned online shooter *Left 4 Dead 2*. Various biometric feeds were analyzed by the game to derive a player's "arousal state", which was then sent over the internet to players on the same team. With this, players on a team could see each other's levels of emotional arousal via the game's interface, which according to the developers, added a layer of humanness that fundamentally changed the way users played and interacted. Fueled by positive feedback from internal testers, the company has pledged to continue research on physiology integration in games [59]. This is not to say that there are no biometrics-based games on the market today. Two recent releases are worth discussing: *Nevermind* and *Ozen*.

Figure 10: Integration of physiological measurements into cooperative zombie shooter Left 4 Dead 2 showed promising results [80].

Masterminded by veteran game developer Erin Reynolds, *Nevermind* [48] is an adventure horror title that uses the player's stress level to adjust the difficulty of the game. Stress levels are assessed via a device that measures the player's heart rate variability. Of course, since *Nevermind* is a horror game, players will inevitably encounter gruesome, shocking, or unsettling situations during their time with the game. In such situations, the player must try to remain calm, even in the face of fear; if the game detects high levels of stress, it modifies aspects of the game world to intentionally impede the progress of the player. The ultimate intention of this feature is to help players become more aware of their stress signals, which, according to Reynolds, will eventually grant players the skills to mediate and reduce their stress levels when faced with demanding situations in the real world. Although *Nevermind* may appear to be an affective game at first glance, it is best classified as a biofeedback game since it requires players to consciously exert control over their physiology to succeed. Since its release, the game has enjoyed positive feedback from players [81].

With its bright, inviting color scheme and honeyed stylization, Ubisoft's *Ozen* [82] clearly seeks to appeal to a different audience than *Nevermind*. The differences are more than skin deep, however; although *Nevermind* and *Ozen* are both biofeedback games, the latter differs in the sense that it actively emphasizes the real-world benefits that can be acquired through playing the game. The activities, challenges and mini-games found within *Ozen* all seek to regulate one's breathing patterns, which according to developer Ubisoft, can help the player achieve cardiac coherence. The physiological benefits of cardiac coherence are plenty: if such a state is achieved, one can experience lower stress levels, improved blood pressure, and an overall state of emotional wholeness [83]. *Ozen* is available solely on mobile devices; a specialized heart rate sensor connects to the user's smartphone or tablet to measure their breathing pattern during gameplay.

As of March 2016, no recent examples of commercially-available affective games could be found.

5.3.2 Research on Affective and Biofeedback Gaming

The research analyzed in this section continues the discussion from section 4.4 and serves to strengthen the justification for the integration of skin conductance and physiology in games.

Liu, Agrawal, Sarkar, Chen [31] conducted an exhaustive experiment that sought to compare the effectiveness of performance-based DDA (i.e. DDA that analyzes only in-game player statistics) versus affective DDA, which measures physiological indicators of stress, such as one's heart rate or electrodermal activity. For the purpose of the experiment, two games were designed and implemented to invoke varying levels of anxiety. The first was a clone of the well-known table tennis game *Pong*, and the other, nameless game tasked players with solving anagrams. In turn, two versions of each game were created: one that used performance-based DDA and another that that was supported by an affect-based DDA engine. The affective versions of the games measured and analyzed various aspects of participants' cardiovascular, electrodermal, and muscular activities to provide an optimal level of difficulty. Participants were then tasked with playing both versions of both games. Results from the experiment affirmed the validity of using a player's affect to modulate difficulty. Specifically, Liu et al. concluded that a) the performance of most participants improved during the affect-based DDA session, b) the majority of participants found the affect-based games to be more satisfying than ones that used performance-based DDA, and that c), participants reported lower levels of anxiety during play of the affective DDA games.

Another researcher, Du Nguyen [38] used Liu et al.'s conclusions to provide a basis for his own work. Nguyen's research goal was nearly identical to that of his predecessor: to investigate whether affective DDA is "better" than performance-based DDA. The experiment was divided into two phases: the first sought to gather physiological data from people in order to help classify emotions, and the second saw Nguyen creating and testing two versions of Tetris, one with affective DDA that assesses the player's heart rate, and another that uses performance-based DDA. The data collected during the first phase was fed into the affective version of Tetris; essentially, the data helped the game discriminate between various emotional states, allowing it to know when and how to adjust difficulty under different conditions. Both versions of the game modulated the level of challenge by adjusting the speed of gameplay; the poorer the player is doing, the slower the blocks fall from the top of the screen. Unfortunately, results showed that there was no statistical difference between the two DDA solutions. However, these findings may have been negatively impacted by oversights in the experiment's design. For instance, the performance-based version of the game continually adjusted difficulty, while the affect-based version only made changes every ten seconds; in addition, Nguyen reported that there may have been issues measuring participants' heart rates. Despite the inconclusive results, Nguyen concluded on a positive note, indicating that participants preferred the DDA-supported versions of Tetris over the commercial version of the game.

Fortunately, other experiments comparing performance-based and affective DDA have produced more concrete results. In a 2005 paper, Rani, Sarkar, and Liu [65] set out to provide a case for the use of affect as a way of adjusting game difficulty. Like the latter two examples, the experiment was divided into two phases. In Phase I, dubbed the "modeling phase", researchers collected data from participants playing an off-the-shelf version of Pong to determine physiological patterns behind different affective states (i.e. different emotions). In Phase II, two variations of Pong were created: one which used a performance-based DDA solution, and another that used the players' affect (specifically, their level of anxiety) to provide an optimal challenge. To ensure that both the emotional arousal and valence of players were properly captured, the affective version of Pong utilized several physiological measures, including EDA, electrocardiograms, and heart sound. The affective game analyzed the aforementioned physiological signals during gameplay to classify the player's level of anxiety into one of three states: low, medium, or high. Each of the three states of anxiety was assigned a corresponding level of difficulty. As such, the game turned down the difficulty whenever it detected overly high levels of player anxiety and increased the degree of challenge upon noting a sustained level of low arousal. Objective and subjective data was collected from two participants while playing both versions of the game. Results collected reinforced Rani et al.'s hypothesis; when playing the affect-powered game, participants exhibited better in-game performance, all while reporting lower levels of anxiety.

Nacke, Kayln, Lough, and Mandryk [79] also explored the active use of biometrics in games, but to different ends; their primary focus was to determine if physiology can be effectively used as a means of interfacing with a game. Born of this research project was a side-scrolling shooter that merged both conventional and physiological input. A standard Xbox 360 controller was used to control the game's character (i.e. to move, shoot and jump). The player's physiology, recorded via specialized sensors, was used to augment interaction with the game; for instance, the player could direct their gaze to an on-screen enemy to freeze them in their position. Skin conductance measurements were used to adjust the sizes of enemies – the higher the skin conductance, the larger enemies appeared in the game world, thus making them easier targets. As such, the game is best considered as a *biofeedback* game, not an affective game, since it relies on conscious manipulation of physiology as a means of interaction. In total, six physiological measurements were leveraged by the game, each one adjusting a different parameter of the game world. Three versions of the game were developed: one that used solely the controller as a means of input, and two that applied players' physiology to control different in-game variables. Overall, response from participants (n = 10) was very positive. Most notably, 9 out of 10 players preferred to use physiological control, and rated the biofeedback versions of the game as more fun to play. However, the use of skin conductance as a means of direct interaction with the game was poorly received, since the electrical conductivity of one's skin is difficult to manipulate willingly. As such, Nacke et al. suggested that skin conductance would be best suited for modifying environmental variables, such as enemy spawn rates. Although this conclusion may appear to be dismissive of the utility of skin conductance, it actually reaffirms the viability of using electrodermal activity as part of an affective DDA system, since DDA implementations typically tweak parameters of the game world to optimize the play experience.

Figure 11. A scene from an unnamed biofeedback game developed by Nacke et al. [78]

In order to facilitate the creation of affective games, Gilleade and Allanson developed a toolkit called the *Intelligent Gaming System* (IGS) in 2003 [34]. The toolkit was designed to leverage data streamed from an electrocardiograph, a device that measures electrical phenomena in the heart (including one's heart rate). In the same year, Gilleade and Allason, accompanied by Dix, developed a practical application of the toolkit in the form of an affective game: an unofficial spin-off of the 1980 Atari hit *Missile Command* [39]. Just like its progenitor, the affective game tasked players with destroying incoming targets by firing missiles at them; targets move up from the top of the screen, and if the player does not succeed in destroying them before they reach the top, the player's health is decremented. The affective component of the game came via its integration of heart rate measurement. It was assumed that increases in the player's heart rate meant that the player was enjoying the game, whereas decreases indicated a lack of engagement. As such, the game sought to balance the player's level of engagement by modifying factors relating to challenge, such as the number of targets and the amount of damage they inflict. Feedback collected from participants who played the game suggested that even trivial forms of affective feedback could be used to create more enjoyable play experiences.

5.4 Summary

Clearly, there is reason why prominent game developers like Valve, Ubisoft and Sony are beginning to shift their attention towards the use of affect and physiology in games. The above studies, although limited in number, have evidenced that using non-traditional biometric-based interfaces in games can both enhance existing gameplay experiences and produce entirely new ways to play. Skin conductance, in particular, has been shown to be an indispensable tool for arousal state measurement in affective DDA systems, but its applicability as a means of direct interaction with a game is limited. Of course, to fully understand the potential of affective gaming, one needs to turn one's attention towards the future.

Chapter VI: Future Developments in Related Fields

6.1 The Future of Affective Gaming

6.1.1 Challenges

Up until this point in time, the incorporation of affect in video games has yielded positive results. Naturally, this does not imply that the medium is free from faults. If the notion of affective gaming is to be moved forward, especially towards the realm of commercial use, a number of current issues with the medium must be addressed. Currently, there are three yet-to-be-solved challenges at the forefront of affective gaming research: the consideration of how uncontrollable real-world variables affect player experience, the diminution of the size of affect-sensing hardware, and standardization of affect-sensing software.

Arguably the most glaring limitation of current affective gaming research lies in the environment where such testing and research occurs. The laboratory environment provides an equitable space to approve or disprove the validity of a researcher's hypothesis, free from distortion of otherwise difficult-to-control real-world variables. However, as researchers and developers begin to shift their attention towards the commercial applications of affective games, it is becoming increasingly important to consider how biometric-based affective games will work in traditional contexts of use. When a player is playing a game in a non-controlled environment (in their home or on public transport, for instance), he or she will likely be subject to a number of unexpected, immitigable interruptions: smartphone notifications, distractions from people in their proximity, background noise, and so on. It is not unreasonable to assume that these disruptions have an impact on the player's level of attention and/or stress. As such, future affective games will need to find a way to discriminate between emotional responses resulting from gameplay and emotional responses resulting from other, unrelated factors; otherwise, the game may make unnecessary adjustments to the game state. This is especially an issue for games using affective DDA, since misinterpreting the player's emotional state could lead to unfair adjustments in game difficulty.

Affect-sensing devices and sensors deserve mention too. Games and devices created as part of research projects have been able to distinguish between players' emotions with considerable accuracy, but since they typically assess a multitude of physiological measures in conjunction, they require a myriad of devices to be strapped onto users (Fig. 12). Such cumbersome solutions have no place outside of academic or research-oriented contexts. Fortunately, notable progress has been made on minimizing the size and obtrusiveness of these devices. The latest version of Microsoft's Kinect, a motion-sensing camera built for the Xbox One and PC, can detect the user's heart rate from several feet away through infrared data [84], [85]. The Intel RealSense camera accomplishes a similar feat by analyzing several indicators of heart rate, including pupil dilation and vein constriction [86]. Both devices are noteworthy in that they do not require any wires or sensors to be connected to the user for accurate physiological measurement. While these devices are at the cutting edge of affect-based human-computer interaction, they hardly represent the end of the road in terms of technological innovation. Section 6.1.2 discusses possible future developments in the field.

Figure 12: The majority of devices used for affect measurement in research projects are obtrusive and cumbersome [42].

The use of less obtrusive devices is largely useless if no software exists to collect and analyze the physiological measurements outputted from these devices. Currently, there are a number of publically-available application programming interfaces (APIs) that are built to leverage biometrics in affective games [39], [67], [84]. While these software libraries are a good first step in the standardization of affect integration in games, none of them have seen widespread use from researchers or developers, likely due to the difficulty of integrating them into games and because they only work with a specific subset of sensors and devices. Other affect-sensing software implementations exist, but the majority of them have not been released for public consumption or were purpose-built for one specific game, thus limiting their applicability [13], [38]. For an affective API to be truly useful, it needs to be flexible, interoperable, and easy to use; in other words, it needs to be compatible with a broad range of devices and games, and determining the player's emotional state should be as easy as invoking a function. At the time of writing, the Gdańsk University of Technology in Poland is orchestrating a large-scale research project that seeks to produce widely compatible, easy-to-use affect-measuring algorithms for use in commercial games [87].

6.1.2 New and Emerging Hardware

The implications of affect integration in future video games are relatively clear. As discussed throughout the course of this thesis, making the computer an active participant in the biofeedback loop means that video games will be able to effectively tailor the experience it offers to the player by analyzing level of emotion, allowing for an optimal level of difficulty, among other things. Unfortunately, the answer to *how* emotions can be measured in a practical manner is not quite as evident. Still, strides have been made to create unobtrusive, simple-to-use hardware devices that can enrich our gaming experiences by harnessing the vast amount of data flowing through our bodies.

Perhaps the future of affect measurement lies not in measurement of physiological components of emotions, but in the analysis of the body's very control center. All physiological processes and responses within the body, affect-related or not, are coordinated by the brain. Using this line of reasoning, several researchers have begun to explore the use of electroencephalograms (EEGs), devices that measure electrical activity in the brain, as a means of determining one's emotional state [54]–[56], [88]. Despite its nascence, game developers have already begun to display interest in the use of EEG in games. Valve Software is especially invested in this matter; in 2011, the company disclosed that they had begun discussions with a company that manufactures EEG implants [59]. More recently, independent developer GainPlay released

MindLight, a game used to treat anxiety disorders that an used EEG headset to measure the player's level of stress [89]. However, viable, cost-effective consumer options are still out of reach. While the EEG headset required for MindLight retails for a relatively sensible $100 USD, other, more sophisticated brainwave-measuring apparatuses can cost up to a few hundred dollars. If EEG sensors are ever to become pervasive in the games industry, their cost has to come down.

In reality, it would be far more practical if players did not have to use superfluous, unwieldy devices to ameliorate their gaming experience. If anything, research efforts from the likes of Sony [58] and Valve [90] have illustrated that commercial developers are not focusing on creating new, purpose-built physiological sensors; rather, they are interested in integrating biometrics into existing gaming peripherals, such as game controllers. Valve boss Newell reinforced this sentiment in 2013, indicating that customers should expect should expect controllers from the company that use "a lot of" biometric data [91]. To date, Valve (nor any other company, for that matter), has not released an affect-sensing game controller, but research in the academic community has supported the viability of the idea. In a 2014 project conducted at Stanford University, Xbox 360 controllers were modified and fitted with a number of physiological sensors for the purpose of determining a player's level of engagement in a game. Data from the controllers was fed into a DDA system, which actuated changes to the difficulty of a custom-made game. McCall, lead researcher on the project, has touted that there has been a substantial amount of positive feedback thus far [92].

6.2 The Future of Dynamic Difficulty Adjustment

Through a number of successful research projects and commercial applications performance-based DDA has been proven to be an effective – albeit tricky-to-implement – means of modulating video game difficulty. Within the concept of performance-based DDA, however, lies an inherent, potentially unsolvable flaw: the performance metrics collected and analyzed by such algorithms are inexact proxies of the player's state (emotional or otherwise) and they cannot necessarily provide an accurate indication of the player's skill level or degree of enjoyment. This conclusion is supported by a handful of studies discussed in chapter 3, all of which assert that the player's affective state is a more reliable indicator of the player's overall gameplay experience. For this reason, the author speculates that affective DDA will eventually overtake performance-based DDA as the preferred method of dynamically modulating the challenge offered by the video game. Such a change is very unlikely to occur instantaneously; instead, it will likely be a slow, gradual process consisting of three chronologically-ordered phases:

1. For the next few years, the vast majority of DDA-powered titles will continue to use performance based-implementations.
2. In the near future, as affect-sensing devices become smaller and less expensive, games will use a mixture of both DDA methods; affect-based for when affect-measuring sensors are connected, and performance-based as a fallback.
3. As the capability to measure affect becomes more ubiquitous and is integrated into commonly-used gaming devices (such as controllers), assessment of emotion will become the dominant way to tailor gameplay experiences to the player.

Chapter VII: Electroderma: A Game Utilizing Affective DDA

7.1 Purpose

One can discuss research and theories on affective gaming and physiology at great length, but such a discussion is ultimately meritless if one does not show *how* such theories and findings can be employed. To demonstrate if skin conductance can be used as a difficulty-modulating variable in an affective DDA system, a small-scale game utilizing affective DDA, dubbed *Electroderma,* was developed. Not only does a discussion of this project serve to illustrate how skin conductance can be used in a video game, but it also brings to light design issues related to affect measurement in video games – something that is sorely lacking from current literature on affective gaming.

7.2 Hardware and Software Utilized

Since the project portion of this thesis requires real-world measurements and readouts (i.e. real-time skin conductance measurements from users), a combination of both hardware and software were employed.

7.2.1. Software

Due to its cross-platform compatibility and excellent documentation, the Unity game engine was chosen to implement the project portion of the thesis. The engine itself is not open-source, but a free version, which satisfies all the needs of the project, is available online. In order to leverage the latest software features and performance enhancements, the author chose to use Unity 5.3.3, the latest stable version of the product.

7.2.2 Hardware

The game will need a device from which it can pull skin conductance information. The Arduino, a low-cost microcontroller, feeds the data to *Electroderma*. By itself, the Arduino cannot detect or sense anything, so it requires sensors or actuators to be connected to it. So, for the purpose of this project, a low-cost EDA sensor, the *SeeedStudio Grove GSR Reader*, was purchased and connected to the Arduino.

The aforementioned devices are small and unobtrusive, but most importantly, they are low cost; the Arduino and Grove can be purchased for a combined total of ~$35 USD[2]. A separate interfacing device, also created by Seeedstudio, was required to be able to connect the Grove to the Arduino, but its price was not factored into the final cost of the project as it came as part of a larger Arduino development kit.

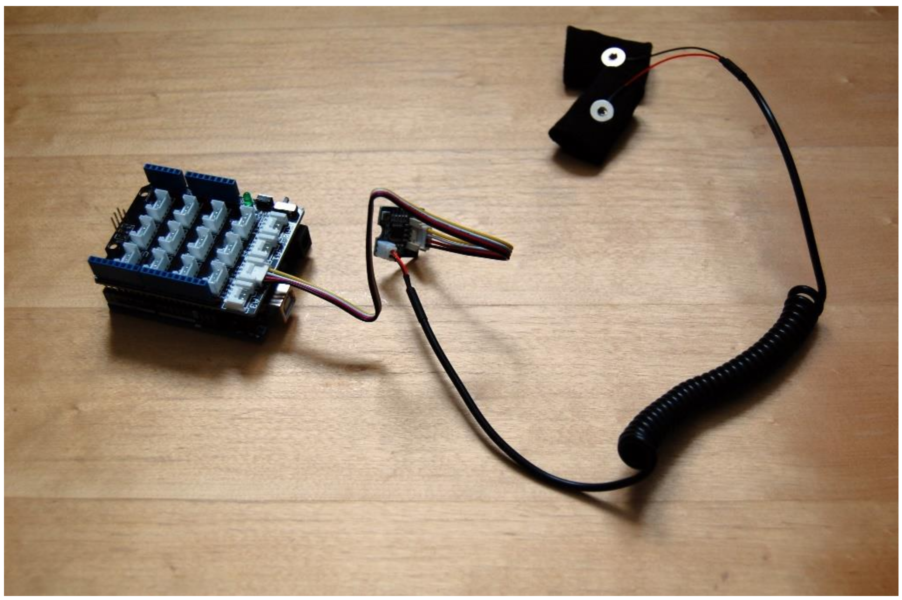

Figure 13. The hardware devices used to implement the project. Left: Arduino; right: Grove EDA sensor

[2] Prices as of March 2016.

7.3 Results

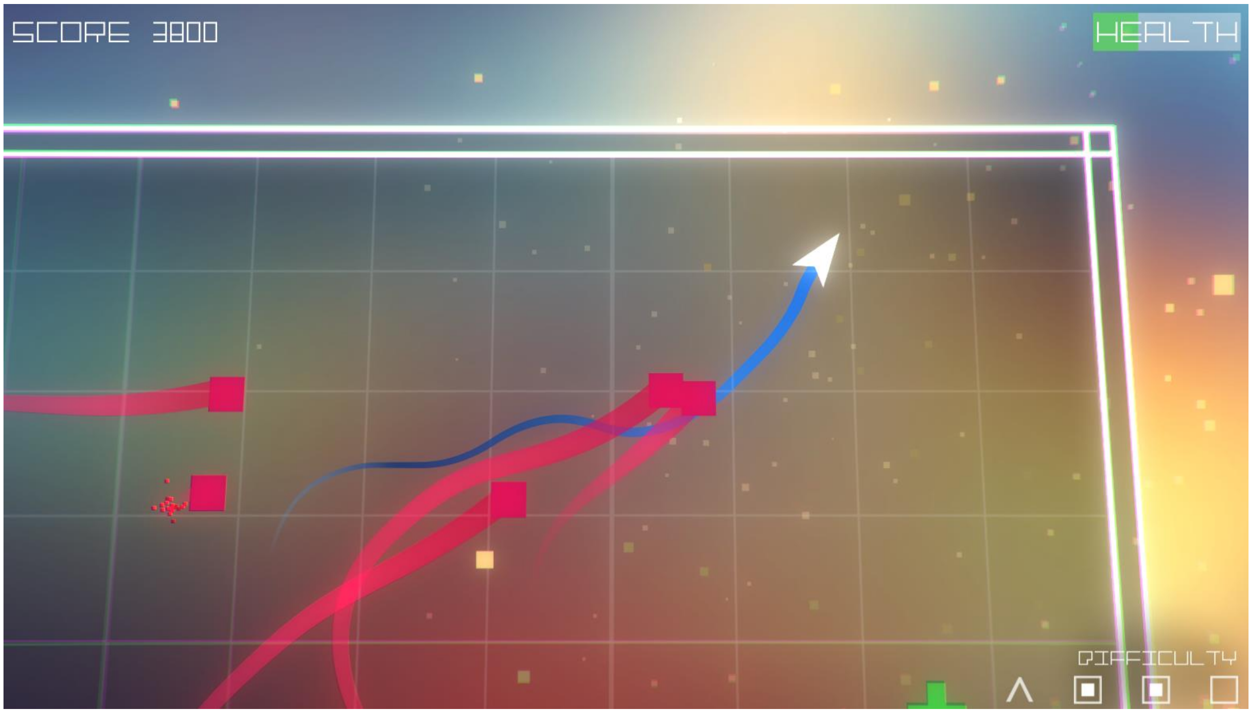

Figure 14: Scene from *Electroderma*. The player character, white, evades a group of enemies.

Born of the development process is *Electroderma*, a top-down shooter in which the player controls a spaceship. Enemy ships swarm the player from all angles; the objective is to rack up a high score by shooting down as many enemies as possible. The degree of challenge offered by the game is adjusted by a custom-built affective DDA system, which cycles between three levels of difficulty based on the player's level of emotional arousal: easy, medium, and hard. To ensure that all players, regardless of their experience and skill level, can have an enjoyable experience, the game follows a pick-up-and-play scheme. The underpinnings of *Electroderma* were founded on three assertions made throughout the course of this document:

1. Even trivial DDA implementations, affective or performance-based, can be used to improve a player's experience with a game [4], [39].
2. Low physiological arousal (and by extension, low skin conductance levels) can indicate boredom or disinterest [14]–[16].

3. Coupling a measure of physiological arousal (specifically skin conductance) with the context of the current gameplay situation can be used to infer the valence of an emotion [13], [48].

Although the game is relatively small in scale, the feature set it offers was polished and sanded down to ensure the best possible player experience. Menus fade between one another instead of appearing out of thin air; particle systems fly in and out of view; bullet shrapnel bounces off walls; bloom and chromatic aberration accentuate the game's bright color palette to create a retro, "neon vector" look. This level of detail was also extended to the game's interaction scheme; not only can the player chose to play with a controller or a keyboard-mouse combination, the game also pauses itself when the player removes the skin conductance sensor from their fingers. All of these embellishments, big and small, add up to create a game that is more accessible, adaptable, and aesthetically pleasing.

7.3.1 How it Works

In total, two versions *Electroderma* were developed. The skin-conductance-measuring algorithm developed as part of the first version of the game was deemed by the author to be ineffective, so a second iteration was developed featuring a much-improved analysis technique. It is worth discussing both versions to illustrate proper and improper ways of assessing users' physiology in games.

7.3.1.1 Final Version

The task of affect analysis is not as simple as pulling values from a sensor. The final iteration of *Electroderma* utilizes *data subset analysis* (DSA), an algorithm devised by the author that is loosely based on work by Fairclough and Gilleade [93] and Leiner, Fahr, and Früh [94][3]. Not only is the algorithm simple in its design, it organically filters out undesirable noise in the user's skin conductance signal (changes in temperature and air humidity, differences in skin types). To be able to perform its work, the algorithm needs only to assess the two most recent skin conductance values obtained from the sensor. It computes the difference between the most recent and second-most recent values, adding the result to a running total. This difference-

[3] A C# implementation of this algorithm is available in appendix A.

calculation process is repeated upon the introduction of each new data sample, until a specified number of samples have been analyzed. At that point, the running total is evaluated to determine if there has been a notable deflection in the user's skin conductance; such a deflection implies a change in the user's level of emotional arousal. In short, the algorithm returns one of three options:

- There was a notable increase in the user's level of emotional arousal
- There was a notable decrease in the user's level of emotional arousal
- There was no notable deflection in the user's level of emotional arousal

After returning a value, the running total is cleared so that the entirety of the process described above can be repeated. This process is repeated throughout gameplay so that the game can continually assess and adjust to the player's emotional state.

The game's DDA engine uses output generated by the DSA algorithm to determine when to adjust the difficulty. As suggested by Erin Reynolds, coupling a measure of emotional arousal (such as skin conductance) with the current context of the game can allow one to deduce valence of emotions experienced by the player. For this reason, Electroderma's DDA implementation assesses the player's in-game health level alongside the output of the DSA algorithm. If the game detects that the player health is low and their level of emotional arousal is high, frustration is implied, and the game's difficulty is turned down; if the game detects high health and low emotional arousal, the game assumes the player is bored and consequently turns the difficulty up. During this process, the difficulty shifts between any one of the game's three difficulty levels: easy, medium, and hard. Each of the three options exerts control over the spawn rates of pertinent objects (such as enemies and health packs) and the speed at which the enemies move towards the player. Basically, as the game's difficulty increases, health packs spawn less frequently, and enemies spawn and move more quickly. The goal of any DDA system is to be transparent, so the game does not change player character attributes since the modification of such values would be immediately obvious to the player. The analytical processes of the game are made visible to the player using two interface components: an indicator of the current level of difficulty and an arrow indicating an upwards or downwards change in emotional arousal (Fig. 15).

Figure 15. The affect-related interface components of *Electroderma*. The indicator, left, shows if there has been an upwards or downwards change in emotional arousal. The three squares correspond to the game's current difficulty level.

7.3.1.2 Initial Version

The gameplay of Electroderma was divided into two phases. Before entering the main game, the player was subject to a baseline acquisition period. This period, lasting a total of 120 seconds, presented players with a "no-fail" version of the game; enemy ships swarmed towards the player character but didn't inflict any damage upon collision. The moderate level of sensory activity generated during this time was used to establish a baseline skin conductance value that changes during the "real" game were to be compared to. For the game to know *how* and *when* to act on the player's physiological data, some statistical analyzes were performed. For the purpose of this game, the Arduino was programmed to poll and report the player's skin conductance every 200 milliseconds. During the baseline period, this information was computed into a running average. When this period was completed, the final running average represented the player's baseline skin conductance value.

Once the baseline procedure was completed, the game began in earnest, and the affective DDA system began exerting its control over the game's state. The skin conductance values outputted by the Arduino were also leveraged during the "real" game, but for a different purpose: they were compared against the baseline to let the game know when it should adjust the level of difficulty. However, such a comparison was not done blindly. The game needed to determine if observed changes in skin conductance resulted from genuine changes in the player's affect or mere startle responses. To accomplish this, the length of the player's emotional arousals was analyzed. If the player's skin conductance deviated from the baseline for four seconds or more (in either a positive or negative direction), the game interpreted this as a change in emotional state and consequently begins deciding if a change in difficulty is required. Other deflections in the skin conductance level were considered as non-significant and are discarded.

Although the approach discussed here may seem viable from a theoretical standpoint, it was a far-from-optimal solution in practice. This is largely because one's skin conductance baseline changes regularly [20]. As such, it is pointless to compare changes to a baseline acquired at a previous point in time, when a different set of real-world variables and conditions (room temperature, moisture content in air, stress level) may have held true.

7.4 Technical details

Modularity is a design concept that runs through Electroderma, from its top-level interface to its architectural design. The game's commitment to modular, flexible design is made apparent in four ways. One, players can interact with the game however they wish – they can choose to play with either a game controller or keyboard-mouse combination. Two, the affective DDA component of the game enables or disables itself dynamically, depending on the presence of proper affect-sensing hardware. Three, the responsibility of measuring, computing, and analyzing is divided between several interrelated software components. Four, the game runs on Windows, Mac, and Linux, thanks to the cross-platform compatibility of the Unity game engine. Of these four design aspects, the one that warrants an in-depth discussion is the software components utilized as part of the affective DDA system.

7.4.1 Software modules created

Three software modules – a device manager, a data manager, and a difficulty controller - were purpose-built for affect sensing in Electroderma. The use of a third-party API was considered for this task, but the author ultimately elected to build a custom solution after investigation revealed that the vast majority of commercially-available affect-sensing APIs are severely lacking (section 6.1.1). Before discussing how the three software modules work together, it is worth identifying what their responsibilities are.

7.4.1.1 Responsibilities of modules

Device manager

As the name implies, this module is responsible for interfacing with the Arduino (and by extension, the skin sensor) via USB. Of the three modules, the device manager performs the lowest-level operations, since it interacts directly with external hardware. It can, among other things:

- Detect if an Arduino is connected to the computer
- Initialize a serial connection to the Arduino
- Return the current skin conductance value as measured by the sensor
- Detect if the user is wearing the skin conductance sensor by assessing the level of electrical resistance encountered by the sensor

Data manager

The data manager collects, stores, and analyzes data obtained from the device manager in order to make sense of the user's skin conductance levels. Its responsibilities are to:

- Poll the device manager for a new skin conductance value at a regular time interval
- Add data points to the moving histogram
- Notify the game to change difficulty when the moving histogram algorithm detects a notable change in arousal

Since this module polls for a new skin conductance value quite frequently (every 200 milliseconds, to be specific), both it and the device manager are housed in a thread that is separate from the game logic. In the interest of efficiency, this thread is killed if the Arduino is not connected, since the computations it performs are useless without the presence of the required external hardware.

Difficulty controller

The difficulty controller actuates changes to the difficulty of the game. The controller offers three levels of difficulty – easy, medium, and hard – all of which adjusts the following game parameters:

- Enemy spawn rate

- Enemy speed
- Health pack spawn rate

The module provides an interface by which other components can request to change the difficulty of the game. Any module can invoke `bumpUp()` or `bumpDown()`, two functions that respectively turn the difficulty of the game up or down.

7.4.1.2 Interaction between modules

To bring the DDA component of *Electroderma* to life, the device manager, data manager, and difficulty controller interact with each other, providing services to and receiving services from one another. The intercommunication of these modules helps form a DDA feedback loop (Fig. 16). In practice, their impact on the performance of the game is minimal; initial testing revealed that there was no loss in framerate when the affect-sensing software components were enabled.

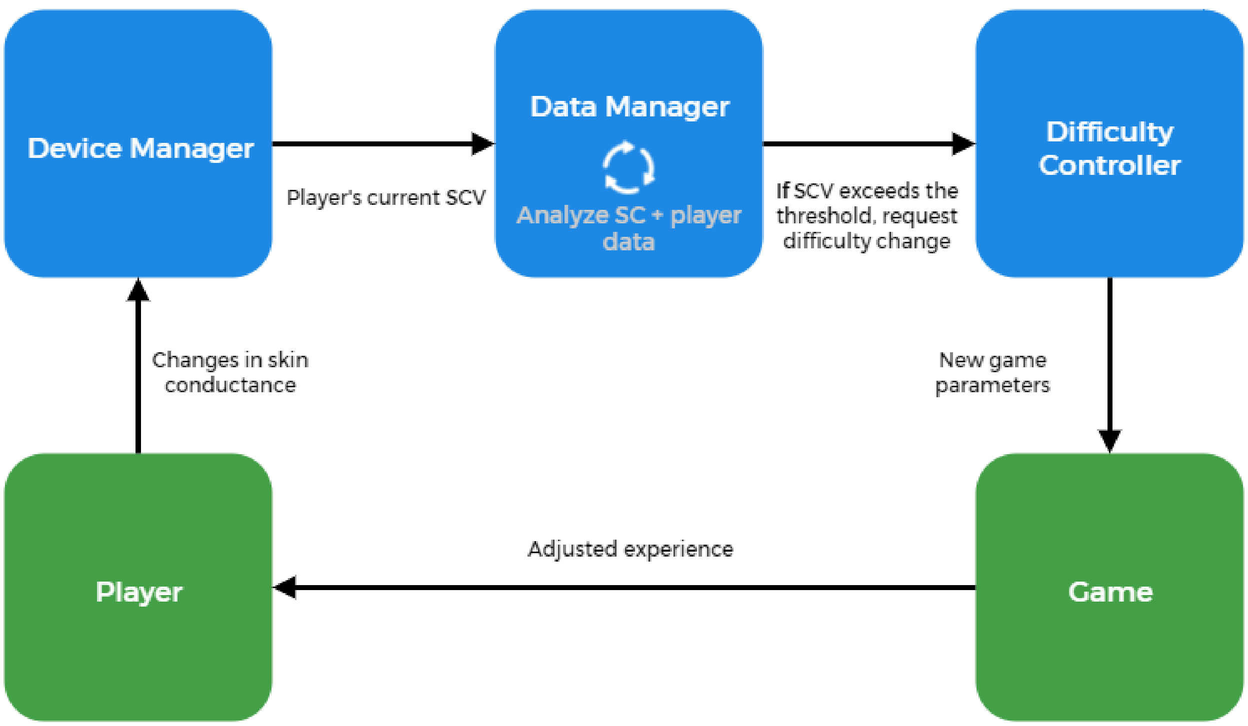

Figure 16: Electroderma's implementation of the affective DDA loop. SCV = skin conductance value

7.5 Future Work

Electroderma represents a near-fully-realized vision of how skin conductance can be used as a variable to adjust the difficulty of a game. Given more development time, however, the game's scope and scale could be expanded to provide an even better experience to players. Most importantly, the author would like to determine if the parameters of the game's algorithm could be further tweaked to ameliorate the affective DDA component. To answer this question and identify other areas for improvement, the game would need to be tested by participants, who would play the game for an extended period of time and fill out a usability questionnaire at the end of their session. Due to its extremely low performance cost, the DSA algorithm could also be tested for use in low-powered affect-sensing devices.

Chapter VIII: Conclusion

The implicit question that this thesis sought to answer is *can physiological signals be used to modify the difficulty of a video game*? The answer is an almost unequivocal *yes*; research – albeit in a limited capacity thus far – has evidenced that using non-traditional biometric-based interfaces in games can both enhance existing gameplay experiences and produce entirely new ways to play. Most importantly, the use of players' emotions in affective DDA systems implicitly solves many longstanding issues that have surrounded performance-based DDA implementations; no longer do games have to guess the player's level of enjoyment or frustration based on arbitrary performance statistics. Instead, games can tap into the vast amount of physiological information flowing through the human body to assess how the player is *really* feeling and to determine how to maximize the player's level of enjoyment. Skin conductance, which was found to be an accurate and easy-to-measure physiological signal, has also been shown to be an indispensable tool for arousal state measurement in affective DDA systems especially when paired with other physiological measures. As emphasized by the discussion of *Electroderma* and the author's DSA algorithm, if one is cognizant of the inherent limitations and design challenges surrounding skin conductance measurement, one can design with relative ease an affective game that uses solely skin conductance.

Despite its youth, the field of affective gaming has seen considerable interest from both commercial organizations and research communities. Enthusiasm from some of the largest developers in the world – *Valve*, *Sony*, and *Ubisoft*, to name a few – have clearly demonstrated that there is commercial interest in games that are smarter, more interactive, and above all, *more emotionally aware*. It is equally daunting and exhilarating to think that games and computer applications of the future will be able to go beyond the hollow, listless inputs of game controllers, keyboards, and mice and thus be able to truly understand and respond to what users are thinking and feeling. Computers and game consoles, currently regarded as mere machines consisting of circuits and wires, will eventually be viewed as real, tangible entities that exist on the plane of human consciousness. The road ahead of affective gaming is long, but its future will be far from uneventful.

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Glossary

Affect A feeling or emotion. The psychological community presses that there is a distinction between affect and emotion, but the difference is pedantic for the purpose of this thesis.

Affective DDA A form of dynamic difficulty adjustment that uses indicators of affect, such as heart rate and skin response, to the optimize difficulty of a game for the player.

Affective gaming A field of research that seeks to improve the coupling and relationship between our emotions and video games; its primary focus is to develop a loop of interaction in which both the player and the video game can understand and respond to emotional signals of one another. Affective games make use of indicators of emotional state (physiological or otherwise) to positively impact the user's play experience.

Arduino A small, low-cost microcontroller that can interface with specialized devices (lights and sensors, for instance), based on instructions written by a programmer. The device is known as the *Genuino* in non-U.S. territories.

Biofeedback The monitoring of a normally automatic bodily function for the purpose of training someone to acquire voluntary control of that function.

Biofeedback game A type of video game in which players must exert conscious control over their physiological processes (e.g., breathing, heart rate) in order to progress through the game.

Biometrics The use of specialized electronic devices for the purpose of measuring a person's physical or physiological traits.

Difficulty selection A method of adjusting the level of challenge offered by a game. The player selects their preferred level of difficulty from a predefined list before entering the game.

Dynamic difficulty adjustment A method of adjusting the degree of challenge offered by a game. Collects relevant metrics from the player to optimize the difficulty level of the game in real-time. There are two types of dynamic difficulty adjustment (DDA): affective DDA and performance-based DDA.

Electrodermal activity Refers to all electrical phenomena that occur in the skin, including *skin conductance*.

Flow A positive experience with an activity; represents a complete, energized focus in the activity with high amounts of enjoyment and productivity. The concept of flow has been linked to fun in games.

Grove GSR reader A small device, comprised of two finger-mounted sensors, that can measure the wearer's level of skin conductivity. Relays data to the Arduino microcontroller.

Model-based emotion classification A type of approach for detecting and modeling users' emotions that uses facts and rules establishes in psychological theories.

Model-free emotion classification A type of approach for detecting and modeling users' emotions that uses machine learning techniques or statistical analysis to derive a computational model that can transduce physiological signals to affective states in real-time.

Performance-based DDA A form of dynamic difficulty adjustment that exists solely in the "virtual world"; these DDA implementations only assess performance metrics generated by the player's interactions with the game (e.g. player deaths, level completion times, accuracy of gunshots) to determine how to best adjust the game to meet the player's skill level.

Physiology The unconscious functions and processes that occur within an organism. Changes in physiology have been linked to changes in emotions, among other things.

Skin conductance A measure of how electrically conductive an individual's skin is. Has been shown as an indicator of an individual's emotional arousal and cognitive load.

Skin conductance level A measure of one's overall skin conductance, absent from the influence of particular events or stimuli.

Skin conductance response The body's physiological responses to discrete stimuli – sights, smells, sounds – and cognitive processes. Such responses are typically sudden in nature and manifest themselves in abrupt, short-lived increases in skin conductance.

Valence An important component of emotion; identifies whether an emotion is of a positive nature (e.g. happiness, excitement) or a negative nature (stress, sadness).

List of Abbreviations

AI	Artificial intelligence
API	Application programming interface
EDA	Electrodermal activity
FPS	First-person shooter
GSR	Galvanic skin response
I/O	Input/output
NPC	Non-player character
SC	Skin conductance

Appendices

Appendix A: C# Source code for DSA algorithm

```
/*
Analyzes passed-in skin conductance values to determine notable changes in arousal
*/

public class MovingHistogram
{
    private int prev;
    private int curr; //The two most recent data points added by addDataPoint()

    private int sampleCount;
    //How many samples should we analyze before reporting if there was a noticeable change in
skin conductance?

    private int totalChange;
    //The total change in skin conductance value for the specified period

    private int currentSampleCount;
    //How many samples have we looked at in this iteration?

    private int threshold;
    //How much should the skin conductance value change in order for the change to be
considered significant?

    public MovingHistogram()
    {
        prev = -1;
        curr = -1;
        currentSampleCount = 0;
        totalChange = 0;
        sampleCount = 20;
        threshold = 20;
    }

    //Add a new data point to the histogram; shift the other value over (this implicitly
deletes whatever was stored in prev)
    //Returns an integer value (-1, 0, or 1) that indicates if there has been a negative,
positive, or no change in skin conductance over a period of time
    public int AddDataPoint(int newData)
    {
        prev = curr;
        curr = newData;

        //Only process the data if both entiries contain valid values
        if (prev != -1 && curr != -1)
        {
            totalChange += curr - prev;
            //Add the difference between the two data points to the total
            currentSampleCount++;

            //Have we checked enough samples to be able to assess if there's been a notable
change in skin conductance?
            if (currentSampleCount == sampleCount)
            {
                //If the total amount of change has exceeded the threshold, that means that
there has been a notable increase in emotional arousal
                if (totalChange >= threshold)
```

```
                {
                    ResetHistogram();
                    return 1;
                }

                //If the total amount of change is negative and it has exceeded the
threshold, that means that there has been a notable decrease in emotional arousal
                else if (totalChange < 0 && totalChange <= threshold*-1)
                {
                    ResetHistogram();
                    return -1;
                }

                ResetHistogram();
            }
        }

        //Otherwise, return 0, indicating that there was no discernable change in skin
conductance
        return 0;
    }

    public void ResetHistogram()
    {
        //Reset the necessary variables so we can do this process again
        currentSampleCount = 0;
        totalChange = 0;
    }
}
```

Appendix B: Specifications of Development Computer

Processor	Intel Core i5 3570K – 3.4GHz
RAM	16GB – DDR3
Video card	AMD R9 390X – 8GB
Storage	Samsung 840 Evo – 240GB